Manufacturing Workplace Support Structures and Technology: Effects on Mental Workload, Performance, Self-Efficacy, and Social Anxiety on Both Neurotypical and ADHD Workers

by

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Abstract

This dissertation delves into the intersection of Attention Deficit Hyperactivity Disorder (ADHD) symptoms, psychosocial stress, and anxiety among adult workers, particularly in the manufacturing sector, focusing on self-efficacy and the efficacy of augmented reality (AR) and other work support tools in mitigating cognitive load. A comprehensive literature review identifies critical gaps in current studies, particularly the lack of field observations and simulated work environment studies that include ADHD workers. Utilizing methodologies such as the Adult ADHD Self-Report Scale (ASRS), the research examines ADHD prevalence across various employment sectors, elucidating the relationship between ADHD symptomatology and workplace outcomes. The need for tailored interventions and workplace accommodations to support ADHD workers is underscored, emphasizing the potential of AR systems to enhance task performance and reduce cognitive strain. This dissertation advocates for inclusive strategies to address the unique challenges faced by neurodiverse employees.

In exploring the impact of augmented reality (AR) technologies on production quality, speed, cognitive load, and usability within a simulated manufacturing environment, this study focuses on participants with varying levels of ADHD symptoms. The research investigates whether different treatments, such as Paper Work Instructions (PWI), Projection-Based Augmented Reality (PBAR), Head-Mounted Augmented Reality (HMAR), and Enhanced Head-Mounted Augmented Reality (EHMAR), influence production outcomes based on self-reported ADHD symptom levels. Statistical analyses, including two-way ANOVAs and regression analyses, examine the effects of ADHD symptom levels categorized as low, medium, and high on primary outcomes: production speed, production quality, cognitive load, and usability. Findings reveal that higher ADHD levels increase production speed for PWI and PBAR but not for HMAR and EHMAR. ADHD symptom levels significantly affect production quality, with decreased error rates as ADHD symptoms increase, notably in the EHMAR treatment. Cognitive load and usability ratings also vary significantly among ADHD levels, indicating the need for tailored interventions and usability assessments to accommodate

individual differences in ADHD symptoms.

Further, the impact of different workplace support systems on cognitive load, usability, performance, and error rates within a simulated manufacturing setting is explored, specifically focusing on participants with varying levels of ADHD symptoms. Utilizing a within-subjects experimental design, the study assesses the effects of Lean tools, Industry 4.0 (I4.0) sensors, and their combination on task performance during a manual assembly task in a simulated environment. Key findings include significant differences in production speed, quality, and cognitive load across different treatments and ADHD symptom levels. For this study, participants with higher ADHD symptoms produced more cars without increasing error rates, demonstrating an ability to maintain quality under increased production speed. I4.0 sensors significantly improved quality by reducing error rates and received higher usability ratings. The study identifies covariate influences on cognitive load and usability metrics, such as age, race, LEGO experience, and educational background, highlighting the need for tailored support systems.

Additionally, a survey of the prevalence of ADHD among U.S. workers, particularly in the manufacturing sector, examines the relationship between ADHD symptoms, self-efficacy, social anxiety, and workplace support systems. Using an online survey with 249 participants across various employment sectors, the study evaluates ADHD symptoms with the ASRS v1.1, self-efficacy with the Global Perceived Self-Efficacy Scale (GPSES), social anxiety with the Liebowitz Social Anxiety Scale (LSAS), and perceptions of workplace support systems. The results indicate that 20% of survey respondents have severe ADHD symptoms, with significant differences in symptoms reported by individuals with and without a diagnosis. Higher ADHD symptom levels correlate with decreased satisfaction with workplace support systems. Social anxiety and self-efficacy levels differ significantly between diagnosed and non-diagnosed individuals, with diagnosed individuals reporting higher anxiety and lower self-efficacy.

Overall, this research underscores the importance of recognizing and addressing ADHD in the workplace. By understanding the prevalence and impact of ADHD on workers, particularly in high-risk sectors like manufacturing, organizations can develop targeted interventions and supportive measures to enhance the well-being and

productivity of neurodivergent employees. The findings contribute to the broader understanding of ADHD in the workplace and its psychological impacts, providing a foundation for future studies and practical applications in occupational health and management.

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List of Abbreviations

ADD	Attention Deficit Disorder
ADHD	Attention Deficit Hyperactivity Disorder
AKA	Also Known As
ANOVA	Analysis of Variance
ASD	Autism Spectrum Disorder
ASRS	Adult ADHD Self-Report Scale
ASRS6	ASRS 6 Question Metric
ASRS18	ASRS 18 Question Metric
ASSP	American Society of Safety Professionals
AR	Augmented Reality
BCS	Behavioral Control Survey (AKA ASRS)
BLS	Bureau of Labor and Statistics
BOT	Automated responses to online surveys, short for Robot
CFR	Code of Federal Regulations
CI	Confidence Interval
CLAM	Cognitive Load Assessment in Manufacturing
EEG	Electroencephalogram
EHMAR	Enhanced head-mounted augmented reality
Fisher LSD	Fisher's Least Significant Difference
GLM	General Linear Model
GPSES	General Perceived Self-Efficacy Scale
HEP	Human Error Probability
HMAR	Head-mounted augmented reality
HMI	Human Machine Interface
HOP	Human and Organizational Performance
HWPP	Healthy Worker Participatory Program
I4.0	Industry 4.0
IDEAS	Intervention Design and Analysis Scorecard
IRB	Institutional Review Board
ITS	Intelligent Tutoring System

LSAS	Liebowitz Social Anxiety Scale
LMM	Labor Market Marginalization
MANCOVA	Multivariate Analysis of Covariance
MANOVA	Multivariate Analysis of Variance
MSE	Mean Squared Error
MWL	Mental Workload
ND	Neurodivergent
NHSR	Not Human Subjects Research
NIOSH	National Institute for Occupational Safety and Health
NSC	National Safety Council
NT	Neurotypical
OCB	Organizational Citizenship Behavior
OCB-I	Organizational Citizenship Behavior – Individuals
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PBAR	Projection-based augmented reality
PI	Performance Motivation Investigation
PWI	Paper work instructions
QI	Quality Motivation Investigation
SE	Standard Error
SKAMP	Swanson, Lotkin, Angler, M-Flynn, and Pelham rating scale
SME	Society of Manufacturing Engineers
SUS	System Usability Scale
SS	Sum of Squares
TLX	Task Load Index
TWH	Total Worker Health
VAST	Variable Attention Selectivity Trait
VIF	Variance Inflation Factor

1.0 Chapter One: Introduction

Manufacturing environments integrate intricate processes, cutting-edge technology, and a diverse workforce to produce the goods and materials that have become integral to our daily lives in our modern industrialized society. Despite the continuous advancements in automation and the adoption of advanced manufacturing methodologies, human beings continue to occupy important roles within these environments (Z. Wang et al., 2022). The well-being and performance of manufacturing workers are subject to many interacting factors. These encompass aspects such as workstation design, safety protocols, performance evaluation systems, environmental conditions, workplace culture, technological interfaces, and interactions of system elements, including humans.

A considerable body of research has been dedicated to analyzing the interplay of these factors among what might be termed "standard" or "typical" workers. However, a gap persists in our understanding of how these elements affect individuals whose cognitive processing deviates from the norm. In a workforce where upwards of 29% of individuals exhibit variations in brain processing, commonly referred to as "neurodivergent," there exists a dearth of research examining the impacts of manufacturing work environments on such individuals (Doyle & McDowall, 2021).

One specific category of neurodivergence that warrants closer examination is attention deficit hyperactivity disorder (ADHD), a neurodevelopmental condition that affects an estimated 4-10% of the workforce (Adamou et al., 2013; Biederman et al., 2005; Nagata et al., 2019a). These studies reveal a pronounced tendency for individuals with ADHD to be in lower-income brackets, face higher unemployment rates, and have diminished financial security, often occupying less skilled positions (Ayano et al., 2023; Das et al., 2012; Gémes et al., 2022; Gordon & Fabiano, 2019, 2019; Kessler et al., 2009). Gordon and colleagues observed increased ADHD prevalence in lower socioeconomic groups, correlating with heightened unemployment and, consequently, limited employment options for many affected workers (Gémes et al., 2022; Gordon & Fabiano, 2019). Further, Kessler and others have documented significant corporate costs and lost workdays due to reduced productivity linked to self-reported ADHD symptoms

(Kessler, Adler, Ames, Barkley, et al., 2005). It is against this backdrop that this dissertation sets its focus. Specifically, this dissertation investigates the effects of technology on both neurotypical individuals and those who report ADHD symptoms, examining their experiences in terms of mental workload, performance, and the subsequent ramifications on their psychological and physical safety within the manufacturing sector.

1.1 Statement of the Problem

Invisible disabilities and diverse cognitive styles present formidable challenges for individuals in the workplace, significantly elevating the potential for accidents and compromising production and quality standards. Traditionally, when employers endeavor to enhance workplace safety and efficiency, their decisions are primarily shaped by the needs and characteristics of neurotypical employees (Breslin et al., 2018; Breslin & Pole, 2009). Adoption of technology is typically driven by neurotypical employees, which is often intended to bolster safety, productivity, quality, or a combination thereof.

However, a critical question arises: what unintended consequences may arise from the implementation of such technologies without accounting for the unique attributes and cognitive profiles of individual workers? While prior research has diligently examined the effectiveness (e.g., productivity and efficiency) of various technologies and tools within manufacturing contexts, this inquiry has primarily focused on the application of the technology – not the impact of those using the technology (Chan et al., 2022; Elia et al., 2016; Funk & Schmidt, 2021; Ho et al., 2022; Keshav Kolla et al., 2021; Lovreglio, 2018; Reljić et al., 2021; C.-H. Wang et al., 2022).

How do technologies like augmented reality, vision inspection cameras, and lean tools impact a worker's mental workload, ability to execute tasks with precision and efficiency, and ability to learn and retain critical information? Furthermore, do these effects differ when the worker possesses neurodivergent traits, such as exhibiting symptoms of attention deficit hyperactivity disorder (ADHD)? The consequences of making decisions in the absence of answers to these fundamental questions affect not only the safety and performance of workers but also their psychological well-being and the economic well-being of their employers.

1.2 Purpose of the Research

This research serves a fundamental purpose: to contribute to the development of comprehensive workplace design recommendations that prioritize both safety and inclusivity. In addressing this objective, the overarching goal of this research is to address an identified gap in existing research, which has overlooked the specific effects of workplace design on neurodiverse individuals (Doyle & McDowall, 2021).

Our inquiry delves into the interplay between introducing diverse tools and technologies within a simulated manufacturing workstation and the resulting impact on worker perceptions of usability, cognitive load, performance, and quality. Importantly, this investigation extends its focus to encompass both neurotypical individuals and those who self-report symptoms of attention deficit hyperactivity disorder (ADHD). This approach sheds valuable light towards identifying potential strategies for integrating these technologies effectively into the workplace.

Furthermore, this study draws upon insights from various sources that have explored suitable accommodations for a range of neurodivergent conditions (Dwyer, 2022; Khan et al., 2022; McConner, CDE, PhD, 2023; Weber et al., 2021). By synthesizing this information, this research offers a glimpse at a much-needed perspective on the nuanced effects of technology on workers, paving the way for more inclusive and informed workplace practices in the future.

1.3 Business Case and Impact Assessment

Companies and workers alike bear a heavy toll of workplace fatalities, a well-documented concern. In 2021, the U.S. Bureau of Labor and Statistics recorded 5,190 workplace fatalities, marking an alarming 8.9% increase from the previous year. The National Safety Council estimates the comprehensive cost of work-related injuries and fatalities for that year to be a staggering $167 billion (National Safety Council, 2023b). Any reduction in these fatalities and the associated costs, in addition to physical harm to workers and resulting economic burdens, is significant and warrants thorough investigation.

As evidenced by Zaloshnja et al. (2006), a 38% injury rate reduction between

1993 and 2002 showed far-reaching economic benefits, amounting to approximately 9% of the average annual gross domestic product increase or $25.5 billion in the United States in this period. When analyzing injury rates across industries, manufacturing consistently ranks among the top ten highest number of fatalities (National Safety Council, 2023a). Alarmingly, the percentage of deaths from 2020 to 2021 rose 16% in the Manufacturing sector, and the death rate *rose* 10% in the same period. Given the nature of the manufacturing industry, where lapses in attention and errors can result in severe safety and quality repercussions, this dissertation focuses squarely on this critical sector. Figure 1 provides a sobering glimpse into the most significant fatal events affecting manufacturing workers in 2021 (National Safety Council, 2023b). Each event can be attributed to 'human error', but notably, they are intrinsically linked to system design.

The paradigms of *Human and Occupational Performance* (HOP) (Conklin, 2019) and *Safety Differently*™ (Dekker, 2014, 2016) have emerged to challenge the traditional "blame the person" mindset, advocating for a systems-thinking approach to preventing safety incidents through continuous improvement in system design. HOP emphasizes the importance of considering human factors in safety practices, recognizing the often intangible yet important psychological health effects of enhancing workplace design to reduce errors, cognitive load, and strain. These improvements yield tangible benefits for employers, including heightened productivity, reduced errors, enhanced profits, and enhanced physical and psychological safety. Moreover, improved workplace design fosters higher employee retention, fewer sick days, and increased overall productivity (Weber et al., 2021).

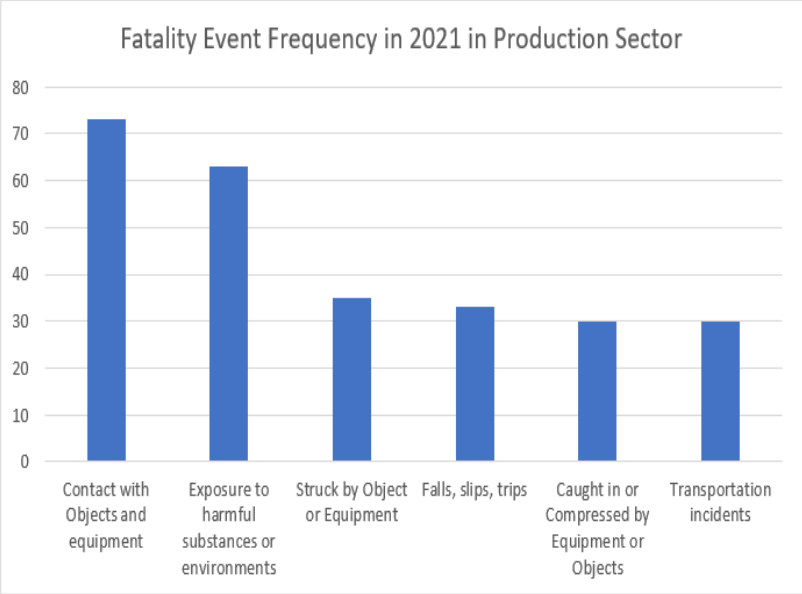

Figure 1: Top Fatal Events in 2021 Production Sector Workers

The significance of psychological health in the workplace extends to its influence on musculoskeletal disorder (MSD) injury rates, as highlighted by Afsharian et al. (2023). Figure 2 illustrates the large number of MSD injuries and illnesses across all sectors, showing a slight decline from 2011 through 2020 but still showing rates over 250,000 per year in the United States, underscoring the need for a more comprehensive evaluation of their causes. Relatively recent initiatives recognize the intricate connections between physical and psychological health factors related to these incidents.

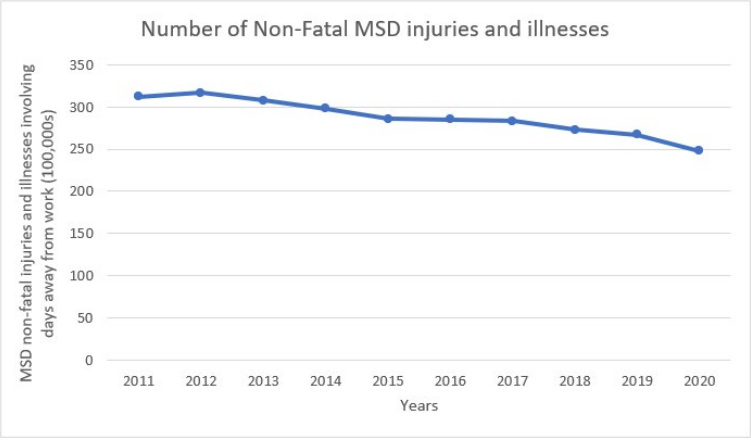

Figure 2: Number of Musculoskeletal non-fatal injuries and illnesses involving days away from work in 100,000s, 2011-2020 (National Safety Council, 2021)

Furthermore, creating a more inclusive workplace that enhances the psychological well-being of neurodiverse workers is a mutually beneficial endeavor. Neurodiversity has typically been framed as a medical model of disability (Chapman, 2021). However, social pressures to highlight the benefits of neurodiversity challenge workplaces to embrace a more ecological approach that incorporates macro and micro environment considerations to workplace design (Chapman, 2021; Duffy & Romero, 2024). In response to studies reporting neurodivergent workers significantly higher rates of unemployment, sick days, workplace injuries, and workplace conflicts, researchers call for consideration of psychosocial programs tailored to their workers' needs (Das et al., 2012; Gémes et al., 2022; Khan et al., 2022). Such an environment reduces unemployment rates among neurodivergent individuals and allows their unique strengths to better benefit the workplace (Khan et al., 2022; Weber et al., 2021). Neurodiverse employees, when provided with psychologically safe accommodations, are more likely to leverage their distinctive cognitive perspectives, thus fostering creativity, innovative problem-solving, collaborative teamwork, the identification of patterns in extensive data, and leveraging hyper-focused bursts of productivity (Chapman, 2021). Conversely, suboptimal conditions for neurodivergent workers, including those with ADHD symptoms, correlate with higher injury rates, increased sick days, and diminished productivity (Das et al., 2012; Kessler et al., 2009). For instance, Kessler et al. (2005) demonstrated a 4-5% decrease in productivity and a 2.0 relative odds increase in workplace accidents and injuries. This further underscores the importance of designing workstations that account for heightened inattention and error rates, ultimately improving product quality and reducing safety incidents.

Incorporating principles from Total Worker Health (TWH) and Human and Occupational Performance (HOP) into safety programs and workplace design carries a multitude of documented advantages, as summarized in Figure 3 (Calvallari & Nobrega, 2021).

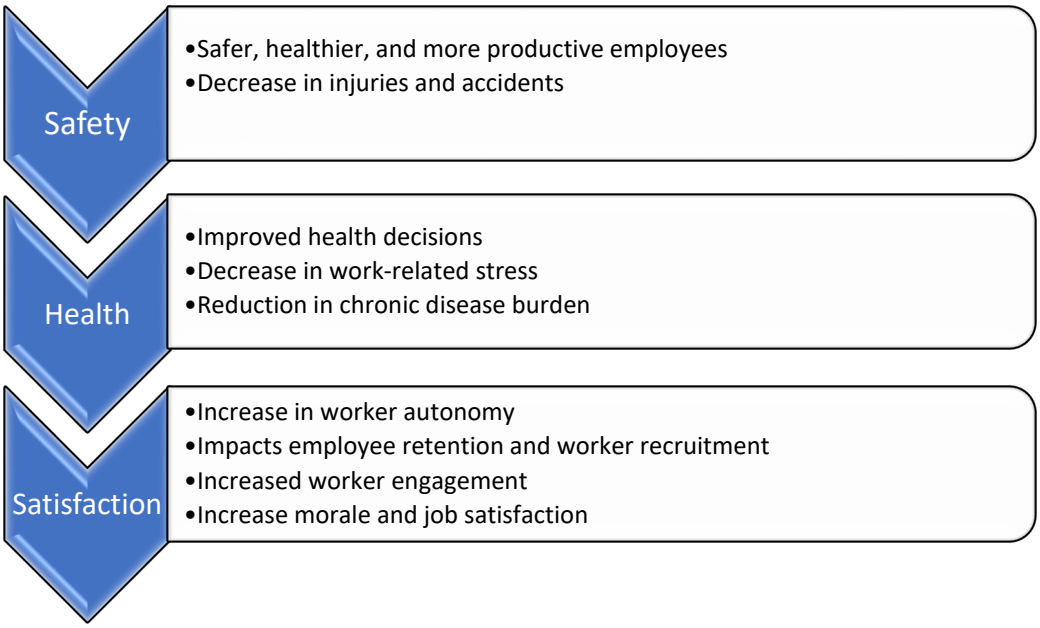

Figure 3: Benefits of TWH and HOP principles in workplace design. Adapted from: (Calvallari & Nobrega, 2021)

In conclusion, this dissertation provides insights into potential benefits, such as enhancing understanding of occupational safety and possibly influencing rates of fatalities and incidents. In addition, it offers a more nuanced perspective on how technology affects workers, especially those with ADHD. This knowledge equips engineers and managers responsible for workstation design with helpful information that might aid in addressing the needs of workers and potentially reducing error rates (Ballard & Pantazes, 2024). The outcomes of this study contribute to a deeper understanding of workplace dynamics, potentially assisting employers in fostering more psychologically supportive work environments. Additionally, the insights gleaned from manufacturing environments may inform broader design principles, offering general guidance for current and future technology implementations and worker well-being.

1.4 Workplace Trends Toward Technology Adoption

Across various workplaces, a discernible trend is emerging: the rapid adoption of technology to replace or augment routine, repetitive tasks. This shift carries particular significance for workers with ADHD, as most workers commonly find such menial tasks

grating and intolerable, but workers with ADHD find them *especially* difficult (Halbesleben et al., 2013). Replacing these menial tasks with automation will benefit all workers, but workers with ADHD will gain even greater benefits.

The future employment landscape is set to demand a greater influx of individuals adept at innovative thinking and creativity, important attributes for guiding organizations through this transformative phase (LeFevre-Levy et al., 2022). Workers with ADHD have fewer sick days when employed in positions that allow flexible scheduling and have less structured jobs (Adamou et al., 2013; Das et al., 2012). For workers with ADHD in positions that already allow for flexibility and creative thinking, these workplace transitions present an encouraging prospect. However, this transition bears less favorable implications for blue-collar workers with ADHD, as their job roles are evolving in uncharted ways, with little prior investigation into the potential impacts on this specific demographic. As discovered through an extensive review of published literature, there is a pronounced scarcity of research surrounding the efficacy of accommodations designed to support workers with ADHD, particularly in the context of emerging technologies like Augmented Reality (AR).

1.5 Research Objectives

This research project encompasses three objectives. First, it aims to shed light on the impact of technology on manufacturing workers, with particular attention to discerning differences in its effects on those reporting significant ADHD symptoms compared to those with little or no self-reported ADHD symptoms. Second, it seeks to evaluate the efficacy of various workplace support systems within a manufacturing simulation, focusing on dimensions such as cognitive load, usability, performance, and quality, especially for participants reporting significant ADHD symptoms. Third, through a survey, it seeks to determine the prevalence of undiagnosed ADHD and the relationship between psychosocial stress and anxiety related to ADHD symptom status of workers.

To achieve these objectives, a pilot study and three distinct investigations have been conducted, each detailed within its respective chapter. A summary of the experimental design parameters for these investigations is provided in Table 1 below.

Table 1: Summary of Experimental Design Parameters

Experiment	Type of Study	Number of Treatments (Treatments)**	Experimental design type	Analysis method
Pilot Study (AR evaluation)*	Within Subjects	2 of 2 (PWI, PBAR)**	Random	ANOVA
Manufacturing Technology Support Investigation (AR type training)	Between Subjects	1 of 4 (PWI, PBAR, HMAR, EHMAR)	Quasi-random***	ANOVA GLM Regression Analysis Post-Hoc Analyses
Manufacturing Workplace Support Investigation (Lean and I4.0 tool effectiveness)	Within Subjects	4 of 4 (PWI, Lean, I4.0, Lean+I4.0)	Random	ANOVA GLM t-test Regression Analysis Post-Hoc Analyses
Workplace Psychosocial Survey	Between Subjects	N/A	Survey Research Correlational Research	ANOVA Binary Logistic Regression Regression Analysis Post-Hoc Analyses

*Serving as an information-gathering study for designing Investigations 1 and 2.
**PWI = paper work instructions, PBAR= Projection based augmented reality, HMAR= head mounted augmented reality, EHMAR = Enhanced head mounted augmented reality, Lean = Three-dimensional check piece technology, I4.0 = vision camera inspection station
*** = Quasi-random conditions occurred due to technology malfunctions and staffing issues when offering the HoloLens trials to specific participants.

1.6 Research Questions

The broad research question is: What are the costs and benefits of implementing assistive tools and technology in manufacturing environments? However, not all costs and benefits can be addressed in this dissertation. More specifically, are there individual differences in experiencing such costs and benefits, particularly in workers with ADHD symptoms?

Probing the costs and benefits of introducing technology into manufacturing environments, with a specific focus on individual differences, particularly among workers with ADHD symptoms, holds substantial significance and practical relevance. Its outcomes will potentially guide additional research that could influence future workplace decisions in the ever-evolving landscape of technology adoption. Understanding how technology influences manufacturing workers overall, irrespective of their neurodivergent status, provides a foundation for making informed choices regarding the integration of technology solutions. In a landscape where such individual difference data are scarce, this research serves as an initial exploration into technology's impact on workers with invisible disabilities, setting the stage for broader investigations into diverse conditions.

1.6.1 Manufacturing Technology Support Investigation Specific Aim

1. This study aims to compare cognitive load, system usability perceptions, production speed, and quality outcomes between adults reporting 'significant' versus 'no or few significant' ADHD symptoms when using three AR technologies versus traditional work instructions.

1.6.2 Manufacturing Workplace Support Investigation Specific Aims

1. This study aims to investigate the impact of using a check piece, a vision camera inspection system, or their combination during **quality** motivating and **performance** motivating scripts on outcomes including cognitive load, system usability perceptions, production speed, and quality.
2. This study aims to assess whether adults reporting 'significant' versus 'no or few significant' ADHD symptoms exhibit differences in cognitive load, system usability perceptions, production speed, and quality during the use of a check piece, a vision camera inspection system, or both, while exposed to **quality** motivating or **performance** motivating script.

1.6.3 Workplace Psychosocial Survey Specific Aims

1. Aims to evaluate ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS v1.1) and compare these to self-reported diagnoses.
2. Aims to determine the prevalence of undiagnosed adults and whether this prevalence is different for different employment sectors.
3. Aims to explore the relationship between self-efficacy and anxiety and ADHD symptom reporting and ADHD diagnosis in adults, especially in the manufacturing sector.
4. Aims to explore the relationship between workplace support systems perception and ADHD symptom reporting and ADHD diagnosis in adults.

2.0 Chapter Two: Narrative Literature Review

This chapter summarizes the domains of Attention-Deficit/Hyperactivity Disorder (ADHD) in adult workers, methodologies employed for the assessment of ADHD, Cognitive Load Theory (CLT), techniques employed for the evaluation of Cognitive Load, the Multiple Resource Theory (MRT), Cognitive Ergonomics, and the methodologies utilized for assessing Augmented Reality in the manufacturing context. Each of these areas contributes insights into the exploration of mental workload application within the area of manufacturing operations, particularly concerning workers with ADHD.

2.1 Attention-Deficit/Hyperactivity Disorder (ADHD) Adult Workers

2.1.1 What is ADHD

Edward Hallowell, M.D., a psychiatrist and recognized authority on ADHD, is the author of Driven to Distraction and 20 other books. Driven to Distraction, co-authored with Dr. John Ratey (Hallowell, M.D. & Ratey, M.D., 1994), clarified the symptoms and treatment of a newly defined disorder: Attention Deficit Disorder (now recognized by the name ADHD). Combating social stigmas against the diagnosis and treatment of individuals who have inherited this condition, Drs. Hallowell and Ratey give details on the executive functioning limitations and challenges for people with ADHD. They also offer advice to those who live with persons with ADHD and management techniques to limit the negative tendencies commonly associated with the disorder.

Since this original publication, Dr. Hallowell has also published in his book ADHD 2.0: New Science and Essential Strategies for Thriving with Distraction (Hallowell M.D & Ratey M.D, 2021) on an increasingly common condition called Variable Attention Stimulus Trait (VAST) that describes all people experiencing ‘ADHD’ traits even though they may not meet the diagnostic criteria for ‘ADHD.’ Due to increasing stimuli from daily life, such as nonstop electronic notifications, busy pace of life, and multiple demands on time and attention, more and more people are experiencing

the symptoms of VAST, also called attention deficit trait (ADT), for those who have not inherited the symptoms, but have onset related to the environment (Hallowell, 2005).

In Hallowell's 2005 article titled "Overloaded Circuits: Why Smart People Underperform," Dr. Hallowell describes the symptoms of ADT, now more commonly referred to as VAST, as fear and survival reactions to situations that "prevent fluid learning and nuanced understanding" (Hallowell, 2005). When a person's physiology reacts to survival mode, executive functioning reverts to black-and-white thinking, seemingly making intelligence dim (Hallowell, 2005). Many other consequences of this mental state include: "impulsive judgments, angrily rushing to bring closure…, forget[ting] the big picture and the goals and values he stands for, los[s of] creativity, and his ability to change plans, … prone to melting down, throwing a tantrum, blaming others, and sabotaging himself " (Hallowell, 2005). VAST is controlled by adjusting the environment and attending to one's emotional and physical health, and it is not treatable by medication, unlike ADHD (Hallowell, 2005). Due to the similarity in symptomology and the shared impact on individuals in a work setting, this dissertation adopts an integrated approach, addressing both VAST and ADHD. ADHD in the data is potentially indicative of VAST since ADT/VAST is expressed similarly in symptomology with ADHD. It is important to note that while these conditions exhibit comparable manifestations, they stem from distinct underlying causes. Subsequent sections of this paper will focus exclusively on the discussion of ADHD.

Attention Deficit/Hyperactivity Disorder (ADHD) has been shown to have morphological, genetic, and chemical distinctions in patients diagnosed with this disorder (Adamou et al., 2013). This means people with ADHD have structural differences in their brains, have genetic markers that predispose them to the condition, and have a distinctive chemistry in their body that affects how their brains function. Historically, ADHD was considered a childhood disorder and culturally stigmatized as a "rowdy little boy" condition (Adamou et al., 2013). Unfortunately, this stigmatization has hindered the accommodation of adult individuals that suffer from the deficiencies caused by this disorder. As many as 50% of childhood-onset ADHD patients have significant symptoms that persevere through adulthood. Current estimates of the prevalence of ADHD in the US and world adult populations (similar for both genders) is at least 4% but possibly

higher and reaching at least 10% (Adamou et al., 2013; Biederman et al., 2005; Nagata et al., 2019a). ADHD is classified as a lifetime condition and accepted as a disability since its sufferers encounter symptoms that affect executive functioning. Some of the most common symptoms of ADHD in adults are difficulty following instructions, feeling the need to be moving, hyper-focus, procrastination, substance abuse, motor coordination issues, working memory issues, and emotional regulation issues (Adamou et al., 2013; Frazier et al., 2007; Küpper et al., 2012). These symptoms translate to several issues in the workplace.

2.1.2 Effect of ADHD on Workplaces

The status of occupational and organizational research on workers with ADHD focuses on how their increased absenteeism, presenteeism, and increased injuries are detrimental to the workforce. One such journal article even estimates that personnel with ADHD cost US businesses an annual amount of $67-116 billion because of increased days off work (Küpper et al., 2012). Other concerning statistics include double the likelihood of workers with ADHD having safety incidents, 22.1 more days of annual absenteeism per year than non-ADHD counterparts, increased substance abuse, increased mood and anxiety disorders, and increased criminality (Küpper et al., 2012). Küpper et al. gathered their data from the MEDLINE database for a literature review with the goal of identifying both direct and indirect effects of ADHD on work, employment, and occupational health.

Though included in the previously mentioned literature review, Kessler et al. surveyed 8,563 workers, 163 reporting significant ADHD symptoms (1.9%), over two years at a *large manufacturing firm* to evaluate the prevalence of ADHD and associated outcomes (Kessler et al., 2009). Kessler suggests that the ADHD prevalence might be conservative for a number of reasons, including diagnosis criteria used were designed for children, not adults, the low response rate for ADHD workers responding to the survey, and bias in the calibration rules to generate diagnoses (Kessler et al., 2009). This is the only study published with participants with ADHD in Manufacturing. Respondents were given the Adult ADHD Self Report Survey (ASRS) and the WHO Health and Work Performance Questionnaire (HPQ) to assess sickness absence, work performance, and

workplace injuries. Scores from the ASRS results were transformed into predicted probabilities of DSM IV adult ADHD and used for the analysis; this technique is different than most other analyses done with ASRS self-report values, which could have also contributed to the low incidence rate (Kessler et al., 2009). The HPQ is a self-report checklist of the previous year's incidence of physical and mental ailments. In this study, the lowest prevalence of ADHD was among executives and the highest among blue-collar skilled workers. This study investigated the presence of comorbid conditions with ADHD and found a higher probability of these conditions. ADHD was found to be higher for 16 of the 17 co-morbid conditions, and the only exception was cancer (Kessler et al., 2009). Chronic back and neck pain had an odds ratio of 1.5 (95% CI 0.9-2.6) for workers with ADHD symptoms (Kessler et al., 2009). The significant co-morbid conditions were reported as: other chronic pain (OR 1.8, 1.0-3.5 95% CI), insomnia (OR 2.6, 1.5-4.4 95% CI), chronic fatigue syndrome (OR 2.3, 1.4-3.9 95% CI), and depression (OR 2.8, 1.3-6.0 95% CI) (Kessler et al., 2009). While the association does not necessarily suggest causal factors, there may be a contribution of untreated ADHD symptoms that may increase the likelihood of these conditions. Job performance was reported to be 4-5% lower for workers with ADHD. ADHD workers also had higher rates of sick days usage. While overall healthcare costs were not found to be greater for ADHD workers, the study monetized the additional sick days and loss of performance estimates to be $4,336 per worker with ADHD per year (in 2009 USD). This manufacturing facility had a meager treatment rate for ADHD based on the insurance records of the employees; approximately 7% of the workers with ADHD were prescribed medication for treatment.

Other significant studies mentioned in the literature review include Breslin and Pole (2009), who gathered data on 14,379 young adult Canadian workers aged 15 to 24. Data of interest on the survey included specifying learning disability and/or ADD/ADHD diagnosis, major injuries in the past 12 months, education status (enrolled in high school or secondary school, completed high school), job status (number of hours worked, industry worked, number of jobs). "When respondents were identified as experiencing more than 1 of [dyslexia, other learning disability, or ADD/ADHD], dyslexia was considered first, followed by the other learning disorders, and finally, ADD or ADHD" (Breslin & Pole, 2009). In doing this, the handling of disability diagnosis in the statistical

analysis was slanted toward dyslexia in participants who reported more than one diagnosis, and researchers failed to mention how this could have affected the outcomes for ADHD and other learning disability results. Results showed higher rates of manual jobs for workers with ADHD compared to higher rates of service industry jobs for non-reporting workers. Manual jobs showed an odds ratio of 2.9 for work-related injuries relative to nonmanual jobs. ADHD workers showed a likelihood of injury twice of those in other groups, but the increased risk was eliminated when the type of job and demographics were accounted for. Researchers conclude that it is more important to look at school completion, literacy, and type of job to mitigate the risks to ADHD workers.

Breslin et al. (2018) also conducted a similar study of Canadian adult workers with disabilities and their exposure to hazards in the workplace. In their sample of 3,334 individuals, participants were surveyed via phone and email using an Occupational Health and Safety vulnerability survey. Their research showed that once a disabled worker achieves employment, despite the barriers to doing so, it is often difficult to sustain employment. In addition, disabled workers "may also experience more hazardous working conditions" due to organizational factors that produce safety risks for workers (Breslin et al., 2018).

ADHD has also been shown to affect the labor market overall. Helgesson et al. (2023) performed a population-based register study to investigate the effect of ADHD diagnosis on the subsequent labor market marginalization (LMM) and severe issues with gaining and keeping employment (Helgesson et al., 2023). They compared the 16,647 ADHD young adults to age-matched young adults in the general population and non-ADHD siblings. The participants were followed five years after ADHD diagnosis. To evaluate LMM, the researchers looked at disability pension payments five years after the ADHD diagnosis, long-term sickness absence (>90 days), and long-term unemployment (>180 days). The results indicate that young adults with ADHD have a tenfold higher risk for disability pension, a threefold higher risk of long-term sickness, and an odds ratio of 1.7 risk of long-term unemployment. Overall, ADHD contributed to significantly decreasing the Swedish young adults' ability to gain and keep jobs. In a similar study in Sweden, Gemes et al. (2022) compared LMM to the sector of work for ADHD and non-ADHD young adult workers. Remarkably, no differences were found in LMM rates

between the sectors of work types (manual labor vs service).

These data paint a somewhat bleak picture for those with ADHD and raise questions as to why employers might want to hire someone with ADHD if it were to cost the company more money, risk increased accidents, and the likelihood of dealing with increased theft of property and other issues. However, these costs are often related to the relative lack of accommodation for people with ADHD. In addition, not looking at the whole picture and putting a class of people with ADHD and similar disorders all in one box together without context or explanation is part of the problem. According to Adamou et al. (2013), individuals with ADHD are twice as likely to get injured at work when demographic and job characteristics are not statistically considered. However, this increased risk was no longer significant after adjusting for these factors (Adamou et al., 2013, p. 840). This finding brings into question the findings of other researchers reporting higher odds of injury for workers with ADHD. It is important to consider how ADHD affects workers to get a more complete picture and better understand potential accommodations.

2.1.3 Effect of ADHD on Workers

The impact of ADHD extends beyond the broader workplace environment and affects the individuals who have the condition. Understanding how ADHD influences workers' performance, self-efficacy, job satisfaction, and overall well-being is important for creating supportive and effective workplace support systems. This section explores various research studies and resources that examine the effects of ADHD on workers, highlighting the diverse experiences, challenges, and potential advantages faced by individuals with ADHD in their professional lives.

ADHD is known to exhibit differently for different individuals and is experienced in a spectrum of severities. The disorder is often treatable with a combination of medication and psychotherapy. Quantifying how the symptoms of the condition affect work outcomes is achieved through various methods in the limited studies investigating ADHD in the workplace. Some psychologists have chosen to study workers in their most incapacitated state – requiring workers to refrain from treatment (i.e. not taking their prescribed medications for a set amount of time) to exacerbate their symptoms for

measurement purposes (Adamou et al., 2013; Biederman et al., 2005; Nagata et al., 2019b). By measuring untreated ADHD, these studies may present those with medically treated ADHD in a less favorable light, potentially exaggerating the condition's impact on their work performance.

In reality, many successful entrepreneurs function very well with their ADHD. The entrepreneurs and business leaders listed in the table below cite their success to their abilities and struggles related to growing up with ADHD (Gilman, 2006). However, it is noted that the individual treatment statuses of these individuals are unknown.

Table 2: Famous Entrepreneurs and Business Leaders with ADHD (Gilman, 2006)

Entrepreneur	Company	Role
David Neeleman	Jet Blue Airways	Founder
Paul Orfelea	Kinko's (Now FedEx Office)	Founder
Diane Swonk	Bank One, Chicago	Chief Economist, Author
Alan M. Meckler	Mediabistro	Former CEO
Charles Schwab	Charles Schwab & Co.	Founder and Chairman

Some call it a "superpower" as it allows them to make decisions quickly and stay flexible in the ever-changing workplace (LeFevre-Levy et al., 2022). "According to ADHD experts Edward Hallowell and John Ratey (2021), the ADHD brain is full of seemingly 'paradoxical tendencies'" (Hallowell M.D & Ratey M.D, 2021). Specifically, they have argued that ADHD, "rather than being a condition characterized by attentional defects, would be better characterized as a condition of attentional abundance in which individuals are constantly scanning their environment for novel or interesting stimuli" (Hallowell M.D & Ratey M.D, 2021, p. 7). This enhances their ability to perform in fast-paced environments.

Persons with ADHD often have significantly increased difficulty doing tasks that are mundane and repetitive, beyond what would be considered "normal" (Hallowell M.D & Ratey M.D, 2021). At levels not typically predicted by theories, such as Yerkes

Dodson "Law"[1], with repetitive tasks, workers with ADHD tend to lose focus and have difficulty maintaining attention to detail that would be required for the job. However, a challenging paradox related to this is the high percentage of persons with ADHD who are unemployed or underemployed, and many entry-level and non-skilled jobs involve menial and repetitive tasks (Fabiano et al., 2018). Studies evaluating job performance for food service jobs found the biggest detriment to the job search and training process to be in the job application and interview steps (Fabiano et al., 2018). Performance of training and job tasks were not found to be different than non-ADHD workers in a simulated pizza job (Fabiano et al., 2018). In an office work simulation experiment, persons with ADHD and non-ADHD characteristics were given assessments and tasks similar to office work; notable differences were found in reading comprehension, math fluency, and self-reported behavior but not attention (Biederman et al., 2005). However, these studies represent yet another set of experiments that did not allow ADHD participants to take their treatment medication prior to participation.

In many studies including participants with ADHD, the validated Adult ADHD Self-Report Scale (ASRS) is used to screen participants for symptoms of ADHD ("Adult ADHD Self-Report Scale (ASRS)," 2021; Biederman et al., 2005; Fabiano et al., 2018; Halbesleben et al., 2013; Kessler et al., 2007; Nagata et al., 2019b). In using this scale, experimenters can reliably classify participants as having significant symptoms of ADHD or not and analyze connections between the severity of the symptoms and particular outcomes. For example, Masako Nagata et al. (2019b) investigated "how ADHD symptoms play an interaction effect on the association between psychosocial work environments and health (psychological distress/work engagement) among workers" (Nagata et al., 2019b, p. 1). They found that job control and social support are

[1] There is debate within the industry as to the proper name of this relationship; some peer-reviewed publications call this the Yerkes-Dodson Law, while other professionals argue it is not a "law" (R. A. Cohen, 2011; Wickens & Carswell, 2021).

increasingly important factors as the severity of ADHD symptoms increases. If social support and job control decrease, workers with ADHD experience heightened increases in psychological distress (Nagata et al., 2019b). Findings such as these lead to a discussion of what can be done by workers and employers to help alleviate this distress and accommodate the ADHD symptoms.

Another interesting finding in Halbesleben et al.'s (2013) work is the mechanism by which workers with ADHD tend to have decreased work performance. This mechanism was not what many, even the researchers, expected (Halbesleben et al., 2013). It was anticipated that decreased work performance would result from loafing around doing unhelpful job tasks or generally being off task. Instead, the study found an increase in organizational citizenship behavior (OCB), particularly OCB-I (which is OCB behavior directed toward individuals). The rationale is that OCB-I behavior is helpful to other workers, tends to add a more urgent nature to the task, and ends up satisfying a more immediate need than the job-related tasks. As such, persons with ADHD were found to choose to engage in more immediately satisfying work that was not in their actual job description instead of completing tasks that would increase their work performance. “In the workplace, the opportunity to help an individual is appealing because it can, in most cases, be more quickly acknowledged and reciprocated compared with periodic reviews of task performance” (Halbesleben et al., 2013, p. 134). Another interesting finding in this study was a disparity in how individuals with ADHD view their off-task work compared to supervisors and coworkers: the workers with ADHD reported less off-task time compared to co-workers' assessments of them. Halbesleben concluded it appeared that workers with ADHD underestimated their time off task (Halbesleben et al., 2013).

Suzuki et al. surveyed 1,240 Japanese workers, all of whom were university graduates, through an online survey (2023). The number of ADHD symptoms for each worker was collected through the use of the ASRS. Other sociodemographic information collected in the survey included: sex, age, socioeconomic status, working time, amount of sleep, consumption of midnight meals, regular meals, occupational position, drinking habits, smoking habits, and physical exercise. Significant results included that as the number of ADHD symptoms increased, subjects reported fewer hours of sleep and a

higher incidence of midnight meals. Other significant results indicate workers with lower incomes had higher levels of ADHD traits. Males had ADHD traits more than females and younger participants had a higher incidence rate than older workers. Less restful sleep and shortened sleep hours by workers with ADHD can result in daytime sleepiness. Conclusions made by researchers highlight the importance of support for workers with ADHD traits, especially related to difficulties sleeping and other job-related outcomes that ADHD traits can affect.

2.1.4 Holistic View of Workers With ADHD

As programs, such as Total Worker Health and *Safety Differently*™, have gained popularity and wider spread implementation in workplaces, workers are being viewed through a different, more holistic lens. This lens considers physical, psychological, and psychosocial influences on workers' well-being. Taking this holistic view toward workers with ADHD highlights the potential benefits of including ADHD workers in all workplaces. In the last ten years, a shift in literature has been seen in how the effects of ADHD are being investigated and reported.

For example, in 2017, Bjerrum, Pedersen, and Larsen performed a qualitative systematic review of the literature on how adults diagnosed with ADHD experience and manage to live with the condition (Bjerrum et al., 2017). The severity of ADHD symptoms was not accounted for in this systematic review; the basis for inclusion was a person's diagnosis of ADHD (Bjerrum et al., 2017). Rather than focusing solely on the adverse effects of this disorder, researchers worked to investigate from the perspective of adults with ADHD what life is like daily. Researchers state, "Attention deficit hyperactivity disorder symptoms affect the individual's quality of life, so living with ADHD becomes 'a way of life'" (Bjerrum et al., 2017). The conclusions from the meta-analysis include the following items:

1. Adults with ADHD are aware of being different from others and strive to be an integrated, accepted part of the community.
2. Adults with ADHD are creative and inventive.
3. Adults with ADHD develop coping strategies in striving for a healthy balance in life.
4. For adults with ADHD, accomplishing and organizing tasks in everyday life is a challenge, but it can also be rewarding. (Bjerrum et al., 2017)

This study highlighted not only the struggles and potential issues adults with ADHD experience but also the potential positive aspects of ADHD experience (Bjerrum et al., 2017). Persons with ADHD tend to have the ability to make quick connections, think on their feet, and see problems from a different perspective than those without ADHD (Bjerrum et al., 2017).

Most recently, Oscarsson et al. conducted phone interviews with twenty ADHD-diagnosed adults in Sweden (Oscarsson et al., 2022). The themes of the directed questioning included working and living with ADHD, needs, and special abilities. Each theme had sub-categories, as seen in the figure below.

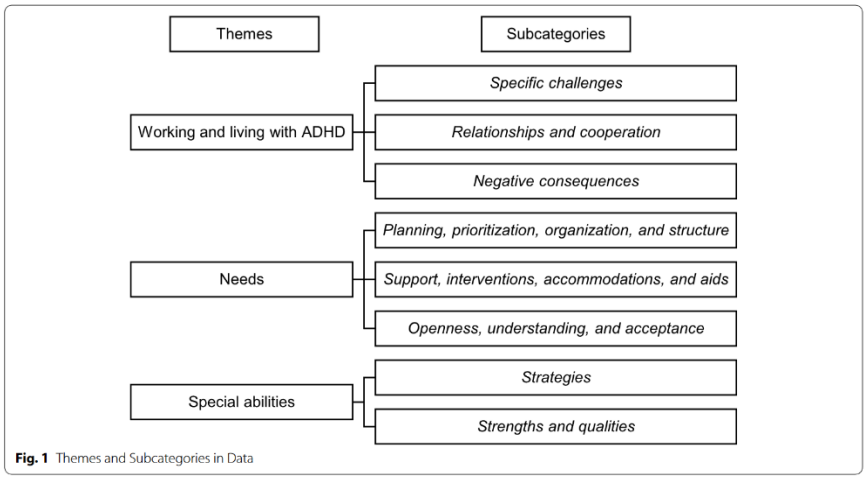

Figure 4: Themes and Subcategories (From Figure 1, (Oscarsson et al., 2022))

Conclusions from this study highlight circumstances where organizational support is insufficient; employees are left to self-accommodate (Oscarsson et al., 2022). Also, disclosure of ADHD to an employer is not an easy or straightforward decision for employees. There is additionally a need for interventions for high-functioning workers. Workers with ADHD were frequently found to have quick-wittedness and high levels of creativity, which, many times, have been proven to counteract any periods of low productivity (Oscarsson et al., 2022). Many workers self-accommodate with personalized strategies, deploying their strengths to improve their personal functioning and alleviate their burden of symptoms (Oscarsson et al., 2022). No studies were found to observe the outcomes of ADHD workers in the field, as all these studies were surveys, government databases, or medical record reports. Very few studies have investigated the outcomes of

workers with ADHD in simulated work environments, which are summarized in the following section.

2.1.5 Workplace Simulation Studies with ADHD Adults

A literature search revealed three workplace simulation studies with adult workers with ADHD. No other workplace simulation studies were identified that were not specifically medication trials but were investigating outcomes of workers with ADHD in work environments.

The first ADHD workplace simulation study was published in 2005. Biederman, Fried, et al. conducted a smaller-scale workplace study in Boston, Massachusetts, with 36 participants, half with a diagnosis of ADHD (Biederman et al., 2005). The workplace simulation was 8 hours long and consisted of sitting at tables completing questionnaires and two sets of the following tasks: reading, logic problems, writing, math fluency, and video comprehension. Participants were evaluated using the Swanson, Lotkin, Angler, M-Flynn, and Pelham (SKAMP) rating scale. The SKAMP rating scale rates two classroom behaviors: attention and behavior. Participants also filled out self-report questionnaires on subjective feelings. Results showed performance deficits in the ADHD group in reading comprehension and math fluency, whereas other tasks did not show deficits. Statistical differences in the SKAMP behavior subscale were noted with the ADHD group but not the attention subscale.

Study two, seven years after the initial workplace study by Beiderman and Fried et al., performed another simulated workplace study for a ten-hour workday for 6-10 workers at a time; half of the participants each day were diagnosed with ADHD, observers were blind to their status (Fried et al., 2012). A total of 119 participants participated in the simulation (56 non-medicated ADHD, 63 without ADHD). The workday consisted of a combination of structured and unstructured time. During structured time, participants were asked to do a variety of activities, including timed math tests, watching recorded lectures and taking quizzes, performing standardized tests, reading comprehension, and editing. During unstructured times, participants were given a packet of tasks and were told once what was expected during the unstructured time without reminders or prompting; additional optional tasks were also included in the

packets. Participants were observed and provided self-reports on ADHD symptoms throughout the day. Results indicated that ADHD participants experienced a heightened feeling of internal restlessness and feeling like they needed to move but were not observed by the raters.

As seen in the results of Figures 5 left and right, the most significant observable difference between the two study groups was during the video task, where ADHD participants were less able to hide their inattentive and hyperactive symptoms. During the Math Fluency task, ADHD participants scored lower than control participants, other tasks the scores were comparable. “Completing routine tasks under timed conditions and attending to detail are key weaknesses for individuals with ADHD that could have major

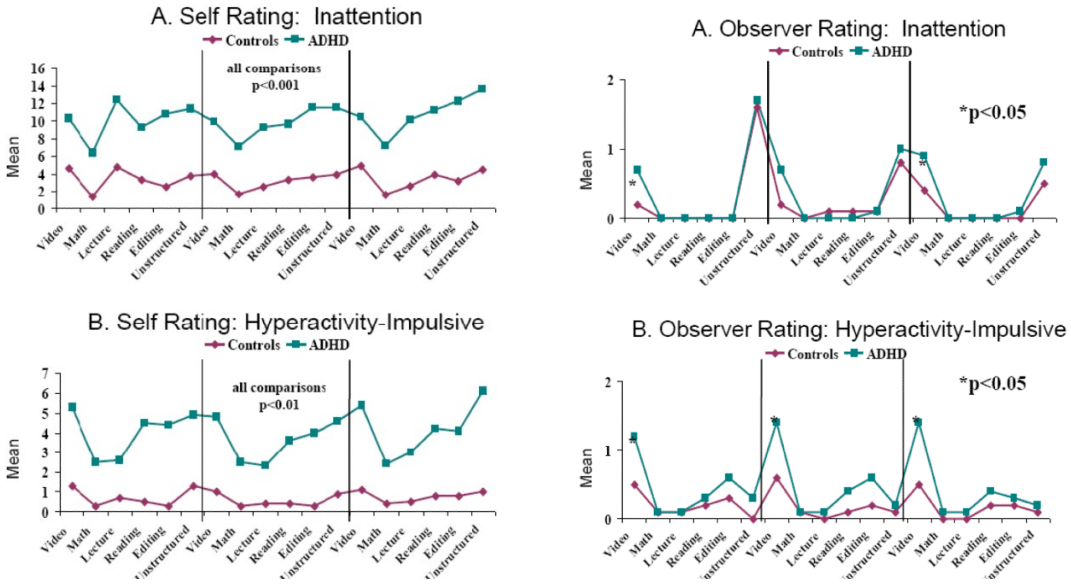

Figure 5: Left (A) Self-Rating by Subjects of Internal Feelings of Mental Restlessness and Inattention; (B) Self-Rating by Subjects of Internal Feelings of Physical Restlessness and Hyperactivity (From Fried et al., 2012, Figure 1)
Right: (A) Observer Blinded Ratings of Subjects' Symptoms of Inattention; (B) Observer Blinded Ratings of Subjects' Symptoms of Hyperactivity. (From Fried et al., 2012, Figure 2)

impact in workplace performance” (Fried et al., 2012). Researchers acknowledge that the participants knew they were participating in an ADHD workplace study and this knowledge could have affected the results and outcomes. “For limited periods of time, such as when under scrutiny, adults with ADHD can successfully mask these symptoms,

struggling with a competing urge to move [their limbs] while attempting to complete a task can be expected to lead to poor performance and job failure over the long term" (Fried et al., 2012). This task was also novel, as such novel activities have shown in previous ADHD studies to increase performance in ADHD participants, only to dramatically decrease once the newness has worn off (Fried et al., 2012).

The third and last ADHD workplace study, published in 2018 by Fabiano, Hulme, Sodano, Caserta, Hulme, Stephan, and Smyth, employed a simulated workplace study with 26 young adults without ADHD and 24 young adults with ADHD (Fabiano et al., 2018). Subjects participated in a pizza restaurant and delivery setting. Participants were observed completing tasks related to a typical first job in the fast-food industry, including job application and interview, food preparation, driving, deliveries, and customer service. Using a multivariate analysis of variance, no significant overall effect of group in the analysis of job application variables was found. However, there was a significant difference in driving history between the groups, with the ADHD group having more traffic violations and more accidents. Job performance for both groups showed no significant differences. However, ADHD participants performed slightly better than non-ADHD. Participants from the non-ADHD group performed better on the job interview, suggesting a potential need for support for ADHD workers.

2.1.6 Accommodation of ADHD in Workplaces

The primary recommendation of professionals highlights the need for identification, diagnosis, and treatment of workers with ADHD (Adamou et al., 2013; Nagata et al., 2019b). Treatment has proven effective at reducing symptoms of ADHD and decreasing the negative outcomes highlighted by so many of the research studies on the disorder. However, due to the many side effects of the common medications for ADHD, many patients choose to self-manage or self-medicate with caffeine or other substances. Reducing the workplace and social stigmas of this disorder is a first step toward workers feeling safe to ask for help and seek treatment and accommodation.

Given that there is no one-size-fits-all formula for accommodating ADHD symptoms, here are some general recommendations that can be made to alleviate some of the main symptoms. Starting with the ADHD symptom of attention and impulsivity,

some of the accommodations that can be provided allow workers to adjust the level of stimulation from work-related noise and activity, allowing others to have a more active role in redirection of work-specific tasks and allowing work hours to be adjusted by the worker (Adamou et al., 2013). Overstimulation and distraction in the work environment can increase off-task behaviors in people with ADHD. Having isolated and reduced distraction offices and workspaces can increase productivity (Weber et al., 2021). Adding the ability to wear noise-cancelling headphones or listen to music of their choice can also increase on-task time and productivity. Other options include adding software to their computers to reduce the distractions of non-work-related program use; this has limited success depending on the level of conscientiousness of the worker and their ability to self-redirect (Mark et al., 2018).

The added tendency toward motion throughout the day is a struggle for those workers with the "H" of ADHD. Hyperactivity can be redirected with increased physical activity between tasks, allowing standing and moving during meetings, and planning breaks more frequently (Adamou et al., 2013). Giving productive time for motion between tasks can increase worker health and decrease stress overall, with the added benefit of releasing excess energy for workers with ADHD.

Another common symptom of ADHD is disorganization, time management issues, and memory problems (Adamou et al., 2013). A variety of time management and organizational programs can prove helpful to workers with ADHD. However, what will work best for a particular individual and the situation will vary greatly depending on the circumstances. Suggestions made by researchers include setting regular alarms, digital calendars, typed agendas and notes, as well as programs that help break down large jobs into manageable tasks (Adamou et al., 2013; Weber et al., 2021). Other technology options that are newer to the workplace exist, such as augmented reality (AR) systems (Dolan, 2020). These systems can project digital information into the real world, guide and remind workers of steps in tasks, and provide real-time data to make decisions (Bottani & Vignali, 2019). No studies were found that investigated the effects of AR on workers with ADHD. A few studies have investigated the effects of AR on cognitive load, which are summarized later in this literature review.

2.1.7 Methodologies employed for the assessment of ADHD-ASRS

In response to the worldwide issue of ADHD being one of the most common psychiatric disorders among adults, the World Health Organization Adult ADHD Self-Report Scale (ASRS) provides a short and simple method for adults to assess the likelihood of ADHD symptoms (Kessler, Adler, Ames, Barkley, et al., 2005).

The ASRS is a set of 18 questions that are answered by the adult being asked to self-report the severity of symptoms. Each of the questions is answered in one of five levels: never, rarely, sometimes, often, and very often. Respondents are not given guidance as to what each of these frequencies means specifically; they must interpret it for themselves. Respondents are asked to reflect on their experience of symptoms in the past six months, not from childhood. The survey can be found in Appendix E.4. The ASRS is scored one question at a time. If the question meets the threshold level of severity, it is considered an ADHD symptom and counted in the total number of symptoms for the respondent. Questions 1, 2, 3, 9, 12, 16, and 18 need a score of "sometimes" or higher to be recorded as an ADHD symptom. The remaining questions need to be recorded at the higher level of "often" or higher to be counted. The first six questions are the primary questions used for screening for ADHD, and the last 12 questions are used to determine which type of ADHD is most likely. This screening tool is generally used for the identification of patients needing further diagnosis and treatment for ADHD but is also used widely in research studies for identifying participants with ADHD symptoms without having to complete a diagnosis (Kessler, Adler, Ames, Demler, et al., 2005).

Kessler et al. compared the DSM-IV adult ADHD diagnostic results to the full 18 questions of the ASRS with a sample of 154 participants to statistically determine a subset of questions that could serve as a "screener." Statistically, six questions stood

apart with better sensitivity, specificity, total classification accuracy, and Cohen's k[2] than the complete 18 questions (Kessler, Adler, Ames, Barkley, et al., 2005). This validated screener (Part A of the ASRS v 1.1, Kessler, 2005) has been cited over 3,482 times (as recorded in Google Scholar) as of June 2024, making it the most cited and used ADHD screening tool in literature (K. Stanton et al., 2018). Since the initial validity tests done by Kessler et al. in 2005, many other validation studies have been done to further investigate this tool and the symptoms of ADHD adults (Kessler, Adler, Ames, Barkley, et al., 2005; Kessler et al., 2007). Another study done by Hines et al. validated the six-question ASRS screening tool in a primary care setting and found, again, that it was easy to use, took very little time to administer, had high sensitivity, and moderate specificity. Hines et al. concluded it is a recommended screening tool for adult ADHD (Hines et al., 2012).

To establish norms in the United States for the ASRS-v1.1, researchers Adler et al. used survey data from the US National Health and Wellness Survey, where 22,397 respondents, including 465 self-reported or diagnosed with ADHD by a physician, of those 174 self-reported using ADHD medication (37.4%) (Adler et al., 2019). From the entire survey, the mean ASRS total score was 2.0 (SD = 3.2) (each symptom level was 0-4 for each question added and divided by 18, the number of questions on the survey). Grouping the participants by age, the following figure shows the increase in the average severity of ADHD symptoms for younger adults.

[2] Cohen's Kappa (k) is a statistical measure of agreement between dependent categorical samples. It is used when you have two people rating a subject, and you want to see how well they agree. (https://datatab.net/tutorial/cohens-kappa)

Interestingly, this study did not discuss the likelihood of the number of survey participants who have ADHD but are not diagnosed. Anyone not reporting an ADHD diagnosis is classified in the No ADHD group of this analysis. Discussion and results are centered around the severity of symptoms reported as 'increased' for those who self-reported ADHD diagnosis and medication. Symptom severity was reported as less for those without medication treatment and without ADHD diagnosis. The mean total ASRS6 symptom rating decreased as age increased, surmised by Adler et al. to be due to a possible lack of diagnosis or coping strategies to mask symptoms. The prevalence of

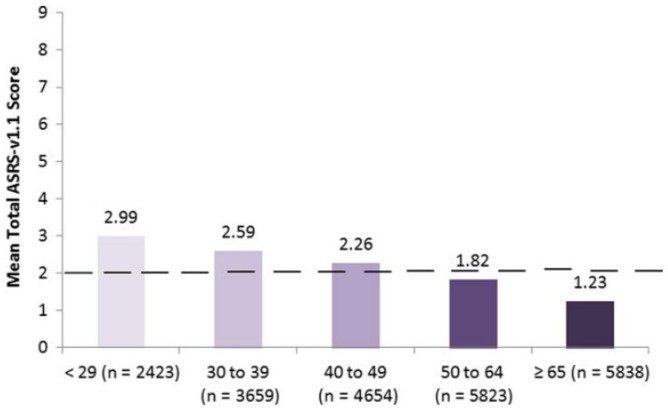

Figure 6: Mean ASRS-v1.1 Symptom Checklist total score by age. Checklist total scores can range from 0 to 18. The Horizontal dotted line represents the mean total normative score of 2.0 for the US general population (Adapted from Adler et al., 2019).

ADHD between male and female groups was almost even; however, symptom severity reporting for females was higher than for males (Adler et al., 2019).

2.2 Human Mental Workload Theories Summary Review

Longo, Wickens, Hancock, and Hancock compiled a comprehensive literature review of research related to human mental workload in 2022 (Longo et al., 2022). The review is a synthesis of "the current state of the art in human mental workload assessment through considerations, definitions, measurement techniques as well as applications" (Longo et al., 2022). Researchers propose the following definition of workload:

> Mental workload (MWL) represents the degree of activation of a finite pool of resources, limited in capacity, while cognitively processing a primary task over time, mediated by external dynamic

> environmental and situational factors, as well as affected by static definite internal characteristics of a human operator, for coping with static task demands, by devoted effort and attention (Longo et al., 2022).

This definition incorporates aspects of all the definitions found in the literature review, combining the theories of mental workload into one statement. All activities involve a level of mental workload and optimizing the mental workload for task results in optimizing performance, engagement, and minimizing errors. Changes in instructional design have not only shown increases in performance but also frustration (Hove & Corcoran, 2008). The theories linked to the construct of mental workload recognized as a framework are shown in the figure below.

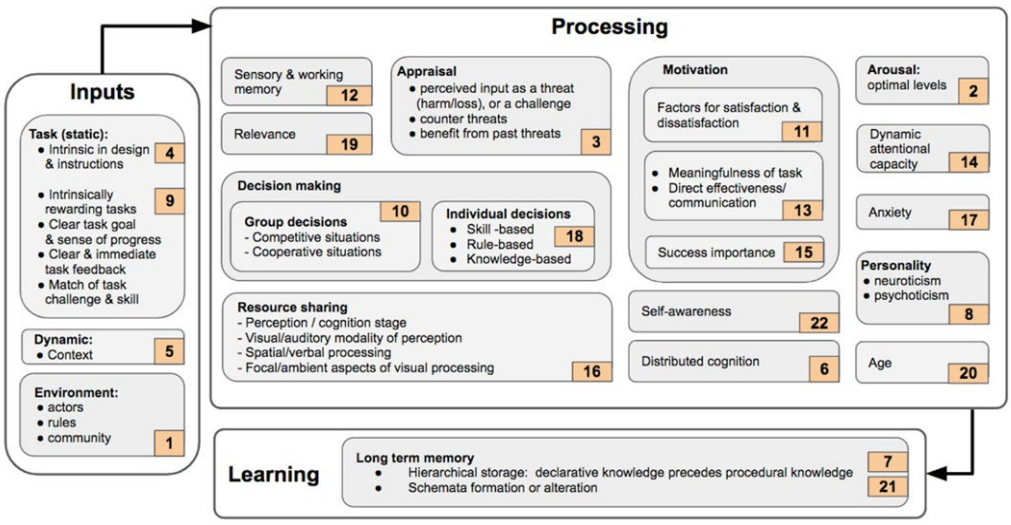

Figure 7: Theories linked to the construct of mental workload organized as a framework. (From Figure 8, (Longo et al., 2022))

Numbers label the theories identified in the figure above; the theories are as follows:

1. Activity theory (Vygotsky, 1980)
2. Arousal theory (Cohen, 2011)
3. Cognitive appraisal theory (Zajone, 1984)
12. Information processing theory (Simon, 1978)
13. Job enrichment theory (Hackman & Oldham, 1976)
14. Malleable attentional resources theory (Young and Stanton, 2002a)

4. Cognitive load theory (Sweller, 2011)
5. Contextual action theory (Stanton, 1995)
6. Distributed cognition (Hollan et al., 2000)
7. Event perception theory (Johansson et al., 1980)
8. Eysneck's theory (Gray, 1981)
9. Flow theory (Csikszentmihaly, 2000)
10. Game theory (Bakr et al., 2008)
11. Herzberg's two-factor theory (Herzberg, 1966)
15. Motivational intensity theory (Richter et al., 2016)
16. Multiple Resource Theory (Wickens, 2002)
17. Processing efficiency theory (Eysenck and Calvo, 1992)
18. Theory of skilled behavior (Rasmussen, 1983)
19. Relevance theory (Smolka and Priker, 2018)
20. Cognitive theory of aging (Salthouse, 2000)
21. Schemata theory (Oldfield, 1954)
22. Self-awareness theory (Oldfield, 1954)

Sources: (R. A. Cohen, 2011; Hollan et al., n.d.; Johansson et al., n.d.; Rasmussen, 1983; Simon, 1978; N. Stanton, 1995; Sweller, 2011; Vygotsky, 1980; Wickens, 2002; Young & Stanton, 2002, 2002; Zajonc, 1984)

Several theories are of particular interest to this investigation. Each is defined and explained below in Table 3. In the *input* stage of this framework, since the environmental factors are controlled and have a static workstation design, cognitive load theory (4) is the most appropriate one to consider. In the *processing* stage of the mental load framework, decisions are made on an individual basis; thus, the theory of skilled behavior (18) applies. Multiple studies investigating mental workload in manual assembly tasks cite the relevance of the multiple resource theory (16) due to the multiple pools of processing that occur with reading instructions, hearing signals, and assembling parts manually (Andreasson et al., 2017; Bommer, 2016; Lindblom & Thorvald, 2017; Thorvald et al., 2019). Based on what researchers have learned about working memory challenges for students with ADHD (Nyden et al., 2010; Schreiber et al., 2014) the following additional theories are of interest: information processing theory (12) and malleable attention resources theory (14).

Each of these theories is summarized in the table below:

Table 3: Relevant Mental Workload Theories Summarized with Source Citations

Theory	Summary	Original Work
Cognitive Load Theory (CLT)	CLT suggests that working (short-term) memory has a limited capacity; overloading that capacity limits a person's ability to transfer information to long-term memory.	(Sweller, 1988, 2011)
Theory of Skilled Behavior	As a worker's skills change over time, the way information is processed also changes. This theory has three levels: skill-, rule-, and knowledge-based levels. Information is perceived through signals, signs, and symbols.	(Rasmussen, 1983)
Information Processing Theory	The basic theory is relating to the sensing, processing, and transformation of information through receptors, processors, memories, and effectors.	(Simon, 1978)
Malleable attention resources theory	This theory posits that attentional capacity changes over time in response to changes in task demands.	(Young & Stanton, 2002)
Multiple Resource Theory (MRT)	In basic terms, when tasks require the same resources (visual, auditory, cognitive, motor, or speech), they must be processed in order. However, if they require different resources, they can be processed simultaneously.	(Wickens, 2002)

In the systematic literature review on mental workload by Longo et al., the most highly cited and referenced mental workload theories are the Multiple Resource Theory (MRT) and the Cognitive Resource Theory (CRT) (Longo et al., 2022). Stork and Schubö present the theoretical background of manual assembly tasks and break the theoretical areas into three areas: information processing and mental resources, selective attention and visual search, and task complexity (Stork & Schubö, 2010b).

Information processing is analyzed for the manual assembly task, which is broken into two main tasks: the *commissioning* and *joining* tasks. Cognitive processes involved in both tasks include perception with stimulus preprocessing, feature extraction, and stimulus identification, which is then translated to executing the action. The commissioning phase includes identifying the part needed in the next step, including the part number, how many will be needed, size, shape, color, etc., and where it is in storage. The commissioning task ends with retrieving the part from the proper location, which includes identifying the proper location, reaching, grasping, gaining control, and delivering the part to the assembly point. In the joining phase, the part positions, locations, and orientations are discovered and remembered from the instructions, whether on paper or offered through an augmented delivery system. The final stage of the joining phase is the installation of the parts. Applying the Multiple Resource Theory of Wickens, the resource dimensions used during these two phases include input modalities,

processing codes, and response modalities (Wickens & Carswell, 2021). According to this theory, some processes can be completed in parallel without interfering with productivity and attention. However, actions in the same resource pool are limited by the individual's capacity in that pool (Stork & Schubö, 2010a).

Selective visual attention is also a resource with limited capacity in this task. There is a limited number of elements that can be attended to visually at a given time. Search strategies can either utilize a top-down or bottom-up method. Bottom-up search strategies are employed in salient situations where there are large differences in the items being identified. Nevertheless, when parts are challenging to distinguish, spatial cues are particularly helpful in aiding the operator in determining the correct part. Augmented reality and other tools are helpful in manual assembly tasks to aid in choosing parts (picking) by reducing the time of visual scan (Egger & Masood, 2020).

Diminishing Reality (DR) is a form of AR where distracting elements from the environment are removed to improve focus and attention (Murph et al., 2021). However, with the potential benefits come other risks, such as reduced situational awareness, which could lead to mishaps and mistakes. Murph et al. mention that DR could be beneficial to workers with ADHD and Autism Spectrum Disorder (ASD). Some applications of DR include decluttering, dimming, size reduction, turning symbols into dots, or removal of aspects from a digital display (Murph et al., 2021).

Task complexity is typically measured by the aspects of the manual assembly task, such as the number of steps, distance to parts, and number of parts. Predetermined time studies, such as the Maynard Operation Sequence Technique (MOST), give a standardized method of estimating the optimal time to complete a set of tasks, thus giving an estimate of the task complexity compared to other tasks (Zandin, 2002).

Performance parameters can give insight into the operational performance of the manual assembly task. Measuring and observing behavioral measurements of hand movement and eye tracking give insight into performance efficiency and learning. Head et al. (2014) results support a resource theory perspective as they found participants made more errors when doing a combination of tasks, concluding that errors resulted from limited mental resources, not from mindlessness (Head & Helton, 2014).

2.2.1 Measuring Mental Workload

Mental workload is empirically measured in three classes of measures: self-report (such as NASA-TLX), task performance (such as error rate and speed), and physiological indices (such as pupil dilation, haptic sensors, and EEG).

Lagomarsino et al. propose an online framework for cognitive load assessment in assembly and industrial tasks, which has not been developed past pilot study stages and is not used in other research studies (Lagomarsino et al., 2021, 2022). Citing high rates of common mental disorders and the related psychosocial effects on workers, the researchers call for an online cognitive load assessment tool using head pose estimation and skeleton tracking to streamline assessments. Lagomarsino concluded that pilot experiments with the system showed potential correlations with physiological and performance measures, particularly workload, as assessed by the NASA-TLX instrument. However, using a video system to assess cognitive load potentially misses the full extent of the load because ADHD researchers have shown significant self-reported mental strain and inattentiveness in ADHD workers that was not apparent to external observers (Fried et al., 2012).

Thorvald et al. developed and evaluated a method for assessing cognitive load in manufacturing that laypeople in the field can use, requiring very little prior knowledge of cognitive load or training (Thorvald et al., 2019). The assessment is called Cognitive Load Assessment in Manufacturing (CLAM), and it employs a workstation observation approach evaluating 11 factors, with a rating of 0 to 8, 8 being the highest cognitive load. The assessment is designed to be performed by a trained practitioner (Thorvald et al., 2019). The factors are weighted on importance based on a pairwise comparison like the NASA-TLX weighting method.

Table 4: Description of the eleven factors evaluated in CLAM with weighting scales (Adapted from: Thorvald et al., 2019)

Saturation (0.17) -	The balance of the assembly task. The factor indicates how much of the available time is occupied by work tasks.
Variant flora (0.11) -	Estimation of the level of variation on a workstation. From no variation to full variation, i.e. one piece production.
Level of difficulty (0.07) -	The estimated required physical and cognitive effort to perform a task. Largely assessed based on the amount of training and experience required for solitary work.
Production awareness (0.07) -	An assessment on how much focused attention must be applied to the task.
Difficulty of tool use (0.02) -	The accessibility and operation of a tool. Relates to the amount of tool use and its subjective complexity.
Number of tools used (0.01) -	The number of tools used from no tools (low) to more than 8 tools (high) used.
Mapping of workstation (0.13) -	The correspondence between workstation layout and assembly sequence.
Parts identification (0.11) -	The presence or absence of alternate, and more cognitively easily processed, parts identification.
Information cost (0.12) -	How much physical or cognitive effort that is required to utilize the information. I.e. if information is easily accessible or not.
Quality of instruction (0.11) -	The general quality of the instructions used to gather information about the work based on HCI principles.
Poke-a-yoke (0.07) -	The presence or absence of poke-a-yoke solutions or other types of constraints.

The evaluation's output is a rating of cognitive load on a scale of 0-8, along with recommendations on which factor contributes the most to the load to facilitate mitigation measures.

Table 5: Output table for CLAM showing ranges of severity (Adapted from Thorvald et al., 2019)

Interval	
6 - 8	High cognitive load
4 - 6	Moderate cognitive load
2 - 4	Low cognitive load
0 - 2	Very low cognitive load

Thorvald states that the limitations of this method include limited applicability to human-robot collaboration (HRC) scenarios, and the intended application for usability possibly sacrifices the scientific validity of the results. “The main focus has been on the external validity and applicability of the CLAM analytic assessment tool in industry, rather than scientific accuracy” (Thorvald et al., 2019). The method utilized the NASA TLX to form a similar basis, but it is not directly correlated to the TLX; it suffers from similar subjectivity. Researchers suggest that several practitioners perform the assessment and compare the results (Thorvald et al., 2019). It is unknown how well the CLAM results correlate to workers with varying mental processing, such as those with ADHD.

2.2.1.1 Self-report Measure – NASA-TLX

Self-report measures can be uni-dimensional, hierarchical, or multidimensional ratings. Uni-dimensional ratings provide a single value or scale with different ranges, which are easy to collect but limited in the information provided. Longo et al. go on to state that hierarchical ratings involve a set of decisions in a flow from one to the next. Two examples of hierarchical ratings include the Modified Cooper Harper Scale and the Bedford Scale. The last type of self-report measure is the multidimensional rating, where separate factors are evaluated individually and can be informative separately or together as a single measure. Examples of multidimensional rates are the NASA-TLX, the Workload Profile, and the Subjective Workload Assessment Technique (SWAT). Of all these measures, the NASA-TLX is employed the most because it is easy to use and has been validated repeatedly in the past 35 years (Hart, 2016).

The NASA-TLX uses six sub-factors to break the self-rating of cognitive load into distinguishable contributions: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration (So, 2020). The NASA-TLX has a published set of instructions and procedures for implementation in paper and computer-based form (See Appendix A.1). Prior to using the NASA-TLX, participants are directed to practice the evaluation procedure with a sample task; many studies fail to perform this step, which can affect the validity of the results as participants learn how to perform the index while doing the study. The index involves two parts: the weighting and the evaluation of the six factors. During the weighting, each pairwise set of factors is ranked by which is most contributing to the cognitive load. This ranking provides a weighting scale for the final calculations. The individual ranking of each of the six factors can be analyzed both separately and weighted for the total value of mental workload (So, 2020). The next type of measure of mental load is performance measures.

2.2.1.2 Performance Measures

Performance measures are used to gauge the participant's "level of task completion efficiency" (Longo et al., 2022). Performance measures can be divided into two types: primary task and secondary task, which are measured externally through observation. The primary task is what the operator is doing for the activity, which is the

main goal of the activity. A secondary task would be an added task inserted into the activity, such as a button push or other task that is measured as response time and accuracy as a "metric of an operator's spare mental capacity" (Longo et al., 2022).

Performance measures are calculated for each experiment in a way that corresponds to the tasks being completed, typically in the form of an error rate and production rate. One method used in several studies is the human error probability (HEP) calculation (Bommer & Fendley, 2018).

HEP = (number of observed errors) / (number of the possibilities for an error)

Production rate is measured as the amount of time to complete a task, which could be the entire process or individual steps. In terms of Lean production, the production rate can be calculated as the number of completed parts divided by the number of expected parts completed for the time worked (Choomlucksana & Doolen, 2017). From previous studies, it is expected that the HEP will increase and the production rate will decrease as the workload increases (Manghisi et al., 2022; Pignoni & Komandur, 2019; Torres et al., 2021).

2.2.1.3 Physiological and Neurophysiological Measures

The third category of measures is physiological and neurophysiological measures. These measures gather data on physical changes to the operator while performing the primary task. Longo et al. identify a variety of measures that have been used to assess mental workload in conjunction with one or both other two measures. Some of these include heart rate, blood pressure, respiratory rate, oxygen consumption, ocular measures, salivary cortisol, skin measures, and neurophysiological measures. Each of these measures has benefits and drawbacks related to sensitivity, quantification of measures, vulnerability to environmental changes, and intrusiveness (Longo et al., 2022). The key considerations for evaluating which measures to use include sensitivity, diagnosticity, reliability, validity, agility, intrusiveness, requirements, acceptability, and selectivity, as detailed by Longo et al. in their systematic review of current technologies (2022). Employing at least two of the three types of measures gives a better picture of the

operator's MWL, and a single measure alone fails to provide a reliable picture of the situation.

Giorgi et al. (2021) evaluated two different wearable technologies compared to laboratory equivalents and found reliable correlations between the consumer wearables and the laboratory equivalents. However, significant issues with the technologies, including very short battery life, missing data caused by participant motion, and limited industrial Wi-Fi availability and permissions, provide significant limitations to the widespread use of consumer wearables for everyday use (Giorgi et al., 2021).

2.4 Prior Studies Measuring Mental Workload in Manufacturing

A few researchers have investigated mental workload in manufacturing environments both with field studies and controlled simulated experiments. Their research summaries are presented in the following section.

A team of researchers at Ludwig Maximilian University, Munich, has investigated some of the fundamental cognitive processes related to manual assembly tasks (Stoessel et al., 2008, 2008; Stork et al., 2008; Stork & Schubö, 2010b, 2010a). Their investigations involve using projected AR systems to guide instructions for manual assembly tasks. They measured eye tracking, specifically gaze lingering times and search times, and hand motion to assess the cognitive processes involved in the manual assembly tasks. Researchers investigated the task-switching paradigm with the order of tasks and the presentation of different types of cuing for picking of parts. The investigations are not developed as full experiments and are based on hypothetical adaptive instructional platforms that have not yet been developed and applied for experimentation.

Stork and Schubö give an overview of the theoretical cognitive processes related to manual assembly tasks and review the results of two augmented manual assembly tasks (Stork & Schubö, 2010b). They found that an augmentation system can lead to performance increases if the appropriate guidance is cued at the exact time to provide cognitive support rather than a disruption.

Vélaz et al. investigated four virtual reality systems compared to a video training

control with sixty participants (twelve in each group) for a between-subjects study of training effectiveness. Researchers collected error rates, training time, the number of times participants were cued (or asked questions), and a usability questionnaire (Vélaz et al., 2014). The study's results showed no significant differences between the five groups in terms of learning transfer.

Hoedt et al. tested the efficacy of learning transfer for a virtual reality training system on a manual assembly task (Hoedt et al., 2017). The study employed a between-subjects design with twenty-eight participants, divided into two groups of fourteen. The test group first built the product in Virtual Reality and then built five more in real life, while the control group built six products entirely in real life. All real-life builds used Paper Work Instructions, and the researchers measured the product assembly times. An interesting choice of analysis for the learning curve showed that training in VR provided an advantage over the control group. The researchers concluded that virtual training resulted in a 20% reduction in learning time. Hoedt et al. cite the Aeronautical Engineer Wright (1936), with mention to the learning curve, but is speaking about the learning of an operator, not the learning of a team of engineers related to production rates as Wright was describing in his article titled “Factors Affecting the Cost of Airplanes.”

Bommer and Fendley (2018) modeled multitasking in a simulated task to validate their theoretical framework for measuring mental workload using both analytical and empirical techniques (Bommer, 2016; Bommer & Fendley, 2018). Bommer tested the model on sample tasks where the cognitive load was measured using subjective (NASA-TLX and Workload Rating Scale), physiological (Tobi Eye Tracking), and performance measures (Human Error Probability [HEP]). The model was found to accurately output the operator’s workload (Bommer & Fendley, 2018). Bommer stated that subjects for this study included eleven graduate students who performed two simulated tasks, high and low levels of cognitive load. Afterward, participants filled out the subjective rating scales. The results give numerical values for workload ranging from 14.5 to 156.5 for the two tasks; however, no units are given nor an explanation of the relative scale of these values. Bommer mentions that going forward, it may be possible to create a MWL index “as a quick reference for design predictions” (Bommer & Fendley, 2018). Bommer also completed dissertation work on this theoretical framework, including investigations of

mental workload in two additional scenarios, one involving LEGO bricks and another using medical devices.

None of these studies included participants identified as workers with ADHD. This presents a significant gap in research that this study intends to address.

2.5 Manual Assembly Workstation Technology in Manufacturing

Workstations in manufacturing can include various technologies implemented to aid the manual assembly worker. Technologies can be implemented for various reasons. For example, the goal may be to increase productivity, safety, or quality—or a combination of these factors. Some of the state-of-the-art technologies and techniques implemented in manual assembly workstations include Augmented Reality (AR) of various types, machine vision, and lean tools such as poke-yoke[3] techniques. Current research on each of these is presented below.

It should be highlighted that existing studies do not explore the impact of these technologies and tools on workers with ADHD. Among them, only one study includes participants with cognitive disabilities. This omission has been recognized as a notable gap in the literature, which the current study aims to address.

2.5.1 Augmented Reality

Augmented Reality can be implemented by overlaying technical digital information onto the real world. This can be done through several types of technology, including projector-based technology, glasses that project an image over the real world,

[3] According to the American Society of Quality, poke-yoke is also called mistake proofing and is defined as "the use of an automatic device or method that either makes it impossible for an error to occur or makes the error immediately obvious once it has occurred" (*What Is Poka-Yoke? Mistake & Error Proofing | ASQ*, 2022).

and handheld devices such as phones and tablets.

Laviola et al. (2023) performed a literature review on Augmented reality in manufacturing, particularly maintenance applications. They found that earlier studies have demonstrated that Augmented Reality (AR) is a valuable instrument for assisting operators in performing manual procedural tasks (Laviola et al., 2023; Mourtzis et al., 2020, 2022; Uva et al., 2018; van Lopik et al., 2020). In the same review, Laviola et al. found numerous investigations conducted within controlled laboratory settings that featured uncomplicated and controlled testing situations (Gattullo et al., 2019; Manghisi et al., 2022; Scurati et al., 2018; Volmer et al., 2018). It was concluded that developing AR systems to aid maintenance workers in sustainable industrial contexts presents a considerable hurdle, attributed to the varied and complex demands of the industrial maintenance tasks (Egger & Masood, 2020; Laviola et al., 2023; Lorenz et al., 2018; Masood & Egger, 2020).

Wang et al. (2022) article titled *A comprehensive review of augmented reality-based instruction in manual assembly, training and repair* gives an insightful summary of the areas of AR research in manufacturing. Specifically, Wang mentions seven studies that considered user cognition in their study designs. Six studies used LEGO brick assembly with AR technology. Four studies considered attentional differences with AR in the design and compared AR instructions to traditional instruction (Z. Wang et al., 2022). Qeshmy et al. reported from interview and survey results that the "main causes of human errors are the amount of thinking, deciding and searching for information which affected the cognitive load of the operator and in result their performance" (Qeshmy et al., 2019). A goal of implementing AR in manufacturing is to reduce the cognitive load of the worker; as such, it is important to evaluate the systems in a variety of settings and configurations to determine the effect of AR technology on workers.

2.5.1.1 Studies Assessing AR Mental Workload and Learning

Researchers have investigated the cognitive load of participants using various types of AR in a few studies, varying by the types and applications of AR and the means of measuring cognitive load.

Dubovi et al. studied sixty-one nursing students' engagement and impacted

learning through a VR-based environment. Psycho-physiological data was gathered from facial expression, eye-tracking, and dermal activity. Participants also completed subjective self-reports with the Positive and Negative Affect Scale (PANAS) (Dubovi, 2022). Knowledge was assessed with pre- and post-test assessments. The study concluded that incorporating multiple channels of data can provide a more significant and holistic understanding of learning and engagement outcomes (Dubovi, 2022).

Herbert et al. (2022) performed a between-subjects randomized control experimental design with thirty participants and two treatments. Users performed four network cabling training tasks with assistance from the study's Intelligent Tutoring System (ITS), an AR-based program. The ITS is programmed to adapt to user mistakes and provide real-time feedback. Different levels of support were tested with the subjects; results found that reducing the information provided in the ITS as users demonstrated greater ability showed a greater gain in learning and fewer mistakes. This is supported by cognitive load theory, which suggests that instructional support becomes less necessary as learning progresses (Herbert et al., 2022).

The only AR study including neurodiverse participants investigated the effects of AR instructions compared to oral and paper instructions with a within-subjects design with forty-four workers with cognitive or motor disabilities (Vanneste et al., 2020). Researchers did not elaborate on the type or severity of the disabilities of the participants. The AR used was a LightGuide system, the same type utilized for the studies in the present research. Assembly tasks included assembling a light fixture, a measurement task for inspection, and a sliding window wheel assembly. The neurodiverse workers using AR instructions outperformed the other neurodiverse participants performing the task without AR in terms of quality, independent of the type or severity of disability (Vanneste et al., 2020). AR participants also sought help less often (Vanneste et al., 2020).

Atici-Ulusu et al. investigated the cognitive load of head-mounted AR glasses on automotive industry workers in a live assembly task at a car manufacturing facility using Sony Smart Eyeglass Sed-E1 glasses. Both NASA-TLX and EEG (Smarting EEG Amplifier™ and EasyCap™) were used to measure the cognitive load of the workers, which were found to indicate a decrease in cognitive load for workers using the AR

technology (Atici-Ulusu et al., 2021). This study was tiny, with only four participants performing five tasks each. The measurement times were also very short. A total of sixty experiments (four participants, five experiments, with three replications) were completed (Atici-Ulusu et al., 2021). NASA-TLX results supported the EEG results. Atici's results showed an average 10% decrease in NASA-TLX scores for treatments with the AR glasses.

Kia et al. investigated the effect of target size and system error rate on the cognitive demand of participants using AR. Participants used HoloLens to complete two tasks. The tasks were repeated with 3x3 full factorial and 3x2 full factorial levels varying target sizes and error rate levels in random order (Kia et al., 2021). Total task times were thirty and fourty-five minutes, with a ten-minute break between tasks. Participants were measured for brain oxygen levels, task speed, and performance outcome. After the tests, the NASA-TLX and Short Stress State Questionnaire were filled out. As the error rate increased, the NASA-TLX scores increased. Both the target size and error rate affected the performance measures; an increased error rate decreased performance, and a decreased target size decreased performance. Kia emphasizes the significance of designing AR interfaces to minimize errors, thereby reducing cognitive load for users. (Kia et al., 2021). Kaplan et al. (2020) performed a meta-analysis of the efficacy of XR technologies compared to traditional training methods and found that XR technologies are equally effective at enhancing performance (Kaplan et al., 2020).

Funk et al. tested emergency door release handle assembly tasks with sixteen participants using a marker-based AR technology viewed through a smartphone compared to paper instruction (Funk & Schmidt, 2021). In a between-subject study with 16 participants, researchers measured assembly time, error rate, SUS, and NASA-TLX. As expected with the cognitive load theory, expert workers were slower with AR, while unskilled workers worked faster with AR than without. No significant difference in errors between the treatments was found (Funk & Schmidt, 2021).

Yang et al. (2020) performed a between-subjects study with seventy-two participants using either Paper Work Instructions or AR instructions (on a mobile phone) to build a LEGO vehicle (Yang et al., 2020). Participants performed the thirty assembly steps (one car, estimated ten minutes) for as long as it took them to complete the task.

Error rate and time to completion were recorded. Participants also filled out the NASA-TLX and the Reduced Instructional Materials Motivation Survey (RIMMS). AR participants took longer than paper instructions, on average. AR participants, on average, made fewer errors of all types. Mental demand increased, and performance increased with AR; no other cognitive load differences between the treatments were found (Yang et al., 2020). It should be noted that this is for building one single LEGO vehicle of 30 parts. In the long term, it is unclear how performance and error rates might change over time (Yang et al., 2020).

With respect to what AR technology to implement in a system, Keshav Kolla et al. concluded that "choosing a software framework or hardware device is based on the problem, capital, in-house skills rather than the advantages and disadvantages of the systems" (Keshav Kolla et al., 2021). They found that the in-house skill of the facility's people in implementing a certain type of technology is a critical factor in the success of the implementation. In addition to the talent of the implementation team, the support with capital and the type of problem that is being solved are also critical. There is no "one size fits all" AR solution.

2.5.2 Machine Vision Technology

Machine Vision (MV) technology involves image capturing, sending the image data to a processor to decipher, and a resulting action taken by the software to output a signal for action. The action could be a display of information, a determination of a good or bad part, or any other action for the system (Javaid et al., 2022). MV can improve productivity, safety, and quality in a manufacturing system. A review of the literature on the applications in manufacturing includes primarily future applications and connections with smart factories implementing Industry 4.0 (I4.0) technologies (Javaid et al., 2022). One hope for this technology is to eliminate human error in applications (Javaid et al., 2022).

As in the study published by Jia et al., many applications of MV are for highly automated inspection systems that use the vision system for precise measurements of specifications and verification of product geometry (Jia, 2009). Ren et al. give a summary of the state of the art of machine vision and highlight the significant improvements that

MV can lend to inspection programs (Ren et al., 2022). Especially in high illumination areas with high resolution image capturing hardware, MV can capture high-quality images (Ren et al., 2022).

Despite the capabilities of MV technology, no studies have been found that investigated the effects on workers using this technology, and no studies have been related to changes in cognitive load or any other potential effects. The closest that was found is a systematic literature review done by Kumar and Lee on the Human-machine interface (HMI) in smart factories, which includes machine vision and other technologies (Kumar & Lee, 2022). Kumar mentions cognitive load five times, learning ten times, and workload eight times; however, none of the technologies evaluated were machine vision.

2.5.3 Lean Jidoka and Poka-yoke Techniques

The origins of Lean production in the 1950s is the Toyota Motor Corporation has proven to be a philosophy that is applicable to not only manufacturing cars but many industries looking for ways to optimize systems and reduce waste (Womack, 2007). One of the key principles of Lean production is the concept of Jidoka, which means automation with a human touch. This concept highlights the importance of customizing automation solutions around the human needs of the system, not just for automation for automation's sake (Malik & Bilberg, 2019). When looking at a manufacturing cell and each workstation therein, the capabilities of the human operator must be considered when implementing changes to the system. Malik and Bilberg present a set of steps to analyze a system and consider technology only in instances where the person has a high potential to fail, such as with repetitive tasks, being vigilant, and high-precision jobs (Malik & Bilberg, 2019).

Widjajanto et al. completed a literature review on Lean poke-yoke approaches in the industry and found a number of mistake-proofing technologies being applied in industry (Widjajanto et al., 2020). Some of the poke-yoke types found in literature included: sensors, interlocks, mechanical changes, computer vision, developing a model, and process flexibility (Widjajanto et al., 2020). Any tool implemented in a process that reduces errors is considered a quality poke-yoke (Saurin et al., 2012). Saurin et al. developed a system for evaluating the effectiveness of poke-yoke devices. However, they

did not include the mental or physical effects of the devices on the workers in this evaluation. There is a gap in the literature for evaluating Lean tools from the perspective of workers of any kind, let alone workers with ADHD.

2.6 Summary of Research Findings

2.6.1 Attention-Deficit/Hyperactivity Disorder (ADHD) in Adult Workers

The studies conducted on ADHD in adult workers reveal several critical findings. Notably, workers with ADHD often engage in self-accommodation strategies due to insufficient organizational support, leveraging their creativity and quick-wittedness to manage symptoms and improve functioning. This self-accommodation becomes important given the complexities of disclosing ADHD and the lack of tailored interventions for high-functioning workers (Adamou et al., 2013; CDC, 2021; Hallowell M.D & Ratey M.D, 2021; Nyden et al., 2010; Oscarsson et al., 2022). A significant research gap is the oversimplification of categorizing individuals as either having ADHD or not, when the condition may be best described as existing on a spectrum. This binary view fails to capture the variability and complexity of ADHD, further underscoring the need for more sophisticated and inclusive research methodologies.

Simulation studies further elucidate ADHD's impact on workplace performance. Biederman Fried et al.'s 2005 study highlighted performance deficits in the ADHD group, particularly in areas like reading comprehension and math fluency. Fried et al. (2012) expanded this understanding, demonstrating the challenges ADHD participants faced with internal restlessness and difficulties in timed tasks. In contrast, Fabiano et al. (2018) found no significant performance differences between ADHD and non-ADHD participants in a simulated fast-food work environment, although ADHD participants showed higher rates of traffic violations.

Professionals emphasize the importance of identifying, diagnosing, and treating ADHD to mitigate adverse workplace outcomes. However, the side effects of not using common ADHD medications often lead to self-management strategies, such as caffeine usage. General recommendations for workplace accommodations include adjusting noise levels and providing support for disorganization and time management issues,

considering the diversity in ADHD manifestations (Adamou et al., 2013; Kessler et al., 2009).

2.6.2 Human Mental Workload Theories

Longo et al.'s comprehensive review in 2022 synthesized the current state of human mental workload assessment (Longo et al., 2022). The key theories for this investigation include Simon's Basic Theory (1978), which relates to the processing and transformation of information, Young & Stanton's Malleable Attention Resources Theory (2002), and Wickens' Multiple Resource Theory (2002), which suggests that different tasks can be processed simultaneously if they require different resources.

2.6.3 Mental Workload

Studies in manufacturing have focused on cognitive processes in manual assembly tasks, with Stoessel et al. and Stork et al. utilizing AR systems for guiding instructions and assessing cognitive load. The Maynard Operation Sequence Technique (MOST) and studies by Head et al. (2014) offered insights into task complexity and the impact of multitasking on mental resources. Bommer and Fendley's work in 2018 further emphasized the importance of multifaceted approaches in measuring mental workload.

2.6.4 Technology in Manufacturing

In manual assembly workstations, advanced technologies such as Augmented Reality (AR) and lean tools like Poka-Yoke techniques play a pivotal role. AR technologies, including Diminishing Reality (DR), aid in part selection and reduce visual scan time, potentially benefiting ADHD and ASD workers by removing distracting elements and improving focus (Egger & Masood, 2020; Murph et al., 2021). A pilot study comparing projection-based AR with traditional methods has shown promising results in enhancing productivity and reducing error rates (Masood & Egger, 2020).

2.7 Summary of Research Gaps

Research on ADHD in adult workers reveals significant gaps, such as the lack of organizational support, leading individuals to rely on self-accommodation strategies. The

oversimplification of ADHD as a binary condition rather than a spectrum further complicates understanding and addressing their needs. Mixed results in studies on workplace performance indicate a need for better-tailored interventions. Additionally, while professionals emphasize proper diagnosis and treatment, current workplace accommodations are insufficient. Theories on mental workload and advanced technologies like AR offer potential solutions but require further exploration to support ADHD and other neurodivergent workers effectively.

A gap in current research is the absence of studies observing ADHD workers directly in the field. Most existing research relies on indirect methods such as surveys, government database reports, or medical record reviews. This approach overlooks the real-time challenges and adaptive strategies ADHD workers employ in situ. Direct observation in workplace settings is essential to gain a comprehensive understanding of how ADHD manifests in a real-world work environment and how it influences day-to-day work life and productivity.

The scarcity of studies in simulated work environments that include workers with ADHD is another significant gap. Current research does not adequately represent the practical challenges and outcomes for these workers. Simulated work environments, which mimic actual work conditions, are important for understanding the impact of ADHD on workplace performance. These studies can provide insights into how ADHD affects task execution, attention to detail, and overall work efficiency in controlled yet realistic settings.

Emerging technologies such as Augmented Reality (AR) systems present a new frontier in workplace aid and design. However, the impact of AR systems on workers with ADHD is yet to be explored. As AR systems gain traction as potential tools to enhance workplace efficiency and learning, understanding their effects on ADHD workers is vital. This research gap suggests a need to investigate how AR tools can support or hinder ADHD workers, potentially offering innovative solutions for workplace challenges they face.

Significantly, previous studies on mental workload, particularly those involving scenarios like working with LEGO bricks and medical devices, have overlooked the inclusion of ADHD workers. This exclusion is a notable deficiency in research, hindering

the understanding of how ADHD affects mental workload across various scenarios. Addressing this gap is important for developing strategies and interventions that cater to the unique mental workload challenges faced by ADHD workers.

3.0 Chapter Three: Manufacturing Technology Support Investigation: Assessing the Effects of Augmented Reality Technology on ADHD Workers

3.0 Manufacturing Technology Support Investigation: Introduction

In contemporary manufacturing environments, the implementation of advanced technologies is often driven by the goal of enhancing performance and quality. (Kaplan et al., 2020)Augmented Reality (AR) technologies are being increasingly adopted to streamline processes, reduce errors, and improve training outcomes (Kaplan et al., 2020). However, the integration of these technologies into workplaces can have unintended consequences on workers, especially those who are neurodivergent, such as individuals with Attention Deficit Hyperactivity Disorder (ADHD) (Doyle & McDowall, 2021). Understanding these possible unintended consequences is important as cognitive load and usability perceptions significantly influence overall productivity and worker well-being (Calvallari & Nobrega, 2021). Ignoring increases in cognitive load can lead to mental fatigue and diminished cognitive processing abilities of workers, which can lead to increases in errors and other adverse outcomes. By focusing on cognitive load and usability, this study provides valuable insights that can inform the development of more inclusive and effective technological interventions in manufacturing settings.

ADHD is a common neurodevelopmental disorder characterized by symptoms of inattention, hyperactivity, and impulsivity. These symptoms can affect a person's ability to maintain focus, manage tasks, and respond to workplace demands (Kessler et al., 2009). Despite the increasing prevalence of ADHD in the workforce, there is a noticeable gap in research regarding how modern technological interventions, like AR, impact individuals with ADHD in manufacturing settings (Oscarsson et al., 2022). Traditional performance metrics often overlook the nuanced effects of these technologies on cognitive load and usability, which are critical for ensuring effective and sustainable technology integration.

The current study aims to address this research gap by investigating the effects of

AR technologies on production quality, speed, cognitive load, and usability within a simulated manufacturing environment, with a particular focus on participants with varying levels of ADHD symptoms. The specific AR treatments explored in this study include Paper-Based Work Instructions (PWI), Paper-Based Augmented Reality (PBAR), Head-Mounted Augmented Reality (HMAR), and Enhanced Head-Mounted Augmented Reality (EHMAR). By employing a two-way ANOVA to analyze the interactions between ADHD symptom levels and these treatments, the study seeks to determine whether different AR technologies influence production outcomes differently across ADHD symptom levels.

Ultimately, the findings from this investigation will contribute to a better understanding of how AR technologies can be optimized to support all workers, including those with ADHD. This knowledge is essential for developing tailored interventions that not only enhance productivity and quality but also promote a healthier and more inclusive workplace.

Augmented Reality (AR) is increasingly finding its way into manufacturing environments in various applications, including training, daily work support, and remote maintenance tasks. As noted in the literature review, previous studies, both experimental and field studies, have investigated the efficacy of these technologies in various settings. However, most of these studies focus primarily on worker outcomes, with little consideration given to the cognitive load and effects on the workers themselves.

This investigation was conducted in parallel with an assessment of the applicability of various augmented reality technologies in a simulated manufacturing environment (O'Leary, In Press). The investigation presented here includes a separate randomized controlled trial (RCT) between-subjects study examining the cognitive effects on workers using three types of AR technology compared to traditional Paper Work Instructions. A particular focus is given to workers reporting a large number of severe ADHD symptoms.

Participants are grouped for analysis based on the severity of their reported ADHD symptoms. The purpose of this investigation is to shed light on the different needs and impacts AR technology has on workers with ADHD compared to their neurotypical counterparts. As an initial step into this area of uncertainty, this study provides insight

into the challenges faced by these workers and offers direction for future research.

3.1 Manufacturing Technology Support Investigation: Investigation Description

The Auburn University Tiger Motors Lean Education Center[4] is a simulated manufacturing facility that utilizes LEGO® bricks to build two models of LEGO vehicles through fifteen assembly stations. Within reach of the workers, the parts for the work content of each station are in bins above the work surface, labeled by part. Each station is designed and balanced to contain approximately one minute of work, with a varying number of steps depending on the time and complexity of the tasks. The assembly line starts with station one with zero parts put together, progressing to a fully assembled

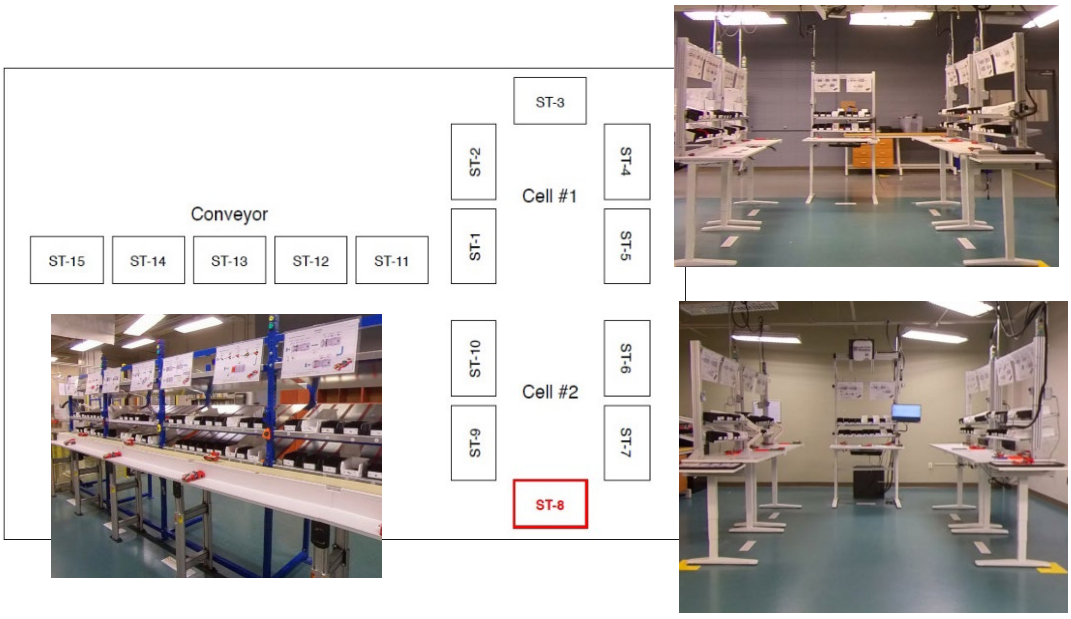

Figure 8: Layout of Tiger Motors Lean Education Center, Pictures of Cell 1, 2, and 3 (Conveyor) workstations.

[4] For more information about Tiger Motors Lean Education Center: http://tigermotors.eng.auburn.edu/

LEGO vehicle after station 15. The workers complete the steps at their station and pass the car to the next station. There are two work cells of five stations and a five-station conveyor line. See the diagram of the facility layout and images of the lab in the figure.

Also, within this facility, state-of-the-art technologies, such as projection-based augmented reality and vision inspection systems, are available for student use during production runs. The line provides a place to investigate the effects of changes in workstations on workers with and without ADHD. Due to the simple nature of using LEGO bricks for manufacturing, simulated runs are designed and administered with limited training.

In general, the variables are measured in the following ways:

- Performance (speed of production) is measured with both electronic timing devices and video capture.
- Quality is measured through error observation and recorded with video capture and photographs of the final assembled products.
- System usability is measured with the UX Usability Scale (SUS) (*UX Principles That Include Cognitive Accessibility*, 2022).
- Cognitive load (or Mental Workload) is measured with the NASA Task Load Index (NASA TLX) (Hart, 2016).
- ADHD symptom prevalence and severity are measured with the Adult Self-Report ADHD Scale (ASRS) (Kessler et al., 2007).
- Qualitative inputs gained through comments, observation of behaviors, and survey responses.

For the analysis, all variables were examined for mean differences. The hypotheses were established *a priori*, drawing on theoretical knowledge of the cognitive processes in neurotypical individuals and those with ADHD. This framework was further informed by prior research by the authors and others into the effectiveness of similar technologies in various applications.

The augmented reality technologies in Tiger Motors are the treatments for this investigation. The Paper Work Instructions (PWI) treatment is the control where only the traditional Paper Work Instructions are provided as instructions on how to perform the task at this station. The other three treatments involve AR technology. Projection Based

Augmented Reality (PBAR), Head-Mounted Augmented Reality (HMAR), and Enhanced Head-Mounted Augmented Reality (EHMAR). Each participant does one of the four treatments, randomly assigned for the between-subjects randomized controlled trial experiment.

3.1.1 Manufacturing Technology Support Investigation: Technology

The technology implemented in the Tiger Motors Lean Education Center offers students a real-world experience engaging with state-of-the-art technology and techniques. The technology incorporated in Tiger Motors includes two types of AR, machine vision, and Lean Tools. The AR technologies programmed for Station 8, that are used in this investigation are described below.

3.1.1.1 LightGuide Projection-Based Augmented Reality (PBAR)

Station 8 is equipped with a LightGuide[5] Projection-Based Augmented Reality (PBAR) system is designed to provide training and guidance for the assembly of its 16 steps. The LightGuide system includes a computer and touchscreen monitor mounted to the side of the station. A projector, similar to those used in classrooms, is mounted above the station along with a video sensor akin to Xbox Kinect[6] technology, which detects the presence of a person at the workstation (Miles, 2012). Additionally, there is a foot pedal on the floor with two buttons that move the program forward and backward.

The initial setup of the LightGuide system involves calibrating the projector and sensors to help set up accurate detection and projection. The system must be aligned with the workstation to project instructions correctly on the workpiece and surrounding areas. Proper calibration is important for the system to function accurately and provide precise guidance. After the initial programming, other than alignment, very little needs to be

[5] LightGuide AR is made and produced by LightGuide, Inc., Xixom, MI http://lightguidesys.com
[6] Xbox Kinect is a 3D Sight technology made and produced by Microsoft

done to the system to keep it up and running if there are no procedure changes.

Figure 9: Heat map from LightGuide Vision Sensor

The colors seen in the figure to the right indicate distance from the sensor: green represents the furthest distance (floor) and orange the closest (parts bins).

The system has pre-programmed parts locations and instructions for both models of LEGO cars, offering two operating modes: training and production. In training mode, the operator must manually advance through each step. In production mode, the system senses when steps are completed and advances automatically. The parts to be picked are highlighted in green above the corresponding bin. If the operator reaches into the wrong bin, the system flashes red. The placement of the parts is highlighted on top of the workpiece at the workstation. The workpiece must be kept aligned with the projector for proper alignment.

“Buttons” are illuminated on the workstation top for “Next” and “Back,” which advance or reverse the program by one step. See the images below for illustrations of how this system works.

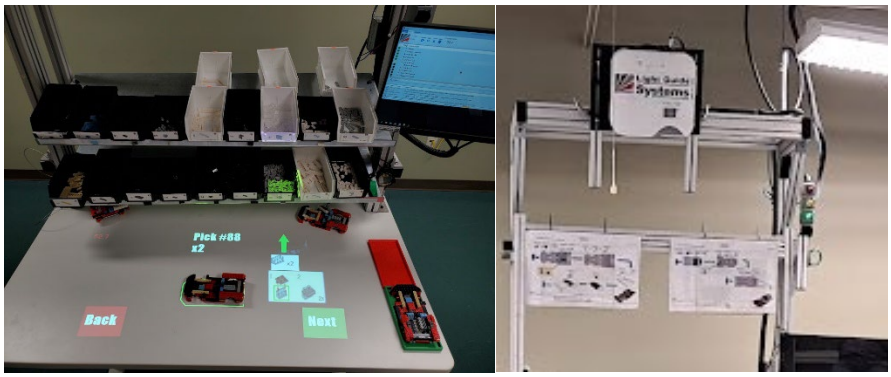

Figure 10: LightGuide PBAR Highlighting Instructions on workstation (left)
Work Instructions and projector above workstation (right)

When using the LightGuide system in a manufacturing environment, safety precautions must be taken. The projector and sensors should be securely mounted to avoid any risk of falling. Additionally, workers should be trained to remain aware of their surroundings to prevent accidents, as focusing on projected instructions might reduce their peripheral awareness.

Operators need to undergo training to effectively use the LightGuide PBAR system. This training includes familiarization with the system's interface, understanding the projected instructions, and learning to interact with the system using the foot pedal and on-screen buttons. Training helps to encourage operators to efficiently follow the assembly steps and utilize the system's features.

The LightGuide system, while highly effective, has some limitations. It requires precise calibration and alignment to function correctly, which can be time-consuming. The system's reliance on visual projections means it may be less effective in brightly lit environments where projections may be harder to see. Additionally, the fixed nature of the system means it cannot adapt easily to changes in the workstation layout or different assembly processes. In this system, the mounting of the LightGuide requires the workstation height to be fixed.

3.1.1.2 HoloLens2 Head-Mounted Augmented Reality (HMAR)

Unlike projected augmented reality systems fixed to the workstation, head-mounted systems are worn by the worker. A system is considered augmented reality (as opposed to virtual reality) if the person can see through the system and the digital information is overlaid on what the person sees in the real world.

Figure 11: Microsoft HoloLens2 (https://www.microsoft.com/en-us/hololens)

The head-mounted AR system, programmed by Dan O'Leary and his research team, is based on Microsoft's HoloLens2 system (O'Leary, In Press). The HoloLens, pictured to the right, projects images and information through a screen worn in front of the worker's eyes, similar to glasses. The system is operated via gestures, allowing the wearer to press "buttons" that appear in the air and are only visible to them.

Each user must calibrate the HoloLens2 system for accurate display and interaction. The initial setup process includes fitting the device comfortably on the user's head and calibrating the visual display to help improve clarity and alignment with the user's field of view. This process helps to confirm that digital overlays are correctly positioned relative to real-world objects. The system allows for recording of what the user sees, including the digital content. This recording feature was utilized in this investigation for all participants, regardless of the treatment.

Using HoloLens2 in a manufacturing environment requires specific safety measures. Workers must be trained to remain aware of their surroundings to avoid accidents, as the device can partially obscure peripheral vision. Regular breaks are recommended to prevent eye strain, neck discomfort, and dizziness. Also, the device should be sanitized between uses to maintain hygiene.

Workers need training to use the HoloLens2 system effectively. This training includes an introduction to the device's features, instruction on gesture-based controls, and practice sessions to become comfortable navigating and interacting with the augmented reality environment. Two versions of the HMAR system were developed. The first version parallels the capabilities of the PBAR system, requiring the worker to keep the workpiece stationary on the workstation. A mounting piece, the same one used in the PBAR system, is attached to the workstation to hold the workpiece in proper alignment. The second version, an enhanced version (EHMAR), allows the user to move and pick up the workpiece. The system tracks the workpiece's location in space, providing guidance regardless of its position. For trials using the EHMAR, the mounting piece was removed, enabling participants to move the workpiece into various orientations as they pleased.

The HoloLens2 has some limitations, including its relatively short battery life, potential discomfort from extended use, and occasional tracking issues in low-light environments. Additionally, the device requires a stable internet connection for certain functionalities, which can be a constraint in some manufacturing settings.

The images below illustrate what the worker sees through the HoloLens display and what is seen by bystanders simultaneously, highlighting that the instructions are only visible to the worker, not to others watching from the sidelines.

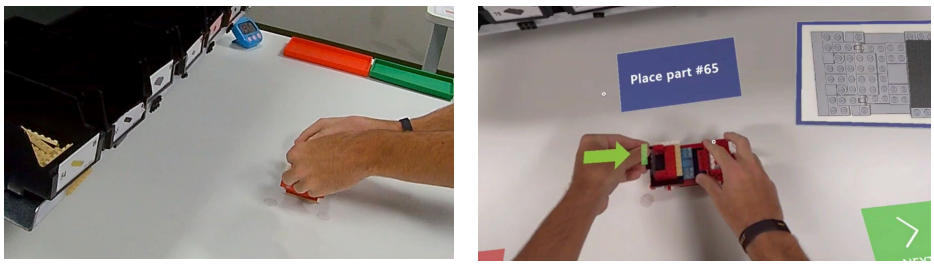

Figure 12: Outsiders' view from the left side (left) and Head Mounted Augmented Reality view from HoloLens (right)

3.2 Pilot Study: Augmented Reality Effects on Performance and Quality

The pilot study conducted at the Tiger Motors Lean Education Center aimed to evaluate the effectiveness of the Light Guide Augmented Reality System (PBAR) in a simulated manufacturing environment. Participants, including Lean Teaching Assistants

and faculty, assembled LEGO® cars using traditional Paper Work Instructions (PWI) and the PBAR system. The study was designed to determine the best methods to incorporate PBAR into both in-person and online curriculums. Results indicated that while PBAR improved compliance with work instructions and reduced assembly errors, it also increased the time required to complete tasks. The study's insights informed the experimental design for future research on AR in educational settings.

The Auburn University Human Research Protection Program classified the study as “Not Human Subjects Research (NHSR),” enabling its smooth execution. Eight participants, aged 22 to 65, alternated between using PWI and PBAR, with the order of methods randomized. Completion times and error rates were recorded, revealing that PBAR, although slower, significantly enhanced assembly quality and compliance with standard procedures. Qualitative feedback, particularly from older participants, highlighted frustration with the AR system's slower pace and occasional technical issues, emphasizing the need for more user-friendly designs and better responsiveness.

Key conclusions from the pilot study underscored PBAR's potential to standardize procedures and improve accuracy in educational training, despite the trade-off with increased completion times. The introduction of new error types and usability challenges necessitated recommendations for future research, including expanded studies, enhanced participant training, and ongoing technological improvements. These findings influenced the experimental designs of subsequent studies in Tiger Motors. For an in-depth review of the methods and findings, refer to Appendix B.1.

3.3 Manufacturing Technology Support Investigation: Projection and Head-mounted Augmented Reality Technology Used in Training

The results of the pilot study informed the experimental design of the subsequent investigations in the Tiger Motors Lean Education Center. This first investigation is titled: *Impact of Reported ADHD Symptom Presence on Performance, Quality, Usability and Perceived Cognitive Load of Participants Utilizing Novel Augmented Reality Technology for Manual Assembly Manufacturing Tasks*. This investigation is a comparison of differences in ADHD and Non-ADHD symptom reporting participant

subjects' cognitive load, their reported thoughts on the usability of the technology, measured time of car completion, and number of errors to compare augmented technologies used for training.

3.4 Manufacturing Technology Support Investigation: Research Objectives

3.4.1 Manufacturing Technology Support Investigation: Research Question

Are there differences between adults reporting significant ADHD symptoms and those with no or few significant ADHD Symptoms during the use of Paper Work Instructions, projection-based AR, head-mounted AR, or enhanced head-mounted AR to significantly affect outcomes such as cognitive load, perceptions of system usability, production speed, and quality?

3.4.2 Manufacturing Technology Support Investigation: Specific Aims

This study aims to compare cognitive load, system usability perceptions, production speed, and quality outcomes between adults reporting 'significant' versus 'no or few significant' ADHD symptoms when using three AR technologies (PBAR, HMAR, or EHMAR) versus traditional work instructions (PWI).

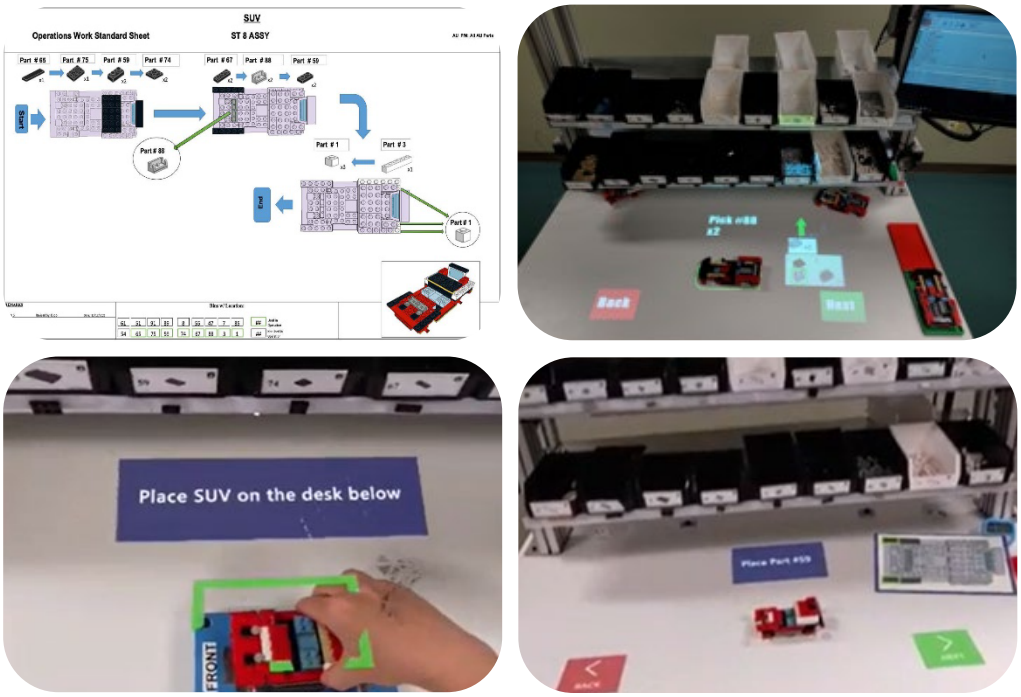

Figure 13: Manufacturing Technology Support Investigation: Images of the four treatments, no digital assistance in training with only PWI (top left), Projected instructions with PBAR (top right), HoloLens instructions with fixed base (bottom left), HoloLens with no base - free to move workpiece (bottom right).

3.4.3 Manufacturing Technology Support Investigation: Hypotheses

There are four main categories of hypotheses investigated for this investigation. These categories include productivity, quality, cognitive load, and system usability. Each of these categories' hypotheses are outlined below.

3.4.3.1 Productivity-Related Hypotheses

H_1: ADHD symptom levels (High, Medium, and Low ASRS6 symptoms) will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

H_2: ADHD Type (ASRS18 Types: Inattentive, Hyperactive/Impulsive, Combined Types) will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

H_3: ADHD symptom levels will not significantly affect production speed across all treatments (PBAR, HMAR, EHMAR, and PWI).

H_4: Participants using PWI will report higher production speed compared to those using PBAR, HMAR, and EHMAR regardless of ADHD symptom levels.

3.4.3.2 Quality-Related Hypotheses

H_5: ADHD symptom levels will not significantly impact production quality across different treatments (PBAR, HMAR, EHMAR, and PWI).
H_6: Participants with higher ADHD symptom levels will show greater improvement in production quality using AR technologies (PBAR, HMAR, EHMAR) compared to traditional Paper Work Instructions (PWI).
H_7: Participants using EHMAR will report higher production quality compared to those using the other treatments, regardless of ADHD symptom levels.

3.4.3.3 Cognitive Load-Related Hypotheses

H_8: ADHD symptom levels will significantly impact Cognitive Load, as measured by the NASA TLX, across different treatments (PBAR, HMAR, EHMAR, and PWI).
H_9: The Weighted NASA TLX scores after Recall will vary between participants using the EHMAR treatment for training and those using other treatments, with the differences influenced by the levels of ADHD symptoms.
H_{10}: The Control Normalized NASA TLX Training scores differ among the levels of ADHD symptoms.

3.4.3.4 System Usability-Related Hypotheses

H_{11}: System Usability Scale Ratings differ among the levels of ADHD Symptoms.
H_{12}: ADHD symptom levels will not significantly affect the Control Normalized System Usability Scale (SUS) scores within each treatment (PBAR, HMAR, EHMAR, PWI).
H_{13}: The SUS Score for each ADHD symptom level will be different between treatments (PBAR, HMAR, EHMAR, PWI).

3.5 Manufacturing Technology Support Investigation: Methods

3.5.1 Experimental Design

Considering the potential limitations of a within-subjects experiment, particularly with participant learning and the time needed to use multiple technology treatments, a between-subjects experimental design was deemed best suited to assess the learning transfer of participants using the technologies. This design helps mitigate the issues of carryover effects and learning bias that can occur when participants are exposed to multiple treatments.

Participants were selected through a convenience sample of Auburn University community adults. Recruiting was done through faculty members, email, and flyer placement. Participants were randomly assigned to one of the four treatment groups to help promote the unbiased distribution of individual differences across conditions. This randomization helped control for confounding variables and helped to minimize any observed effects due to the treatment rather than participant characteristics.

Using effect sizes obtained from the pilot study, a power analysis was conducted to determine the necessary sample size for the experiment. The analysis aimed to confirm that the experiment would have sufficient power to detect significant effects. Anticipating a substantial effect size among the treatments, the sample size for the Manufacturing Technology Support Investigation was set at 60 participants, with 15 in each of the four treatment groups. This sample size estimates a power of 0.8 at a significance level of 0.05, designing the study to be adequately powered to detect meaningful differences.

The four treatment groups correspond to the different types of technology being evaluated. Each group receives only one type of technology treatment to isolate the effects of that particular technology on learning transfer. The treatments include traditional paper instructions, PBAR, HMAR, and EHMAR.

Each participant undergoes a ten-minute training session using the assigned technology. The training consists of completing a series of tasks designed to simulate a real manufacturing environment. The tasks are standardized across all groups to promote comparability. During the training, data on task completion time, error rates, and participant feedback are collected. After a brief reset, the participants were asked to build four cars, recalling how to do the 16 steps at the workstation with only the PWI for reference and no technology aids.

Understanding that each individual differs in their abilities and capabilities with technology, demographic information, and baseline technology proficiency were collected and analyzed in post-hoc analysis. Participants for this study were pre-screened and excluded if they had prior experience with similar AR devices or Tiger Motors lab experience. These steps help to control for individual differences and provide a deeper understanding of how these factors may influence the effectiveness of each technology.

The collected data were analyzed using statistical methods appropriate for a

between-subjects design. ANOVA tests were used to compare the means across the four groups, and post-hoc tests will identify specific group differences.

Auburn University Institutional Review Board approved the human subjects' research for the study, and all participants provided informed consent. Participants were informed of their right to withdraw at any time and assured of the confidentiality of their data. Details of the IRB approval is provided in Appendix E.2.

The main limitation of the between-subjects design is the need for a larger sample size compared to within-subjects designs. Additionally, individual differences in technology proficiency and learning styles may introduce variability in the results. These factors are addressed through randomization and post-hoc analysis.

These calculated sample sizes and methodological considerations help guarantee that this investigation into the effects of augmented reality technologies on learning transfer in manufacturing is robust and capable of producing meaningful conclusions. The sample size calculations were made using the online software provided by Statistics for Psychologists (Sample Size Calculator, 2023).

3.5.2 Experimental Protocols

Investigating the effectiveness of various technologies on task retention, this investigation involves the use of one of four treatment conditions to train an operator for station eight in the Tiger Motors Lean Education Center manufacturing line simulation. All participants wore the device during both phases of the testing to control for the effects of wearing the HoloLens device. However, only those selected for that technology had it activated and were given instructions through HoloLens. The testing conditions included

PWI, PBAR, HMAR, and EHMAR. All participants completed a basic biographical information survey as well as the Adult ADHD Self Report Scale (ASRS). The

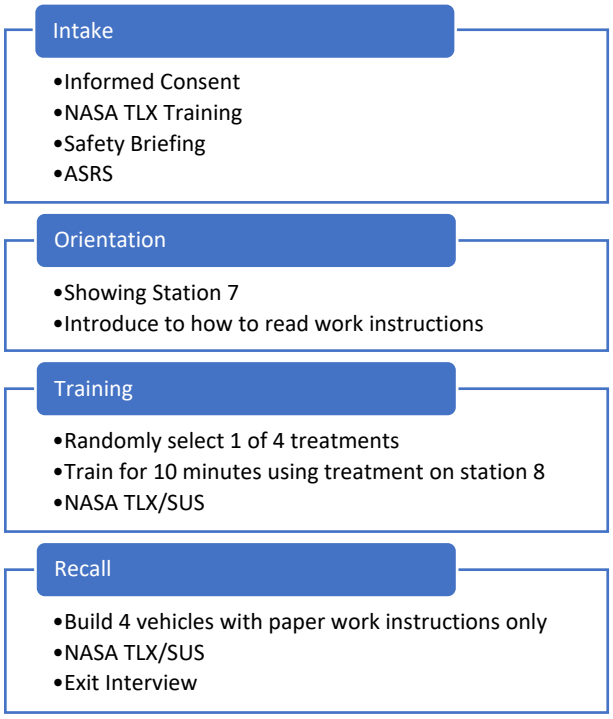

Figure 14: Manufacturing Technology Support Investigation: Investigation Procedure

participants were instructed on how to read work instructions and build with LEGO at the station prior to using the station for the investigation. To begin the investigation, each participant built for ten minutes using one of the three randomly selected technologies or PWI only (no AR technology). Then, they completed the NASA TLX and System Usability Scale (SUS). The participant then returned to the station to build four cars as quickly and accurately as possible using only the Paper Work Instructions. Following the recall portion of the investigation, participants return to the conference room and complete a follow-up NASA TLX and SUS. They are interviewed with exit survey questions.

A strict procedure and script were followed for every participant to provide a consistent experience with the experiment for all participants. Each participant, independent of treatment, performed the same steps and tasks.

Figure 15: Manufacturing Technology Support Investigation: Three camera view, through the HoloLens with EHMAR program (upper left), full camera view from side (right), zoomed in side camera view (bottom left).

3.5.3 Variables

This section outlines the measures and variables utilized in the investigation, focusing on the factors influencing worker performance and cognitive load in a simulated manufacturing environment. The experimental design involved detailed analyses of both independent and dependent variables, as well as controlling factors that could impact the reliability and validity of the results. The primary aim is to understand how different workplace training technologies impact cognitive load, usability, quality, and performance, with particular attention to variations among participants with ADHD symptoms and neurotypical workers.

3.5.3.1 Independent Variables

Independent variables are the factors manipulated to observe their effects on the dependent variables. In this study, the following independent variables were considered:

1. Technology Used: The type of training technology utilized during the task, including traditional paper instructions (PWI), Projection-Based AR (PBAR), Head-Mounted AR (HMAR), or Enhanced Head-Mounted AR (EHMAR).
2. Number of Reported ADHD Symptoms: The total count of significant ADHD symptoms reported by the participants.
3. Categories of ADHD Symptoms: Specific categories or types of ADHD symptoms reported by the participants.

3.5.3.2 Dependent Variables

Dependent variables are the outcomes measured to assess the effects of the independent variables. In this study, the following dependent variables were measured:

1. Number of Cars Completed in 10 Minutes: The total number of LEGO cars assembled by each participant within ten minutes. This was confirmed through photographic evidence collected on the day of the study.
2. Number of Errors: The total count of assembly errors made by the participants was also confirmed through photographic evidence.
3. Types of Errors: The specific types of errors observed during the assembly process, categorized and recorded through photographic evidence. While collected, these were not used in this analysis.
4. General Comments/Behaviors: Observations and comments made by participants during the study were recorded in real time. While collected, these were not used in this analysis.
5. Cognitive Load for Six Factors: Cognitive load was assessed across six specific factors, recorded on the day of the study using the NASA TLX.
6. Cognitive Load Overall: The overall cognitive load experienced by participants was recorded using the NASA TLX.
7. Cognitive Load Weighted: This is a weighted measure of cognitive load, providing a nuanced understanding of the participants' mental workload.
8. System Usability Scale (SUS): Participants' perceptions of the usability of the support systems were measured using the SUS on the day of the study.

3.5.3.3 Covariates

Covariates are variables that are not of primary interest but may influence the dependent variables and need to be controlled for in the analysis. In this study, the following covariates were included:

1. Age: The age of the participants, which may influence their performance and cognitive load.

2. Gender: The gender of the participants is considered to explore potential differences in responses to the support systems.
3. Education Level: The highest level of education completed by the participants.
4. LEGO Experience Level: The participants' prior experience with LEGO could affect their familiarity and comfort with the task.
5. Ethnicity: The ethnic background of the participants.
6. Race: The racial background of the participants.
7. College Major: The field of study of the participants, which might correlate with their technical skills and performance.

3.5.3.4 Controlled Factors

Controlled factors are variables that are kept constant to help confirm that the results are attributable to the manipulation of the independent variables. In this study, the following factors were controlled:

1. Environmental Conditions: The physical environment of the Tiger Motors Lab, including lighting, noise levels, and workstation setup, was kept consistent for all participants. Conditions may vary slightly from day to day, but they did not vary significantly and were relatively constant for all data collection sessions.
2. Instructional Procedures: The instructions given to participants were standardized using detailed scripts to promote uniformity in understanding and execution of the tasks.
3. Task Complexity: The complexity of the assembly task was maintained at a constant level for all participants. All participants performed the same task at the same station in Tiger Motors.
4. Timing: The duration of each phase and the breaks between phases were consistent for all participants.
5. Data Collection Methods: The methods used to collect data, including photographic evidence, real-time recordings, and survey responses, were standardized to promote reliability.

By controlling these factors and including relevant covariates, the study aims to isolate the effects of the independent variables on the dependent variables, providing a

clear understanding of how different workplace support systems impact cognitive load, usability, and performance in a simulated manufacturing environment.

3.6 Manufacturing Technology Support Investigation: Results

This results section presents the findings of the Manufacturing Technology Support Investigation based on the data collected and analyzed. It encompasses quantitative analyses of various hypotheses related to System Usability Scale (SUS) scores, NASA TLX Cognitive Load measures, error rates, and production outputs. Key hypotheses examined include differences in performance, quality, Cognitive Load (NASA TLX scores), and System Usability (SUS scores) based on ADHD symptom levels.

3.6.1 Description of Data

3.6.1.1 Sample Demographic Characteristics

Each participant filled out a demographic information sheet prior to completing the experiment. The demographic information sheet contained no personally identifiable information, such as name, email address, and phone number, which were collected on a separate code sheet. The demographic information collected included age, gender, ethnicity, birth country, primary language, schooling, major, LEGO experience, and manufacturing experience. The following tables summarize the participants.

Table 6: Sample Age Characteristics

Variable	Mean	St. Dev	Minimum	Median	Maximum
Age	23.033	6.901	19.000	20.000	47.000

Table 7: Sample Characteristics

Characteristics	Descriptor	Count	Percent
Gender	Female	28	45.16
	Male	33	53.23
	Other	1	1.61
Race	Asian	8	5.69
	Black	3	3.20
	White	50	88.97
	More than one	1	2.24
Ethnicity	Hispanic or Latino	2	3.23
	Not Hispanic	59	95.16
	Unknown	1	1.61

Characteristics	Descriptor	Count	Percent
Birth Country	Australia	1	1.61
	China	2	3.23
	Germany	1	1.61
	India	1	1.61
	Indonesia	1	1.61
	N/A	1	1.61
	Nigeria	1	1.61
	Poland	2	3.23
	South Korea	3	4.84
	Saudi Arabia	1	1.61
	UK	1	1.61
	USA	47	75.81
Primary Language	English	56	90.32
	Other	6	9.68
Schooling	Some College	49	66.22
	Associate	2	3.60
	Bachelor	2	4.50
	Master	6	16.22
	PhD	7	9.46
Major In School	Engineering	51	82.26
	COSAM	2	3.60
	Consumer and Design Sci	1	1.61
	Business	4	6.45
	Hospitality	1	1.61
	N/A	3	4.84
LEGO Experience	Little/no experience	21	17.36
	Some experience	27	44.63
	Lots of experience	10	24.79
	Expert	4	13.22
Manufacturing Experience	No experience	41	41.84
	One or more classes	10	20.41
	Part-time/temporary	7	21.43
	One or more years	4	16.33

The Manufacturing Technology Support Investigation involved a sample of 62 participants. Their demographic and background characteristics revealed several notable similarities and differences. The demographic survey asked participants about their gender, not other ways of representing this factor, such as sex or sex at birth. In terms of gender distribution, the sample consisted of 53.23% male participants, 45.16% female participants, and 1.61% identifying as other. This indicates a predominantly male study population with a notable representation of females.

The birthplace of participants highlighted some diversity, with 75.81% from the USA. Other countries represented included Australia (1.61%), China (3.23%), Germany (1.61%), India (1.61%), Indonesia (1.61%), Nigeria (1.61%), Poland (3.23%), South Korea (4.84%), Saudi Arabia (1.61%), and the UK (1.61%). This shows a high degree of international diversity. Primary language data revealed that 90.32% of participants spoke English as their primary language, while 9.68% spoke other languages.

In summary, the demographic and background characteristics of the study participants revealed a balanced gender, White, and USA-born sample with a strong focus on engineering majors and some amount of LEGO and little or no manufacturing experience. These characteristics provide valuable context for understanding the study's findings.

3.6.1.2 Sample ADHD Symptom Prevalence

This section presents the prevalence and characteristics of ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS). The sample comprised 62 participants. This analysis focused on several key metrics, including the ASRS6 number of significant symptoms, the ASRS6 total points category, ADHD levels, and ADHD types. How to calculate these factors is detailed in Section 5.5.5.3 starting at step 6. These variables are subsequently compared to the measured outcomes of the study and statistically compared to determine significant differences. The table below summarizes the frequencies calculated for each of these factors for the investigation.

Table 8: ADHD Symptom Prevalence by Investigation and Total, Including ASRS6, ASRS6 Total Points Scale, ADHD Levels, and ADHD Types

		Total Sample N = 62	
Characteristics	Descriptor	Count	Percent
ASRS6 Question Sub-Scale	0 Significant Symptoms	7	11.3
	1 Significant Symptoms	7	11.3
	2 Significant Symptoms	16	25.8
	3 Significant Symptoms	12	19.4
	4 Significant Symptoms	12	19.4
	5 Significant Symptoms	6	9.7
	6 Significant Symptoms	2	3.2
ASRS6 Questions Total Points Category	High Negative (0-9 Points)	16	25.8
	Low Negative (9-13 Points)	31	50.0
	Low Positive (14-17 Points)	11	17.7
	High Positive (18-24 Points)	4	6.5
ASRS 6 Questions ADHD Level Sig. Symptoms	Low = 0-1 Symptoms	14	22.6
	Med. = 2-3 Symptoms	28	45.2
	High = 4-6 Symptoms	20	32.3
ADHD type Based on ASRS 18 Question Severities	Inattentive	18	29.0
	Hyperactive/Impulsive	7	11.3
	Combined	16	25.8
	None	21	33.9

Additional sample characteristics descriptions are provided in Appendix B.3.

3.6.1.3 Data Screening and Cleaning

Data collection was conducted using paper forms designed for this study and approved by the IRB. These forms, detailed in Appendix E.2: IRB Documents, tracked the number and types of errors for each car built, the total number of cars completed, cars started but not finished, and any anomalies such as dropped cars. The NASA TLX and SUS scales were also recorded manually.

The raw data from these paper forms were subsequently digitized using Microsoft Excel (Version: Microsoft® Excel® for Microsoft 365 MSO (Version 2405 Build 16.0.17628.20006) 64-bit). The data were entered by researchers and research assistants, who organized it into separate worksheets based on participant number and classifications, including demographics, treatment type (PWI, PBAR, HMAR, EHMAR), and the Behavioral Control Survey (ASRS). Following data entry, various metrics were calculated from the raw data. The following calculations were made:

1. **NASA TLX**—The following metrics were calculated for each of the five NASA TLX instances (see the table below).

Table 9: NASA TLX Metrics: Name, Description, and Formula

NASA TLX Metric Name	Description	Formula
Weighted Subscales: Mental Physical Temporal Performance Effort Frustration	Weighted Subscale gives a sub-scale level perspective of the loads reported. The formula divides by 15 because of the 15 weighting pairs, Multiplies by 100, and divides by 7 to scale the 7-point TLX scale to a 100-scale. (So, 2020)	Weighted Subscale = (#Times Weighted Higher)*(TLX Score for Category)/15*100/(Scale of the NASA TLX) Depending on the NASA TLX used, the Scale could be a 7-point scale or a 100-point scale
Weighted TLX	Weighted NASA TLX is more comprehensive and sensitive to individual differences in the perception of workload, as it considers the relative importance of each dimension. It is particularly useful in complex tasks where specific dimensions might be more critical than others. (So, 2020)	Weighted NASA TLX = Sum (Weighted Subscales) $Weighted\ Score = \frac{\sum(Rating_i\ x\ Weight_i}{\sum Weight_i}$

NASA TLX Metric Name	Description	Formula
Unweighted TLX	Unweighted NASA TLX is more straightforward and quicker to administer, making it suitable for situations where a rapid assessment is needed or when the task is not complex enough to warrant differential weighting of dimensions. Multiplies by 100 and divide by 7 to scale the 7-point TLX scale to 100 scale. (So, 2020)	=AVERAGE(Reported Values for Each Subscale)*100/(Scale of the TLX) $Unweighted\ Score = \frac{\sum Rating_i}{6}$ Depending on the NASA TLX used, the Scale could be a 7-point scale or a 100-point scale
Control Normalized TLX	To compare the percentage change relative to the control, normalization to the control is calculated for each participant, for each treatment, except the control (Yiyuan et al., 2011).	$Control\ Normalized\ TLX\ Score = \frac{TLX_{treatment} - TLX_{control}}{TLX_{control}} x100$
Min-Max Normalized TLX	Min-Max Normalization can be beneficial if the goal is to compare workload scores directly across participants by bringing all scores to a common scale. However, it might be sensitive to outliers in participants' ratings (Barajas-Bustillos et al., 2023)	$Min - Max\ Normalized\ TLX\ Score = \frac{TLX_{treatment} - minTLX_{global}}{maxTLX_{global} - minTLX_{global}} x100$

2. **SUS**—The following metrics were calculated for each of the four SUS instances (see the table below).

Table 10: SUS Metrics: Name, Description, and Formula

SUS Metric Name	Description	Formula
SUS	For odd-numbered items (1, 3, 5, 7, 9): Subtract one from the score. For even-numbered items (2, 4, 6, 8, 10): Subtract the score from 5. Sum the adjusted scores. Multiply by 2.5 to scale to 100 (Klug, 2017).	Likert Scale 1= Strongly Agree, 5= Strongly Disagree Even Questions Adjusted Score = Score-1 Odd Questions Adjusted Score =5-Score SUS Score = (Sum Adjusted Scores) x 2.5
Control Normalized SUS	To compare the percentage change relative to the control, normalization to the control is calculated for each participant, for each treatment, except the control (Yiyuan et al., 2011).	$Control\ Normalized\ SUS\ Score- = \frac{SUS_{treatment} - SUS_{control}}{SUS_{control}} x100$
Normalized SUS	Z-score Normalization is typically done with the SUS, as it has a large validated data set that provides a known mean (68) and standard deviation (12.5) (Klug, 2017; Lewis, 2018; Lewis & Sauro, 2018)	$Z = \frac{SUS_{treatment} - 68}{12.5}$ Normalized SUS= NORM.S.DIST(Z, TRUE) * 100

3. **Performance and Quality**—The following metrics were calculated for each of the treatment instances (4 total); see the table below.

Table 11: Performance and Quality Metrics: Name, Description, and Formula

Performance/Quality Metric Name	Description	Formula
Total Built	For the ten-minute training phase, indicate the number of complete cars made to the end of the steps for Station 8.	Raw value
Number of Participants Making 8+ Cars	The TAKT time for this station is 60 seconds, meaning one finished car should be produced each minute. Participants working at 80% Takt Time should make eight cars. This metric evaluates how many participants are reaching at least 80% of the desired production speed.	For each participant who reached 8 or more cars during the training session, mark a 1; for all others, mark a 0.
Average Defects	The average of the defects made over the study's phases. A separate metric was calculated for the training and recall phases.	Training Average Defects =Number of Uncorrected Errors made/ Total Built Recall Average Defects = Number of Uncorrected Errors made/4
Number of Participants Making Errors	To analyze the number of participants making uncorrected errors at any point during the trial.	For each participant who makes an error during the trial, mark a 1; for all others, mark a 0.

4. BCS (ASRS)—The following metrics were calculated for the ASRS, completed once at the beginning of the study. See the table below.

Table 12: ASRS Metrics: Name, Description, and Formula

ASRS Metric Name	Description	Formula
ASRS6	The number of symptoms of significant frequency. Four or more symptoms from the first six questions of the ASRS are shown to correlate with a high liklihood that the adult has ADHD (Kessler, Adler, Ames, Demler, et al., 2005).	Total the number of questions at a significant level (Questions 1-6) Questions Significant at 2+ (Sometimes): 1, 2, 3 Questions Significant at 3+ (Often): 4, 5, 6
ASRS6 Symptom Level	Grouping the ASRS6 symptoms into three groups has shown an effective way of analyzing the correlation of the ASRS symptoms with other study variables (Kessler et al., 2009; Waite et al., 2022a).	Assign a category of likelihood for ADHD based on the number of significant symptoms in the ASRS6. 0-1 Symptoms = Low 2-3 Symptoms = Medium 4-6 Symptoms = High
ASRS6 Total Points	The four-stratum classification scheme is made up of scores in the range 0–9, 10–13, 14 –17 and 18 –24 (Kessler et al., 2007).	Total points for the first six (0 = Never, 1 = Rarely, 2 = Sometimes, 3 = Often, 4 = Very Often). Score each question based on the number of points and total the first six questions.
ASRS6 Total Points Categories	Assign the category to each of the ranges of points in the ASRS6 Total Points.	0-9 = High Negative 10-13 = Low Negative 14-17 = Low Positive 18-24 = High Positive
ASRS18	An additional metric to analyze the adult participant's level of ADHD symptoms uses all 18 questions of the scale. This metric is the number of significant symptoms from all 18 questions.	Total the number of questions at a significant level (All Questions) Questions Significant at 2+ (Sometimes): 1, 2, 3, 9, 12, 16, 18 Questions Significant at 3+ (Often): 4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 17

ASRS Metric Name	Description	Formula
ADHD Type	Classify the type of ADHD based on the number of symptoms for specific questions ("Adult ADHD Self-Report Scale (ASRS)," 2021).	**Inattentive**: Questions=1, 2, 3, 4, 7, 8, 9, 10, 11 **Hyperactive/Impulsive**: Questions =5, 6, 12, 13, 14, 15, 16, 17, 18 If an adult has both, it is classified as **Combined Type** Four or more symptoms in the categories are classified as that type.

Data was imported into Minitab 22.1 (64-bit). During the transfer, data points were checked for errors, particularly in mixed number and text fields. Corrections were made as needed. Outlier analysis was performed to identify and handle extreme values that could skew results. This step promotes the integrity and accuracy of the data used in the analysis.

3.6.1.3.1 Outlier Analysis

Outlier removal is a critical consideration in statistical analysis, particularly in experimental studies, to enhance the integrity and validity of the results. The process involves deciding whether to exclude entire participants or specific observations that deviate significantly from the norm. The removal of outliers should be done systematically to avoid "p-hacking," which refers to selectively excluding data to achieve desired statistical significance. This practice undermines the reliability of the findings. Excluding outliers at the participant level is justified when a participant's overall behavior or performance significantly deviates from the expected protocol, impacting multiple observations. In contrast, removing outliers at the observation level involves excluding specific data points that are anomalous due to errors or external factors without dismissing the participant's entire data set. It is important to apply consistent and transparent criteria for outlier removal to maintain the robustness of the study's conclusions.

In this study, one particular participant (1063) was removed from the analysis because they failed to adhere to the experimental protocol and instructions. This participant only managed to build two cars during the training session, indicating a significant deviation from the expected performance. Multiple instances of lack of adherence to protocol compromised the integrity of the data collected from this

participant; therefore, it likely did not reflect the true effects of the treatment being tested. After discussion with the other researcher, Dan O'Leary, this subject's data were considered an outlier. This data point was excluded from the analysis to help the study results accurately represent the impact of AR technologies on production quality, speed, cognitive load, and usability among participants with varying levels of ADHD symptoms.

3.6.2 Study Distinctions

Co-collaborator Dan O'Leary is investigating performance changes, usability, and learning afforded by the technologies of this study, some of which are shown in the results below (O'Leary, In Press). He is analyzing the complete set of data without considering the ADHD classification of the participants. This study, however, differentiates itself by incorporating ADHD symptom status into the analysis, providing a better understanding of ADHD symptom-reporting participant interactions with AR technologies.

This analysis extends beyond O'Leary's study by examining the influence of ADHD symptom reporting status and ADHD type on production speed and defect rates when using AR technologies. The study categorizes participants into three ADHD symptom levels based on the ASRS6: Low/Unlikely (0-1 significant symptoms), Medium/Possible (2-3 significant symptoms), and High/Likely (4-6 significant symptoms). Additionally, the ASRS18 Type categorization identifies participants with Inattentive ADHD, Hyperactive/Impulsive ADHD, and Combined Type ADHD.

By incorporating ADHD symptom status, this study aims to provide a deeper understanding of how ADHD influences the efficacy of AR technologies in a manufacturing training environment. The balanced distribution of participants with significant ADHD symptoms across treatments helps guarantee that the findings are not biased by any particular group, allowing for a comprehensive analysis of the interaction between ADHD symptoms and AR technology performance. The full analysis of these metrics is provided in the Main Analyses section of this report.

3.6.3 Main Analyses: Hypothesis Testing

In this section, is the transition from the experimental setup to the analysis of the

results obtained. The study tested 13 hypotheses through the application of various statistical measures, assessing the collected values and computed metrics. Detailed procedures and extended statistical analyses are thoroughly documented in Appendix B.5. Below, we provide a concise summary of the crucial metrics, pivotal results, and key findings that highlight the most significant insights from this research.

3.6.3.1 Productivity-Related Hypotheses

Visualizing aspects of the data is also helpful in gaining a better understanding of the trends. In the three figures below, the metric for the Number of Cars Built during Training is graphed in box plots, one dividing the treatments by the level of ADHD symptoms, one by the Types of ADHD, and the other by the treatments.

The boxplot of the total number of cars built for each treatment shows an increase in the average number of cars built for the Projection-Based AR (PBAR) treatment and the Control (PWI) treatment. Both head-mounted AR (HMAR and EHMAR) technologies had significantly fewer cars made during treatment.

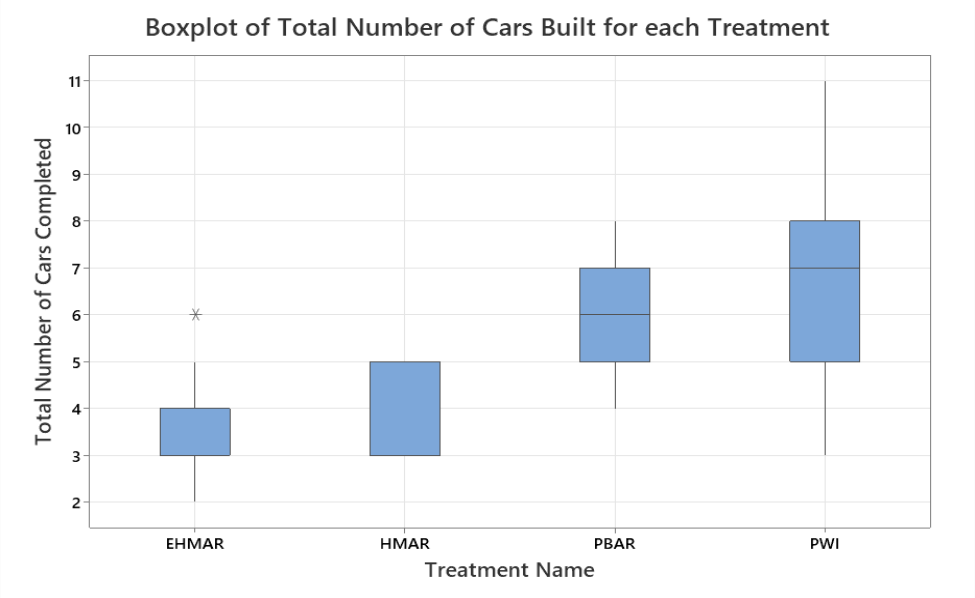

Figure 16: Boxplot of Total Number of Cars Built for Each Treatment

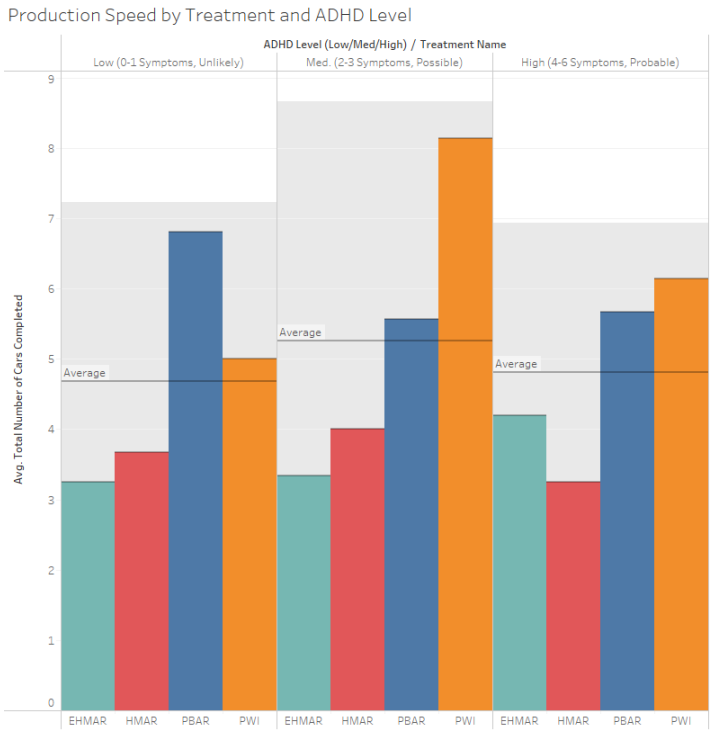

Figure 17: Production Speed by Treatment and ADHD Level

The hypotheses testing results related to productivity are summarized below:

Failed to Reject -H_1: ADHD symptom levels will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

- None of the ANOVA p-values indicate statistically significant differences in production speed across ADHD symptom levels for any treatments.
- The results support the hypothesis, indicating no significant impact of ADHD symptom levels on production speed across the various treatments.
- The PWI and PBAR treatments demonstrated larger variances in production speed among different ADHD levels, hinting at potential differences that might be more pronounced with larger sample sizes.

Failed to Reject - H2: ADHD Type will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

- None of the ANOVA p-values indicate statistically significant differences in production speed across ADHD types for any treatments.

Although the differences in mean values suggest some variability in production speed across ADHD types, these differences were not statistically significant, supporting

the hypothesis that ADHD type does not significantly impact production speed across the various treatments.

Rejected - H3: ADHD symptom levels will not significantly affect production speed across all treatments (PBAR, HMAR, EHMAR, and PWI).

- The main effect of treatment was found to be statistically significant ($p = 0.000$), indicating that different treatments significantly affect production speed.
- The interaction between ADHD symptom levels and treatments was statistically significant ($p = 0.033$), suggesting that the impact of ADHD symptom levels on production speed varies depending on the treatment administered.
- Effect size of the Two-Way ANOVA: Partial Eta Squared[7] for the terms of the model are ADHD Level $\eta^2 = 0.04$ (small-to-medium), Treatments vs Other $\eta^2 = 0.49$ (large), and Interaction $\eta^2 = 0.24$ (large).
- None of the interactions with ADHD Level 0 (Low Likelihood of ADHD) and treatments were statistically significant, indicating consistent treatment efficacy for this group.
- ADHD Level 1 (Medium Likelihood of ADHD) showed a statistically significant positive effect on production speed with the PBAR treatment, suggesting potential benefits of PBAR for this group, while other treatments did not exhibit significant interactions.
- ADHD Level 2 (High Likelihood of ADHD) revealed that the PBAR treatment significantly improved production speed, while EHMAR and HMAR treatments showed significant negative effects, suggesting these treatments may be less effective or detrimental for individuals with high ADHD symptoms.
- The main effect of ADHD symptom levels alone did not significantly influence production speed ($p = 0.370$), but the interaction with treatments did, highlighting the importance of considering both factors together.
- The PWI treatment did not show a significant interaction effect with any ADHD level, indicating its consistent efficacy across different ADHD symptom levels.

In conclusion, this analysis provided evidence to reject the null hypothesis (H3), demonstrating that ADHD symptom levels do significantly affect production speed when considering the interaction with different treatments.

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[7] Partial Eta Squared, $\eta^2 = (SS\ Treatment)/(SS\ Treatment + SS\ Error)$ $\eta^2 = 0.01$ Small effect size, $\eta^2 = 0.06$ Medium effect size, $\eta^2 = 0.14$ Large effect size (J. Cohen, 1988).

Failed to Reject - H4: Participants using PWI will report higher production speed compared to those using all other AR treatments regardless of ADHD symptom levels.

- The main effect of treatment (PWI vs. all other treatments) was statistically significant ($p = 0.001$), indicating that participants using PWI reported higher production speed versus those using all other treatments.
- The interaction between ADHD symptom levels and the treatment (PWI vs. all other treatments) was statistically significant ($p = 0.034$), indicating that the impact of ADHD symptom levels on production speed varies depending on whether participants are using PWI or all other treatments.
- The main effect of ADHD symptom levels alone did not significantly influence production speed ($p = 0.081$), though it approached significance, suggesting a potential trend worth further investigation.
- Effect size of the Two-Way ANOVA: Partial Eta Squared for the terms of the model are ADHD Level $\eta^2 = 0.09$ (medium), Treatment PWI vs Other $\eta^2 = 0.18$ (large), Interaction $\eta^2 = 0.12$ (medium-to-large).
- ADHD Level 0 (Low Likelihood of ADHD): The interaction between ADHD Level 0 and treatment (PWI vs. all other treatments) did not reach statistical significance, indicating that the difference in production speed between PWI and all other treatments is not significant for individuals with a low likelihood of ADHD.
- ADHD Level 1 (Medium Likelihood of ADHD): The interaction between ADHD Level 1 and treatment (PWI vs. all other treatments) did not reach statistical significance, indicating that the difference in production speed between PWI and all other treatments is not significant for individuals with a medium likelihood of ADHD.
- ADHD Level 2 (High Likelihood of ADHD): The interaction between ADHD Level 2 and treatment (PWI vs. all other treatments) was statistically significant ($p = 0.034$), suggesting that individuals with a high likelihood of ADHD using PWI reported higher production speed compared to those using all other treatments.

In conclusion, the findings of this analysis support the hypothesis (H4) that participants using PWI report higher production speed compared to those using all other treatments, with the effect being particularly pronounced for individuals with a high likelihood of ADHD. While the severity of ADHD symptoms alone may not directly impact production speed, the interaction between ADHD symptom levels and treatment (PWI vs. all other treatments) plays an important role in determining production speed outcomes.

3.6.3.2 Quality-Related Hypotheses

The graphs below visually depict a summary of the data collected for average errors per car for both the Training and Recall sessions by Treatment, ADHD Level, and ADHD Type. Notable trends are the increased defects per car in the Control (PWI) and a general downward trend in errors as the ADHD level increases.

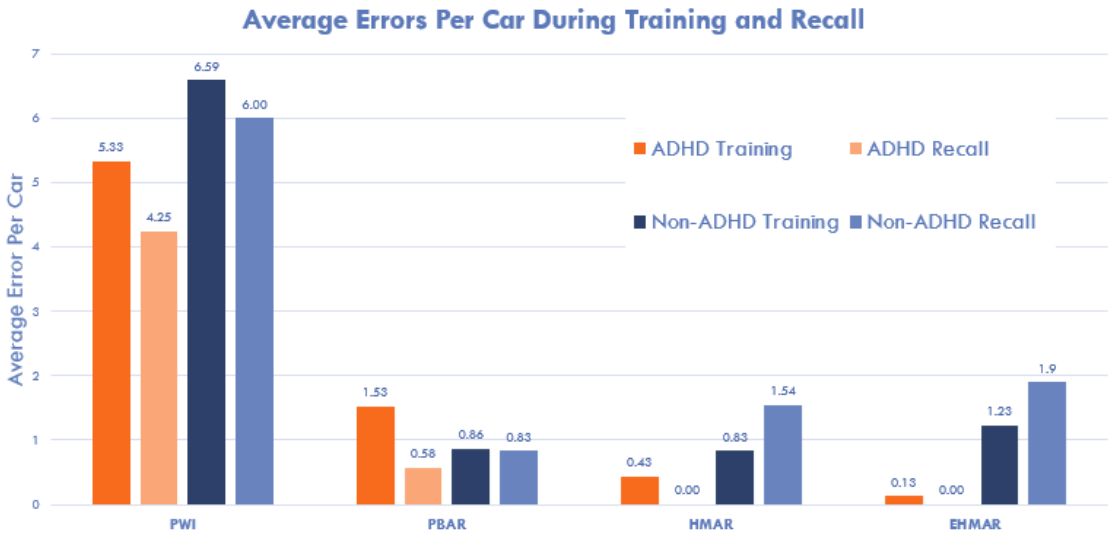


Figure 18: Average Errors Per Car During Training and Recall by ADHD (High Level vs Low/Medium)

The hypotheses testing results related to quality are summarized below:

Reject - H5: ADHD symptom levels will not significantly impact production quality across different treatments (PBAR, HMAR, EHMAR, and PWI).

- For the EHMAR treatment, ADHD symptom levels significantly impacted production quality ($F = 4.68$, $p = 0.031$, Cohen's $d = 1.98$ (large effect size)). Post-hoc comparisons showed that the high ADHD symptom group had significantly lower errors per car compared to the medium and low ADHD symptom groups.
- The main effect of ADHD symptom levels in the two-way ANOVA did not reach statistical significance ($F = 1.97$, $p = 0.150$), suggesting a potential trend that warrants further investigation.
- Effect size of the Two-Way ANOVA: Partial Eta Squared for the terms of the model are: ADHD Level $\eta^2 = 0.02$ (low-to-medium), Treatment $\eta^2 = 0.41$ (large), Interaction $\eta^2 = 0.06$ (medium).

- The EHMAR treatment resulted in higher error rates for both the low (mean = 2.50) and medium (mean = 0.83) ADHD groups compared to the same groups in the PBAR treatment (low mean = 1.30, medium mean = 0.50). Thus higher ADHD levels resulted in fewer errors.
- The Tukey Pairwise Comparison for EHMAR by ADHD level indicated significant differences between the low and high ADHD symptom groups.
- The main effect of treatment was statistically significant ($p < 0.001$) in the two-way ANOVA, indicating that the type of treatment significantly affects production quality.
- The interaction effect between ADHD symptom levels and treatments was not statistically significant, suggesting that the impact of ADHD symptom levels on production quality does not vary significantly across different treatments.

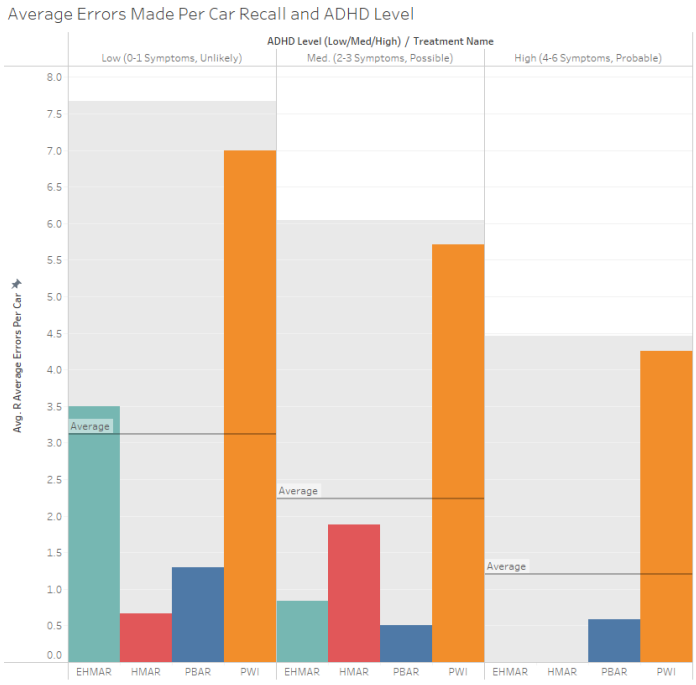


Figure 19: Average Errors Made Per Car During Recall by ADHD Level

In conclusion, the analysis found that ADHD symptom levels do significantly impact production quality across different treatments. The EHMAR treatment showed significant differences in error rates based on ADHD symptom levels. Also, the type of treatment significantly affected production quality, emphasizing the importance of treatment selection in improving outcomes.

Rejected - H6: Participants with higher ADHD symptom levels will show greater improvement in production quality using AR technologies (PBAR, HMAR, EHMAR) compared to traditional Paper Work Instructions (PWI).

- The main effect of treatment (PWI vs. all other AR treatments) was statistically significant ($F = 29.04$, $p = 0.000$), indicating that participants using AR technologies reported higher production quality than those using PWI.
- The main effect of ADHD symptom levels alone did not significantly influence production quality ($F = 2.19$, $p = 0.122$), suggesting a potential trend that is not quite significant but could be worth exploring further.
- Effect size of the Two-Way ANOVA: Partial Eta Squared for the terms of the model are: ADHD Level $\eta^2 = 0.07$ (medium), Treatment PWI vs Other $\eta^2 = 0.35$ (large), Interaction $\eta^2 = 0.004$ (small).
- The model indicates a moderate effect size with an R^2 value of 39.69%, and its predictive R^2 of 26.14% suggests a reasonable ability to generalize to new data.
- The interaction between ADHD symptom levels and the treatment (PWI vs. all other AR treatments) was not statistically significant, indicating that the impact of ADHD symptom levels on production quality does not vary significantly between PWI and the other AR treatments.
- Although the severity of ADHD symptoms alone did not significantly impact production quality, the use of AR technologies (PBAR, HMAR, EHMAR) significantly improved production quality by reducing production errors compared to traditional Paper Work Instructions (PWI).

In conclusion, the findings support the rejection of the hypothesis (H6) that participants with higher ADHD symptom levels will show greater improvement in production quality using AR technologies compared to PWI. The results indicate that while ADHD symptom levels alone do not significantly impact production quality, AR technologies significantly reduce production errors and improve production quality across all ADHD symptom levels. This suggests that AR technologies are beneficial for improving production quality regardless of ADHD symptom severity.

Rejected - H7: Participants using EHMAR will report higher production quality compared to those using the other treatments, regardless of ADHD symptom levels.

- None of the factors, including ADHD symptom levels, treatment type (EHMAR vs. all other treatments), or their interaction, showed statistically significant effects on production quality.
- None of the p-values were approaching significance; all were well above the threshold.
- The lack of significant findings suggests that the effect of EHMAR on production quality is not as pronounced as hypothesized.

In conclusion, the results of the ANOVA do not support the hypothesis (H7) that participants using EHMAR report higher production quality compared to those using other treatments, regardless of ADHD symptom levels.

3.6.3.3 Cognitive Load Related Hypotheses

The NASA TLX was administered alongside the SUS after each treatment. Similar to the SUS, the NASA TLX can be analyzed in multiple ways, with the calculations and justifications for the metrics discussed earlier. The figures below present Weighted and Unweighted NASA TLX scores segmented by treatment and ADHD classification. Keep in mind that the NASA TLX scores identified as a treatment are for the participants who used that treatment for their training. All participants only used the posted instructions without technology for the recall session.

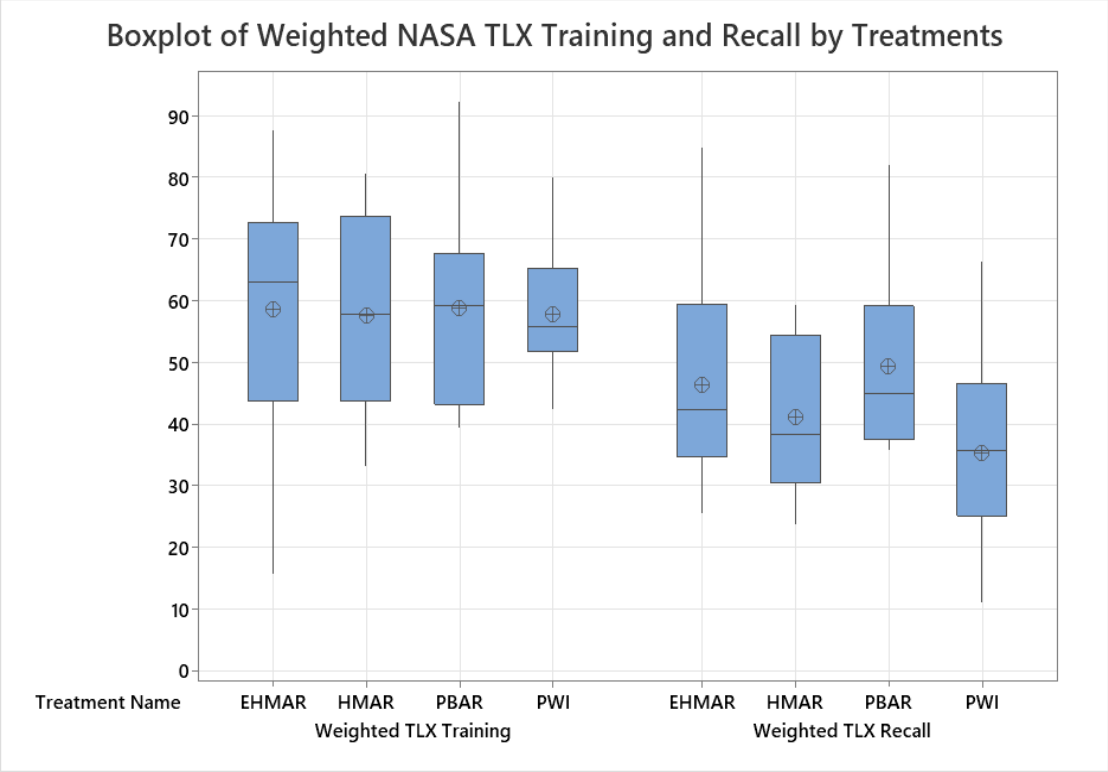


Figure 20: Weighted NASA TLX by Treatment for Training and Recall.

The graphs showed some slight differences. The NASA TLX Scores in the figure above show lower overall scores for the Recall session than the training session with the technology treatment.

Note: Tables of each of the metrics and measures for this investigation are provided in Appendix B.4.

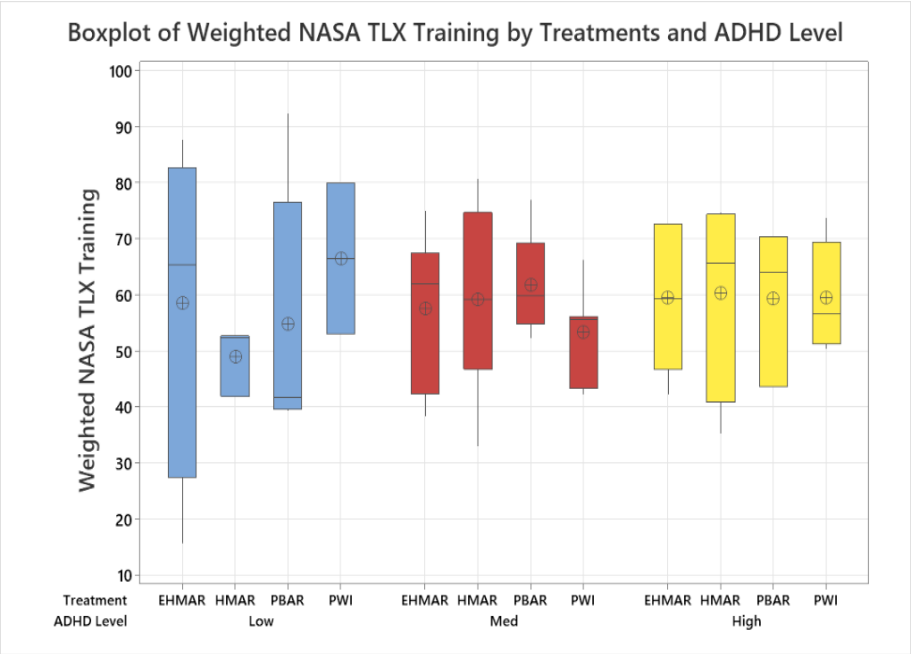


Figure 21: Weighted NASA TLX Training by Treatment and ADHD Level

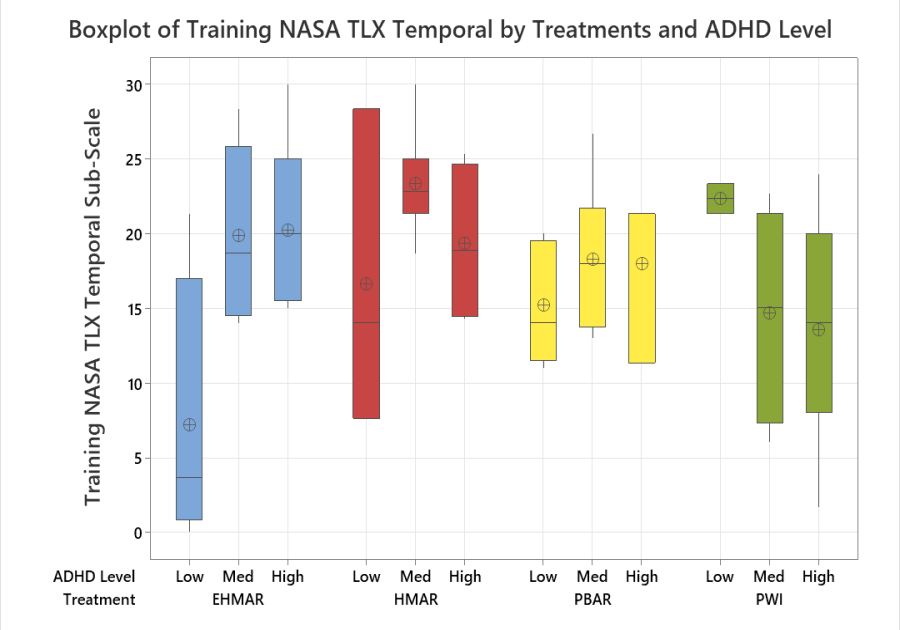


Figure 22: Training NASA TLX **Temporal** by Treatment and ADHD Level

The hypotheses testing results related to cognitive load are summarized below:

Failed to Reject - H8: ADHD symptom levels will significantly impact Cognitive Load, as measured by the NASA TLX, across different treatments (PBAR, HMAR, EHMAR, and PWI).

- EHMAR, Temporal TLX: The ANOVA showed a significant effect ($F = 4.99$, $p = 0.026$, Cohen's $d = 1.86$ (large effect size)). Tukey's post-hoc test indicated that the Low ADHD group had significantly lower Temporal TLX scores compared to both the Medium and High ADHD groups. This suggests that individuals with higher ADHD levels experienced significantly higher temporal demand in the EHMAR treatment compared to those with low ADHD levels.
- HMAR, Control Normalized TLX: The differences in Control Normalized TLX scores across ADHD levels approached significance ($F = 3.26$, $p = 0.074$, Cohen's $d = 1.6$ (high effect size)), indicating a trend where the High ADHD group experienced higher cognitive load.
- For participants with Low ADHD levels, the interaction term for HMAR was negative ($\beta = -6.10$), indicating a possible reduction in cognitive load with HMAR treatment under this ADHD level.
- For Medium ADHD levels, HMAR interaction was positive ($\beta = 3.34$), suggesting an increase in cognitive load with HMAR treatment.

In conclusion, while the two-way ANOVA did not find significant main effects of ADHD levels or treatment types on weighted TLX scores, the significant result for Temporal TLX in the EHMAR treatment highlights the potential impact of higher ADHD levels on temporal demand.

Rejected - H9: The Weighted NASA TLX scores after Recall will vary between participants using the EHMAR treatment for training and those using other treatments, with the differences influenced by the levels of ADHD symptoms.

- There were no statistically significant findings for the two-way ANOVA's main effects or the interaction effect.
- The main effect of treatment (EHMAR vs. all other treatments) approached significance, suggesting a potential trend that merits further investigation.
- The interaction between ADHD level and treatment also approached significance, indicating a potential relationship worth exploring further.

In conclusion, while the two-way ANOVA did not find statistically significant effects of ADHD levels, treatment types, or their interaction on the weighted NASA TLX

scores after recall, the nearing significant findings for treatment and the interaction terms indicate potential trends worth investigating further.

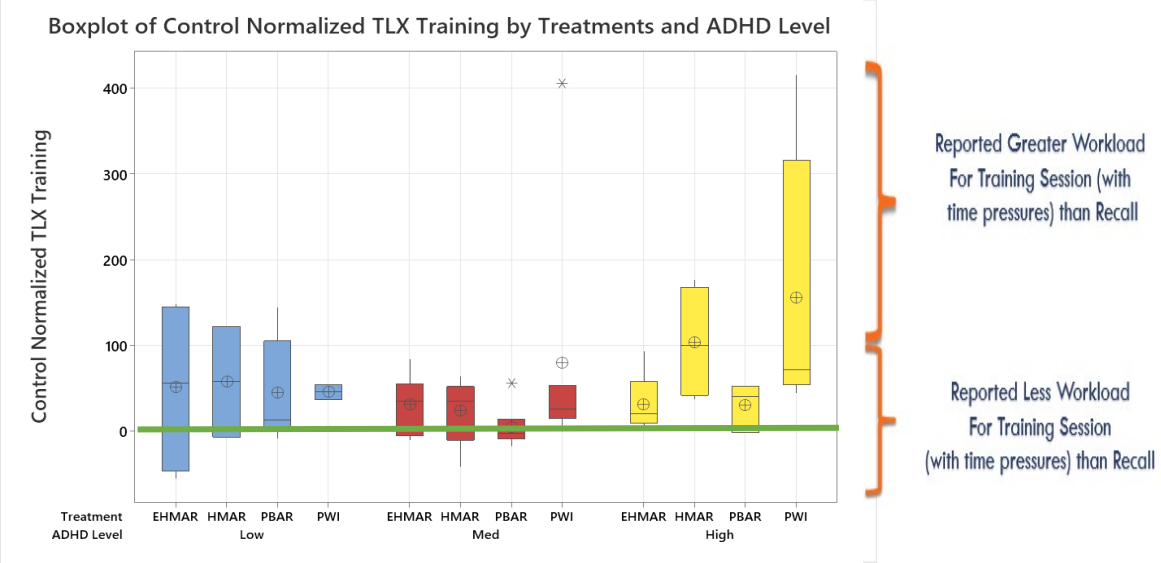


Figure 23: Control Normalized NASA TLX Training by ADHD Level vs Treatment

Reject - H10: The Control Normalized NASA TLX Training scores differ among the levels of ADHD Symptoms.

The overall one-way ANOVA for Control Normalized TLX Training scores approached significance ($F = 2.41$, $p = 0.099$, Cohen's $d = 0.65$ (medium effect size)), suggesting a trend that participants with higher ADHD levels might perceive increased cognitive load compared to those with lower ADHD levels.

- The Fisher Pairwise Comparison shows a significant difference between the medium and high ADHD groups ($p = 0.034$), indicating that participants with high ADHD levels experienced significantly higher cognitive load compared to those with medium ADHD levels during training.
- For participants with Low and Medium ADHD levels, the minimum values of the Control Normalized TLX scores were negative, indicating a reduction in cognitive load compared to the PWI Recall session. Conversely, for the High ADHD level group, the minimum values were predominantly positive, suggesting an increase in cognitive load for these participants in all treatments.
- The mean Control Normalized TLX Training scores varied across ADHD levels, with the High ADHD group having the highest mean (92.4), followed by the Low ADHD group (50.1), and the Medium ADHD group (35.8), though not statistically significant.

- The PWI treatment for the training session possibly showed higher NASA TLX scores than the PWI Recall session, likely due to the time pressure during training. This suggests that time pressure may have a greater impact on participants with ADHD, although this trend was not statistically significant.

In conclusion, while the overall results of the one-way ANOVA did not reach statistical significance, the significant differences identified in the Fisher Pairwise Comparison suggest that ADHD symptom levels may influence cognitive load during training sessions. Though not statistically significant in overall ANOVAs, these results suggest that participants with higher ADHD levels tend to experience greater cognitive load, emphasizing the need for further investigation into how ADHD affects cognitive load under varying task conditions.

3.4.3.4 Usability (SUS) Related Hypotheses

Next, participant feedback is examined for the treatments through the System Usability Scale (SUS). After each treatment, participants completed the SUS, which measures usability. Responses varied widely, with a high standard deviation across all treatments, scripts, and ADHD classifications. For the Control Normalized SUS scale, negative values indicate lower usability compared to the control (PWI).

For the SUS Training score by ADHD Level, there is a noticeable trend between ADHD level and a decrease in SUS score. See the figure below. Also, notably, for all of the high-level ADHD participants, the Control Normalized SUS scores indicate a lower score for the treatments than the Control. All other levels showed a mix between lower and higher scores than the control.

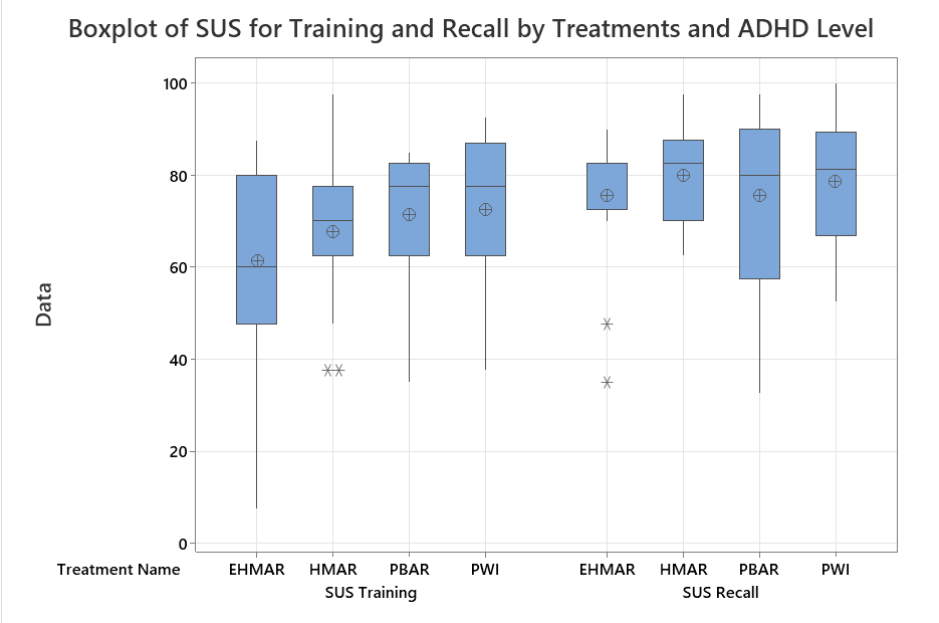


Figure 24: Boxplot of SUS for Training and Recall by Treatment and ADHD Level

Figure 25: Control Normalized SUS by ADHD Level

The hypotheses testing results related to quality are summarized below:

Failed to Reject - H11: System Usability Scale Ratings differ among the levels of ADHD Symptoms

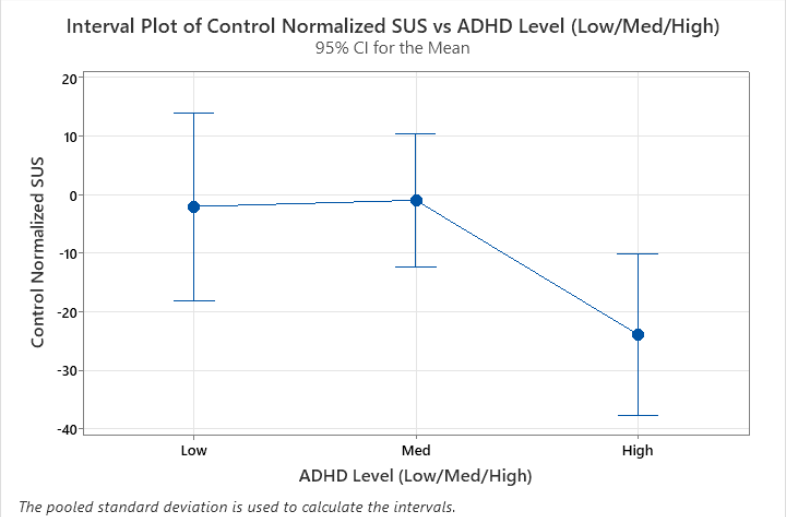


Figure 26: Interval Plot of Control Normalized SUS vs ADHD Level

- The Control Normalized SUS scores showed a statistically significant difference among ADHD levels (F= 3.71, p = 0.030, Cohen's d = -0.73 (medium-to-high effect size). The high ADHD group had a notably lower mean (-23.9) compared to the low (-2.1) and medium (-1.0) ADHD groups. Scoring lower indicates a lower usability rating for the training treatment than the recall session.
- Fisher pairwise comparisons for the control normalized SUS scores indicated significant differences between the high ADHD group and both the low (T = -2.07, adjusted p = 0.043) and medium (T = -2.57, adjusted p = 0.013) ADHD groups.
- The Normalized Training SUS scores also revealed significant differences among ADHD levels (F = 3.42, p = 0.039), with the high ADHD symptom group scoring significantly lower than the other two groups. A lower normalized SUS indicates a lower usability rating.
- The SUS scores during the training phase had a p-value of 0.131 (F = 2.11), indicating no statistically significant difference in SUS scores among the three ADHD levels during training. However, this value suggests a potential trend worth further exploration.
- During the recall phase, the mean SUS scores were slightly higher for the high ADHD group (81.7) compared to the low (76.6) and medium (75.2) ADHD groups. However, the differences were not statistically significant.
- Despite the lack of statistical significance in the training phase SUS scores and recall phase SUS scores, the trends observed suggest that higher ADHD symptom levels may be associated with lower perceived usability, particularly in the context of the control normalized SUS scores.

In conclusion, the hypothesis test results indicate significant differences in SUS

ratings among different levels of ADHD symptoms. The control normalized SUS scores and the normalized SUS scores both showed statistically significant differences, particularly highlighting that individuals with high ADHD symptoms tend to have lower SUS ratings. This suggests that ADHD symptom levels influence perceived system usability, with higher symptoms correlating with lower usability ratings.

Rejected - H12: ADHD symptom levels will not significantly affect the Control Normalized System Usability Scale (SUS) scores within each treatment (PBAR, HMAR, EHMAR, and PWI).

- The HMAR treatment revealed significant differences in Control Normalized SUS scores among ADHD levels ($F= 8.28$, $p = 0.006$, Cohen's $d = 0.48$ (medium effect size)). The low ADHD group had a mean SUS score of 8.3, the medium group was -7.5, and the high group was -42.2. Therefore, the high symptom ADHD group rated the treatment training session as less usable than the recall session.
- The Control Normalized SUS by ADHD Level for HMAR model demonstrates a strong effect size with an R^2 value of 57.98% and its predictive R^2 of 31.0% indicates a decent ability to generalize to new data.
- Fisher pairwise comparisons for the HMAR treatment confirmed significant differences between the high ADHD group (-42.2) and both the low (8.3) and medium (-7.53) groups, with adjusted p-values of 0.003 and 0.007, respectively.
- None of the other treatments (PWI, PBAR, EHMAR) showed nearing significant differences in SUS scores among ADHD levels.
- The general trend observed across treatments suggested that as ADHD symptom levels increased, the Control Normalized SUS scores tended to decrease, particularly noticeable in the HMAR treatment.

In conclusion, the hypothesis that ADHD symptom levels would not significantly affect the Control Normalized SUS scores was not entirely supported. While the PWI, PBAR, and EHMAR treatments showed no significant differences in SUS scores among ADHD levels, the HMAR treatment exhibited significant differences. Specifically, participants with high ADHD symptoms had significantly lower usability ratings compared to those with low and medium symptoms.

Failed to Reject - H13: The SUS scores for each ADHD symptom level will differ between treatments (PBAR, HMAR, EHMAR, and PWI).

- The GLM coefficient for the SUS Training, EHMAR treatment was -7.67 with a p-value of 0.048 ($T = -2.03$), indicating that EHMAR had a significantly lower SUS score than other treatments.

- The GLM interaction term for the outcome of SUS Training, between low ADHD level and EHMAR treatment was -12.62 with a p-value of 0.032 (T = -2.03), indicating a significant negative impact on SUS scores for low ADHD participants using EHMAR.
- Effect size of the Two-Way ANOVA: Partial Eta Squared for the terms of the model are: ADHD Level $\eta^2 = 0.08$ (medium), Treatment $\eta^2 = 0.09$ (medium), Interaction $\eta^2 = 0.13$ (medium-to-large).

In conclusion, the hypothesis that SUS scores would differ between treatments for each ADHD symptom level was partially supported. The EHMAR treatment showed significantly lower SUS scores, particularly for participants with low ADHD symptoms. While the overall interaction between ADHD levels and treatments was not statistically significant, the trends appear to indicate that further research is warranted to understand these relationships fully.

3.6.4 Covariate Analysis

Covariates in any experiment can affect the outcomes, and while experimental designs with randomization of treatments and random population sampling are intended to mitigate these effects, some influence of covariates typically persists based on the resulting population of participants. In this study, demographic information was collected, including age, gender, race, ethnicity, birth country, primary language, schooling attainment, college major, LEGO experience level, and manufacturing experience level. Additionally, participants were surveyed about the number and significance of ADHD symptoms, which also served as a covariate.

The covariate analysis revealed several significant effects of various factors on production quality and user experience metrics. Training consistently showed significant effects across multiple metrics, underscoring its strong influence on production quality and user experience. This finding highlights the importance of well-designed training programs in enhancing production outcomes and user satisfaction. Age was found to significantly affect SUS Training scores, suggesting a possible age-related difference in user satisfaction or system usability.

Manufacturing experience also significantly affected average defects and recall, especially for those with part-time or temporary jobs and those with over one year of experience. Interestingly, the quality of production decreased for participants with

manufacturing experience, although the small sample size limits the ability to generalize this finding. These results indicate that demographic factors such as age and gender, as well as specific experiences like manufacturing background, need to be considered when designing training and work environments. Overall, the covariate analysis highlights the multifaceted influences on production quality and user experience, pointing to the necessity of considering these variables in experimental designs and practical applications.

3.7 Manufacturing Technology Support Investigation: Conclusions

The study aimed to investigate the impact of ADHD symptom levels on production speed, production quality, cognitive load, and system usability across different AR treatments (PBAR, HMAR, EHMAR) and traditional Paper Work Instructions (PWI). The hypotheses tested revealed several key findings:

3.7.1 Impact of ADHD Symptoms on Production Speed and Quality:

- ADHD symptom levels across all treatments together were statistically significant in the impact on production speed. (H3)
- Increasing ADHD symptom level increased production speed for PWI and PBAR, but not HMAR and EMAR (H3, H4).
- A connection between increased production speed in PWI treatment and the highest level of ADHD symptoms showed statistical significance (H4).
- ADHD symptom levels did not significantly affect the production speeds of different treatments (H1, H2). However, nearing significant trends indicate possible effects that need further investigation.
- ADHD symptom levels significantly impacted production quality, statistically significant only in the EHMAR treatment, with lower error rates observed in participants with high ADHD levels compared to medium and low levels (H5).
- Participants with higher ADHD levels did not show greater improvement in production quality using AR technologies compared to PWI; significant quality improvements observed with AR treatments were independent of ADHD symptom level (H6, H7).

3.7.2 Impact on Cognitive Load

- EHMAR, Temporal TLX: The ANOVA showed a significant effect ($p = 0.026$). This suggests that individuals with higher ADHD levels experienced significantly

higher temporal demand in the EHMAR treatment compared to those with low ADHD levels (H8).

- Control Normalized TLX showed significant differences between the levels of ADHD across all treatments, showing an increase of cognitive load for all ADHD symptom-high-level participants and a range of high and lower cognitive loads for the other two groups (H10).
- EHMAR did not decrease cognitive load significantly for ADHD levels, as hypothesized (H9).
- The weighted NASA TLX scores after recall varied between participants using EHMAR and other treatments, influenced by ADHD levels, but not significantly (H9).

3.7.3 Impact on System Usability

- System Usability Scale ratings differed significantly among ADHD levels, with high ADHD symptom levels correlating with lower usability ratings, particularly in the EHMAR treatment (H11, H13).
- ADHD symptom levels significantly affected the control normalized System Usability Scale (SUS) scores in the HMAR treatment, with participants with higher ADHD levels reporting lower usability (H12).
- SUS scores for the recall phase were not significantly different across ADHD levels (H11).

3.7.4 Investigation Inferences

- Complex Relationship: The relationship between ADHD symptoms and the studied variables (production speed, production quality, cognitive load, and system usability) is complex. While ADHD levels did not consistently affect production speed or cognitive load, they had a more pronounced impact on production quality and system usability in certain treatments.
- Variability in Treatment Efficacy: The efficacy of different treatments (AR technologies and PWI) varied across ADHD levels, suggesting that certain treatments may be more suitable for individuals with specific ADHD symptom profiles.
- Tailored Interventions Needed: The significant differences in system usability ratings and the trends observed in production quality highlight the need for tailored interventions and usability assessments that consider individual differences in ADHD symptoms.

4.0 Chapter Four: Manufacturing Workplace Support Investigation: Assessing Effects of Technology Used in Improving Quality and Performance

4.0 Manufacturing Workplace Support Investigation: Introduction

Workplace functioning for individuals in manufacturing settings revolves around several critical factors, including standardizing systems such as Lean methodologies, the quality of information from the line through systems such as Industry 4.0, company culture and climate, and the psychological safety of the workplace. Adapting workplace support systems to accommodate workers with neurodivergent conditions, such as ADHD, is important to the success of individual workers and their organizations as a whole (Ramsay, 2010).

Physical adjustments to the workplace can significantly enhance the performance and well-being of neurodivergent workers while often benefiting neurotypical workers simultaneously (Weber et al., 2021). However, as detailed in Chapter 2: Narrative Literature Review, there is a notable gap in experimental research exploring the effects of modifications to manufacturing workstations on workers' cognitive load, perceptions of usability, performance, and quality outcomes, particularly among those with ADHD symptoms.

This series of studies aims to address this gap by examining how changes to manufacturing support systems, specifically through the implementation of a Lean tool and an Industry 4.0 sensor, affect both workers self-reporting ADHD symptoms and neurotypical workers. These investigations were conducted in parallel with the recent work of Md. Monir Hossain, who explored the effectiveness of Lean tools and I4.0 sensors in improving workstation quality and performance (Hossain et al., In Press; Hossain, 2024).

Dr. Hossain's research integrates Lean Production Systems with I4.0 technologies, providing a framework to investigate their effectiveness (Hossain & Purdy, 2023). His findings, based on 48 trials from both investigations (Quality and Performance

Motivation Investigations), indicated that the I4.0 sensing device significantly improved overall equipment effectiveness (OEE), which includes factors of productivity, quality, and workstation availability (Hossain et al., In Press; Hossain, 2024).

Building on Hossain's work, this study focuses on the impacts of these workplace support system changes on the workers themselves. The goal is to provide recommendations for workplaces on how to support both workers with ADHD symptoms and neurotypical workers and to highlight potential negative effects to avoid or be cautious about implementing based on the findings of this research.

4.0.1 Purpose and Significance of the Research

This research aims to compare the effects of Lean and Industry 4.0 workplace support systems on workers' psychological health, specifically cognitive load, reported usability, performance, and quality in a simulated manufacturing environment during a manual assembly task. This investigation occurred in the Auburn University Tiger Motors Lean Education Center, utilizing Station 10 in Cell 2 of the simulated manufacturing environment.

This within-subjects experiment was designed to measure outcomes related to quality and performance with four different treatments: no support tools (control), Lean tool alone, Industry 4.0 sensing device alone, and a combination of the Lean tool and Industry 4.0 sensing device. The study aims to understand how these tools impact cognitive load, usability perceptions, performance speed, and quality of work among participants, particularly differentiating between those with and without significant ADHD symptoms.

Previous research has shown that standardizing systems such as Lean and advanced technologies like Industry 4.0 can significantly enhance manufacturing processes by reducing waste and improving quality and productivity (Erboz, 2017; Hossain & Purdy, 2023). However, there is limited experimental evidence on how these systems impact the cognitive load and usability perceptions of workers, especially those with neurodivergent conditions like ADHD.

Lean methodologies, particularly the Jidoka method, aim to build quality into the product by detecting anomalies in the process (Baudin, 2007). Industry 4.0 technologies,

such as machine vision, leverage big data to enhance productivity, innovation, and competition by providing real-time quality assessments (Erboz, 2017). These technologies are expected to support workers by reducing errors and improving task performance.

This study contributes to the existing body of knowledge by providing empirical evidence on the psychological impacts of these workplace support systems. By measuring cognitive load using the NASA Task Load Index (NASA TLX) and system usability using the System Usability Scale (SUS), along with performance and quality outcomes, this research offers valuable insights into how different support systems affect workers' efficiency and well-being.

4.0.2 Research Questions Summary

The study is divided into the Quality Motivation Investigation and the Performance Motivation Investigation. The primary research questions focus on whether there are differences in cognitive load, system usability perceptions, production speed, and quality during the use of a check piece, vision camera inspection system, or their combination, especially in connection to the number and severity of participant-reported ADHD symptoms.

4.1 Manufacturing Workplace Support Investigation: Investigation Description

Comparing the Effects of Lean and I4.0 Workplace Support Systems on Workers' Psychological Health, Specifically Cognitive Load, Reported Usability, Performance, and Quality in a Simulated Manufacturing Environment for a Manual Assembly Task.

The Manufacturing Workplace Support Investigation occurred in the Auburn University Tiger Motors Lean Education Center. This is the same facility detailed in the previous investigation utilizing Station 10, the last station in Cell 2, of this simulated manufacturing environment. This station has features similar to Station 8 used in the previous investigation, such as the parts bin above the workstation and PWI posted above the station illustrating the steps to assemble the sixteen parts for this workstation.

Figure 27: Tiger Motors Workstation 10 Setup

Differences in this station include the absence of the PBAR and HMAR training tools and the presence of a Lean tool-check piece and an I4.0 sensing device – machine vision. The Lean tool and I4.0 sensing device are described and explained in the following section. Workers at this station take the workpiece completed at station nine and add the additional parts, check the quality of their work, and then place the completed car on the tray at the right of the station.

This within-subjects experiment was designed to measure the quality and performance outcomes of the two workplace support system tools used in this experiment. Each participant performs four treatments: a control using no support tools,

the lean tool alone, the I4.0 sensing device alone, and a combination of the Lean tool and I4.0 sensing device. A sample size of twenty-four was determined to have sufficient power for moderate to large effect sizes and provided one trial for each of the twenty-four combinations of the four treatments.

In general, the variables are measured in the following ways:

- Performance (production speed) is measured with electronic timing devices and video capture.
- Quality is measured through error observation and recorded with video capture and photographs of the final assembled products.
- System usability index is measured with the System Usability Scale (SUS) (*UX Principles That Include Cognitive Accessibility*, 2022).
- Cognitive load (or Mental Workload) is measured with the NASA Task Load Index (NASA TLX) (Hart, 2016).
- ADHD symptom prevalence and severity are measured with the Adult Self-Report ADHD Scale (ASRS) (Kessler et al., 2007).
- Qualitative inputs gained through comments, observation of behaviors, and survey responses.

The details of the protocol are given in the experimental design section, but a summary is given below to give context to the reader. Each participant is allowed time to train on the station building four cars. Following the training, each participant builds four sets of ten cars, each with a randomly assigned order of the four treatments. The participants complete a NASA TLX and SUS survey on the treatment between treatments. All treatments are completed in one visit to the Tiger Motors Lab.

As data were collected, it became apparent that the majority of the subjects were putting more emphasis on quality than producing the desired number of cars in the ten-minute trials (ten cars per trial was desired and was expressed as the goal). However, several participants produced very few cars with almost no errors in the ten minutes of each trial. The decision was made to finish the initial experiment with the existing script and then modify the script to repeat the twenty-four trials in a new experiment. This first experiment is now called the Manufacturing Workplace Support Investigation: Quality Motivation (abbreviated as Quality Motivation Investigation [QI]) because subjects

appeared to prioritize quality over production. These data were collected during Spring Break in March of 2023. As a result of the availability and enthusiasm of the participants, two more than the original 24 participants sought were recorded.

The second experiment intended to investigate the impact of the tools on quality, performance, and cognitive load for participants based on a script that emphasized productivity. The second experiment is titled Manufacturing Workplace Support Investigation: Performance Motivation (abbreviated Performance Motivation Investigation [PI]). The specifics of the script change are detailed below. Both scripts (QI, PI) and the combined dataset (CI) are analyzed for each hypothesis test.

4.2 Manufacturing Workplace Support Investigation: Workplace Support Tools Used During Production

The workplace support systems implemented in the Tiger Motors Lean Education Center offer a real-world experience for students to engage with state-of-the-art technology and techniques. The technology incorporated in Station 10 in Tiger Motors includes machine vision and a Jidoka Lean tool. The workplace support systems that are used in this investigation are described below.

4.2.1 Lean Tool – Jidoka Method: Check Piece

Lean methodologies aim to reduce waste within the system, with the goal of creating an optimally functioning system. Defects in work are a waste in the system that results in rework or loss of product. Jidoka is the second pillar of Lean Manufacturing and is a Japanese word meaning “building quality in the product by detecting anomalies in the process” (Rosin et al., 2020). At each of the stations in Tiger Motors, a model of what the workpiece is supposed to look like before moving to the next station is provided to the workers for a quality check. This model is called a check piece. As a supplement to the two-dimensional printed work instructions posted above the workstation, the three-dimensional physical model of the completed work for that station provides a clear

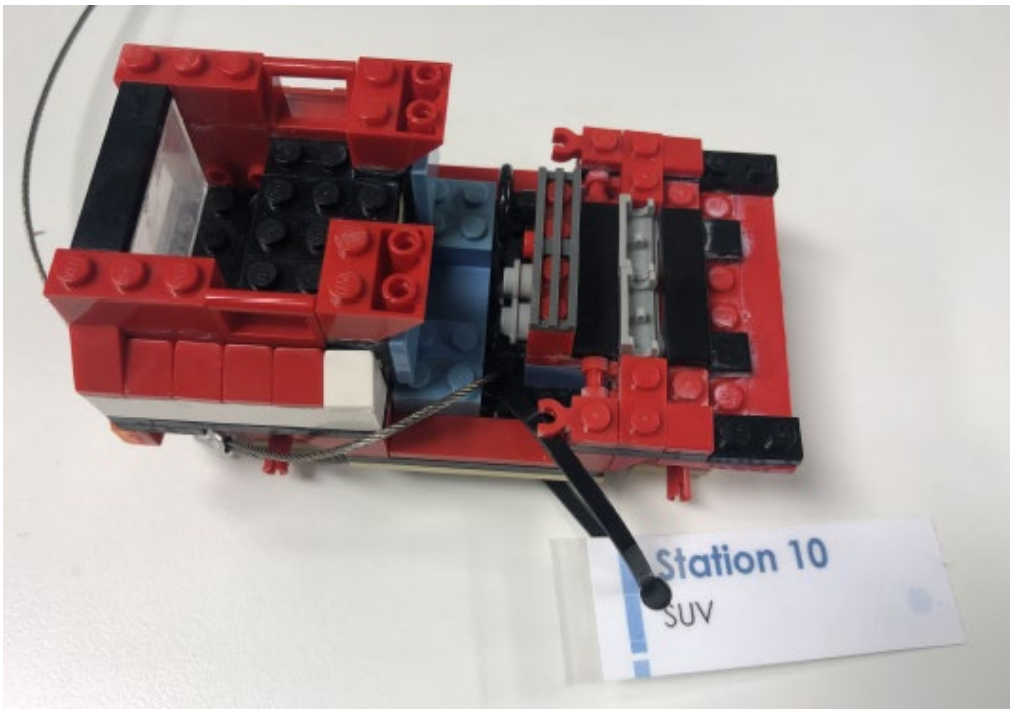


Figure 28: Station 10 SUV Check Piece

example of the quality work required for each station. Pictured is the check piece for Station 10 that was used for this investigation. Any method implemented to reduce errors from leaving the station is considered a Jidoka method, an essential part of implementing Lean tools in a system. This check piece workstation support method is expected to reduce the number of errors that leave this workstation and help the worker perform the task correctly and catch errors before placing the car on the completion tray.

4.2.2 Industry 4.0 – Sensor Technology: Machine Vision

Industry 4.0, considered by many to be the future of manufacturing, is characterized by nine main pillars: big data, autonomous robots, simulation, horizontal and vertical system integration, internet of things, cloud computing, and additive manufacturing (Erboz, 2017). As a part of the first pillar, big data, the "increase in level of data and improvements on technological capabilities accelerates firms' competitive

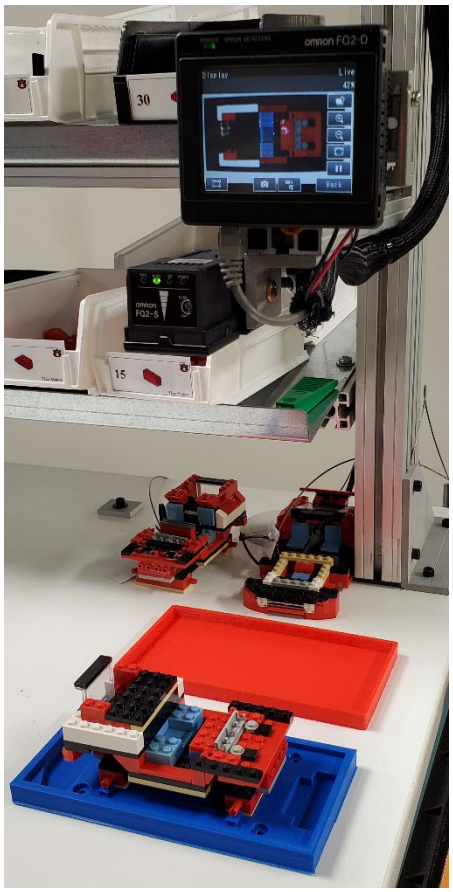


Figure 30: Station 10 Machine Vision System, camera, output screen, and part stand with finished workstation piece placed under camera

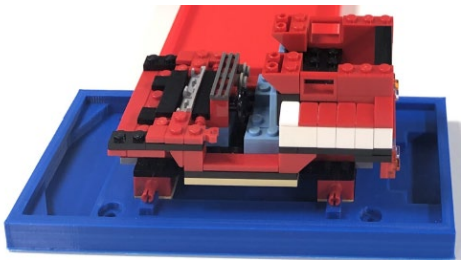


Figure 29: Part Stand for Machine Vision with completed workpiece on stand.

advantage by increasing productivity, innovation, and competition" (Erboz, 2017).

Technology that gathers data from the manufacturing system, processes it and outputs a quality determination qualifies as an Industry 4.0 sensor technology. At station 10 of the Tiger Motors Lab, a machine vision system was programmed to perform a quality check on the topmost parts installed in that workstation. Pictured below is the output screen and reference card used to translate the output screen.

Workers at the station complete the assembly steps and place the completed workpiece in the custom printed part stand (designed to align the workpiece underneath the vision camera precisely), pictured. Once the part is correctly aligned, the camera senses the part and displays the output results for each of the ten programmed parts on

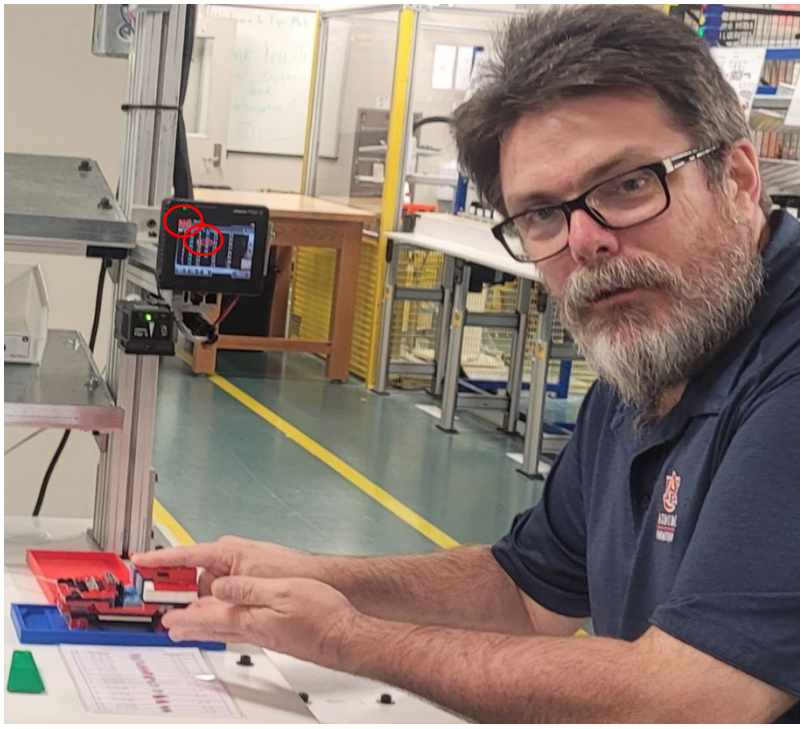


Figure 32: Researcher Dan O'Leary demonstrating the “NG” output when a part is covered on the top of the workpiece under the Machine Vision system.

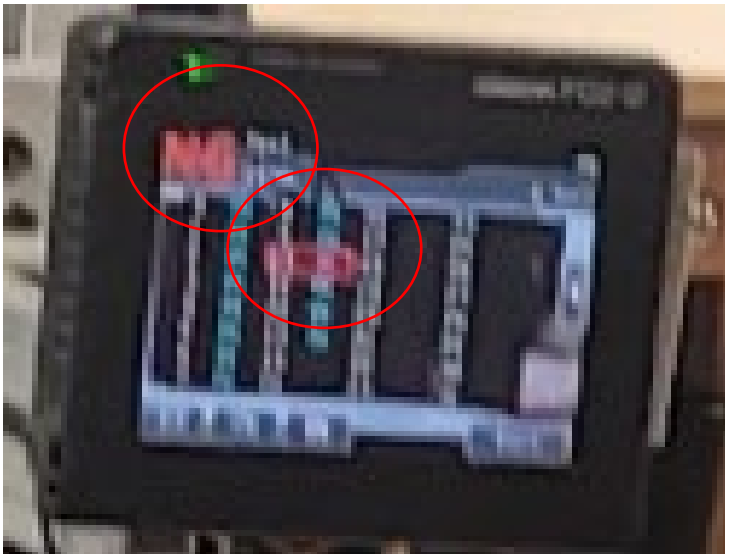


Figure 31: Zoomed in view of the Machine Vision output screen showing the “NG” in red overall for the workpiece, and the “NG” in red for the specific piece missing.

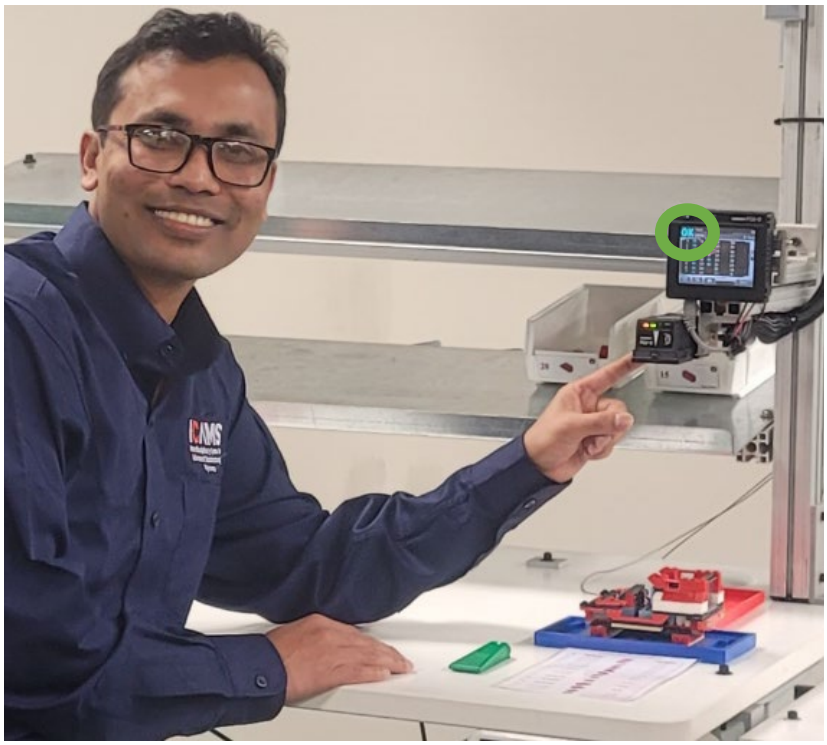
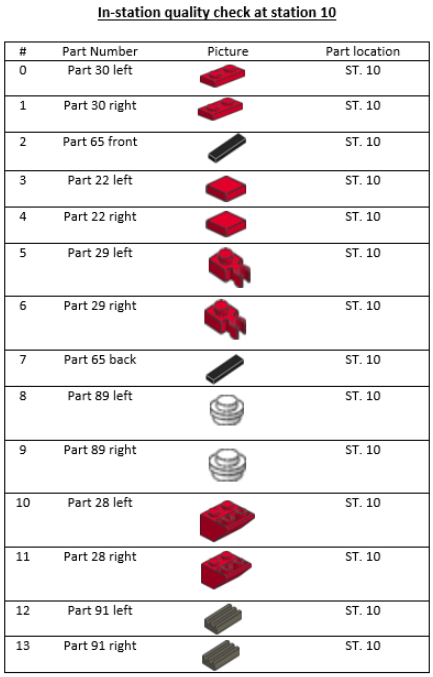


Figure 33: Researcher Monir Hossain demonstrating the “OK” output when all the parts on the top of the workpiece under the Machine Vision system are correct.

the screen and gives a decision on each part, “OK” for each properly placed part and “NG” for Not Good for each missing or improperly placed part. At the top of the screen is a large “OK” in green or “NG” in red for all the parts together. As seen in the figures above. If found to be missing, the parts can be referenced on the card provided on the workstation that shows the picture of the part, the number on the machine vision screen, and the corresponding part number found on the part bins above the workstation. The reference card for the machine vision system at Station 10 is pictured below.

The vision camera system can only sense the parts on the top of the unit, not the parts underneath the top layer. Therefore, not all parts installed at the station can be quality-checked by the machine vision camera in this configuration. Additional cameras at other angles would be required to inspect the other parts. Another limitation of this camera system is the sensitivity to light, requiring light to flash on the part to “see” the colors of the parts properly. Alignment is also a limitation of this system, as it is programmed to sense colors to be in a specific area; if the part is misaligned even a little

bit, it will be indicated as NG and possibly give a false reading. False readings result in delays in production as the operator then looks up the part number referenced as NG on the reference card (pictured to the right) and traces it back to the PWI to see where they went wrong, all taking time and delaying production. However, if a part is missing, the vision camera can prevent errors from leaving the workstation and continuing.



In-station quality check at station 10

#	Part Number	Picture	Part location
0	Part 30 left		ST. 10
1	Part 30 right		ST. 10
2	Part 65 front		ST. 10
3	Part 22 left		ST. 10
4	Part 22 right		ST. 10
5	Part 29 left		ST. 10
6	Part 29 right		ST. 10
7	Part 65 back		ST. 10
8	Part 89 left		ST. 10
9	Part 89 right		ST. 10
10	Part 28 left		ST. 10
11	Part 28 right		ST. 10
12	Part 91 left		ST. 10
13	Part 91 right		ST. 10

Figure 34: Reference card for Machine Vision codes to parts.

Because people make poor inspectors, our brains are trained to see what one expects to see, especially when completing repetitive tasks (Wickens & Carswell, 2021). Having technology available to do the final inspection can be a valuable support mechanism to catch momentary lapses in manual assembly tasks, such as in this investigation (Erboz, 2017). The expectation is that this technology will increase production quality by reducing errors in the final output at this station.

4.2 Manufacturing Workplace Support Investigation: Research Questions

As explained previously, the research questions for this investigation are divided into two sub-investigations: the *Quality* and *Performance* Motivation Investigations.

4.2.1 Quality Motivation Investigation: Research Questions

When motivated to produce as many **quality** cars as possible, are there differences between participants' cognitive load, perceptions of system usability, production speed, and quality, while using a check piece, vision camera inspection system, or do both significantly affect outcomes?

When motivated to produce as many **quality** cars as possible, are there differences between adults reporting significant ADHD symptoms and no or few significant ADHD Symptoms during the use of a check piece, vision camera inspection system, or both significantly affect outcomes such as cognitive load, perceptions of system usability, production speed, and quality?

4.2.2 Performance Motivation Investigation: Research Questions

When motivated to **produce** as many cars as possible (1 car per minute), are there differences between participants cognitive load, perceptions of system usability, production speed, and quality during the use of a check piece, vision camera inspection system, or do both significantly affect outcomes?

When motivated to **produce** as many cars as possible (1 car per minute), are there differences between adults reporting significant ADHD symptoms and no or few significant ADHD Symptoms during the use of a check piece, vision camera inspection system, or both significantly affect outcomes such as cognitive load, perceptions of system usability, production speed, and quality?

4.3 Manufacturing Workplace Support Investigation: Specific Aims

The specific aims for this investigation are divided into two sub-investigations,

the Quality and Performance Motivation Investigations, as explained previously.

4.3.1 Quality Motivation Investigation: Specific Aims

- This study aims to investigate the impact of using a check piece, a vision camera inspection system, or their combination during a quality motivating script on outcomes including cognitive load, system usability perceptions, production speed, and quality.
- This study aims to assess whether adults reporting 'significant' versus 'no or few significant' ADHD symptoms exhibit differences in cognitive load, system usability perceptions, production speed, and quality during the use of a check piece, a vision camera inspection system, or both, while exposed to a quality motivating script.

4.3.1 Performance Motivation Investigation: Specific Aims

- This study aims to investigate the impact of using a check piece, a vision camera inspection system, or their combination during a performance motivating script on outcomes including cognitive load, system usability perceptions, production speed, and quality.
- This study aims to assess whether adults reporting 'significant' versus 'no or few significant' ADHD symptoms exhibit differences in cognitive load, system usability perceptions, production speed, and quality during the use of a check piece, a vision camera inspection system, or both, while exposed to a performance motivating script.

4.4 Manufacturing Workplace Support Investigation: Hypotheses

The hypotheses for this investigation are tested for the Quality (QI) and Performance (PI) Motivation Investigations and the Combined (CI) Investigation, as explained previously.

4.4.1 Performance and Quality Metrics Hypotheses

H_{1a} : Higher Average Errors Per Car if PWI is first in treatment order, compared to later.

H_{1b}: Slower production speed (lower Number of Cars per Trial) using tools compared to PWI.

$H_{.1c}$: Quality increases (lower Average Errors Per Car) with the number of vehicles built, independent of treatment.

H_{1d}: Quality (lower Average Errors per Car) is higher for treatments with vision inspection camera system for the same treatment order.

$H_{.1e}$: Participants with higher number of ADHD symptoms will produce cars at a different rate than those with lower number of symptoms.

$H_{.1f}$: Participants with higher number of ADHD symptoms will have a different average error rate than those with lower number of symptoms.

4.4.2 Cognitive Load (NASA TLX) Hypotheses

H_{2a}: Higher cognitive load for control (PWI) than for tools.

H_{2b}: Cognitive load differs among the four treatments.

H_{2c}: Cognitive load is independent of treatment order.

H_{2d}: Cognitive load from the individual sub-scales will differ between treatments.

H_{2e}: Cognitive load differs among the levels of ADHD Symptoms.

4.4.3 Usability (SUS) Hypotheses

H_{3a}: Higher SUS for treatments with I4.0 sensor – machine vision inspection system.

H_{3b}: The SUS score for PWI will differ for treatment orders of 2 or greater compared to the SUS score for PWI in order 1.

H_{3c}: SUS is independent of treatment order.

H_{3d}: System Usability Scale ratings differ among the levels of ADHD Symptoms.

H_{3e}: Individuals with varying levels of ADHD symptoms will rate each treatment differently on the System Usability Scale (SUS).

4.4.4 Comparative Analysis – QI and PI Investigation Comparisons Hypotheses

$H_{4.a}$: Lower Average Errors in QI compared to PI.

$H_{4.b}$: More cars produced per trial in PI than in QI.

$H_{4.c}$: SUS index is expected to be the same for QI and PI.

$H_{4.d}$: NASA TLX is expected to be the same for both QI and PI.

4.5 Manufacturing Workplace Support Investigation: Methods

4.5.1 Experimental Design

With an understanding of individual differences in reactions to workplace support systems and accepting the greater time commitment required for data collection in a within-subjects, or repeated measures, experimental design, the research team decided that this approach would be the strongest and most capable of producing significant results.

The within-subjects design offers several advantages that must be carefully considered in experimental research. One significant advantage is the reduction in variability associated with individual differences since each participant serves as their own control. This increases statistical power and often requires a smaller sample size than a between-subjects design. Additionally, this design is highly efficient as it reduces the error variance attributed to differences between subjects, allowing for more precise estimates of treatment effects.

However, within-subjects designs also present notable challenges. One primary concern is the potential for carryover effects, where the influence of one treatment persists and affects subsequent treatments. This can confound results and complicate the interpretation of treatment effects. To mitigate this, the researchers carefully counterbalanced the order of treatments and considered appropriate washout periods between conditions. Another issue is the risk of fatigue or practice effects, where participants' performance may improve or decline due to repeated exposure to the tasks rather than the experimental manipulation itself. Despite these concerns, the benefits of the statistical power gained by having each participant complete every treatment were deemed to outweigh the drawbacks. These potential confounding factors were analyzed statistically and discussed in the conclusions and limitations of the study.

A power analysis was conducted to determine the necessary sample size for the experiment using effect sizes obtained from the pilot study (described in Section 3.2). The analysis aimed to confirm that the experiment would have sufficient power to detect

significant effects. Anticipating a substantial effect size among the treatments, the Manufacturing Workplace Support Investigation sample size was set at twenty-four participants, completing one of the twenty-four possible combinations of four treatments. This sample size achieves greater than a power of 0.8 at a significance level of 0.05, helping to provide the necessary power to detect meaningful differences. The experiment was performed twice, with a sample of 24 participants for each script: the quality and performance motivation scripts.

The Auburn University Internal Review Board (IRB) approved the human subjects research for the study, Protocol 22-538 EP2301, and all participants provided informed consent. Participants were informed of their right to withdraw at any time and assured of the confidentiality of their data. IRB approval is provided in Appendix E.2.

Participants were selected through a convenience sample of Auburn University community adults. Recruitment was conducted through faculty members, email, and flyer placement. Participants were randomly assigned to one of the twenty-four treatment orders to promote the unbiased distribution of individual differences across conditions. This randomization helps control for confounding variables and helps guarantee that any observed effects are due to the treatment rather than participant characteristics.

The anonymized data collected were analyzed using statistical methods appropriate for a within-subjects design. ANOVA was used to compare the means across the support technologies for various variables, and post-hoc tests identified specific group differences.

These calculated sample sizes and methodological considerations confirm that this investigation into the effects of work support systems on individual workers' cognitive load, perceptions of usability, performance, and quality outcomes in manufacturing is robust and capable of producing meaningful conclusions.

4.5.2 Experimental Protocols

Investigating the effectiveness of workplace support systems on performance, quality, usability, and cognitive load, this investigation involves using four treatment conditions in station ten in the Tiger Motors Lean Education Center manufacturing line simulation.

The experimental protocol began with the recruited participants coming to the Tiger Motors Lean Education Center in Shelby Center for Technology at Auburn University, Auburn, Alabama. They began the session by reading and signing the informed consent form, completing a survey of basic demographic information, a practice NASA TLX exercise, and the ADHD ASRS.

Participants were randomly assigned a treatment order of one of the twenty-four possible combinations of the four treatments. As detailed in Section 4.2: Workplace Support Investigation: Workplace Support Tools Used in the Investigation, the check piece and machine vision technology were implemented as the workplace support systems being investigated in this study. The testing conditions included traditional Paper Work Instructions (PWI), Lean Tool Check Piece (LT), Industry 4.0 sensing technology Machine Vision Inspection Camera (I4.0), and the Lean Tool and I4.0 technology used together (LT+I4.0).

Participants were then oriented to the Tiger Motors Lab. The features of the workstation were explained and pointed out to the participants. This included explaining the PWI above the station, referencing the part numbers indicated on the diagram and the corresponding part bins above the workstation. The researcher also demonstrates one example of a part in the diagram and where it can be found in the bins below.

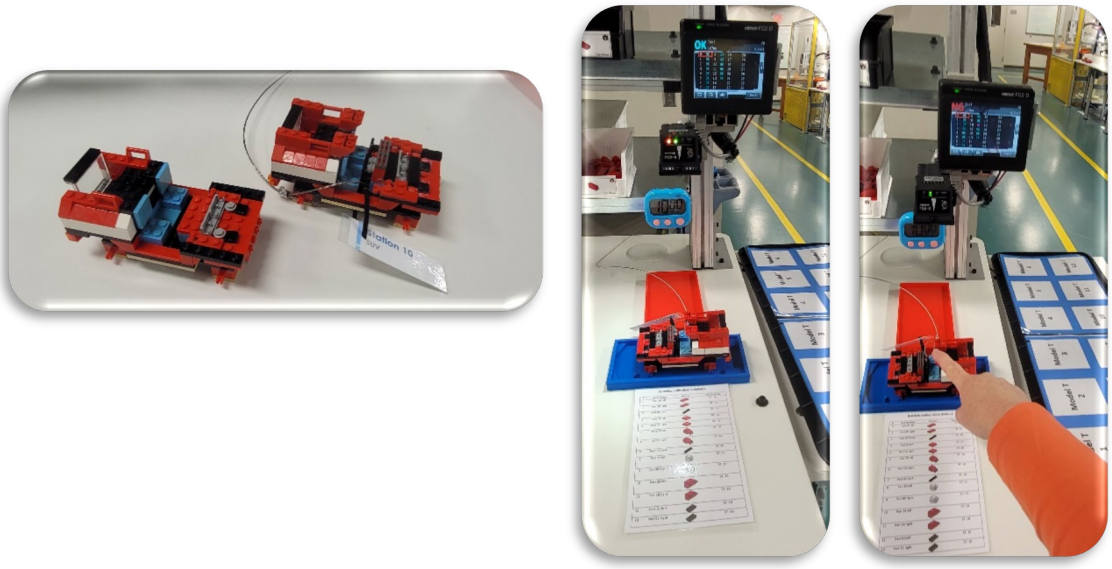


Figure 36: Quality Motivation and Performance Motivation Investigation: Treatments – Lean tool check piece (left), Industry 4.0 technology vision inspection camera (middle and right)

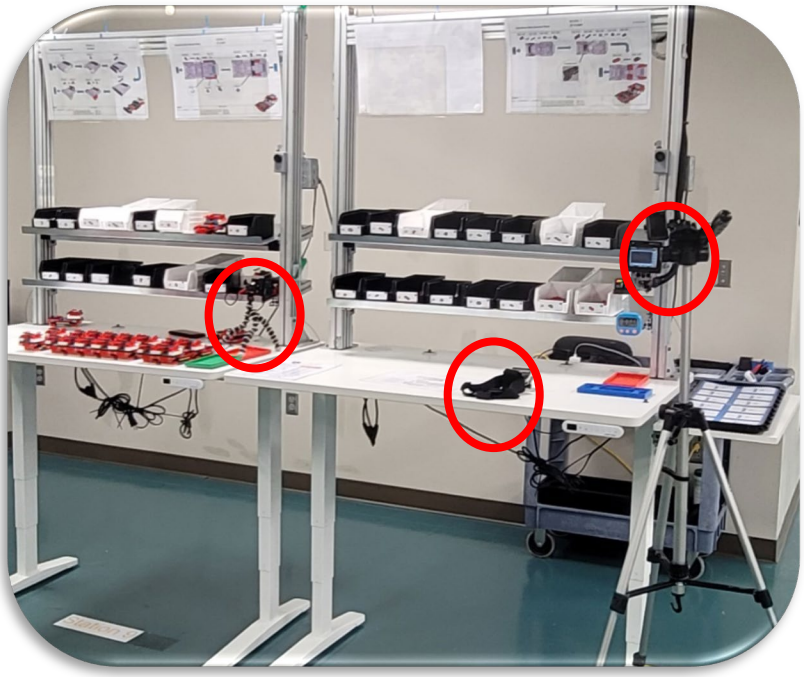


Figure 35: Quality Motivation and Performance Motivation Investigation: Tiger Motors Lean Education Center Stations 9 and 10, video cameras circled in red.

The participant is also shown where the starting workpieces are staged for the training and the trial (e.g., on Station 9, just to the left of Station 10). The tray to the right

of station 10 is where the finished workpieces are placed when the steps are finished. At this point of the experiment, the vision camera and check piece have not yet been introduced to the participant. A head-mounted camera, worn by the participant, records all interactions with the participants, a camera on Station 9 viewing the part bins and workpiece, and a third camera is turned on to view the machine vision camera when the participant is using it. The three cameras are pictured in the image below, as well as the other features of the station that are pointed out to the participants.

Next, participants underwent a training session on assembling four vehicles. During this training session, participants were asked to perform the assembly task at the station following the instructions printed on the posted PWI. They were not given any other instruction on assembling the car unless they asked questions, which was only allowed during the training portion, and only the specific question asked was answered. Participants who appeared to be struggling or performing the task incorrectly were not corrected or asked if they needed help—following this protocol allowed each participant to demonstrate their ability to learn how to perform the task independently. After the training session, participants were not told if they had made any errors. The researcher would respond truthfully if the participant asked if they made them correctly. Most participants did not ask.

This is where the two protocols diverge for the Quality Motivation and the Performance Motivation Investigations. These protocols will be explained separately, and differences will be highlighted.

4.5.2.1 Quality Motivation Investigation Protocol

Following the initial training session, participants were instructed (using the exact words on the script) on the workstation support tool used for the first treatment (randomly assigned order) and given ten minutes to build ten cars by placing sixteen LEGO pieces on each workpiece. Completed cars were checked for quality using the workstation support tool, corrected if necessary, and placed on the completion tray. **After each treatment, the participants were not told whether they performed well or not or whether they made any quality errors in their work during that trial.** After each ten-minute trial, participants returned to the conference room and completed a NASA TLX

and SUS on the support system they had just experienced. This cycle repeated until all four treatments were completed. After the final NASA TLX and SUS, participants were interviewed and asked qualitative questions about their experience with the support systems and the experiment. Participants were then thanked for their time and dismissed.

The treatment order is illustrated below.

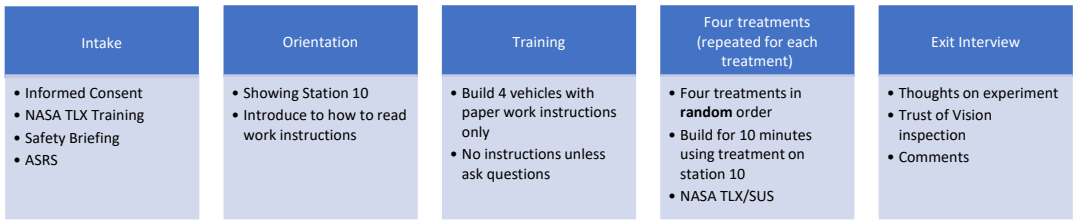


Figure 37: Quality Motivation Investigation: Treatment Order

4.5.2.2 Performance Motivation Investigation Protocol

Following the initial training session, participants were instructed (using the exact words on the script) on the workstation support tool used for the first treatment (randomly assigned order) and given ten minutes to build ten cars by placing sixteen LEGO pieces on each workpiece. Completed cars were checked for quality using the workstation support tool, corrected if necessary, and placed on the completion tray. **After each treatment, the participants were told a motivating statement intended to encourage either faster production in subsequent treatments or encouragement to maintain the demonstrated pace.** Following the motivational statement, the participant went to a conference room, completed the NASA TLX, System Usability Scale (SUS), and returned immediately to the experiment location. After all four treatments, the participant is interviewed for feedback on the system and tools.

The treatment order is illustrated below.

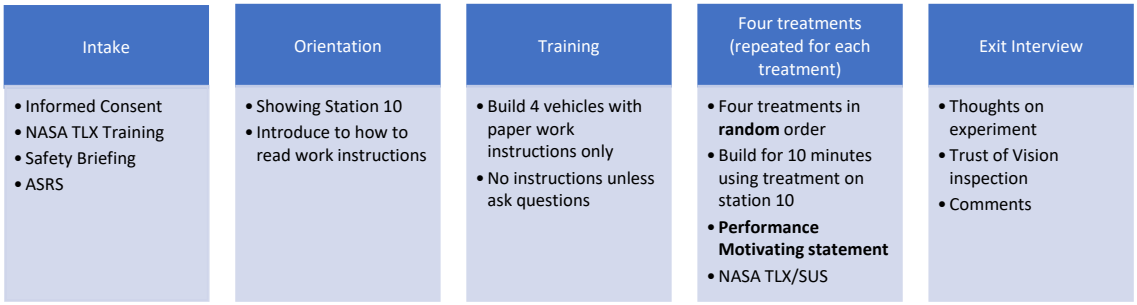


Figure 38: Treatment order for Performance Motivation Investigation

The differences in scripts between the Quality Motivation Investigation and the Performance Motivation Investigation are detailed in the next section.

4.5.2.1 Script change between investigations

As mentioned in the Investigation Description, the research team and I were concerned by the observation of an emphasis on quality during the observation of the first twenty-four participants' performance, presumably based on the script of the study; it was decided to investigate how changing the script with the goal of encouraging takt time production (one car per minute for this manufacturing line) would affect cognitive load, usability, performance, and quality for the tools being investigated on the simulated manufacturing line. Two things were changed in how the script was implemented in the experiment.

First, the motivational phrasing for the statement given before the participant began each trial was altered. In the original (Quality Motivation) script, the participant was told:

"You are given ten minutes to make ten model Ts. You will try to build as many cars as you can with no mistakes."

This statement was emphasized before each trial began. As a result, participants were told this four times. Once the participants finished the trial, nothing (positive or negative) was told about how many errors they made or how well/poorly they did with

the number of cars produced.

In the Production Motivation Script, the participants were instead told:

"You are given ten minutes to make ten model Ts. You will try to build as many cars as you can ~~with no mistakes~~ [indicating text removed]. This is very doable; workers regularly make ten or more cars in ten minutes. We have actually had participants make 13 cars in ten minutes before."

The second change was implemented after the participant completed each set of ten minutes. For the Production Motivation Script, the participants, based on how many cars they made, were told a phrase before filling out the NASA TLX and SUS for that trial.

They were told one of the following performance motivating statements:

Built 8 or more cars:

<SAY> You have done well making (SAY NUMBER OF CARS) keep up the good work, and continue to try to make 10 cars each time.

Built 6- 7 cars:

<SAY> You are almost there, work faster to make your quota of 10 cars in 10 minutes, so you don't hold up the manufacturing line.

Built 5 or fewer cars:

<SAY> You are holding up the manufacturing line, your manager is disappointed, you need to build cars much faster and make your quota of 10 cars in ten minutes.

No errors were mentioned to the participants, even if they asked a researcher. This performance motivation script resulted in most participants reaching very close or over the quota of cars in the ten minutes.

4.5.3 Measures and Variables

This section outlines the measures and variables utilized in the investigation, focusing on the factors influencing worker performance and cognitive load in a simulated manufacturing environment. The experimental design involves a detailed analysis of both independent and dependent variables and controlled factors that enhance the reliability

and validity of the results. The primary aim is to understand how different workplace support systems impact cognitive load, usability, and performance, with particular attention to variations among participants with ADHD symptoms and neurotypical workers.

4.5.3.1 Independent Variables

Independent variables are the factors manipulated to observe their effects on the dependent variables. In this study, the following independent variables were considered:

1. Technology Used: The type of support system utilized during the task, including traditional paper instructions (PWI), Lean Tool (LT), Industry 4.0 sensor (I4.0), and a combination of Lean Tool and Industry 4.0 sensor (Lean+I4.0).
2. Order of the 4 Treatments: The sequence in which the four treatments were administered to the participants which was randomized to control for order effects.
3. Script of Study: The specific motivational script used during the study, either the Quality Motivation Script or the Performance Motivation Script.
4. Number of Reported ADHD Symptoms: The total count of significant ADHD symptoms reported by the participants.
5. Categories of ADHD Symptoms: Specific categories or types of ADHD symptoms reported by the participants.

4.5.3.2 Dependent Variables

Dependent variables are the outcomes measured to assess the effects of the independent variables. In this study, the following dependent variables were measured:

1. Number of Cars Completed in 10 Minutes: The total number of LEGO cars assembled by each participant within ten minutes. This was confirmed through photographic evidence collected on the day of the study.
2. Number of Errors: The total count of assembly errors made by the participants was also confirmed through photographic evidence.

3. General Comments/Behaviors: Observations and comments made by participants during the study, noted on paper by the researcher in real-time, not video or audio recorded.
4. Cognitive Load for Six Factors: Cognitive load was assessed across six specific factors, recorded on the day of the study using the NASA TLX.
5. Cognitive Load Overall: The overall cognitive load experienced by participants was recorded using the NASA TLX.
6. Cognitive Load Weighted: A weighted measure of cognitive load, providing a nuanced understanding of the participants' mental workload.
7. System Usability Scale (SUS): Participants' perceptions of the usability of the support systems were measured using the SUS on the day of the study.

4.5.3.3 Covariates

Covariates are variables not of primary interest which may influence the dependent variables and need to be controlled for in the analysis. In this study, the following covariates were included:

1. Age: The age of the participants, which may influence their performance and cognitive load.
2. Gender: The participants' gender, considered to explore potential differences in responses to the support systems.
3. Education Level: The highest level of education completed by the participants.
4. LEGO Experience Level: The participants' prior experience with LEGO, could affect their familiarity and comfort with the task.
5. Ethnicity: The ethnic background of the participants.
6. Race: The racial background of the participants.
7. College Major: The participants' field of study, which might correlate with their technical skills and performance.

4.5.3.4 Controlled Factors

Controlled factors are variables that are kept constant to support results

attributable to manipulating the independent variables. In this study, the following factors were controlled:

1. Environmental Conditions: The physical environment of the Tiger Motors Lab was kept consistent for all participants, including lighting, noise levels, and workstation setup.
2. Instructional Procedures: The instructions given to participants were standardized using detailed scripts to help uphold uniformity in understanding and executing the tasks.
3. Task Complexity: The complexity of the assembly task was maintained at a constant level for all participants. All participants performed the same task at the same station in Tiger Motors.
4. Timing: The duration of each treatment and the breaks between treatments were consistent for all participants.
5. Data Collection Methods: The methods used to collect data, including photographic evidence, real-time recordings, and survey responses, were standardized to enhance reliability.

By controlling these factors and including relevant covariates, the study aims to isolate the effects of the independent variables on the dependent variables, providing a clear understanding of how different workplace support systems impact cognitive load, usability, and performance in a simulated manufacturing environment.

4.6 Manufacturing Workplace Support Investigation: Results

This results section presents the Manufacturing Workplace Support Investigation findings based on collected and analyzed data. It encompasses quantitative analyses of various hypotheses related to NASA TLX Cognitive Load measures, error rates and production outputs, System Usability Scale (SUS) scores, and qualitative feedback from participants on their experiences during the experiment. Key hypotheses examined include differences in quality, production speed, cognitive load (NASA TLX), usability (SUS scores) based on treatment order, ADHD symptom levels, and production scripts (QI vs. PI). Participants' comments on the experimental setup, including the vision

camera system and check piece, are also discussed.

4.6.1 Sample Demographic Characteristics

Each participant filled out a demographic information sheet prior to completing the experiment. The demographic information sheet contained no personally identifiable information, such as name, email address, and phone number, collected on a separate code sheet. The demographic information collected included age, gender, ethnicity, birth country, primary language, schooling, major, LEGO experience, and manufacturing experience. The following tables summarize the participants from each of the two phases of the experiment (Quality Motivation and Performance Motivation Investigations).

Table 13: Sample Age Characteristics by Investigation

Variable	Script	Mean	StDev	Minimum	Median	Maximum
Age	Quality	31.27	8.05	21.00	29.00	56.00
	Performance	22.67	5.69	19.00	21.00	47.00

Table 14: Sample Characteristics by Investigation

		Quality Investigation N = 26		Performance Investigation N = 24		Total Sample (Both Investigations) N = 50	
Characteristics	Descriptor	Count	Percent	Count	Percent	Count	Percent
Gender*	Female	3	11.54	11	45.83	14	28.00
	Male	23	88.46	13	54.17	36	72.00
Race	Asian	10	38.46	3	12.50	13	26.00
	Black	2	7.69	2	8.33	4	8.00
	White	12	46.15	18	75.00	30	60.00
	Unknown	2	7.69	1	4.17	2	4.00
Ethnicity	Hispanic or Latino	4	15.38	1	4.17	5	10.00
	Not Hispanic	19	73.08	21	87.50	40	80.00
	Unknown	3	11.54	2	8.33	5	10.00
Birth Country	Bangladesh	5	19.23	0	0.00	5	10.00
	China	0	0.00	1	4.17	1	2.00
	Colombia	1	3.85	0	0.00	1	2.00
	Dominican Republic	1	3.85	0	0.00	1	2.00
	El Salvador	2	7.69	0	0.00	2	4.00
	Germany	0	0.00	1	4.17	1	2.00
	Greece	2	7.69	0	0.00	2	4.00
	India	3	11.54	0	0.00	3	6.00
	Iran	1	3.85	0	0.00	1	2.00
	Jordan	1	3.85	0	0.00	1	2.00
	Nepal	1	3.85	0	0.00	1	2.00
	Russia	1	3.85	0	0.00	1	2.00
	South Korea	0	0.00	2	8.33	2	4.00
	Taiwan	1	3.85	0	0.00	1	2.00
	USA	7	26.92	20	83.33	27	54.00
Primary Language	English	10	38.46	21	87.5	31	62.00
	Not Given	1	3.85	0	0.00	1	2.00
	Other	15	57.69	3	12.5	18	36.00
Schooling	High School	2	7.69	2	8.33	4	8.00

		Quality Investigation N = 26		Performance Investigation N = 24		Total Sample (Both Investigations) N = 50	
Characteristics	Descriptor	Count	Percent	Count	Percent	Count	Percent
	Some College	1	3.85	16	66.67	17	34.00
	Associate	0	0.00	4	16.67	4	8.00
	Bachelor	5	19.23	2	8.33	7	14.00
	Graduate	7	26.92	0	0.00	7	14.00
	Master	9	34.62	0	0.00	9	9.00
	PhD	2	7.69	0	0.00	2	4.00
Major In School	Engineering	21	80.77	18	75.00	39	78.00
	Education	1	3.85	1	4.17	2	4.00
	Physics	1	3.85	0	0.00	1	2.00
	Business	0	0.00	3	12.5	3	6.00
	Computer science	0	0.00	1	4.17	1	2.00
	N/A	3	11.54	1	4.17	4	8.00
LEGO Experience	Little/no experience	6	23.08	5	20.83	11	44.00
	Some experience	15	57.69	10	41.67	25	50.00
	Lots of experience	5	19.23	7	29.17	12	24.00
	Expert	0	0.00	2	8.33	2	4.00
Manufacturing Experience	No experience	1	3.85	11	45.83	12	24.00
	One or more classes	15	57.69	9	37.50	24	48.00
	Part-time/temporary	6	23.08	3	12.50	9	18.00
	1 year	1	3.85	0	0.00	1	2.00
	1 or more years	1	3.85	0	0.00	1	2.00

**Note*: The demographic survey asked participants about their gender, not other ways of representing this factor such as sex or sex at birth.

The Manufacturing Workplace Support research study involved a sample of 50 participants, divided into two groups: 26 participants in the Quality Investigation (QI) group and 24 participants in the Performance Investigation (PI) group. The demographic and background characteristics of these participants revealed several notable similarities and differences.

In summary, the demographic and background characteristics of the study participants revealed significant differences between the Quality Investigation and Performance Investigation groups. The QI group was more male-dominated, racially diverse, and internationally varied, with higher educational attainment and less extensive LEGO and manufacturing experience. In contrast, the PI group had a more balanced gender distribution, a higher percentage of White and USA-born participants, and a greater representation of native English speakers. These differences highlight the distinct compositions of the two groups and provide valuable context for understanding the study's findings.

4.6.2 Sample ADHD Symptom Prevalence

This section presents the prevalence and characteristics of ADHD symptoms

among participants using the ADHD Adult Self-Report Scale (ASRS). The sample comprised 50 participants and was divided into two groups: 26 in the Quality Investigation (QI) and 24 in the Performance Investigation (PI). This analysis focused on several key aspects, including the ASRS6 number of significant symptoms, the ASRS6 total points category, ADHD levels, and ADHD types. How to calculate these factors is detailed in Section 5.5.5.3 starting at step 6. Further, in this study, these variables are compared to the measured outcomes of the study and statistically compared to determine significant differences. The table below summarizes the values calculated for each of these factors for each of the investigations and the sample together.

Table 15: ADHD Symptom Prevalence by Investigation and Total, Including ASRS6, ASRS6 Total Points Scale, ADHD Levels, and ADHD Types

		Quality Investigation N = 26		Performance Investigation N = 24		Total Sample (Both Investigations) N = 50	
Characteristics	Descriptor	Count	Percent	Count	Percent	Count	Percent
ASRS6 Question Sub-Scale	0 Significant Symptoms	4	15.4	5	20.8	9	18.0
	1 Significant Symptoms	7	26.9	5	20.8	12	24.0
	2 Significant Symptoms	9	34.6	5	20.8	14	28.0
	3 Significant Symptoms	4	15.4	3	12.5	7	14.0
	4 Significant Symptoms	1	3.9	4	16.7	5	10.0
	5 Significant Symptoms	1	3.9	2	8.3	3	6.00
	6 Significant Symptoms	0	0.0	0	0.0	0	0.0
ASRS6 Questions Total Points Category	High Negative (0-9 Points)	12	46.2	12	50.0	24	48.0
	Low Negative (9-13 Points)	10	38.5	8	33.3	18	36.0
	Low Positive (14-17 Points)	3	11.5	3	12.5	6	12.0
	High Positive (18-24 Points)	1	3.9	1	4.2	2	4.0
ASRS6 Questions ADHD Level Sig. Symptoms	Low = 0-1 Symptoms	11	42.3	10	41.7	21	42.0
	Med. = 2-3 Symptoms	13	50.0	8	33.3	21	42.0
	High = 4-6 Symptoms	2	7.7	6	25.0	8	16.0
ADHD Type Based on ASRS18 Question Severities	Inattentive	4	15.4	15	62.5	19	38.0
	Hyperactive/Impulsive	1	3.9	1	4.2	2	4.0
	Combined	2	7.7	2	8.3	4	8.0
	None	19	73.1	6	25.0	25	50.0

4.6.3 Data Screening, Processing, and Cleaning

Data were collected using paper data collection sheets designed for this investigation and approved by the IRB. These sheets, detailed in Appendix E.2: IRB Documents, recorded the number and types of errors for each car built, total cars completed, cars started but not finished, and any anomalies such as dropped cars. The NASA TLX and SUS scales were also recorded on paper.

Microsoft Excel was used to digitize the raw data from the paper forms. Researchers and research assistants entered the data, organizing it into separate worksheets by participant number and the following classifications: demographics, treatment order, practice TLX, PWI treatment, Lean Treatment, I4.0 Treatment, Lean+I4.0 Treatment, and Behavioral Control Survey (ASRS). After the data transfer, the following metrics were calculated on the raw data. The following calculations were made:

2. **NASA TLX** – For each of the NASA TLX instances (five total), the following metrics were calculated; see the table below.

Table 16: NASA TLX Metrics: Name, Description, and Formula

NASA TLX Metric Name	Description	Formula
Weighted Subscales: Mental Physical Temporal Performance Effort Frustration	Weighted Subscale gives a sub-scale level perspective of the loads reported. Formula divides by 15 because of the 15 weighting pairs, Multiplies by 100 and divides by 7 to scale the 7 point TLX scale to 100 scale. (So, 2020)	Weighted Subscale=(#Times Weighted Higher)*(TLX Score for Category)/15*100/7
Weighted TLX	Weighted NASA TLX is more comprehensive and sensitive to individual differences in the perception of workload, as it considers the relative importance of each dimension. It is particularly useful in complex tasks where certain dimensions might be more critical than others. (So, 2020)	Weighted NASA TLX = Sum (Weighted Subscales) $Weighted\ Score = \frac{\sum(Rating_i\ x\ Weight_i}{\sum Weight_i}$
Unweighted TLX	Unweighted NASA TLX is simpler and quicker to administer, making it suitable for situations where a rapid assessment is needed or when the task is not complex enough to warrant differential weighting of dimensions. Multiplies by 100 and divides by 7 to scale the 7 point TLX scale to 100 scale. (So, 2020)	=AVERAGE(Reported Values for Each Subscale)*100/7 $Unweighted\ Score = \frac{\sum Rating_i}{6}$
Control Normalized TLX	To compare the percentage change relative to the control, normalization to the control is calculated for each participant, for each treatment, except the control (Yiyuan et al., 2011).	$Control\ Normalized\ TLX\ Score-= \frac{TLX_{treatment} - TLX_{control}}{TLX_{control}} x100$
Min-Max Normalized TLX	Min-Max Normalization can be beneficial if the goal is to compare workload scores directly across participants by bringing all scores to a common scale. However, it might be sensitive to outliers in participants' ratings (Barajas-Bustillos et al., 2023)	$Min - Max\ Normalized\ TLX\ Score = \frac{TLX_{treatment} - minTLX_{global}}{maxTLX_{global} - minTLX_{global}} x100$

3. **SUS** – For each SUS instance (four total), the following metrics were calculated; see the table below.

Table 17: SUS Metrics: Name, Description, and Formula

SUS Metric Name	Description	Formula
SUS	For odd-numbered items (1, 3, 5, 7, 9): Subtract 1 from the score. For even-numbered items (2, 4, 6, 8, 10): Subtract the score from 5. Sum the adjusted scores. Multiply by 2.5 to scale to 100 (Klug, 2017).	Likert Scale 1= Strongly Agree, 5= Strongly Disagree Even Questions Adjusted Score = Score-1 Odd Questions Adjusted Score =5-Score SUS Score = (Sum Adjusted Scores) x 2.5
Control Normalized SUS	To compare the percentage change relative to the control, normalization to the control is calculated for each individual participant, for each treatment, except the control (Yiyuan et al., 2011).	$Control\ Normalized\ SUS\ Score-= \frac{SUS_{treatment} - SUS_{control}}{SUS_{control}} x100$
Normalized SUS	Z-score Normalization is typically done with the SUS, as it has a large validated data set that provides a known mean (68) and standard deviation (12.5) (Klug, 2017; Lewis, 2018; Lewis & Sauro, 2018)	$Z = \frac{SUS_{treatment} - 68}{12.5}$ Normalized SUS= NORM.S.DIST(Z, TRUE) * 100

4. **Performance and Quality** – For each treatment instance (4 total), the following metrics were calculated; see the table below.

Table 18: Performance and Quality Metrics: Name, Description, and Formula

Performance/Quality Metric Name	Description	Formula
Total Built	For each ten-minute treatment, how many complete cars were made to end of the steps for Station 10.	Raw value
Number of Participants Making 8+ Cars	The TAKT time for this station is 60 seconds, meaning one finished car should be produced each minute. Participants working at 80% Takt Time should make 8 cars. This metric evaluates how many participants are reaching at least 80% desired production speed.	For each participant that reached 8 or more cars during the training session, mark a 1, all others a 0.
Average Defects	The average number of defects made over the ten-minute treatment. A separate metric calculated for each treatment.	Average Defects =Number of Uncorrected Errors made/ Total Built
Number of Participants Making Errors	To analyze the number of participants making uncorrected errors at any point during the trial.	For each participant that makes an error during the trial mark a 1, all others a 0.

5. **BCS (ASRS)** – The following metrics were calculated for the ASRS, completed once at the beginning of the study; see the table below.

Table 19: ASRS Metrics: Name, Description, and Formula

ASRS Metric Name	Description	Formula
ASRS6	The number of symptoms of significant frequency. Four or more symptoms from the first six questions of the ASRS are shown to correlate with a high liklihood that the adult has ADHD (Kessler, Adler, Ames, Demler, et al., 2005).	Total the number of questions at a significant level (Questions 1-6) Questions Significant at 2+ (Sometimes): 1, 2, 3 Questions Significant at 3+ (Often): 4, 5, 6
ASRS6 Symptom Level	Grouping the ASRS6 symptoms into three groups has shown an effective way of analyzing the correlation of the ASRS symptoms with other study variables (Kessler et al., 2009; Waite et al., 2022a).	Assign a category of likelihood for ADHD based on number of significant symptoms in the ASRS6 0-1 Symptoms = Low 2-3 Symptoms = Medium 4-6 Symptoms = High
ASRS6 Total Points	The four-stratum classification scheme made up of scores in the range 0–9, 10–13, 14 –17 and 18 –24 (Kessler et al., 2007).	Total points for the first six (0 = Never, 1 = Rarely, 2 = Sometimes, 3 = Often, 4 = Very Often). Score each question based on the number of points and total the first six questions.
ASRS6 Total Points Categories	Assign the category to each of the ranges of points in the ASRS6 Total Points.	0-9 = High Negative 10-13 = Low Negative 14-17 = Low Positive 18-24 = High Positive
ASRS18	An additional metric to analyze the adult participant's level of ADHD symptoms uses all 18 questions of the scale. This metric is the number of significant symptoms from all 18 questions.	Total the number of questions at a significant level (All Questions) Questions Significant at 2+ (Sometimes): 1, 2, 3, 9, 12, 16, 18 Questions Significant at 3+ (Often): 4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 17
ADHD Type	Classify the type of ADHD based on the number of symptoms for specific questions ("Adult ADHD Self-Report Scale (ASRS)," 2021).	**Inattentive**: Questions=1, 2, 3, 4, 7, 8, 9, 10, 11 **Hyperactive/Impulsive**: Questions =5, 6, 12, 13, 14, 15, 16, 17, 18 If adult has both, it is classified as **Combined Type** 4 or more symptoms in the categories are classified as that type.

Data were imported into Minitab 21.4.3 (64-bit). Data points were checked for errors during transfer, particularly in mixed number and text fields. Corrections were made as needed. Outlier analyses were performed to identify and handle extreme values that could skew results. This step promotes the integrity and accuracy of the data used in the analyses.

4.6.4 Main Analyses: Hypothesis Testing

The hypotheses for this investigation are tested for the Quality (QI) and Performance (PI) Motivation Investigations and the Combined (CI) Investigation, as explained previously. All hypotheses (cognitive load, quality, usability, and performance) were tested for groups and sub-groups with ADHD.

In this section, is the transition from the experimental setup to the analysis of the results obtained. The study tested 20 hypotheses through the application of various statistical measures, assessing the collected values and computed metrics. Detailed procedures and extended statistical analyses are thoroughly documented in Appendix C.6. Below, we provide a concise summary of the crucial metrics, pivotal results, and key findings that highlight the most significant insights from this research.

4.6.5.1 Summary of Findings: Productivity and Quality-Related Hypotheses

Visualizing aspects of the data is also helpful to better understanding the trends. In the two figures below, the metric for the Number of Cars Built is graphed in Boxplots, one dividing the treatments by the level of ADHD symptoms, the other dividing the treatments by the motivation script.

The following graphs illustrate the Average Defects Per Car metric for each treatment, segmented by motivation script (left), script and ADHD level (right). Notably, the addition of the I4.0 sensor brought the averages to zero, as seen in the graphs below.

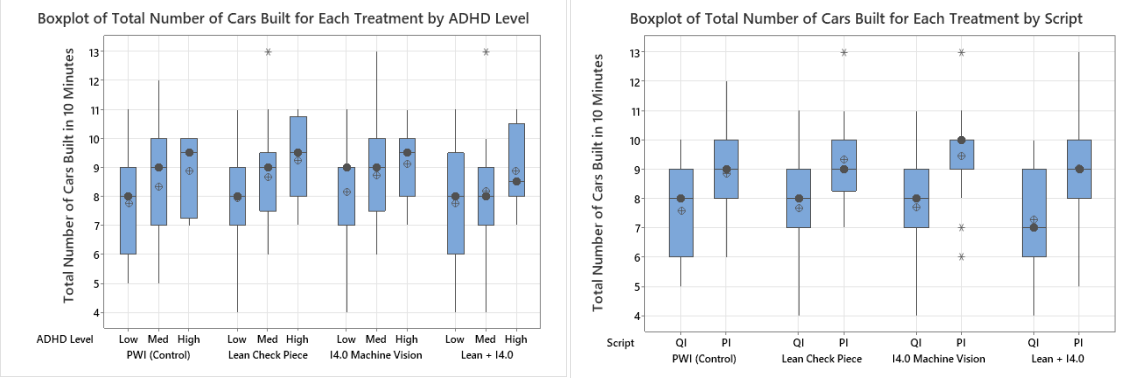


Figure 39: Boxplots of Total Number of Cars Built for Each Treatment. (Left) CI Dataset by ADHD Level (Right) By QI and PI Scripts

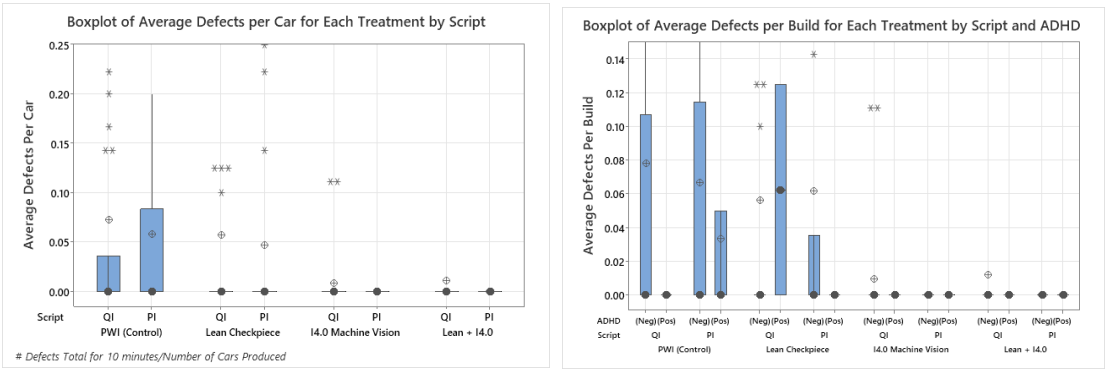


Figure 40: Boxplots of Average Defects per Car for Each Treatment, (left) Segmented by Motivation Script, (right) Segmented by Motivation Script and ADHD Category

Reject - H_{1a} : Higher Average Errors Per Car if PWI is first in treatment order, compared to later.

- None of the One-Way ANOVA p-values indicate statistically significant differences in average errors if PWI is the first treatment compared to all other treatment orders.

Reject - H_{1b}: Slower production speed (lower Number of Cars per Trial) using tools compared to PWI.

- None of the One-Way ANOVA p-values indicate statistically significant differences in average cars built per trial for PWI compared to all other treatments.

Failed to Reject - H_{1c}: Quality increases (lower Average Errors Per Car) with the number of vehicles built, independent of treatment.

- Average defect rate decreased for all data sets (QI, PI, and CI) from the first to the fourth treatment; however, differences failed to reach significance for the QI and PI datasets. The combined CI data set reached significance ($p = 0.032$).
- Cohen's d calculation for the paired comparison between the first and fourth treatments yields an effect size of approximately 0.268, indicating a small effect size.

Failed to Reject - H1d: Quality (lower Average Errors per Car) is higher for treatments with vision inspection camera system for the same treatment order.

- Significant improvement in quality observed with vision inspection systems in the treatment, supported by various p-values nearing or reaching significance across QI, PI, and CI data sets.
- Average defects per car, Treatment Order 1, I4.0 and L + I4.0 vs. PWI and Lean, PI data set, $p = 0.045$, Cohen's $d = -0.538$, moderate effect size.
- Average defects per car, Treatment Order 2, I4.0 and L + I4.0 vs. PWI and Lean, CI data set, $p = 0.023$, Cohen's $d = -0.433$, small-to-moderate effect size.
- Average defects per car, Treatment Order 3, I4.0 and L + I4.0 vs. PWI and Lean, CI data set, $p = 0.029$, Cohen's $d = -0.407$, small-to-moderate effect size.
- Average defects per car, Treatment Order 4, I4.0 and L + I4.0 vs. PWI and Lean, QI data set, $p = 0.038$, Cohen's $d = -0.370$, small-to-moderate effect size.

Failed to Reject - H_{1e}: Participants with higher number of ADHD symptoms will produce cars at a different rate than those with lower number of symptoms.

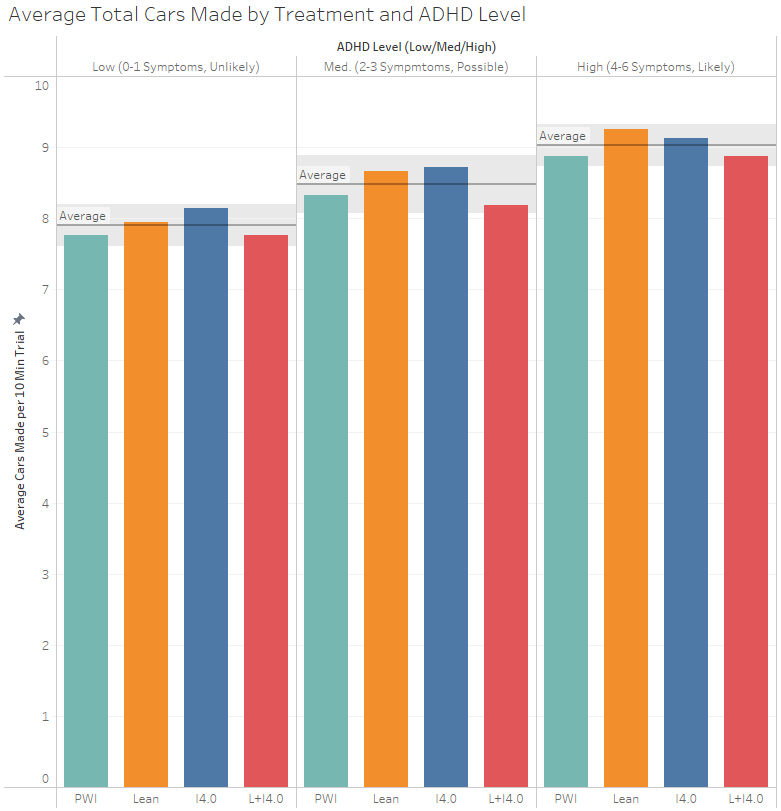


Figure 41: Average Total Cars Made by Treatment vs ADHD Level

- Significant difference between levels of ADHD symptoms and production rate, p=0.002 for CI dataset.
- Significant increase in production rate between Low and High symptom groups (p=0.005, F = 5.51). Participants with high ADHD levels produced significantly more cars (over one full car) on average (Mean = 9.03, SD = 1.36) compared to those with low ADHD levels (Mean = 7.90, SD = 1.80).
- The resultant Cohen's d effect size is 0.65, considered a moderate-to-large effect size.

Reject - H_{1f}: Participants with higher number of ADHD symptoms will have a different average error rate than those with lower number of symptoms.

- No statistically significant results for differences between ADHD levels.
- Results possibly trend toward fewer errors with higher ADHD symptoms but not reaching statistical significance.

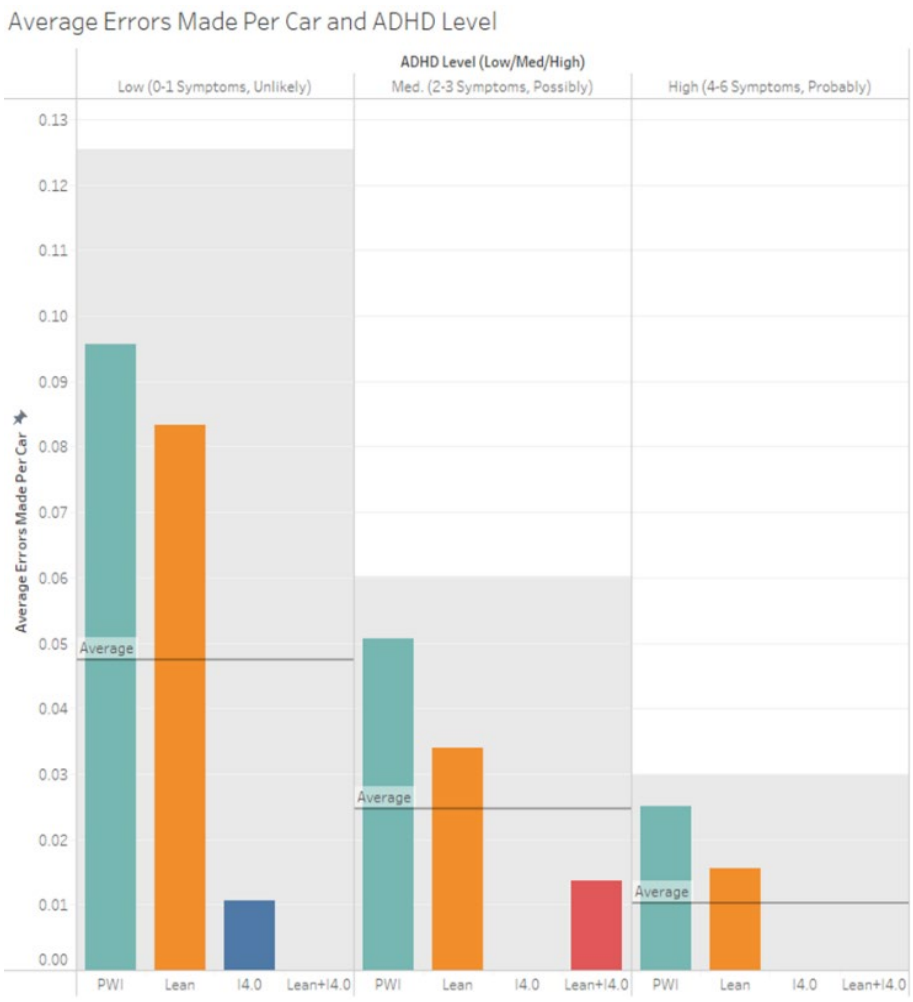


Figure 42: CI Dataset: Average Errors Made Per Car vs ADHD Level

4.6.5.2 Summary of Findings: Cognitive Load (NASA TLX) Hypotheses

The NASA TLX was administered alongside the SUS after each treatment. Similar to the SUS, the NASA TLX can be analyzed in multiple ways, with the calculations and justifications for the metrics discussed earlier. The figures below present Weighted and Unweighted NASA TLX scores segmented by treatment, script, and ADHD classification.

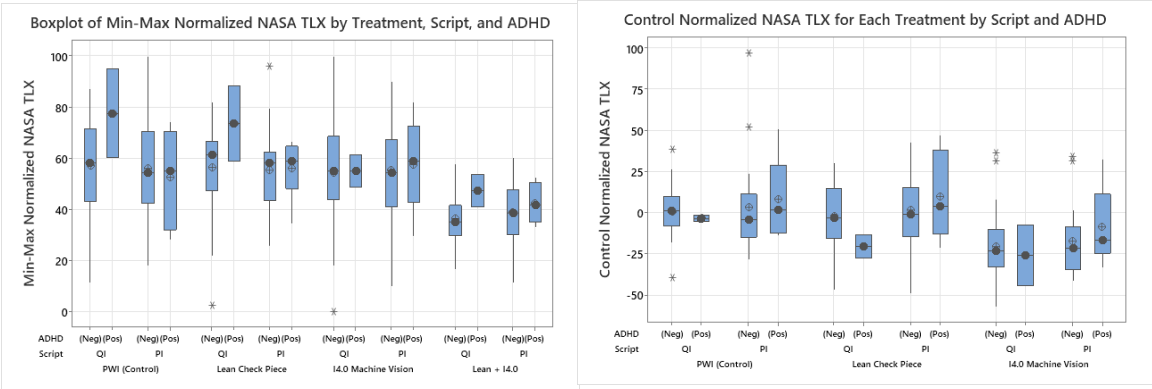


Figure 44: Normalized NASA TLX by Treatment, Script, and ADHD, (left) Min-Max Normalized, (right) Control Normalized.

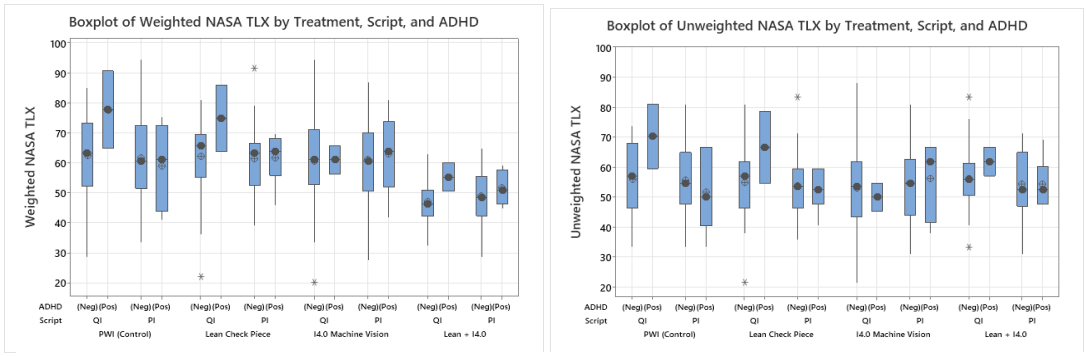


Figure 43: NASA TLX by Treatment, Script, and ADHD, (left) Weighted, (right) Unweighted.

Some slight differences were observed in the graphs. For instance, the Unweighted scores are consistently about ten points lower than the Weighted scores, with some additional outliers.

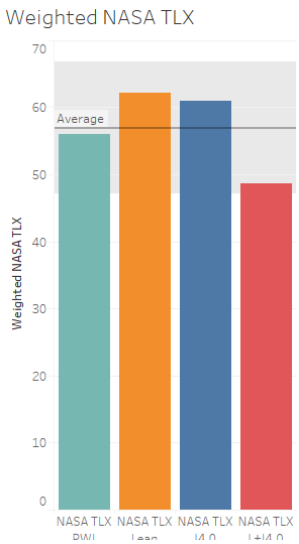


Figure 45: CI Dataset: Weighted NASA TLX by Treatment

Failed to Reject - H2a: Higher cognitive load for control (PWI) than for tools.

- For the CI, Min-Max NASA TLX metric significant results (F = 5.02, p=0.027) showed a greater cognitive load reported by participants for the PWI treatment compared to the other treatments.
- The model of Min-Max NASA TLX for PWI vs Other treatments for the CI script has a Cohen's d of 0.366, a low-to-moderate effect size.

Failed to Reject - H_{2b}: Cognitive load differs among the four treatments.

- Statistically significant results (F = 13.12, p<0.001) suggest that the cognitive load reported for each treatment is not the same.
- Lean+I4.0 was statistically significantly lower than the other three treatments (p<0.001), which had means that were statistically the same as each other.
- The model of Weighted NASA TLX for L+I4.0 vs other treatments for the CI script has a Cohen's d of 0.954, a large effect size.

Failed to Reject - H_{2c}: Cognitive load is independent of treatment order.

- These results suggest that cognitive load does not significantly vary with treatment order, implying that participants' cognitive load remains consistent regardless of when they encounter a specific treatment (p=0.993).

Failed to Reject - H_{2d}: Cognitive load from the individual sub-scales will differ between treatments.

- Mental, Temporal, Performance, Effort, and Frustration sub-scales are statistically different for treatments (p=0.000-0.048).
- Physical sub-scale was not statistically different between treatments.
- Mental Demand sub-scale showed statistical significance between treatment groups (F= 9.26, p<0.001), with Lean+I4.0 having a significantly lower cognitive load than all other treatments, which are all statistically the same (Cohen's d effect size = 0.71)
- Temporal Demand sub-scale: statistically, Lean is highest, Lean+I4.0 is the lowest, and PWI and I4.0 are in the middle and not separable from the top and bottom groups, (F = 2.68, p = 0.048, Cohen's d = 0.19).
- Performance, statistically significant differences between treatments in the Performance sub-scale (F = 5.32, p = 0.002, Cohen's d = 0.76). Statistically, PWI and I4.0 are the highest. Lean is middle and not separable, Lean+I4.0 the lowest.
- Effort sub-scale statistically different between the treatments, (F = 24.69, p<0.001, Cohen's d = 1.53), with Lean+I4.0 significantly lowering cognitive load from all other treatments. The means of all other treatments are statistically the same as each other.
- Frustration sub-scale treatments are statistically different from one another, (F = 15.51, p<0.001, Cohen's d = 1.207). Lean+I4.0 treatment has a significantly higher cognitive load than all other treatments. All other treatment means for the Frustration sub-scale are statistically the same. This is the opposite trend from all other sub-scales; Lean+I4.0 has reported a lower cognitive load than the others for all other sub-scales.

Rejected - H_{2e}: Cognitive load differs among the levels of ADHD Symptoms.

- No statistically significant results.

4.6.5.3 Usability (SUS) Hypotheses

Next, participant feedback on the treatments was examined through the System Usability Scale (SUS). After each treatment, participants completed the SUS, which measures usability. Responses varied widely, with a high standard deviation across all treatments, scripts, and ADHD classifications.

When comparing the descriptive statistics for the SUS metrics in this section, recall how each of the SUS metrics is calculated. (Covered in Section 4.6.3: Data Screening, Processing, and Cleaning) SUS is the direct output of the SUS instrument, with a range of 0-100. The Normalized SUS is normalized to a normal curve with an average of 65 and a standard deviation of 12.5, and the range is 0 to infinity; the smaller

the numbers are because many of the SUS results from the study were well below the normalized mean of 65, they have also been grouped by this normalization. The Control Normalized SUS is calculated by referencing each individual's SUS score for the Control (PWI) treatment; thus, the value for the PWI treatment for this metric is zero since it is referencing itself. For the Control Normalized SUS scale, negative values indicate lower usability compared to the control (Paper Work Instructions). Most participants rated the workstation support systems (the three treatments) as less usable than the control, despite the treatments significantly reducing errors. This discrepancy may be due to participants not being informed about their errors; many believed they made no errors when they actually had. Awareness of how the treatments improved their work quality could potentially enhance usability ratings, a factor not explored in this study but recommended for future research.

The Control Normalized SUS is particularly susceptible to outliers if the participants rank the Control (PWI) at an extreme level, then it affects the scores of the other scales. The Outlier test highlighted a few results, which led to an investigation of the causes of the outliers; see the graph below. Participant 2001 ranked PWI at a scale of 22.5, which caused a problem of falsely inflating the other scales outside of the range of

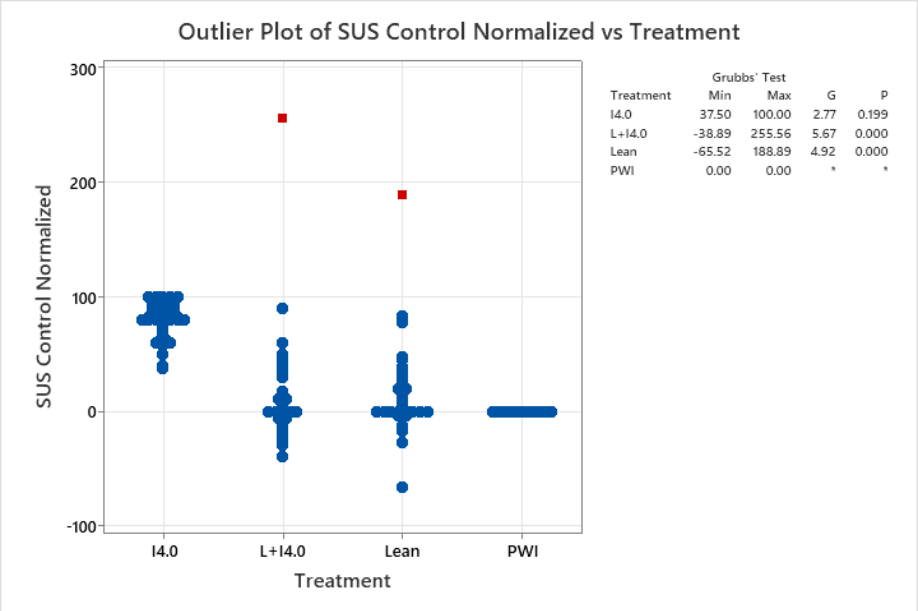


Figure 46: Outlier Plot of Control Normalized SUS vs. Treatment

all other scales for the other treatments. These data points were changed from falsely high values to 100, which is the limit of the scale. This follows the technique outlined by Victoria Hodge in A Survey of Outlier Detection Methodologies (Hodge & Austin, 2004).

Failed to Reject - H_{3a}: Higher SUS for treatments with I4.0 sensor – machine vision inspection system.

- System Usability scores: for multiple scales, achieved statistical significance, with higher scores for I.40 sensor treatments compared to PWI/Lean treatments (p = 0.025-0.046)
- SUS, CI Script, I4.0 Treatments vs others (F = 4.08, p =0.046, Cohen's d = 0.40)
- Control Normalized SUS, QI Script, I4.0 Treatments vs others (F = 5.05, p =0.027, Cohen's d = 0.51)
- Control Normalized SUS, CI Script, I4.0 Treatments vs others (F = 5.11, p =0.025, Cohen's d = 0.47)

Rejected - H_{3b}: The SUS score for PWI will be different for treatment orders of 2 or greater compared to the SUS score for PWI in order 1.

- None of the SUS metrics achieved statistical significance.

Failed to Reject - H_{3c}: SUS is independent of treatment order.

- None of the SUS metrics achieved statistical significance.

Failed to Reject - H_{3d}: System Usability Scale ratings differ among the levels of ADHD Symptoms.

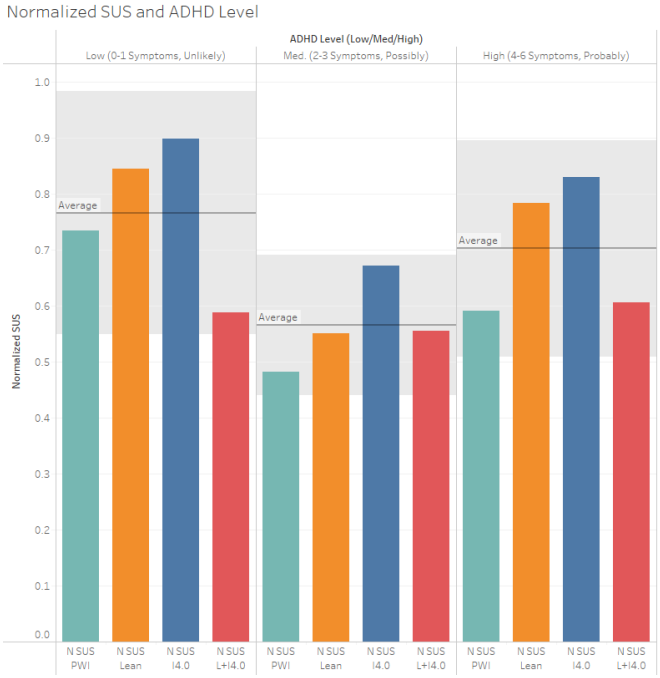


Figure 47: PI Dataset: Normalized SUS by Treatment and ADHD Level

- Some SUS metrics and data sets showed statistically significant differences between SUS ratings and ADHD symptom levels ($p = 0.021$).
- Normalized SUS vs ADHD Level, PI script, ($F = 4.04$, $p = 0.021$, Cohen's $d = 0.27$).

Reject - H_{3e}: Individuals with varying levels of ADHD symptoms will rate each treatment differently on the System Usability Scale (SUS).

- Control (PWI) – no statistically significant differences
- Lean – no statistically significant differences
- I 4.0 – no statistically significant differences
- Lean + I 4.0 – no statistically significant differences

4.6.5.4 Comparative Analysis – QI and PI Investigations Comparisons Hypotheses

Rejected - $H_{4.a}$: Lower Average Errors in QI compared to PI.

- Not statistically significant, scripts produced statistically the same number of average errors per car.

Failed to Reject - $H_{4.b}$: More cars produced per trial in PI than in QI.

- Statistically significant ($p<0.001$), script change made a significant difference in production rate.
- Performance Investigation Script significantly produced more cars per trial, on average 1.7 cars more per trial (QI (Mean = 7.5, St. Dev = 1.6), PI (Mean = 9.2, St. Dev = 1.5).
- Total built vs Script ($F = 53.16$, $p < 0.001$, Cohen's $d = 1.03$)
- Build 8+ vs Script ($F = 29.24$, $p < 0.001$, Cohen's $d = 0.78$)

Failed to Reject - $H_{4.c}$: SUS index is expected to be the same for QI and PI.

- No statistical difference in SUS scores between the scripts.

Failed to Reject - $H_{4.d}$: NASA TLX is expected to be the same for both QI and PI.

- No statistical difference in NASA TLX between the scripts.

4.6.5 Qualitative Data

Qualitative data were recorded during participant trials and at the end of the study interview. Unusual behaviors, comments made by the participants, and general observations about the participants were recorded. The results of the qualitative data analyses are included in Appendix C.3.

4.6.6 Covariate Analysis

Covariates in any experiment can affect the outcomes; experimental designs with randomization of treatments and random population sampling are designed to mitigate these effects as much as possible. Despite these efforts, there is usually some effect of covariates on the outcomes of a study based on the resulting population of participants. In this study, the following demographic information was collected: age, gender, race, ethnicity, birth country, primary language, schooling attainment, college major, LEGO

experience level, and manufacturing experience level. We also surveyed the participants about the number and significance of ADHD symptoms; this is also a covariate.

The covariate analysis revealed notable influences in this investigation. Interestingly, none of the covariates reached significance at the 95% level for the performance/quality metrics—Number of Cars Built and Average Defects—across all treatments. The NASA TLX and SUS metrics, however, experienced significant covariate influences. Each treatment showed significance in either the TLX or SUS metrics, but not both, with the Control (PWI) treatment having the most covariate significance. The tables of results and analysis are included in Appendix C.4.

Age, race, and LEGO experience showed significant effects on cognitive load, as measured by the NASA TLX scores. Age had a positive effect on cognitive load, indicating older participants experienced a higher mental workload. This suggests the possible need for age-appropriate support systems to reduce cognitive load in older workers.

Race also played a role, with White participants reporting higher cognitive load in the PWI treatment compared to other races. This highlights the necessity of considering racial differences in designing interventions to cater effectively to diverse populations. Additionally, participants with little or no LEGO experience rated the SUS higher in the Lean treatment, emphasizing the importance of user-friendly designs for inexperienced users.

ADHD levels significantly influenced the usability ratings of the I4.0 treatment. Participants with lower ADHD symptom levels rated the I4.0 technology higher in usability, suggesting that they found it more accessible. This insight may be important for developing inclusive technologies that accommodate individuals with varying ADHD symptom levels, ensuring effective engagement with the tools provided.

Education level significantly impacted task performance. Participants with some college education demonstrated fewer average defects in the Lean treatment, indicating better performance compared to those with different educational backgrounds. This finding underscores the value of tailored training programs aligned with educational backgrounds to enhance performance and reduce errors in manufacturing tasks.

The study observed a slight increase in average defects among male participants

in the Lean treatment, although this was not statistically significant. This suggests potential gender differences in task performance, warranting further investigation to understand the underlying causes and develop strategies to address them.

These findings underscore the complexity of human factors in manufacturing environments and the importance of considering a wide range of covariates in experimental designs. The significant effects of age, race, LEGO experience, ADHD levels, and educational background on cognitive load, usability, and task performance highlight the possible need for inclusive and adaptive support systems. Future research should continue to explore these relationships with larger sample sizes and more diverse populations to validate and extend these insights. By understanding how these covariates influence outcomes, researchers and practitioners can design more effective interventions that enhance performance, reduce cognitive load, and improve usability for all users.

4.7 Manufacturing Workplace Support Investigation: Conclusions

The results of this study provide a comprehensive look into the effects of various treatments on production/quality, cognitive load, usability, and script comparisons, particularly considering the influence of ADHD symptoms. The findings offer valuable insights for optimizing manufacturing processes and tools.

4.7.1 Production Speed and Quality Treatment and ADHD Effects

- Treatment order does not significantly impact error rates; specifically, starting with PWI does not adversely affect subsequent performance (H_{1a}).
- Using the tools was not significantly slower than PWI; as such, it suggests that tool-assisted workplace support systems can possibly be as efficient as traditional approaches (H_{1b}).
- Quality was shown to increase significantly over time, highlighting the benefits of practice and familiarity with the task in reducing errors (H_{1c}).
- Vision inspection system (I4.0) treatments were statistically the most effective in improving quality compared to the other support systems in this investigation (H_{1d}).
- ADHD symptom levels significantly impacted production speed across all treatments. Participants with higher ADHD symptoms showed significantly higher production rates compared to those with lower symptoms, especially in the CI dataset (H_{1e}).

- No significant differences in error rates between ADHD levels were found (H_{1f}).

The significant impact of ADHD symptoms on production speed, particularly in increasing rates among higher ADHD levels, suggests that individuals with ADHD can be highly productive under the right conditions. This could be leveraged in designing roles and tasks that align with their strengths. The lack of significant differences in error rates indicates that these individuals do not necessarily compromise quality for speed, making them potentially valuable in high-output roles.

4.7.2 Cognitive Load and Treatment Effects

- Higher cognitive load was reported for the PWI treatment compared to other treatments, particularly in the CI dataset (H_{2a}).
- Cognitive load differed significantly among the four treatments, with Lean+I4.0 showing the lowest cognitive load (H_{2b}).
- Cognitive load was independent of treatment order, indicating consistent mental strain regardless of the exposure sequence (treatment order) (H_{2c}).
- Individual sub-scales of cognitive load showed significant differences between treatments. Lean+I4.0 had the lowest mental demand, and Lean had the highest temporal demand (H_{2d}).
- The temporal sub-scale showed a reversal of the general trend of Lean+I4.0 being the lowest cognitive demand. Lean+I4.0 had the highest temporal cognitive load.
- No significant differences in cognitive load were found based on ADHD symptom levels (H_{2e}).

The higher cognitive load for PWI treatments and the significantly lower load for Lean+I4.0 treatments indicate the importance of task design in managing mental strain. Advanced technologies and lean principles can create more manageable work environments, enhancing productivity and reducing burnout. The independence of cognitive load from treatment order suggests that workers adapt to different tasks consistently, reinforcing the need for well-designed tasks and tools.

4.7.3 Usability of Treatments

- Higher SUS scores were reported for treatments with I4.0 sensor systems compared to PWI and Lean treatments, indicating better usability (H_{3a}).
- No significant differences in SUS scores were found based on treatment order (H_{3b}, H_{3c}).
- Some SUS metrics showed mixed results differences based on ADHD symptom levels (H_{3d}).

- No significant difference for various levels of ADHD symptoms and SUS ratings for different treatments (H_{3e}).

Higher usability scores for I4.0 treatments emphasize the potential benefits of advanced sensor systems in creating user-friendly environments. The varying usability perceptions across ADHD symptom levels highlight the need for inclusive designs that cater to diverse cognitive profiles. Ensuring that tools and systems are intuitive for all users can enhance overall efficiency and satisfaction.

4.7.4 Comparative Analysis of QI and PI Scripts

- No significant differences in average errors per car between QI and PI scripts were found, indicating similar error rates (H_{4a}).
- PI scripts led to significantly higher production rates than QI scripts, supporting the effectiveness of performance-focused instructions (H_{4b}).
- No significant differences in SUS scores between QI and PI scripts were observed, suggesting similar SUS scores (H_{4c}).
- No significant differences in NASA TLX scores between QI and PI scripts, suggesting similar cognitive loads (H_{4d}).

The efficiency benefits of PI scripts without increasing error rates suggest that performance-focused instructions can potentially optimize productivity. This supports using PI scripts in training and operational settings to possibly enhance output.

This conclusion seems to be in conflict with signal detection theory (SDT), which posits the speed-accuracy trade-off (faster decisions lead to more errors). However, as actions become automatic, requiring less cognitive effort and conscious attention, this reduction in cognitive load allows for faster performance without a corresponding increase in error rates (Heitz, 2014). It is possible that the workers in the study experienced an increase in automaticity that led to more consistent and reliable performance.

4.7.9 Some Additional Considerations

Customized Training and Support: Given the varied impacts of ADHD symptoms and cognitive load across treatments, customized training programs considering individual cognitive profiles could potentially enhance overall productivity and well-being and maximize their potential.

Strategic Implementation of Technologies: The incremental implementation of

advanced technologies, coupled with continuous feedback mechanisms, can possibly enhance their effectiveness *and* worker acceptance. Ensuring that workers are well-trained and comfortable with new systems is important for successful integration.

This study highlights the importance of considering individual differences, such as ADHD symptomology, in optimizing work environments. Advanced inspection technologies like the I4.0 Machine Vision Camera can significantly enhance product quality, though users may perceive their usability differently. Performance motivation scripts can increase production speed without compromising quality, and participants tend to improve their performance with practice. These findings provide valuable insights for designing effective workplace support systems and tailoring interventions to accommodate individuals with varying cognitive profiles. Future research should continue to explore these dynamics, considering larger sample sizes and additional factors that may influence performance and usability in manufacturing settings.

5.0 Chapter Five: Workplace Support Structures and ADHD Prevalence Survey: Effects on Self-Efficacy and Social Anxiety

5.0 Workplace Psychosocial Survey Introduction

Attention Deficit Hyperactivity Disorder (ADHD) can affect workers in a variety of ways, especially if their workplaces are not supportive of their neurodivergent condition (Hallowell M.D & Ratey M.D, 2021). Having a better understanding of how workers perceive the supportiveness of their workplace and how that affects their sense of self-efficacy, social anxiety, and workplace stress is an important first step toward making changes that can improve the working conditions for those who are neurodivergent, such as workers with ADHD. A very limited amount of research has been done in this area, especially related to the prevalence of workers with varying ADHD symptomology, ADHD diagnosis status, workplace-related stress, and anxiety. The most recent prevalence study working to establish US norms for ADHD failed to analyze the prevalence of undiagnosed ADHD persons experiencing and living with a significant number of ADHD symptoms (Adler et al., 2019). Al-Yateem et al. surveyed a population of young United Arab Emirates adults (aged 18-20) and found 141 out of 406 respondents reporting a significant number of ADHD symptoms, at a rate of 34.7%, much higher than other surveys that report from 4-8% medically diagnosed ADHD prevalence (Adamis et al., 2022; Al-Yateem et al., 2023; Faheem et al., 2022; Kessler et al., 2009). Kessler et al. performed a survey in a single manufacturing facility to assess the prevalence and workplace cost of ADHD. They determined higher rates of injury and low medication treatment rates for ADHD-diagnosed workers (Kessler et al., 2009). Adler et al. reported a high burden of symptoms of other conditions, such as insomnia, depression, and anxiety, in those respondents who have been diagnosed with ADHD (Adler et al., 2019). Waite et al. performed a similar survey to the instrument proposed here, with the target audience US college students, finding a prevalence of undiagnosed ADHD of ten percent and higher rates of diminished self-efficacy and increased rates of social anxiety for those participants reporting higher ADHD symptoms (Waite et al., 2022b). This study plans to expand this investigation to workers in the US, particularly

workers in manufacturing, to investigate the prevalence of ADHD diagnosed and undiagnosed and possible connections to rates of stress, anxiety, and perception of self-efficacy.

The aim of this study was to assess the prevalence of ADHD in workers in the USA and particularly in manufacturing, and evaluate potential connections with workplace support systems, self-efficacy, and social anxiety with and without ADHD symptom presence and diagnosis.

5.1 Workplace Psychosocial Survey: Survey Title

Determination of prevalence and relationship between psychosocial stress and anxiety related to health factors of workers.

5.2 Workplace Psychosocial Survey: Research Questions and Hypotheses

- Research Question 1: Is there a statistically significant difference in the mean number of ADHD symptoms, as measured by the ASRS v1.1, between adults who self-report an ADHD diagnosis and those who do not, across the surveyed employment sectors?

  Hypothesis 1.1: There is a difference between the mean number of ADHD symptoms (measured by the ASRS v1.1) between adults who self-report an ADHD diagnosis and those who do not, across all surveyed employment sectors.

  - Sub-question: Does the difference in the mean number of ADHD symptoms, as measured by the ASRS v1.1, between adults who self-report an ADHD diagnosis and those who do not, vary across different employment sectors?

  Hypothesis 1.2: There is a difference between the mean number of ADHD symptoms (measured by the ASRS6) between adults who self-report an ADHD diagnosis and does not vary between surveyed employment sectors.

- Research Question 2: Do the odds of being diagnosed with ADHD among adults differ significantly between various employment sectors?

  Hypothesis 2.1: ASRS6 symptom level associates with a self-reported ADHD Diagnosis.

Hypothesis 2.2: The odds of being **diagnosed** with ADHD among adults do not vary significantly between different employment sectors.

Hypothesis 2.3: The odds of being **undiagnosed** with ADHD and having significant ADHD symptomology among adults varies significantly between different employment sectors.

- Research Question 3: Is there a significant difference in the combined means of self-efficacy and social anxiety levels between adults with and without an ADHD diagnosis, with a focus on the manufacturing sector?

Hypothesis 3.1: There is a significant difference in the means of self-efficacy and social anxiety levels between adults with and without an ADHD diagnosis.

Hypothesis 3.2: There is a significant difference in the means of self-efficacy and social anxiety levels depending on ADHD symptom level.

Hypothesis 3.3: Self-efficacy and/or social anxiety scales associates with the probability of an ADHD diagnosis.

Hypothesis 3.3a: Self-efficacy (GPSES) scale associates with the probability of an ADHD diagnosis.

Hypothesis 3.3b: Social anxiety (LSAS) scale associates with the probability of an ADHD diagnosis

- Sub-question: Does the relationship between self-efficacy, anxiety, and ADHD symptom reporting differ significantly between the manufacturing sector and other employment sectors?

Hypothesis 3.4: There is no interaction effect between ADHD symptoms and employment sector on the means of self-efficacy and social anxiety levels.

Hypothesis 3.5: The relationship between self-efficacy, social anxiety, and ADHD symptom reporting differs significantly between the manufacturing sector and other employment sectors.

- Research Question 4: How does the presence of a self-reported ADHD diagnosis and reporting of ADHD symptoms among adults impact self-report of satisfaction with workplace support systems, with a focus on the manufacturing sector?

Hypothesis 4.1: Adults with a self-reported ADHD diagnosis self-report lower satisfaction with workplace support systems compared to those without an ADHD diagnosis.

Hypothesis 4.2: The impact of ADHD symptoms on satisfaction with workplace support systems (Q14) is more pronounced in the manufacturing sector compared to other sectors.

Hypothesis 4.3: The impact of ADHD symptoms on satisfaction with workplace support systems effectiveness perceptions (Q16) are more pronounced in the manufacturing sector compared to other sectors.

- Research Question 5: How do the datasets that resulted from the data cleaning process (High Quality, Failed Quality Check, and Suspected Bot datasets) compare in terms of the measured metrics?

Hypothesis 5.1: There is a significant difference in the mean of ADHD Symptoms reported between the High Quality, Quality Check Failed, and Bot Datasets.

Hypothesis 5.2: There is a significant difference in the means of self-efficacy and social anxiety levels between the High Quality, Quality Check Failed, and Bot Datasets.

5.3 Workplace Psychosocial Survey: Specific Aims

1. **Specific Aim 1**: To evaluate ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS v1.1) and compare these to self-reported diagnoses.
2. **Specific Aim 2**: To determine the prevalence of undiagnosed adults and whether this prevalence varies for different employment sectors.
3. **Specific Aim 3**: To explore the relationship between self-efficacy and anxiety and ADHD symptoms and ADHD diagnosis reporting in adults, especially in the manufacturing sector.
4. **Specific Aim 4**: To explore the relationship between workplace support systems perception and ADHD symptom reporting and self-reported ADHD diagnosis in adults.

5.3 Workplace Psychosocial Survey: Methods

5.3.1 Workplace Psychosocial Survey: Survey Design

This research uses an online survey conducted via Qualtrics, targeting participants from selected manufacturing facilities and a broader national sample of adults. The survey comprises six main sections: demographics, ADHD symptom reporting, social anxiety scale questions, self-efficacy scale questions, workplace support questions, general survey comments (free response), and ADHD diagnosis questions. At the end of the survey, participants have the option to complete an additional set of questions from the ADHD Adult Self-Report Scale (ASRS Part B).

5.3.1.1 Survey Structure

The survey includes quality check questions to confirm that participants are attentively completing the survey. These questions direct participants to select specific answers to identify and exclude responses from individuals who are not fully reading the questions or are carelessly filling out the survey.

Table 20: Survey components with a number of questions in each part

Parts of the Survey	Number of Questions if Working	Number of Questions if **Not** Working
Information Letter/Consent	1	1
Demographics	10	8
ADHD Symptom Reporting (ASRS Part A)	6	6
Social Anxiety Scale (LSAS)	14 (2 Quality Check)	14 (2 Quality Check)
Self-Efficacy Scale (GPSES)	5	5
Workplace Support	5	1
ADHD Diagnosis	2-4	2-4
General Survey Comments/End Survey	1 (optional)/ 1	1 (optional)/1
ADHD Symptom Reporting (optional, ASRS Part B)	0 or 13 (1 Quality Check Question)	0 or 13 (1 Quality Check Question)

5.3.1.2 Demographic Questions

The demographic section includes questions on sex, age, ethnicity/race, education level, marital status, and employment status. For employed participants, additional questions are asked about their employment sector and current company role.

5.3.1.2 Survey Instruments

The survey employs the following instruments:

- ADHD Adult Self-Report Scale (ASRS v1.1)
- Liebowitz Social Anxiety Scale (LSAS) (three 4-item subscales)
- Global Self-Efficacy Scale (five items)

These instruments are supplemented with custom questions to capture basic demographic information and participants' perceptions of workplace support for managing stress and anxiety. Detailed descriptions of these scales are provided in a section below.

5.3.1.3 ADHD Diagnosis Questions

Participants are asked if they have been diagnosed with ADHD by a medical professional. If they respond “no,” they are then asked if friends or family have suggested they might have ADHD based on their actions and tendencies and if they themselves believe they have ADHD. The final ADHD-related questions inquire about how they manage their condition, with possible responses being no treatment, self-medication with caffeine, daily prescription medication, or medication taken as needed.

5.3.1.4 Optional ADHD Symptom Reporting

All participants complete the first six questions of the ASRS (Part A). They are then given the option to answer the final 12 questions of the ASRS (Part B) if they have more time. These optional questions are presented after the ADHD diagnosis section.

5.3.1.5 Raffle Entry

At the conclusion of the survey, participants are offered the opportunity to enter a raffle drawing for a $50 Amazon.com gift card. If they choose to participate in the raffle, they are directed to a separate survey to enter their name and email address. If they

decline, they are thanked for their time, and the survey ends. No personally identifiable information is collected in the research survey unless participants voluntarily provide it in the optional free response sections. All participants, regardless of their employment sector, use the same raffle entry survey.

5.3.2 Workplace Psychosocial Survey: Survey Participants

Participants were recruited through two main methods: direct contact with manufacturing facilities and global distribution via social media and email lists. Each recruitment method is detailed in Appendix D.2.

5.3.3 Workplace Psychosocial Survey: Survey Subscales

Instruments used in the survey include the ASRS v1.1, five items from the Global Self-Efficacy Scale, and three 4-item subscales from the Liebowitz Social Anxiety Index, supplemented by questions capturing basic demographic information and participants' perceptions of workplace support for managing stress and anxiety.

5.3.3.1 ADHD Adult Self Report Scale v1.1

As described earlier, in section 2.1.7 (Methodologies employed for the assessment of ADHD-ASRS), the ASRS is a self-report scale used to screen adults for symptoms of a frequency and severity indicative of all three classifications of ADHD (inattentive, hyperactive, and combined-type) (Kessler et al., 2007). The survey respondents all presented the first six questions of the ASRS (the screening questions of part A) (Adler et al., 2006) after the demographic questions. However, they are offered the opportunity to answer the final 12 questions (Part B) of the ASRS if they have more time. Part B questions were answered after the ADHD diagnosis questions.

5.3.3.2 Liebowitz Social Anxiety Scale: For Adults

The Liebowitz Social Anxiety Scale: For Adults (LSAS) is a questionnaire, developed by psychiatrist Dr. Michael R. Liebowitz, that is widely used and validated in research related to social anxiety and its connections to other conditions (Beard et al., 2011; Liebowitz, 1987; Mennin et al., 2002; Rytwinski et al., 2009).

Participants are asked to rate each question in the survey in two ways. An

example situation is: “Participating in small groups”. First, the participant is asked to rate how anxious or fearful the situation makes them. Second, they are asked to indicate how often they avoid the given situation. The full questionnaire consists of 24 questions. It is scored by giving points to each increasing level indicated, with the total number of points being grouped into six levels of social anxiety. See the following table for the scoring of the full scale and the scaled scoring for using half of the questions, as used in this survey.

Table 21: LSAS Response Category Scoring (Liebowitz, 1987)

Response Category	0 Points	1 Point	2 Points	3 Points
Anxious/Fearful	None	Mild	Moderate	Severe
Avoidance	Never (0%)	Occasionally (1-33%)	Often (34-66%)	Usually (67-100%)

This survey scaled this survey down to eight questions. As a result, the final scoring categories also needed to be scaled proportionately.

Table 22: LSAS Scoring Scale Scaling for partial questionnaire survey (Mennin et al., 2002)

Full questionnaire scale (24 questions)	Partial questionnaire used in survey (8 questions)	Outcome Classification
0-29	0-10	You do not suffer from social anxiety
30-49	11-16	Mild social anxiety
50-64	17-21	Moderate social anxiety
65-79	22-26	Marked social anxiety
80-94	27-31	Severe social anxiety
Greater than 95	Greater than 31	Very severe social anxiety

The two sub-categories used in this questionnaire relate to performance anxiety and social situations. Totaling the score for the four questions from each of these sub-categories can give insight into the specific areas of concern for social anxiety for an individual (Rytwinski et al., 2009). The LSAS has shown “overall good psychometric properties as indicated by results of test-retest reliability, internal consistency, and convergent and discriminant validity” (Baker et al., 2002).

5.3.3.3 The General Perceived Self-Efficacy Scale (GPSES)

The General Perceived Self-Efficacy Scale (GPSES) assesses “an individual’s belief in his or her own ability to respond to novel or difficult situations and to deal with any associated obstacles or setbacks” (Schwarzer, 2012). In administration of the full

scale, ten statements are given to the participant to rank each as one of the following: 1-Not at all true, 2-Hardly true, 3-Moderately true, 4-Exactly true. Statements in the scale include situations such as: “When I am confronted with a problem, I can usually find several solutions” and “Thanks to my resourcefulness, I know how to handle unforeseen situations.” (Schwarzer, 2012). In the survey for this research, a subset of five of the ten questions were used. The questions used can be found in the copy of the survey and the IRB packet in Appendix E.3 and E.4.

As reported by the scale translator from German to English, Dr. Schwarzer, concurrent validity of the scale has been established based on correlations with other tests (Schwarzer, 2012). Previous studies have found positive correlations with measures of self-esteem, internal control beliefs, and optimism. Moreover, they have found negative correlations with general anxiety, performance anxiety, shyness, and pessimism. Predictive validity is stronger for women than men two years later (Schwarzer, 2012)

Table 23: GPSES Response Category Scoring (Schwarzer, 2012)

1 Points	2 Point	3 Points	4 Points
Not at all true	Hardly true	Moderately true	Exactly true

The scale is scored with the total of the point values found in the table above. The total points for each participant are classified based on the groupings found in the table below.

Table 24: GPSES Scoring Scale Scaling for partial questionnaire survey (Schwarzer, 2012)

Full questionnaire scale (10 questions)	Partial questionnaire used in survey (5 questions)	Outcome Classification
0-10	0-5	Low self-efficacy
11-20	6-10	Mild low self-efficacy
21-30	11-15	Moderate self-efficacy
31-40	16-20	High self-efficacy

5.3.3.4 Workplace Psychosocial Survey: Custom Questions

The survey also asks custom questions related to ADHD diagnosis to the participants. If they answer no, they have not been diagnosed by a medical professional;

then they are asked if friends and family mention they think they have ADHD based on their actions and tendencies, and then are asked if they think they have ADHD. All participants are asked the final ADHD medical-related question that asks if the participant treats their ADHD. Possible answers are no and three yes choices – self-medicate with caffeine, prescription medication taken daily, or prescription medication taken as needed.

Participants are offered an opportunity to type comments in a large text entry field; this is optional. Some participants chose to enter comments related to the survey, their experiences with ADHD in the workplace, or experiences of family members with ADHD.

At the end of the survey, the participants are offered the opportunity to enter a raffle drawing for a $50 Amazon.com gift card. If they select "yes," they would like to enter the raffle, then the research survey is closed, and they are directed to a separate survey to enter their name and email address for the raffle entry. If they enter no, they are thanked for their time, and the survey ends. No personally identifiable information is gathered in the research survey instrument unless the participant self-identifies in the open-response comment questions (there are two optional free-response questions).

5.5.4 Workplace Psychosocial Survey: Experimental Protocols

To determine the prevalence of undiagnosed ADHD in the manufacturing sector and other employment sectors and to explore its connection to social anxiety and self-efficacy, a survey was designed based on the work of Waite et al. Due to the unavailability of the original survey questions, confirmed through correspondence with Dr. Roberta Waite, a new set of survey questions was developed and tailored to the research objectives.

5.5.4.1 Pilot Testing

The initial version of the survey was piloted with colleagues from the Occupational Safety and Ergonomics department. This pilot testing aimed to identify any issues with question clarity, survey length, and overall design. Feedback from the pilot participants was used to refine and finalize the survey instrument.

5.5.4.2 Participant Recruitment

Upon receiving IRB approval, commenced data collection by recruiting participants through various channels, including email invitations, social media platforms, and professional networks. Participants were provided with an informational letter detailing the purpose of the study, the voluntary nature of participation, and the measures taken to protect their confidentiality.

Data collection occurred between May 4, 2024, through June 11, 2024, 5 weeks in the Auburn University Qualtrics system. Responses were continuously monitored to identify and address any issues related to survey accessibility quality or participant engagement. Results are securely and anonymously stored in the secured Auburn University Qualtrics database. After the data collection period concluded, the data were processed and cleaned. This process involved removing incomplete responses, suspected bot-generated entries, and responses that failed quality checks. Detailed procedures for data cleaning are outlined in a subsequent section.

5.5.4.3 Security Measures for the Survey

In the modern era, survey fraud is a real concern for online digital data collection. Auburn University students and faculty have access to the full capabilities of Qualtrics with regard to security and fraud detection (Qualtrics, 2024). There are several options on how potentially fraudulent data can be handled within the Qualtrics data collection system:

> "With Expert Review Fraud Detection, you can do the following with responses identified as fraudulent:
>
> 1. Discard them, preventing them from being counted against auditable responses or quotas.
> 2. Redirect these responses for analysis separately.
> 3. Flag these responses so they can be filtered, reported on, etc.
> 4. Analyze the number of fraudulent responses you've received, breaking them down by duplicates and bots." (Qualtrics, 2024)

The survey for this study was set up with all possible fraud detection and flagging options but was not set up automatically to delete entries. The feeling was that it would be beneficial to see the full data set and clean the data after collection to retain the most control over the process.

The following security settings **were enabled** on the survey prior to deployment:

- "Bot Detection: We'll look for bots that might be taking your survey and flag their responses with an embedded data field (reCAPTCHA)."
- "Security Scan Monitor: Prevent security scanners from accidentally starting surveys when they test your link (reCAPTCHA)."
- "RelevantID: Analyze a respondent's browser, operating system, and location to prevent fraudulent responses."
- "Prevent indexing: Block search engines from including your survey in their search results."
- "Anonymize responses: Don't record respondents' IP Address, location data, and contact info." (Qualtrics, 2024)

The following security measures were **not** chosen for implementation:

- "Prevent multiple submissions: Prevent respondents from taking your survey multiple times. You can choose to end the survey, redirect them to a website, or flag the response."
  Note: This feature was enabled in the survey pilot, and it was found that participants in the same office or household were not allowed to take the survey. Since it was desired to allow participants from the same workplace, household, or general local to take the survey, it was chosen to disable this feature.
- "Add a referral website URL: Allow people to take your survey only if they select a survey link included on a specific website.
  Note: Due to the planned distribution strategy for this survey instrument, this security measure was not practical."
- "Password Protection: Require respondents to enter a password before they can take your survey." (Qualtrics, 2024)
  Note: It was feared that enabling this security measure would greatly reduce the number of legitimate survey participants; thus, it was decided against enabling it.

According to the documentation within the Qualtrics training site, the advanced algorithms behind their security measures use many metrics to calculate the probability of fraudulent activity. Some of the metrics are related to the response patterns and survey completion times (potential for suspected bot fraud and inattentive/rushing human participants). Qualtrics also monitors and analyzes the IP address and geolocation filtering looking for multiple requests from unexpected geolocations that might indicate bot activity. Metadata is also analyzed for user-agent strings that could suspiciously be from known bot or script sources or automated responses. Captcha technology itself is a barrier to automated and non-human survey participants.

Besides enabling the built-in security measures, other techniques were implemented that allowed for the post-analysis of quality responses. One method is adding "Attention Check," also called "Quality Check" questions. This survey had three such questions that directed the participants to click a specific answer to prove they were reading the questions carefully. Also, including short answer response questions (either optionally or required) is another way to filter for quality responses.

With free-response questions, bots will often follow some unusual text entry patterns that are easily recognizable as bot activity. Some of these patterns are as follows:

1. Repetitive or Nonsensical Phrases
    - Repetitive Answers: Bots often generate repetitive responses and lack context. For example, the same phrase might be repeated multiple times across different responses.
    - Nonsensical Text: Responses might include strings of words that do not form coherent sentences or relevant content.

2. Keyword Stuffing
    - Unnatural Use of Keywords: Bots might stuff responses with keywords in an attempt to match expected topics, resulting in awkward or forced sentences.

3. Grammatical Errors and Odd Phrasing
    - Unusual Grammar and Syntax: Although humans can also make grammatical errors, bot responses might exhibit unusual patterns, such as incorrect word order, misplaced modifiers, or unnatural phrasing.
    - Inconsistent Tense and Person: Switching between tenses or using inconsistent first, second, or third person pronouns.

Despite all the security measures in place for the survey deployment, many bot responses were detected by the Qualtrics algorithm. The results and cleaning methods for the data are covered in subsequent sections.

5.5.4.4 Data Analysis and Cleaning

Despite implementing security measures to enhance the integrity of survey respondents, Qualtrics algorithms detected a significant percentage of fraudulent activity. The primary issue stemmed from suspected bot activity, which correlated with public posts made on LinkedIn and Facebook pages. This led to spikes in responses overnight,

with several hundred respondents, followed by a slowdown to approximately 20-30 per day until another public post was made.

Key indicators of bot activity included multiple submissions per second and unusual, duplicate entries in the free response comment box at the end of the survey. Additional metrics available in Qualtrics, when the appropriate settings are enabled before publishing the survey, such as Q_RecaptchaScore, Q_RelevantIDFraudScore, and Q_RelevantIDDuplicateScore, provide insights into suspected bot activity. These metrics, based on algorithms within Qualtrics, analyze survey timing, mouse activity, and other suspicious behaviors (Qualtrics, 2024). Duplicate responses are flagged when repeated submissions come from the same IP area/address. Qualtrics provides guidelines for interpreting these metrics to decide whether to exclude suspected bot data.

Q_RecaptchaScore, based on Google's invisible reCAPTCHA technology, ranges from 0-1, with scores of 0.5 or higher likely indicating a human respondent, and lower scores indicating a bot (Qualtrics, 2024). The Q_RelevantIDFraudScore, utilizing Qualtrics' RelevantID technology, ranges from 0-130, with scores of 30 or higher likely indicating fraudulent activity (Qualtrics, 2024).

Recorded Date	Q_RecaptchaScore	Number of Scores Indicating Bot Activity	Q_RelevantIDFraudScore	Additonal Comments
5/10/2024 23:41	0.40	2	30	Survey on healthy body and mind
5/10/2024 23:41	0.40	2	30	Investigate how to relieve stress
5/10/2024 23:41	0.40	2	30	Investigate how to relieve stress
5/10/2024 23:41	0.70	0	0	Investigate how to relieve stress
5/10/2024 23:41	0.00	2	30	Stress and anxiety related to health problems in the workplace.
5/10/2024 23:41	0.90	1	30	Health survey on stress
5/10/2024 23:41	0.40	2	55	Stress and anxiety related to health problems in the workplace.
5/10/2024 23:41	0.70	1	30	Survey on healthy body and mind
5/10/2024 23:41	0.70	1	30	Survey on healthy body and mind
5/10/2024 23:41	0.70	1	30	Health survey on stress
5/10/2024 23:41	0.70	1	30	Health survey on stress
5/10/2024 23:41	0.40	2	30	Stress and anxiety related to health problems in the workplace.
5/10/2024 23:41	0.40	2	30	Health survey on stress
5/10/2024 23:41	0.70	1	30	Health survey on stress
5/10/2024 23:41	0.70	1	30	Health survey on stress

Figure 48: Qualtrics results screenshot of suspected BOT results.

For the suspected bot activity in the survey, the following concerns were noted:

- Repeating comments in the free response box.
- Comments not addressing the question, “Please provide any additional comments or information you feel is relevant to this study: (optional).”
- Responses arrive multiple times per minute.
- Q_RecaptchaScores below the human threshold.
- Q_RelevantIDFraudScores of 30 or above, indicating bot activity.

In the suspected bot activity data figure, a column shows how many metrics indicate bot activity (0, 1, or 2). Even with obvious bot activity, the metrics are not 100% reliable; hence, relying solely on them is insufficient for data cleaning.

For several reasons, it was opted not to use Q_DuplicateID as a metric. First, when a company distributed the survey directly to its employees, results were flagged as duplicate responses due to the shared internet service. Additionally, during the pilot study, the “Prevent duplicate responses” setting prevented participants from finishing the survey later or family members from completing it within the same household. To establish a broad participant population and not limit responses to one per household or office, data was chosen not to be filtered by this metric.

Although Qualtrics offers “Expert Review” filters, employing this tool left a significant amount of bot activity in the data, as evidenced by repeating nonsensical comments in the free-response section. Due to this inadequate automatic filtering, after researching bot removal methods, techniques recommended by other researchers were employed (Anduiza & Galais, 2017; Berinsky et al., 2021; Brainard et al., 2022; Golds, 2023; Pozzar et al., 2020). However, since IRB already approved the survey and it was launched, the methods were limited to filtering out fraudulent data rather than preventing it through screening methods suggested by these authors.

Examples of unusual activity are shown in the Appendix table, with the full list of suspected bot comments and their frequencies included in Appendix D.3.

Table 25: Examples of BOT answers to the Comment Question on Survey with Frequency of Responses

Free Answer Comment	Frequency
Stress and anxiety related to health problems in the workplace.	174
Survey on healthy body and mind	179
Investigate how to relieve stress	172
Health survey on stress	187

One bot even self-identified as AI with this elaborate comment in the free response question shown below.

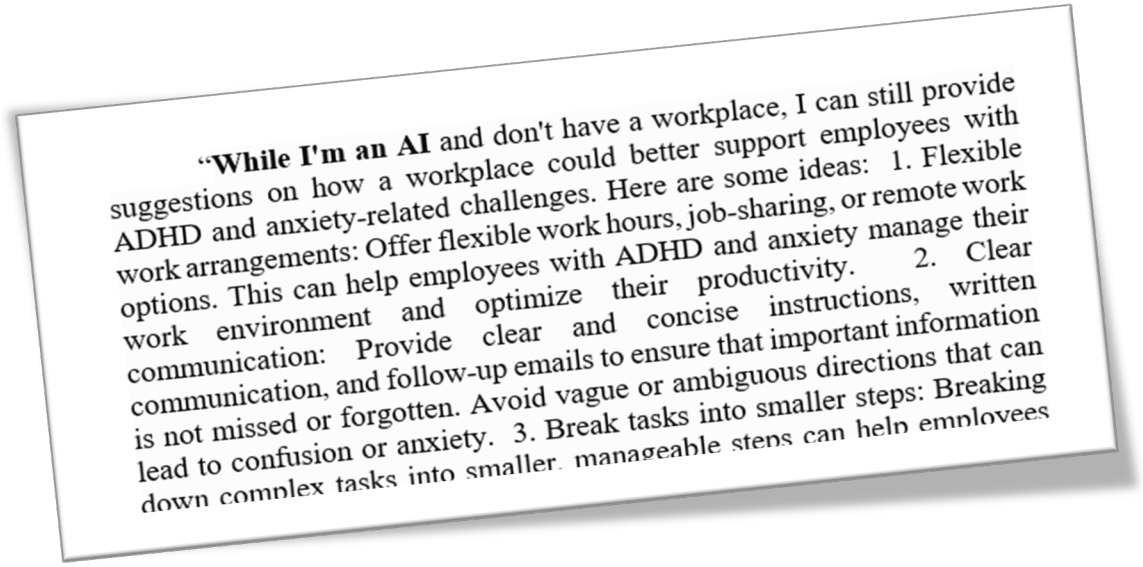


Figure 49: AI Participant Response Self-Identifying as a Bot

The steps taken to clean the data and process it into a format ready for export to Minitab are detailed below.

1. Export all Qualtrics quality data to R (without employing Qualtrics automatic quality response filters)
2. Add a column to the front of the data for participant numbers numerically 1 through the end of the data to more easily reference which data point each is.
3. Add a column named "Failed Quality check," using the R code to label each data point as one of the following:

Table 26: Failed Quality Check Column Code and Qualifications and Totals of Each Code Identified

Code	Number Identified	Meaning	Test
0	250	No faults	Designated as passed all the quality checks- best quality response, most likely to be a human
1	193	Failed Quality Check Questions	If any of the quality check answers are incorrect
3	799	Bot suspected comments	Questions that do not make sense for the survey response, like talking about green energy or the Chinese economy, and question responses that repeat (except for N/A or none).
4	222	Quit survey early	Incomplete surveys (not including choosing not to do the extra questions)
6	277	Timing	Multiple responses per minute, rapid succession
7	170	ReCaptcha AND Fraud Scores triggered	Triggering both reCaptcha and Fraud metrics in Qualtrics

4. ASRS, LSAS, and GPSAS scales are scored and coded for totals for the scores and categorized based on levels.
   ASRS scoring outputs four metrics, and the method of calculating each is explained below.
   ASRS6 = Number of significant symptoms in the six-question screener
   ASRS18 = Number of significant symptoms in the full 18 questionnaire

Table 27: ASRS6/18 Scoring Reference: Score each question as an ADHD symptom if the score is equal to or higher than the threshold value. (Kessler et al., 2007)

ASRS6 and ASRS18 Total of Significant Symptoms	Questions
Questions Significant at 2+ (Sometimes)	1, 2, 3, 9, 12, 16, 18
Questions Significant at 3+ (Often)	4, 5, 6, 7, 8, 10, 11, 13, 14, 15, 17

ASRS6 Level = Low (Unlikely) 0-1 significant symptoms, Medium (Possible) 2-3 significant symptoms, High (Likely) 4-6 significant symptoms.

Figure 50: ASRS Point Total 6 Scoring reference levels based on total. (Kessler et al., 2007)

	Low (Unlikely)	Medium (Possible)	High (Likely)
Total of Significant Symptoms from ASRS6	0-1	2-3	4-6

Table 28: GPSES Self-Efficacy Scaling Reference: Total points for each response (1 = Not at all true, 2 = Hardly true, 3 = Moderately true, 4 = Exactly true) (Schwarzer, 2012)

	Low self-efficacy	Mild Low Self-Efficacy	Moderate Self-Efficacy
Full Scale	<10	20	30
Scaled for Survey	0-5	6-10	11-15

Table 29: LSAS Social Anxiety Scaling Reference: Total points for each response (0 = None, Never, 1 = Mild, Occasionally, 2 = Moderate, Often, 3 = Severe, Usually) (Beard et al., 2011)

	You do not suffer	Mild	Marked	Moderate	Severe	Very Severe
Full Scale	0-29	30-49	50-64	65-79	80-94	95-100
Scaled for Survey	0-10	11-16	17-21	22-26	27-31	31-33

7. Import data into Minitab for analysis.

The final data set, containing the cleaned data, is considered the most likely to be human participants who were paying attention to the questions and not just clicking through the survey. This dataset is analyzed in the rest of the hypothesis testing. However, a brief analysis of the other data is performed in Appendix D.6. Failed Quality Check Dataset Analysis. In this section, the Suspected Bot Dataset and the Failed Quality Check datasets are compared to the dataset used for this analysis, named the High-Quality dataset, and some general comparisons are made.

The High-Quality dataset was then analyzed using Microsoft Excel and Minitab. Descriptive statistics were computed to summarize the demographic characteristics of the sample and the prevalence of ADHD symptoms. Graphical analysis depicted general trends and summaries of the results. Inferential statistical analyses, including correlation and regression analyses, were conducted to test the research hypotheses related to the relationships between ADHD symptoms, social anxiety, and self-efficacy across different employment sectors.

5.5.5 Workplace Psychosocial Survey: Ethical Approval

After a comprehensive two-month review process and one revision, the Auburn University Institutional Review Board (IRB) for Research Involving Human Subjects approved protocol 24-748, titled “Determination of Prevalence and Relationship Between

Psychosocial Stress and Anxiety Related to Health Factors of Workers." The approval was granted on Thursday, April 25, 2024, and categorized as "Exempt" under federal regulation 45 CFR 46.104(b)(2). A copy of the IRB approval is included in Appendix E.3.

An information letter was presented on the first page of the Qualtrics survey, ensuring informed consent from all participants. This letter detailed the purpose of the study, the voluntary nature of participation, the measures in place to protect participant confidentiality, and the criteria for participation. Participants were required to affirm their consent by selecting "Yes, I consent to participate in the study, and I am 18 years old or older." If a participant chose "No," they were immediately redirected and excluded from completing the survey.

This ethical approval process confirmed that the study adhered to all necessary regulations and standards for research involving human subjects, safeguarding the rights and well-being of the participants.

5.6 Workplace Psychosocial Survey: Results

The Workplace Psychosocial Survey Results section presents a comprehensive overview of the data, including its description, descriptive statistics, main analyses, and qualitative insights. This section starts by detailing the data screening and cleaning processes, highlighting the challenges of eliminating fraudulent responses and the outcomes of these efforts. It then moves to an analysis that provides comparative data, general trends, and initial findings across the entire dataset. Subsequent sections delve into hypothesis testing using various statistical methods to assess the significance of findings related to each research question.

In the Failed Quality Check Data Set Analysis, data removed due to failed quality checks were compared for the analysis (in Appendix D.6). Also explored are qualitative responses from the survey's free-response sections to identify trends and gather insightful observations (in Appendix D.5). The final analyses examine covariates, comparing demographic variables against the entire dataset to discern their impact on the results. The section concludes with a summary of the findings, encapsulating the key results and their implications.

5.6.1 Description of Data

5.6.1.1 Sample Characteristics

The data cleaning process resulted in a more complex sample than initially intended, with additional categories being created. The specific categories for each survey response are detailed in the Data Analysis and Cleaning section. Overall, the breakdown of the 1,911 data points is shown in the graph below. The two exploded pie pieces represent responses deemed highly likely to be human responses, either with or without missing one or more of the quality check questions within the survey.

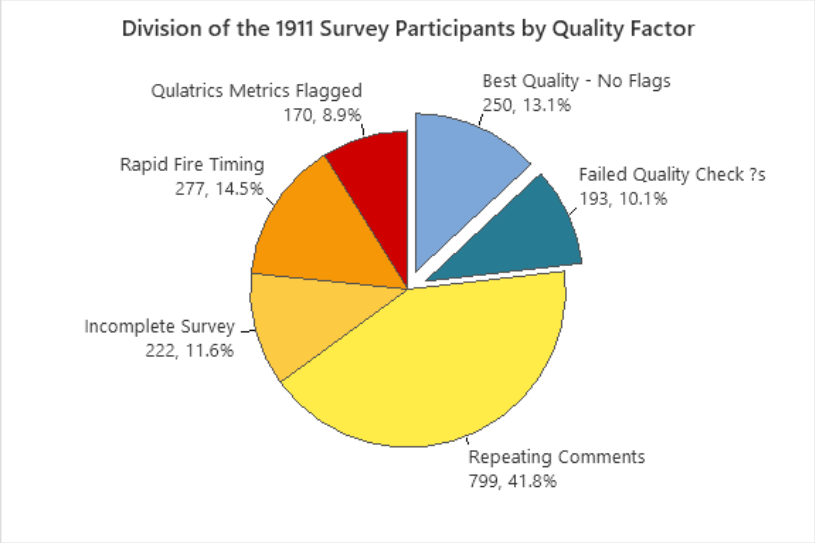


Figure 51: Division of the 1,911 Survey Participants by Quality Factor

The sample characteristics are summarized by the entire data set, suspected bot, responses that failed, and the highest quality data set.

Table 30: Age Descriptive Statistics for Groups of Survey Data

Age Descriptive Stats	N	Mean	Median	St. Dev	Min	Max
Sus Bots	1246	34.2	33	7.8	18	77
Failed QC Check	193	33.9	32	11.3	18	77
High Quality	250	34.6	31	11.5	18	77

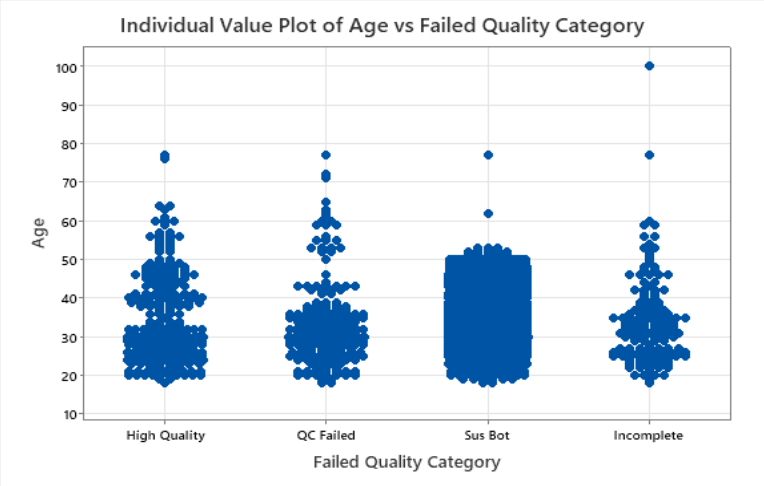


Figure 52: Individual Value Plot of Age vs Failed Quality Category

A summary of the frequency and percent of each demographic value answered by the participants is shown in the table below. The table is summarized by three categories of cleaned data: Suspected Bots, Failed Quality Check participants, and High-Quality responses. The Failed Quality Check and Suspected Bots are only included for interest but are not included in the analysis of the data.

Table 31: Sample Characteristics Summary Table

		Suspected Bots		Fail QC Check		High Quality	
Characteristics	Descriptor	N	Percent	N	Percent	N	Percent
Sex at Birth	Female	660	52.97	74	38.34	134	53.82
	Male	586	47.03	119	61.66	114	45.78
	Prefer not to answer	-	-	-	-	1	0.40
Ethnicity/Race (Choose all that apply)	American Indian	27	2.17	17	8.81	3	1.20
	American Indian + Black	-	-	-	-	2	0.80
	American Indian +White	-	-	1	0.52	1	0.40
	Asian	14	1.12	17	8.81	14	5.62
	Asian + Other	1	0.08	-	-	-	-
	Asian + Am. Indian	-	-	2	1.04	-	-
	Asian + Am. Indian +White	-	-	-	-	1	0.40
	Asian + Black	-	-	1	0.52	-	-
	Asian + White	1	0.08	-	-	4	1.61
	Black	52	4.17	45	23.32	46	18.47
	Black + White	1	0.08	-	-	-	-
	Black + Hispanic + White	-	-	-	-	1	0.40
	Black + Native Hawaiian	-	-	-	-	1	0.40
	Hispanic	28	2.25	9	4.66	9	3.61
	Hispanic + White	2	0.16	3	1.55	4	1.61
	Native Hawaiian	24	1.93	2	1.04	3	1.20
	Native Hawaiian + White	1	0.08	2	1.04	-	-
	White	1095	87.88	84	43.52	156	62.65

		Suspected Bots		Fail QC Check		High Quality	
Characteristics	Descriptor	N	Percent	N	Percent	N	Percent
	Other	-	-	1	0.52	1	0.40
	Prefer not to answer	-	-	1	0.52	-	-
Education	Less than HS diploma	4	0.32	4	2.07	-	-
	High school diploma	160	12.84	19	9.84	15	6.02
	Some College	169	13.56	26	13.47	20	8.03
	Associate	231	18.54	26	13.47	13	5.22
	Bachelor	391	31.38	75	38.86	111	44.58
	Master	286	22.95	35	18.13	75	30.12
	PhD	5	0.40	8	4.15	15	6.02
Marital Status	Divorced	11	0.88	14	7.25	10	4.03
	Married/Dom Relationship	689	55.34	111	57.51	137	55.24
	Separated	539	43.29	-	-	2	0.81
	Single	539	43.29	64	33.16	94	39.11
	Widowed	6	0.48	4	2.07	2	0.81
Employment (Choose all that apply)	Full-Time	1148	92.13	106	54.92	130	52.21
	Full-Time + Student	10	0.80	1	0.52	-	-
	Full-Time + Part-Time			-	-	2	0.80
	Full-Time +Homemaker			1	0.52	-	-
	Full-Time + Part-Time +Seek			-	-	1	0.40
	Full-Time + Seek			-	-	1	0.40
	Full-Time + Student			-	-	12	4.82
	Part-Time	26	2.09	22	11.40	21	8.43
	Part-Time + Job Seek	8	0.64	-	-	-	-
	Part-Time +Self-Employed	1	0.08	1	0.52	2	0.80
	Part-Time + Student	8	0.64	1	0.52	22	8.84
	Part Time +Student +Job Seek	-	-	-	-	1	0.40
	Part-Time + Student + Self-Employed	1	0.08	-	-	1	0.40
	Part-Time + Student + Self-Employed + Homemaker	-	-	-	-	1	0.40
	Part-Time +Unemployed	1	0.08	-	-	-	-
	Homemaker	-	-	-	-	1	0.40
	Job Seek	7	0.56	10	5.18	7	2.81
	Retired	1	0.08	3	1.55	3	1.20
	Self-Employed	8	0.64	5	2.59	4	1.61
	Student	24	1.93	28	14.51	34	13.65
	Student + Job Seek	1	0.08	-	-	1	0.40
	Student + Retired	-	-	1	0.52	-	-
	Unemployed	1	0.08	4	2.07	1	0.40
	Unable to Work	-	-	2	1.04	-	-
	Unemployed +Job Seek +Self Employed	-	-	-	-	1	0.40
	Student + Unemployed	-	-	-	-	1	0.40
	Unemployed +Job Seek	1	0.08	1	0.52	1	0.40
Employment Sector	Accommodation and Food Services	107	8.84	10	6.99	7	3.50
	Recreation	98	8.09	5	3.50	6	3.00
	Construction	106	8.75	12	8.39	7	3.50
	Education	110	9.08	21	14.69	33	16.50
	Government	89	7.35	8	5.59	10	5.00
	Healthcare	116	9.58	13	9.09	20	10.00
	Manufacturing	257	21.22	38	36.57	51	25.50
	Mining	89	7.35	4	2.80	1	0.50
	Retail	8	0.66	12	8.39	9	4.50
	Transportation and Warehousing	114	9.41	9	6.29	9	4.50
	Other	117	9.66	11	7.69	47	23.50
Job Level	Executive Leadership	129	10.65	6	4.20	9	4.50
	Senior Management	175	14.45	13	8.39	23	11.50
	Middle Management	279	23.04	33	23.08	36	18.00
	Professional/Technical	200	16.52	37	25.87	62	31.00
	Admin Support	193	15.94	25	17.48	20	10.00
	Operational Staff	229	18.91	27	18.88	34	17.00
	Other	6	0.50	3	2.10	16	8.00

The sample demographics reveal several key points and trends across the groups categorized as Suspected Bots, Failed QC Checks, and High-Quality responses.

The average age is similar across the groups, with Suspected Bots having a mean age of 34.2 years, Failed QC Check at 33.9 years, and High-Quality responses at 34.6 years.

In terms of sex at birth, there is a higher proportion of females in the High-Quality responses (53.82%) compared to the Failed QC Check group (38.34%) and Suspected Bots (52.97%). Males are more prevalent in the Failed QC Check group (61.66%) than in the other groups.

Ethnicity and race data show that the Suspected Bots group has a high percentage of White respondents (87.88%), which significantly decreases in the Failed QC Check (43.52%) and High Quality (62.65%) groups. Black respondents are more prevalent in the Failed QC Check group (23.32%) compared to the Suspected Bots (4.17%) and High Quality (18.47%) groups. Asian respondents are relatively consistent across the groups, with a slight increase in the High-Quality responses (5.62%).

Education levels reveal that the majority of respondents in the High-Quality group hold a bachelor's degree (44.58%) or a Master's degree (30.12%). The Failed QC Check group has a similar distribution, with a higher percentage holding a bachelor's degree (38.86%) and a notable portion with some college education (13.47%). Suspected Bots show a high percentage of associate degrees (18.54%) and bachelor's degrees (31.38%).

Marital status data indicates that single respondents are more prevalent in the Failed QC Check (33.16%) and High Quality (39.11%) groups than in the Suspected Bots group (43.29%). Married/domestic relationship status is similarly distributed across all groups, ranging from 55.24% to 57.51%.

Employment data show that full-time employment is notably higher in the Suspected Bots group (92.13%) compared to the Failed QC Check (54.92%) and High Quality (52.21%) groups. Part-time employment and student status are more common in the Failed QC Check and High-Quality groups.

Regarding the employment sector, manufacturing is the predominant sector across all groups, with 21.22% in Suspected Bots, 36.57% in Failed QC Check, and 25.50% in High-Quality responses. Education and healthcare sectors show higher representation in

the High-Quality group (16.50% and 10.00%, respectively) compared to the other groups.

Job level data indicate that middle management and professional/technical roles are the most common in the High-Quality group, with 18.00% and 31.00%, respectively.

It is also noted that the suspected bot data chose fewer combinations of the "choose all that apply" selections for categories such as Ethnicity and Job Status compared to both the High-Quality and Failed Quality Check Question data sets.

Overall, the demographic distribution suggests that the High-Quality responses are more diverse regarding ethnicity and education level compared to Suspected Bots. The employment sector and job level data indicate that respondents in the High-Quality group are more likely to be in professional or technical roles, which may influence the quality of their responses. The presence of a substantial number of single respondents in the Failed QC Check and High-Quality groups might reflect a younger or more independent demographic.

These differences highlight the importance of careful data cleaning and categorization to facilitate the integrity and representativeness of survey responses. The subsequent analysis delves deeper into the statistical outcomes and hypotheses based on these cleaned data sets.

Metrics of particular interest to the analysis of these survey results are the employment sectors and the job level of the respondents. These metrics are illustrated in the graphs below for both the High-Quality data set. The data set has over one-quarter of the respondents from the target sector, Manufacturing. Lesser represented sectors range from 0.5% to 10%, with mining being the least represented sector and healthcare being the greatest. The 23.5% classified in "Other" included a variety of sectors such as non-profit, aerospace, accounting, research, and veterinary medicine.

The level of job question asked the participants to select their current job type. The options included Administrative Support (e.g., Administrative Assistant, Coordinator), Executive Leadership (e.g., CEO, VP, C-level positions), Middle Management (e.g., Manager, Team Leader), Operational Staff (e.g., Line Worker,

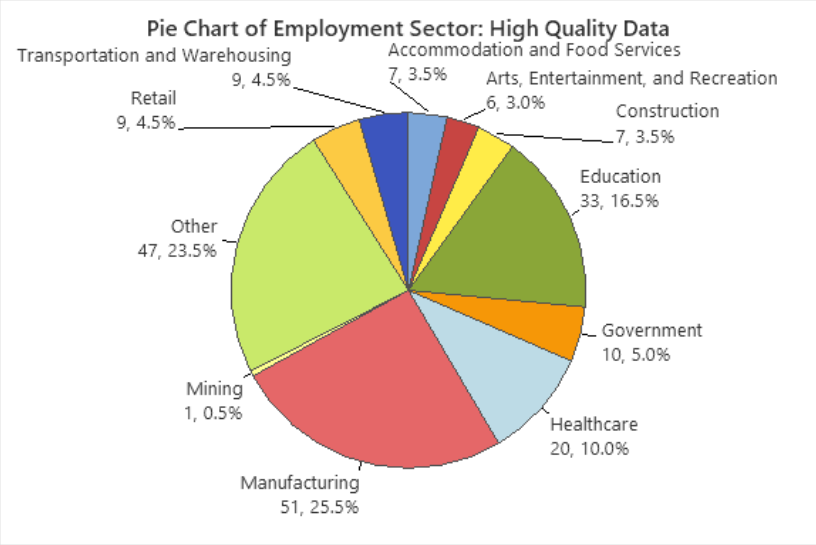


Figure 53: Pie Charts of Employment Sector for High Quality Data Set

Customer Service Representative), Professional/Technical (e.g., Engineer, Analyst, Specialist), Senior Management (e.g., Director, Senior Manager), and Other. Respondents also indicated their job level within the company. There was a balance of respondents across all categories, with the majority of the High-Quality group being in middle management and technical roles (Engineers), followed by operations.

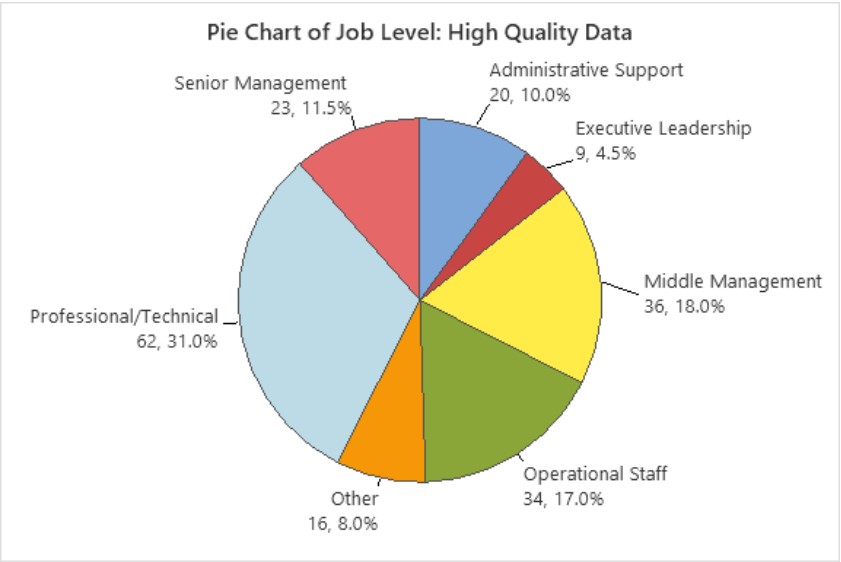


Figure 54: Pie Chart of Job Level for both High and Medium Quality Data Sets

The next section will provide more specific details on the statistics of the survey outcomes, followed by the analyses of the hypotheses. Additional general statistics on the responses of the participants from the survey are included in Appendix D.1. Also in the appendix is an analysis of the qualitative responses from the multiple selection and free answer responses from the survey, found in Appendix D.5.

5.6.2.2 Survey Sample ADHD Symptom Prevalence

This section presents the prevalence and characteristics of ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS). The sample of High-Quality survey respondents is comprised of 249 participants. This analysis focused on several key aspects, including the ASRS 6 number of significant symptoms, the ASRS 6 total points category, ADHD levels, and ADHD types. How to calculate these factors is detailed in Section 5.5.5.4, starting in step 6. Further, in the results of this study, these variables are compared to the measured outcomes of the study and statistically compared to determine significant differences. The table below summarizes the values calculated for each of these factors.

Table 32: ADHD Symptom Prevalence, Including ASRS 6, ADHD Levels, ASRS +/- vs. Diagnosis

Characteristics	Descriptor	Count	Percent
ASRS 6 Question Sub-Scale	0 Significant Symptoms	41	16.67
	1 Significant Symptoms	38	15.26
	2 Significant Symptoms	46	18.47
	3 Significant Symptoms	49	19.68
	4 Significant Symptoms	41	16.47
	5 Significant Symptoms	19	7.63
	6 Significant Symptoms	15	6.02
ASRS 6 Questions ADHD Level Sig. Symptoms	Low = 0-1 Symptoms	79	31.73
	Med. = 2-3 Symptoms	95	38.15
	High = 4-6 Symptoms	72	30.12
ASRS+/- and Medically Diagnosed	Undiagnosed ASRS-	135	54.22
	Undiagnosed ASRS+	50	20.08
	Diagnosed ASRS-	39	15.66
	Diagnosed ASRS+	25	10.04

The ASRS 6 Question Sub-Scale results show that 16.67% of participants reported zero significant symptoms, while 19.68% reported three significant symptoms,

the most common response. A detailed breakdown reveals that 31.73% of respondents fall into the low ADHD level category (0-1 symptoms), 38.15% into the medium level (2-3 symptoms), and 30.12% into the high level (4-6 symptoms).

Additionally, when comparing ASRS results with medical diagnoses, 54.2% of participants were undiagnosed with Low or Medium ASRS6 level (ASRS-). The likelihood of undiagnosed survey respondents is a group of the medically undiagnosed but had an ASRS6 High Level (ASRS+), a prevalence of 20.1%. Conversely, 15.7% were diagnosed but had a negative ASRS score. Those self-reported ADHD medical diagnoses with an ASRS negative score could be explained by possible implementation of treatments that have lessened the severity of symptoms in the past six months, the time length participants were asked to reflect on for the ASRS. This treatment interaction is investigated later in this study. Further investigation of this group's status on medication and other impacting factors can lend insight into this anomaly. Self-reported medical ADHD diagnosed and classified by the ASRS6 was 10.0% of the participants. These findings highlight the variability in ADHD symptoms and diagnoses among the participants.

The results are further illustrated in two graphs: one depicting the ASRS6 Levels and the other showing the relationship between ASRS scores and medical diagnoses (ASRS+/- vs. Self-report ADHD Medically Diagnosed). These visual representations provide a clear overview of the distribution of ADHD symptoms and the diagnostic status within the study population, facilitating a deeper understanding of the prevalence and characteristics of ADHD among the respondents.

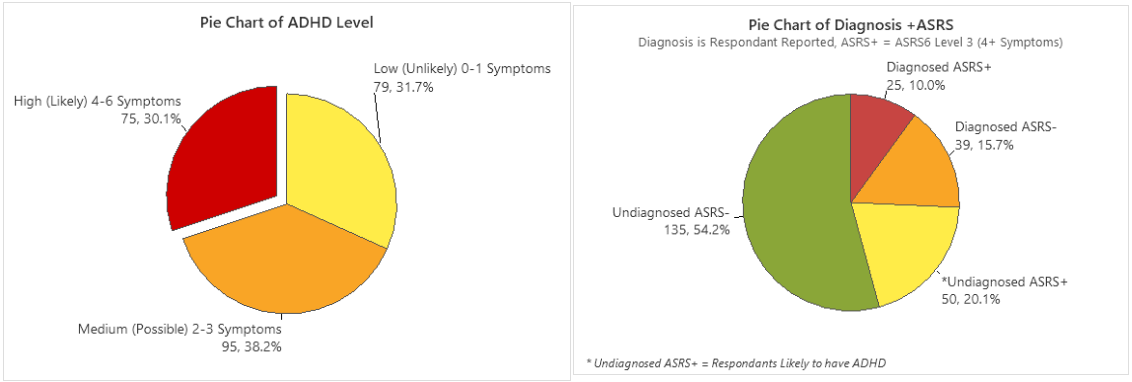


Figure 55: Pie Charts of ADHD Metrics, ASRS6 Level (left), Self-Reported ADHD Diagnosis vs ASRS Level (right)

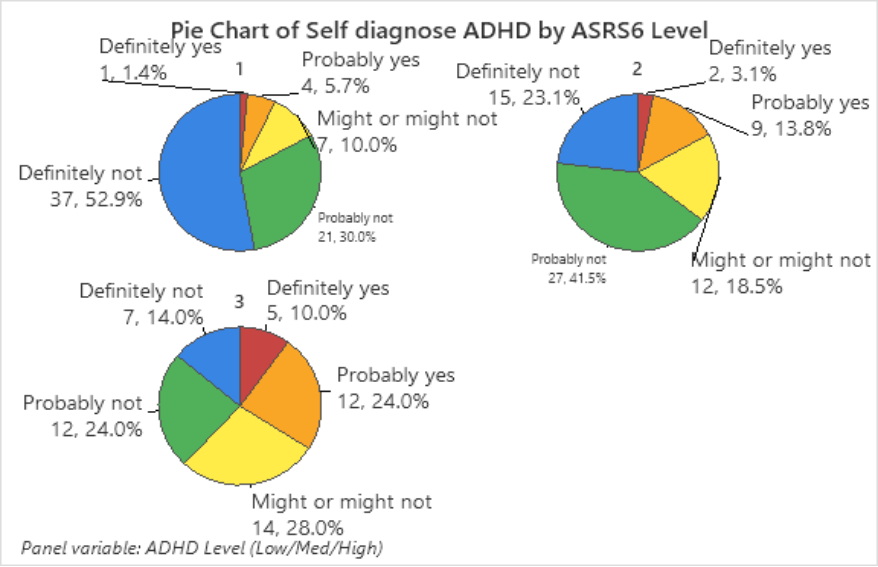


Figure 57: Pie Chart of Self Diagnosis of ADHD by ASRS6 Level

When investigating the responses of participants who indicated no medical diagnosis of ADHD, it is interesting to note the percentage of their family and friends who tell them they have ADHD. This information is plotted in the pie chart below, based on the ASRS6 levels of ADHD symptoms. As expected, as the ASRS6 level reaches "Likely ADHD" (level 3), the occurrence of family and friends suggesting the person has

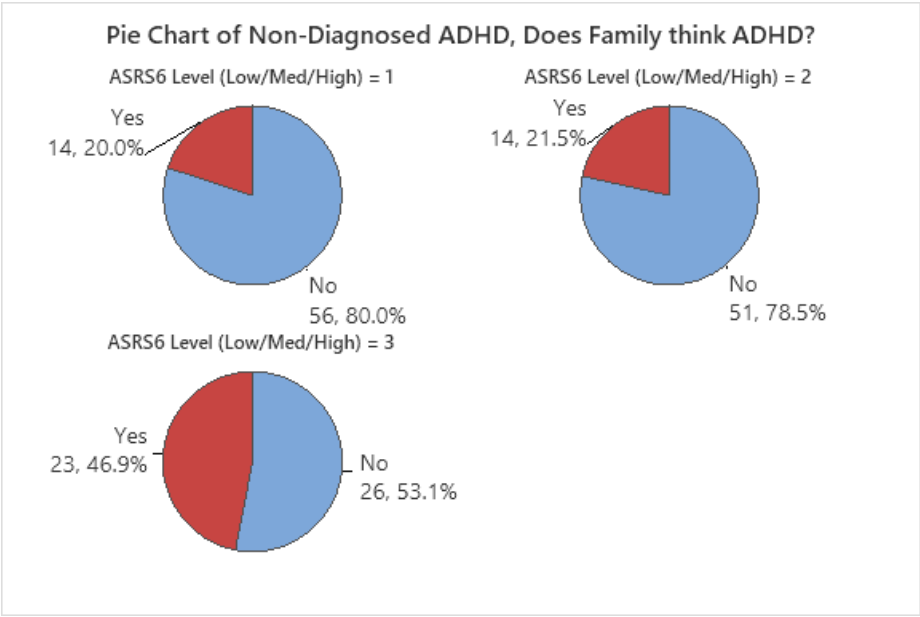


Figure 56: Pie Chart of Non-Medically Diagnosed ADHD, Does Family think I have ADHD?

ADHD more than doubles, increasing from around 20% at low and medium levels to 46.9% at the high level (3).

The next question in the survey, for those indicating no medical ADHD diagnosis, was whether they believe they have ADHD based on their own experience. The results of this question are broken down by the ASRS6 Level in the following pie chart. As the symptom level increases, the "Definitely Yes" percentage goes from 1.4% in Level 1 to 10.0% in Level 3. This says that of the people who are not diagnosed with ADHD medically but report significant enough and frequent enough symptoms to be referred for diagnosis, 10% of those people believe they definitely have ADHD, and another 24% indicated "Probably Yes." Overall, for the percentage of people scoring high enough on the ASRS6 to "Probably" have ADHD, 62% indicated "Might or Might Not", "Probably Yes", or "Definitely Yes".

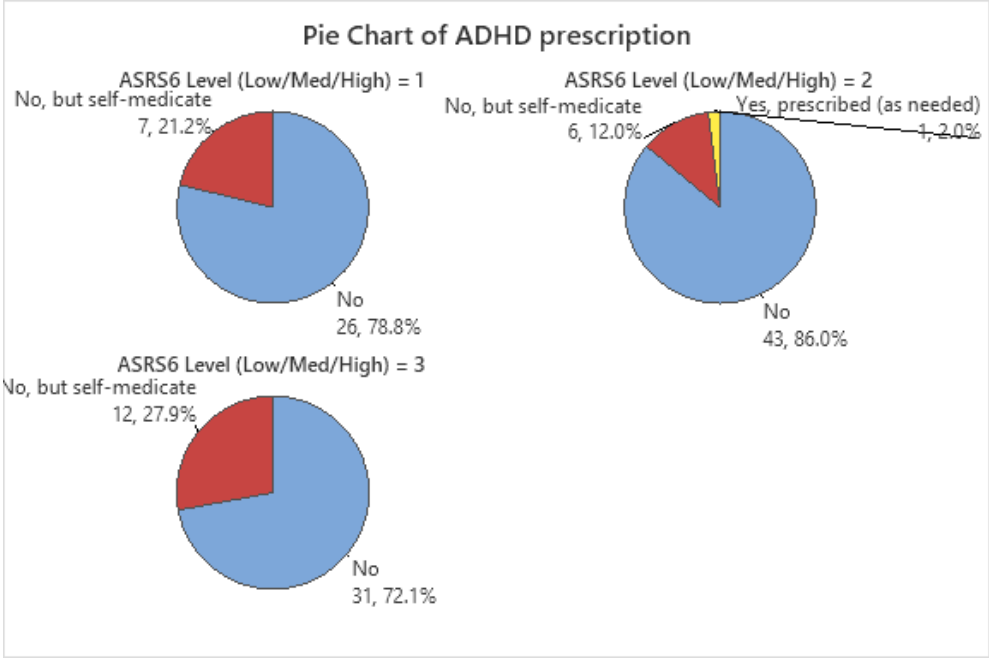


Figure 58: Pie Chart of ADHD Prescription Response vs. ASRS6 Level

To investigate the rate of self-medication for the non-diagnosis reporting participants, the following graph shows the division by ASRS6 level for their answers to this question. For this sub-group of non-diagnosed participants, the results of the ADHD prescription question show possible trends. The options for responses to whether you take prescription ADHD medication were: "No," "No, but I self-medicate with caffeine or

other stimulants," "Yes, prescribed to be taken as needed," Yes, prescribed to be taken daily." Based on the ASRS6 level, the results for this group are shown below. As expected, the self-medicating frequency increases as the ASRS6 level increases between levels 1 and 3, but there is an unexpected drop in frequency for level 2.

5.6.3 Main Analyses: Hypothesis Testing

In this section, is the transition from the experimental setup to the analysis of the results obtained. The study tested 14 hypotheses through the application of various statistical measures, assessing the collected values and computed metrics. Detailed procedures and extended statistical analyses are thoroughly documented in Appendix D.4. Below, we provide a concise summary of the crucial metrics, pivotal results, and key findings that highlight the most significant insights from this research.

5.6.3.1 ADHD Prevalence Results Summary

- This analysis focuses exclusively on the High-Quality dataset to ensure genuine human responses and accurate quality check compliance.
- Mean scores and standard deviations for key metrics: LSAS (23.5 ± 9.5), GPSES (15.9 ± 3.2), ASRS (54.1 ± 12.6).
- ADHD medical diagnosis: 25.7% of participants self-reported, 74.3% did not.
- Subjects not self-reporting an ADHD diagnosis were asked if they thought they might have ADHD with the following results: 31.89% "Definitely Not," 13.51% "Probably Yes," 4.32% "Definitely Yes."
- Subjects not self-reporting ADHD diagnosis asked about ADHD medication usage: 56.84% do not use medication, and 16.84% self-medicate with caffeine.
- Workplace support: 60.50% find their workplace supportive, 19.50% find it unsupportive.
- Personal stress management: 48.98% take regular breaks, 46.55% use planning tools.
- ADHD symptom prevalence: 31.73% with low symptoms, 38.15% with medium symptoms, 30.12% with high symptoms.
- Participants without a self-reported medical ADHD diagnosis but with likely ADHD symptoms (ASRS6 Level 3) have a higher rate of family and friends suggesting they have ADHD (46.9%).

- Of undiagnosed participants (not self-reporting ADHD diagnosis) with high symptom levels (ASRS6 Level 3) 34% believed they “Definitely” or “Probably” have ADHD.
- Prevalence of self-medication with caffeine tends to increase with symptom level.

The analysis revealed respondents of this survey with a self-reported ADHD diagnosis consistently reported higher symptom levels and severity compared to those without a diagnosis. This highlights the reliability of self-reported measures in identifying ADHD symptomatology across diverse employment sectors. Interestingly, the average of ASRS6 symptom level for those diagnosed with ADHD was lower than the typical cut-off for referring patients for further ADHD diagnosis (which is four or more symptoms on the ASRS6). The Interval plot of the results is shown below.

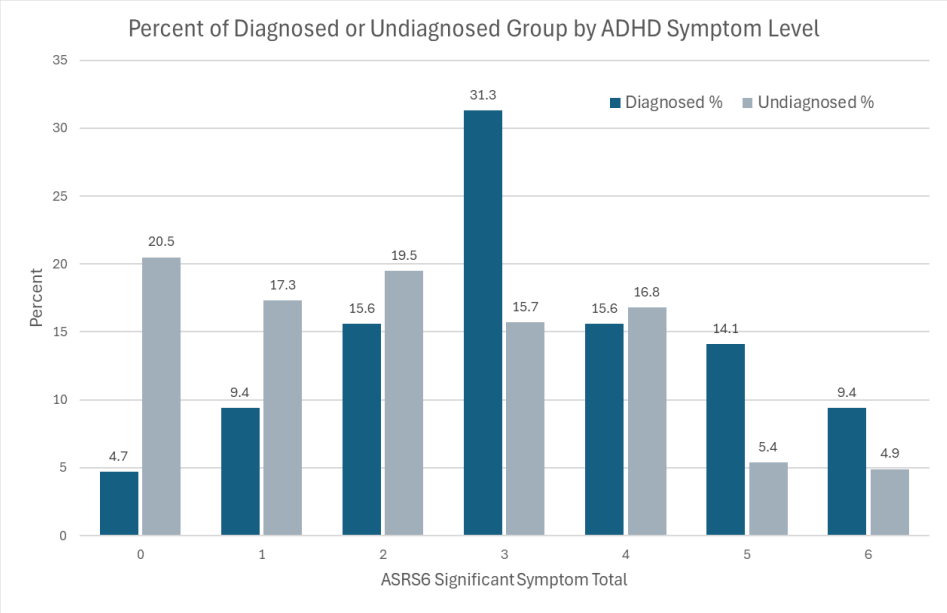


Figure 59: Percent of Diagnosed or Undiagnosed Group by ADHD Symptom Level

The hypothesis that there is a difference in the mean number of ADHD symptoms between adults who self-report an ADHD diagnosis and those who do not across all employment sectors is supported by the data. Individuals with a self-reported ADHD diagnosis exhibit significantly higher mean ASRS6 symptom counts and levels than those without a diagnosis.

However, in the diagnosed ADHD group, as seen in the figure above, there are unexpected numbers of participants with ADHD levels in the 0-1 and 2-3 symptom categories. It was anticipated that ADHD-diagnosed participants would have ASRS6 symptom numbers around four and above, possibly three and above, but not 0 or 1 symptoms, which fall into the "unlikely ADHD" category. This expectation is based on previous research on ASRS6 diagnostic criteria (Kessler, 2009). It was not unexpected to have the undiagnosed participants present throughout the whole range of symptoms, this is because there are likely ADHD participants that have not been diagnosed within this sample.

Given that the survey results showed a more normal distribution, the participants' responses were investigated further. It was suspected that the reporting of medication use could influence symptom reporting. Therefore, the group of ADHD-diagnosed participants was divided into those reporting the use of ADHD prescription medication

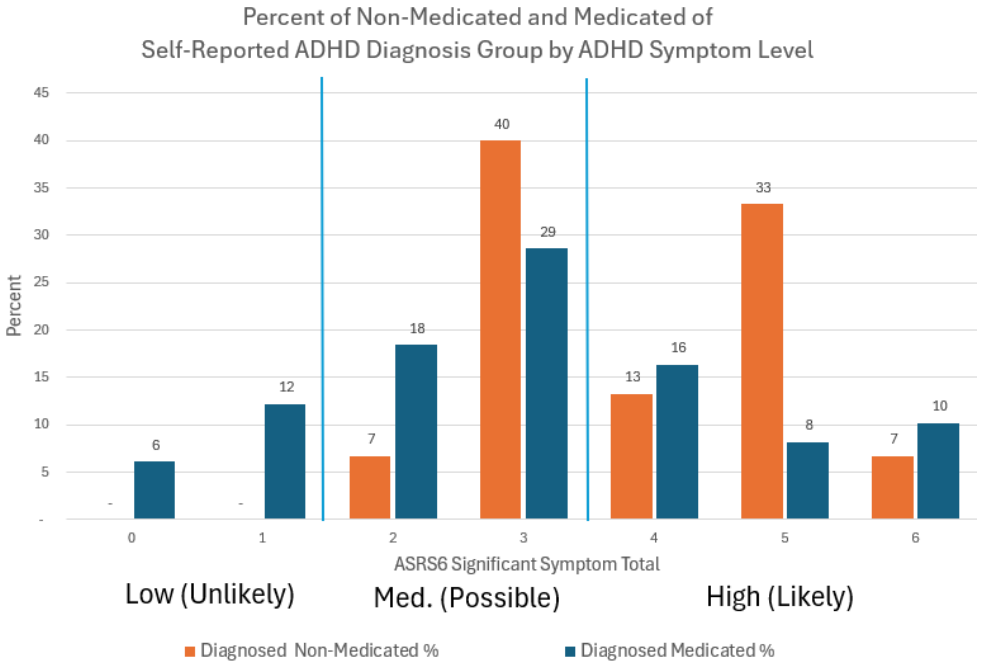


Figure 60: Percent of Diagnosed or Undiagnosed Group by ADHD Symptom Level

and those who did not. An ANOVA was calculated for the symptom levels of these two groups, and the difference in means was found to be statistically significant ($p = 0.05$).

Plotting the diagnosed participants by medication status revealed that the low symptom reporting participants were, in fact, those who reported taking medication. This

possibly explains why their ADHD symptom severity is less than the significant levels required to trigger the ASRS6 to report them as having ADHD symptoms. The non-medicated participants fell higher on the scale, with 40% at three symptoms and 53% at four or more symptoms—typically the cutoff for referral for further diagnosis of ADHD. Notably, all of the non-medicated ADHD-diagnosed participants fell in the "Possible" and "Likely" categories of the ASRS6 levels, as seen in the figure.

This finding is significant as it potentially explains the disparity between the resulting distribution of ADHD participants and the expected symptom levels. If their medication treatment is effective, the question of reflecting on symptoms in the past six months would potentially result in fewer and less severe symptoms due to effective medication treatment and other potential therapies, though not investigated.

5.6.3.2 ADHD Symptoms and Self-Reported Diagnoses Results Summary

Failed to Reject - Hypothesis 1.1: There is a difference between the mean number of ADHD symptoms (measured by the ASRS v1.1) between adults who self-report an ADHD diagnosis and those who do not across all employment sectors.

- There is a statistically significant difference between the number of ASRS6 symptoms reported by subjects self-reporting ADHD diagnosis compared to those who reported no diagnosis ($F = 15.43$, $p<0.001$, Cohen's $d = 0.57$ (medium effect size)).
- There is a statistically significant difference between the ASRS6 Level reported by subjects self-reporting ADHD diagnosis compared to those who reported no diagnosis ($F = 10.19$, $p = 0.002$, Cohen's $d = 0.46$).
- There is a greater number of reported ASRS6 symptoms and a higher ASRS6 Level for those subjects self-reporting ADHD diagnosis (Tukey Analysis, $p < 0.05$).

Failed to Reject - Hypothesis 1.2: There is a difference between the mean of ADHD Levels (measured by the ASRS6) between adults who self-report an ADHD diagnosis and does not vary between employment sectors.

- There is not a statistically significant difference between the ASRS6 Level reported by subjects self-reporting ADHD diagnosis compared to those who reported no diagnosis by the employment sector ($F = 1.66$, $p = 0.093$).
- Effect size of the Two-Way ANOVA: Partial Eta Squared for the terms of the model are ADHD Self-Diagnosis $\eta^2 = 0.05$ (small-to-medium) and Employment Sector $\eta^2 = 0.8$ (medium-to-large).

- The employment sector did not show significance in its interaction with ADHD Level and Diagnosis within the GLM.
- Manufacturing showed a possible slight decrease in average ADHD levels ($T = -1.80$, $p = 0.074$), and individuals in the Government sector ($T = 1.65$, $p = 0.100$) and Transportation and Warehousing sector ($T = 1.87$, $p = 0.063$) sectors exhibited higher ADHD levels. However, these findings did not reach statistical significance.

5.6.3.3 ADHD Prevalence

Failed to Reject - Hypothesis 2.1: ASRS 6 symptom level associated with self-reported ADHD Diagnosis.

- ASRS 6 symptom level was found to be associated with self-reported ADHD Diagnosis, a statistically significant finding.
- Significant coefficients ($p<0.05$) of the binary logistic regression were observed for ADHD6 Symptom levels 3, 4, 5, and 6.
- The highest odds ratio of all the symptoms for five significant symptoms is 11.40 (95% CI: 2.6,50.1), relative to 0 symptoms as the baseline.

Reject - Hypothesis 2.2: The odds of being diagnosed with ADHD among adults do not vary significantly between different employment sectors.

- Hypothesis not supported; results support differences between sectors in odds of being diagnosed with ADHD.
- Significant employment sectors based on coefficients of the Binary Logistic Regression: Manufacturing ($Z = 1.95$, $p = 0.05$), Healthcare ($Z = 2.79$, $p = 0.005$), Retail ($Z = 3.54$, $p < 0.001$).
- Significant Odds Ratios include:
    - Retail workers are 35 times more likely to be diagnosed with ADHD compared to those in Education, and 9.25 times more than Manufacturing.
    - Healthcare employees have odds 8.18 times greater than Education workers.
    - Other notable comparisons include Retail relative to Government, with an odds ratio of 8.17, indicating significantly higher risk.
    - Manufacturing workers are possibly 3.78 times more likely to be diagnosed with ADHD compared to those in Education, approaching significance with a confidence interval of (0.9943, 14.3996).
- These odds ratios, however, while statistically significant these findings have large 95% CIs.

Failed to Reject - Hypothesis 2.3: The odds of being **undiagnosed** with ADHD and having significant ADHD symptomology among adults varies significantly between different employment sectors.

- Hypothesis is supported; results support differences between sectors in odds of being undiagnosed with ADHD.
- Individuals in Transportation and Warehousing are six times more likely to have undiagnosed ADHD than those in Manufacturing.
- The odds for Government sector workers are five times that of Manufacturing workers.
- Transportation and Warehousing showed a 7.2-fold increase over the Healthcare sector.
- Government and Transportation and Warehousing both showed a decrease in odds of undiagnosed ADHD compared to all Others, with OR 0.2 and 0.17, respectively.

5.6.3.4 Impact on Self-Efficacy and Social Anxiety

The pie charts display the differences in reported General Perceived Self-Efficacy Scale (GPSES) scores and ADHD diagnoses for all participants in the High-Quality dataset. Notably, the non-ADHD group lacks participants with "Low Self-Efficacy." In contrast, the "Mild" and "Moderate" self-efficacy groups are larger, reducing the highest self-efficacy group among those diagnosed with ADHD. This section gives the results of the statistical analysis of these differences.

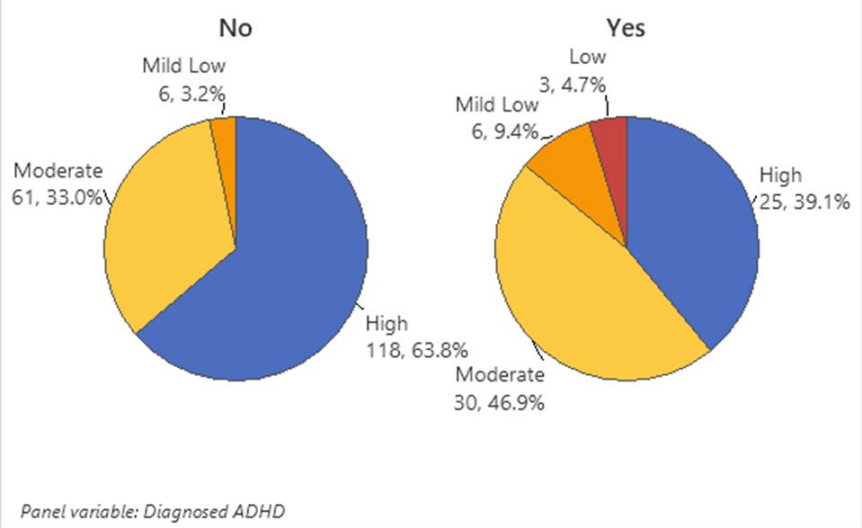


Figure 61: Pie Chart of GPSES (Self-Efficacy) Classification by Self-Reported ADHD Diagnosis

This section explores the relationship between ADHD and social anxiety, measured by the Liebowitz Social Anxiety Scale (LSAS). The pie charts below compare LSAS scores with ADHD diagnoses. For participants with ADHD, there is an increased percentage in the "Very Severe Social Anxiety" category and an absence of the "No Social Anxiety" category.

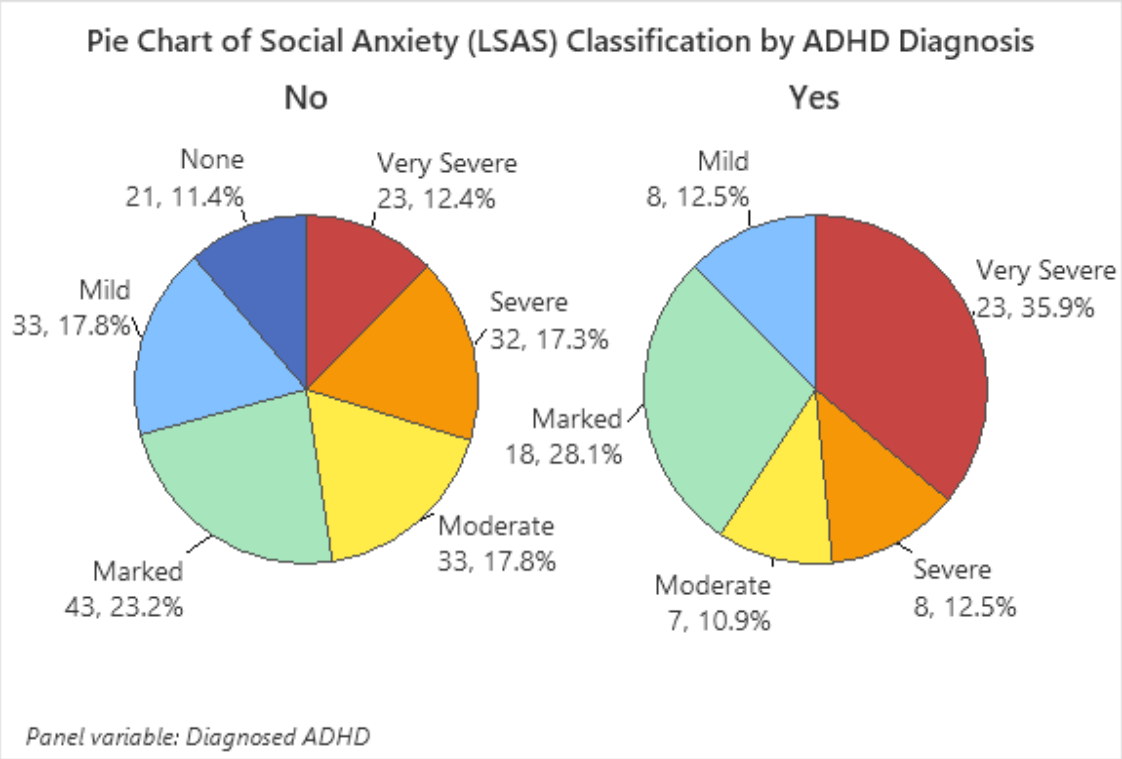


Figure 62: Pie Chart of LSAS (Social Anxiety) Classification by Self-Reported
I ADHD Diagnosis

The section also investigates the connections between reported ADHD symptoms and levels of self-efficacy and social anxiety. The pie charts show the scales compared to three levels of ADHD symptoms: Low (0-1 significant symptoms, unlikely ADHD), Medium (2-3 significant symptoms, possibly ADHD), and High (4-6 significant symptoms, probably ADHD).

Noteworthy in the GPSES pie charts, the most severe two levels of Self-Efficacy do not have participants for the ADHD Low group. ADHD High group has the largest proportion of the most severe self-efficacy deficiencies. The Mild Low Self-Efficacy sector increases over six-fold between levels 2 (Medium) and 3 (High).

The LSAS pie charts by ADHD level reveal interesting trends. The "Very Severe Social Anxiety" category is present at a small percentage (3.8%) in the lowest ADHD symptom level. Still, it increases almost fivefold between ADHD Levels 1 and 2 and nearly twofold between Levels 2 and 3. The "No Social Anxiety" category disappears completely at ADHD Level 3. These trends are illustrated in the pie charts below. Statistical significance is tested in the hypothesis testing section that follows this summary.

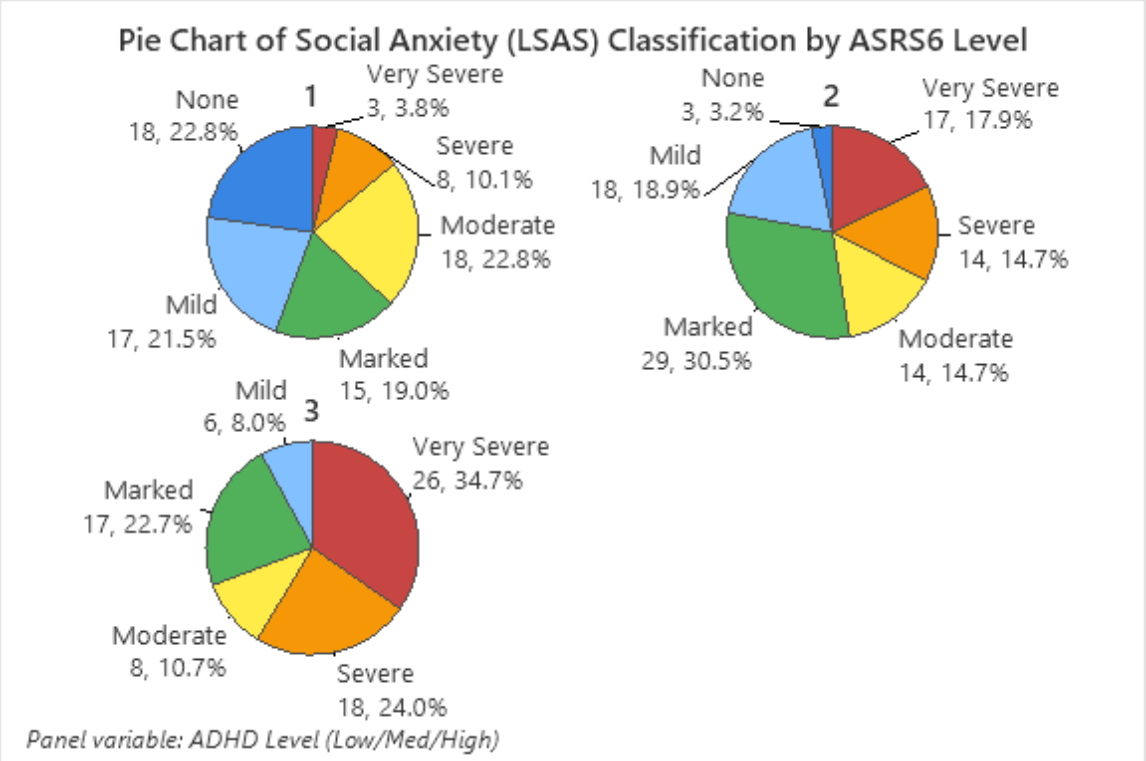


Figure 64: Pie Chart of LSAS (Social Anxiety) Classification by ADHD Level

Failed to Reject - Hypothesis 3.1: There is a significant difference in the means of self-efficacy and social anxiety levels between adults with and without an ADHD diagnosis.

- Significant differences in both self-efficacy ($F = 17.28$, $p < 0.001$, Cohen's $d = 0.66$ (medium effect size)) and social anxiety levels between adults with and without a self-diagnosis of ADHD ($F = 16.25$, $p < 0.001$, Cohen's $d = 0.61$ (medium effect size)).
- Self-efficacy: Self-diagnosed ADHD Mean = 14.53 (Moderate Self-Efficacy [11-15]), Non-Self Diagnosed ADHD Mean = 16.32 (High Self-Efficacy [16-20]).

- Social anxiety: Self-diagnosed ADHD Mean = 27.61 (Severe Social Anxiety [27-31]), Non-Self Diagnosed ADHD Mean = 22.06 (Marked Social Anxiety [22-26]).
- Individuals with self-reported ADHD diagnosis had higher levels of social anxiety and lower self-efficacy compared to their non-ADHD counterparts.

Failed to Reject - Hypothesis 3.2: There is a significant difference in the combined means of self-efficacy and social anxiety levels depending on the ADHD symptoms level.

- Significant differences in both self-efficacy and social anxiety levels between adults with various levels of ADHD Symptoms ($F = 13.76$, $p < 0.001$).
- The LSAS vs ADHD 6 Symptoms model demonstrates a moderate effect size with an R^2 of 25.44%, indicating that approximately a quarter of the variance in the dependent variable is explained by the independent variable.
- The GPSES vs ADHD 6 Symptoms model demonstrates a low effect size with an R^2 of 9.98%, indicating that approximately a tenth of the variance in the dependent variable is explained by the independent variable.
- Individuals with a higher number of ADHD symptoms reported higher levels of social anxiety and lower self-efficacy compared to those with fewer ADHD symptoms.

Reject - Hypothesis 3.3: Self-efficacy and social anxiety scales associated with the probability of an ADHD diagnosis.

- No significant association of combining self-efficacy and social anxiety levels for self-reported ADHD diagnosis.

Reject - Hypothesis 3.3a: Self-efficacy (GPSES) scale associated with the probability of an ADHD diagnosis.

- No significant connection of self-efficacy levels to self-reported ADHD diagnosis; self-efficacy does not appear to be associated with self-reported ADHD diagnosis.

Failed to Reject - Hypothesis 3.3b: Social anxiety (LSAS) scale associated with the probability of an ADHD diagnosis.

- Social anxiety, as measured by LSAS, is significantly associated with higher levels of social anxiety, increases the likelihood of a self-reported ADHD diagnosis.

Failed to Reject - Hypothesis 3.4: There is no interaction effect between ADHD symptoms and employment sector on the means of self-efficacy and social anxiety levels.

- Both employment sector ($p = 0.003$) and ADHD6 symptoms ($p = 0.006$) are significantly associated with self-efficacy (GPSES) and social anxiety (LSAS) levels.
- The interaction term between the employment sector and ADHD6 symptoms had no significant interaction effect that could be assessed. Thus, the hypothesis is supported.

Reject - Hypothesis 3.5: The relationship between self-efficacy, social anxiety, and ADHD symptom reporting differs significantly between the manufacturing sector and other employment sectors.

- The relationship between self-efficacy and anxiety with ADHD symptom reporting does not differ significantly between the manufacturing sector and other employment sectors.
- Significant independent effects of the employment sector and ASRS6 symptoms on LSAS point totals, suggesting that while the sectors themselves and the symptom levels influence social anxiety, their interaction does not.
- LSAS results showed significantly that the Other than Manufacturing sectors positively affected LSAS point total (increased social anxiety) ($p = 0.035$).
- GPSES results showed no significant results between the Manufacturing sector and other sectors.

5.6.3.5 Satisfaction with Workplace Support Systems

Questions in the survey that evaluated subject satisfaction with the workplace support systems were presented in two ways. Question 14 asked: “How would you rate the overall work environment in terms of supporting employees with ADHD or anxiety issues?” giving a four-part Likert scale answer option: Very Supportive, Supportive, Unsupportive, and Very Unsupportive. Additionally, question 16 asked: “Do you feel that your workplace provides effective support for managing stress and anxiety?” giving a five-part Likert scale answer option: not effective at all, slightly effective, moderately effective, very effective, and extremely effective. Question 14 is referred to as “Supportive Work” as a variable in the following section, and Question 16 responses are referred to as “Effective Support.”

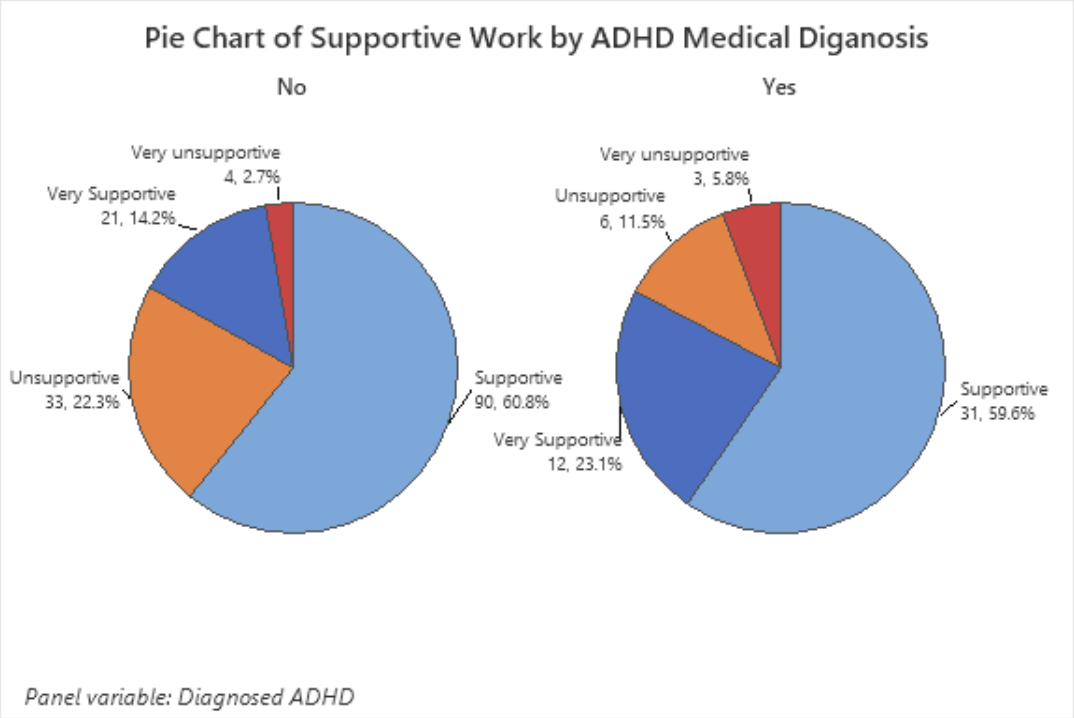


Figure 66: Pie Chart of Supportive Work by ADHD Medical Diagnosis

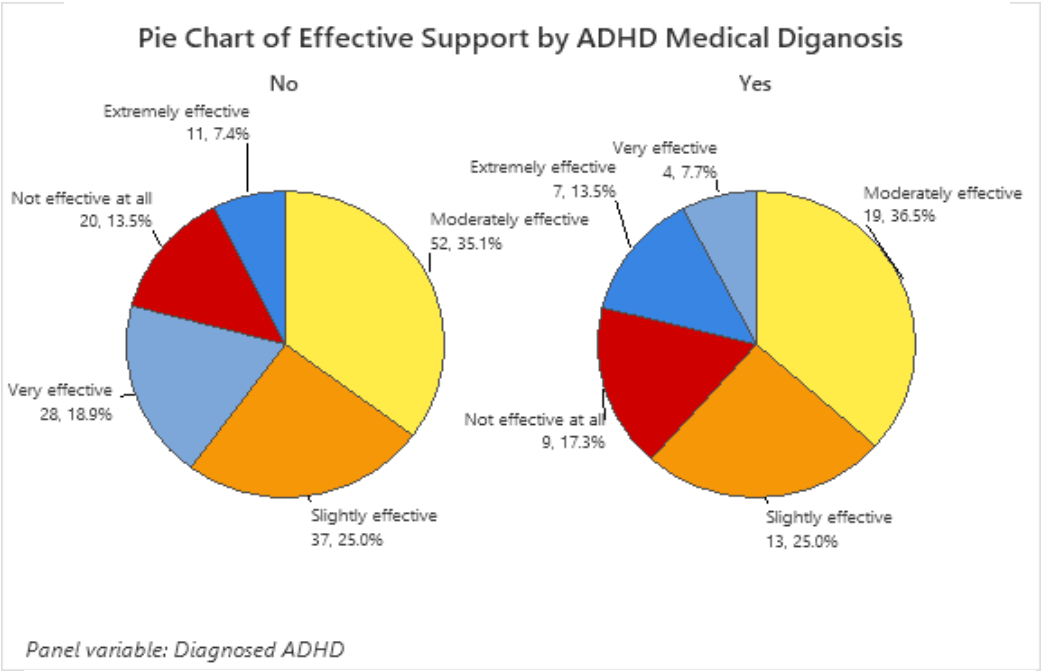


Figure 65: Pie Chart of Effective Support by Self-Reported ADHD Medical Diagnosis

Adults taking the survey were asked two questions assessing their feelings on the supportiveness and effectiveness of workplace support systems. Each of these questions

is evaluated to determine the significance of this hypothesis. Percentages of the responses for each question divided by self-reported ADHD Diagnosis are given in the figures below.

Reject - Hypothesis 4.1: Adults with an ADHD diagnosis self-report lower satisfaction with workplace support systems compared to those without a self-reported ADHD diagnosis.

- No statistically significant difference in workplace support satisfaction or the perceived effectiveness of workplace support systems between adults with a self-reported ADHD diagnosis and those without.
- Both groups reported similar levels of satisfaction and effectiveness, leading to the conclusion that a self-reported ADHD diagnosis does not significantly impact these perceptions in the workplace.

Reject - Hypothesis 4.2: The impact of ADHD symptoms on satisfaction with workplace support systems (Q14) is more pronounced in the manufacturing sector compared to other sectors.

- The general impact of ADHD symptoms on satisfaction with workplace support systems does not differ significantly across sectors.

Failed to Reject - Hypothesis 4.3: The impact of ADHD symptoms on satisfaction with workplace support systems effectiveness perceptions (Q16) are more pronounced in the manufacturing sector compared to other sectors.

- The presence of ADHD symptoms significantly influences satisfaction levels in the manufacturing sector, with both low and high symptom levels negatively affecting perceived support effectiveness.
- Effect size of the Two-Way ANOVA: Partial Eta Squared[8] for the terms of the model are Employment Sector (Manufacturing vs Others) $\eta^2 = 0.04$ (small-to-medium), ADHD6 Symptoms $\eta^2 = 0.07$ (small-to-medium), and Interaction $\eta^2 = 0.06$ (small-to-medium).

[8] Partial Eta Squared, η^2 = (SS Treatment)/(SS Treatment + SS Error) $\eta^2 = 0.01$ Small effect size, $\eta^2 = 0.06$ Medium effect size, $\eta^2 = 0.14$ Large effect size (J. Cohen, 1988).

- The Manufacturing/Other Sector variable had a significant positive coefficient (T = 2.84, Coef. = 1.029, p = 0.005), indicating higher satisfaction with support systems in the manufacturing sector.
- The interaction term for ADHD symptom level 1 with the manufacturing sector was significant and negative (T = -2.40, Coef. = -1.271, p = 0.017), indicating that for individuals with low ADHD symptom levels, those in the manufacturing sector reported lower satisfaction compared to those in other sectors.
- The interaction term for ADHD symptom level 6 was also significant and negative (T = -2.41, Coef. = -2.029, p = 0.017), suggesting that individuals with high ADHD symptom levels in the manufacturing sector reported significantly lower satisfaction.

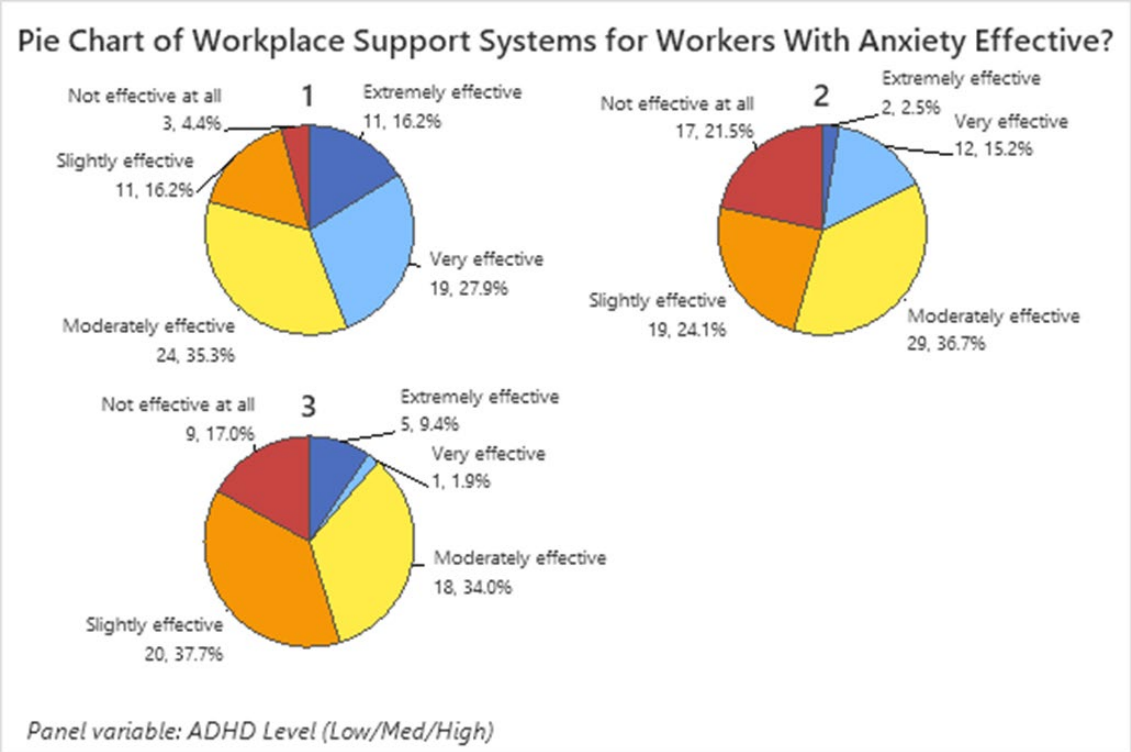


Figure 67: Pie Chart of Workplace Support Systems for Workers with Anxiety Effective? by ASRS6 Level

5.6.4 Covariate Analysis

Covariates in any experiment can affect the outcomes; experimental designs with random sampling of the population are designed to mitigate these effects as much as possible. Despite these efforts, there is usually some effect of covariates on the outcomes of a study based on the resulting population of participants. In this study, the following demographic information is collected: age, sex at birth, marital status, schooling attainment, employment sector, job level, and self-reported ADHD diagnosis status.

A General Linear Model (GLM) was conducted to evaluate the effects of various demographic and employment-related covariates on several outcome variables, including GPSES (General Perceived Self-Efficacy Scale) point total, LSAS (Liebowitz Social Anxiety Scale) point total, ADHD6 Symptoms, supportive work environment perception, and perception of workplace supportiveness. The analysis included covariates such as sex at birth, age, education level, marital status, employment sector, employment level, and diagnosed ADHD status. The analysis was performed in Minitab using the "Stat", "ANOVA", "General MANOVA" feature, putting the independent metrics and variables in the "Responses" and the covariates in "Model" and "Covariates".

The MANOVA analysis provided valuable insights into how employment-related factors and self-reported ADHD diagnosis impact various psychological and work-related outcomes. Employment level emerged as a significant predictor for multiple outcomes, including GPSES point total, LSAS point total, ADHD6 symptoms, and perceptions of workplace supportiveness. Self-reported ADHD diagnosis status significantly influenced GPSES point total, LSAS point total, and ADHD6 symptoms. These findings highlight the importance of considering employment level and self-reported ADHD diagnosis when assessing psychological well-being and perceptions of workplace environments. The presence of outliers in the data suggest that further investigation is warranted to understand the underlying causes and potential implications of these atypical responses. For those interested, the full set of analyses for the covariates is included in Appendix D.7.

5.7 Workplace Psychosocial Survey: Conclusions

This research provides insights into the relationship between ADHD symptoms, self-reported ADHD diagnoses, and various demographic and workplace factors. The findings indicate significant differences in ADHD symptom levels and self-reported diagnosis rates across different employment sectors, highlighting the potential need for targeted awareness and diagnostic efforts in specific sectors.

One of the primary conclusions is that individuals who self-report an ADHD diagnosis exhibit significantly higher levels of ADHD symptoms, as measured by the ASRS v1.1, compared to those who do not report an ADHD diagnosis. This difference is evident both in the number of symptoms and the severity levels, underscoring the validity of self-reported ADHD diagnoses in reflecting actual symptomatology.

The results found that 20% of the participants (50 participants) surveyed indicated enough severe ADHD symptoms to be considered "Likely ADHD." In the undiagnosed sub-group (those participants that did not indicate a self-reported ADHD diagnosis), it was found that the likelihood of family and friends suggesting they have ADHD significantly increases as their ASRS6 symptom levels rise. At the highest symptom level (50 participants), 46.9% of these participants reported receiving such comments, compared to about 20% at lower levels. Additionally, when asked about their own belief in having ADHD, the percentage of those who responded "Definitely Yes" grew from 1.4% at the lowest symptom level to 10% at the highest level, with another 24% indicating "Probably Yes." In total, 62% of non-diagnosed participants with high ASRS6 scores indicated they might have ADHD to some degree. In this same group, when queried about ADHD medication, the study revealed that self-medication with caffeine or other stimulants increased with higher ASRS6 levels.

The research also reveals that the employment sector plays a role in the prevalence and reporting of ADHD symptoms. The logistic regression analysis elucidates the association of the ASRS 6 symptom level in self-reported diagnosis of ADHD. Significant coefficients for symptom levels 3, 4, 5, and 6 indicate that higher symptom levels have a strong association with self-reported ADHD diagnosis. The highest odds ratio of 11.40 for five significant symptoms compared to zero symptoms highlights the substantial increase in diagnosis probability with increasing symptom severity. This emphasizes the importance of symptom severity and frequency in the diagnostic process.

Additionally, the research finds that the odds of being diagnosed with ADHD

vary significantly between different employment sectors. Sectors such as Retail and Education show notably higher odds of self-reported ADHD diagnosis compared to the Manufacturing sector. This variability suggests that the need for accommodation of ADHD may differ based on the occupational sector, warranting further investigation.

The study also explores the odds of being undiagnosed with correspondingly high levels of ADHD symptoms, revealing significant differences across sectors. Individuals in the Manufacturing, Healthcare, and "Other" sectors have significantly lower odds of being undiagnosed with high ADHD symptoms than those in the Transportation and Warehousing sector. This finding may mean that persons working in certain sectors may be more or less likely to seek medical assistance for ADHD symptoms. However, this is outside the scope of this investigation and is speculative.

Furthermore, the research highlights the impact of ADHD on self-efficacy and social anxiety. Individuals with ADHD report higher levels of social anxiety and lower self-efficacy compared to their non-ADHD counterparts. This relationship is also evident among individuals with varying levels of ADHD symptoms, where higher symptom levels correlate with increased social anxiety and decreased self-efficacy. These findings suggest that ADHD may significantly affect individuals' psychological well-being and their perception of their capabilities, which can have profound implications for their professional and personal lives.

The study also examines satisfaction with workplace support systems, finding no significant differences between adults with and without an ADHD diagnosis. This suggests that a self-reported ADHD diagnosis does not necessarily impact individuals' satisfaction with workplace support, indicating that other factors may possibly play a more critical role in shaping these perceptions.

In conclusion, this research underscores the complexity of ADHD as a condition that varies significantly across different demographic and occupational contexts. The findings highlight the possible need for targeted diagnostic and support strategies tailored to specific sectors, as this may affect the individual's psychological well-being and professional lives. Future research could explore how these sector-specific factors may better support neurotypical and neurodiverse individuals in diverse occupational environments.

6.0 Chapter Six: Conclusions and Recommendations

6.1 Manufacturing Technology Support Investigation

Augmented Reality (AR) is being integrated into manufacturing environments, serving diverse functions ranging from training and daily work assistance to remote maintenance. Although previous studies, as reviewed in the literature, have explored the effectiveness of AR in both experimental and real-world settings, they often focus primarily on worker outcomes without addressing the cognitive demands placed on the workers themselves.

This investigation parallels ongoing assessments of AR technologies by researcher Dan O'Leary in a simulated manufacturing environment (O'Leary, In Press). It encompasses a randomized controlled trial (RCT) that scrutinizes the cognitive impacts of three different AR technologies in comparison to traditional Paper Work Instructions, with a specific emphasis on workers who report severe ADHD symptoms.

Participants were categorized for analysis based on the severity of their ADHD symptoms, aiming to illuminate how AR technology affects workers with ADHD differently from their neurotypical peers. This study acts as an initial exploration into this nuanced area, providing potentially valuable insights into the unique challenges these workers face and setting a direction for future research.

6.1.1 Manufacturing Technology Support Investigation: Conclusions

This study delved into the effects of ADHD symptoms on production speed, quality, cognitive load, and system usability in various augmented reality (AR) treatments alongside traditional Paper Work Instructions. The findings reveal intricate dynamics between ADHD symptoms and workplace technologies, offering valuable insights for workplaces and individuals with ADHD.

The research demonstrated that ADHD symptoms have a significant impact on production speed across all treatment types, with individuals exhibiting higher ADHD symptoms tending to work faster. This increase in speed was particularly notable with traditional Paper Work Instructions and one type of AR treatment, suggesting that certain

conditions can enhance the productivity of individuals with ADHD. However, this was not uniformly the case across all AR treatments, indicating variability in how different technologies interact with ADHD symptomatology.

Regarding production quality, only one specific AR treatment (EHMAR) showed a significant variation in error rates based on ADHD symptom levels, whereas those with lower symptoms had higher error rates. This suggests that while ADHD symptoms can influence quality, the effects may be dependent on the specific type of technology being used.

Cognitive load presented a significant challenge, particularly with the more advanced AR treatment, where individuals with higher levels of ADHD symptoms experienced greater cognitive demands. This finding implies that while AR technologies have the potential to improve workplace tasks, they may also increase the cognitive burden for those with more pronounced ADHD symptoms.

System usability also varied significantly with ADHD symptom levels, particularly in the more complex AR treatments, which were found to be less user-friendly by individuals with higher ADHD symptoms. This variation in usability highlights the potential need for workplace technologies to be adaptable and accessible to all users, regardless of their neurological profiles.

The relationship between ADHD symptoms and the different variables studied—production speed, production quality, cognitive load, and system usability—is complex. The efficacy of different treatments varied across ADHD levels, underscoring the necessity for tailored interventions and usability assessments. These findings emphasize the importance of designing workplace interventions that consider individual differences in ADHD symptoms to ensure that technological advancements are beneficial and inclusive. This approach not only enhances the productivity of individuals with ADHD but also helps ensure that workplace environments are supportive and effective for all employees.

6.1.2 Manufacturing Technology Support Investigation: Limitations

Despite a rigorous experimental design that included pilot studies and comprehensive literature reviews of similar studies, this research encountered several

limitations. Some of these limitations were anticipated to have a minimal impact on the outcomes, while others became more apparent as the study progressed. These limitations are listed and explained below to provide transparency and inform future researchers, helping them understand the constraints faced and consider these factors in their work.

- Participant Demographics: The study primarily involved undergraduate and graduate students in university engineering and business classes. This demographic does not necessarily represent the broader population, particularly the typical workforce in manufacturing fields. This limitation affects the generalizability of the findings to other populations.
- Medical and Health Factors: Participants were not asked to disclose their medical history, mental health conditions, mental health status, medication use, or caffeine use. These factors can significantly influence cognitive performance, production quality, and usability perceptions, thus affecting the generalizability of the study's conclusions.
- Single Treatment Exposure: Participants were exposed to only one technology treatment. Individual differences in response to each treatment type could influence performance and usability outcomes, making it difficult to compare the relative effectiveness of each treatment across different ADHD symptom levels.
- Variability in Study Conditions: The time of day for the study varied, leading to potential differences in participant fatigue levels. This variability could affect cognitive load, production quality, and usability ratings, introducing an additional source of variability that may confound the results.
- Short-Term Assessment: The study was conducted over a short period, providing a limited assessment of the long-term effects of different treatments on production quality, cognitive load, and usability. Longitudinal studies are needed to understand the sustained impact of these treatments.
- Limited Sample Size: Although the study included 60 participants, the sample size for each ADHD level and treatment combination was relatively small. This limited sample size reduces the statistical power to detect significant differences and may limit the robustness of the findings.

- Potential Bias in Self-Reported Data: The study relied on self-reported System Usability Scale (SUS) scores and NASA TLX ratings, which may be subject to bias. Participants' perceptions of usability and cognitive load could be influenced by subjective factors that are not directly related to the treatments or ADHD symptom levels.
- Lack of Control for External Variables: Though the study controlled for external variables, such as participants' prior experience with AR technologies and familiarity with the LEGO Lab, it did not control for other variables, such as individual differences in learning styles and LEGO building experience. These factors could influence the outcomes and limit the generalizability of the findings.
- Task and Environment Specificity: The tasks and environment used in the study were specific to a simulated manufacturing setting. The findings may not apply to other types of tasks or work environments, limiting the broader applicability of the results.

Addressing these limitations in future research would enhance the robustness and generalizability of the findings, providing a more comprehensive understanding of the impact of ADHD symptom levels on production speed, quality, cognitive load, and usability across different treatments.

6.1.3 Manufacturing Technology Support Investigation: Recommendations for Future Studies

- Larger Sample Sizes: Future studies could include larger sample sizes to understand the trends better and possibly provide increased statistical power. Larger datasets will also allow for more robust subgroup analyses.
- Longitudinal Studies: Longitudinal studies are needed to explore how ADHD symptoms interact with different treatments over time, providing insights into long-term efficacy and user experience.
- In-depth Usability Studies: More detailed usability studies could be conducted to investigate the specific aspects of AR technologies that impact usability for individuals with varying levels of ADHD symptoms. This could involve

qualitative methods, such as interviews and focus groups, to gain deeper insights into user experiences.

- Customized AR Interventions: Research could focus on developing and testing customized AR interventions tailored to the needs of individuals with different ADHD symptom profiles or other neurodiverse traits. These interventions could aim to optimize both production quality and system usability.
- Exploring Cognitive Load Mechanisms: Further research is needed to explore the mechanisms underlying cognitive load in AR environments, especially for participants with ADHD. This could involve examining specific cognitive processes and how they are affected by different types of AR content and interaction modalities.
- Broader Range of Metrics: Future studies could consider a broader range of metrics, including subjective measures (e.g., user satisfaction, perceived effort) and objective measures (e.g., eye tracking, physiological responses, EEG) to provide a more comprehensive understanding of the user experience.
- Real-World Application Testing: Future research could expand beyond laboratory settings to evaluate the effectiveness of interventions in real-world work environments. This would involve field studies and on-site testing to assess how ADHD symptoms impact job performance in various industries and roles. Real-world application testing will help validate laboratory findings and provide practical insights for implementing effective strategies in everyday work settings.

By addressing these research directions, future studies can contribute to developing more effective and user-friendly AR technologies, particularly for individuals with ADHD, ultimately enhancing their productivity and user experience in various task environments.

6.2 Manufacturing Support Systems Investigation

Workplace functioning in manufacturing settings incorporates various factors, including adopting lean methodologies and integrating Industry 4.0 systems intended for improved information quality, company culture, and employees' psychological safety.

Adapting these technology systems to accommodate neurodivergent workers, such as those with ADHD, is crucial for organizational success and worker well-being (Ramsay, 2010; Weber et al., 2021). This research builds on Dr. Hossain's investigations into Lean tools and I4.0 sensors, which have been shown to enhance overall equipment effectiveness (OEE) and workstation performance (Hossain et al., In Press; Hossain, 2024). By examining these support systems' specific impacts on neurotypical and ADHD-symptomatic workers, this study aims to fill a notable research gap and offers actionable recommendations aiming to help optimize workplace environments to support neurodiverse workers, particularly ADHD symptomatic persons, effectively.

6.2.1 Manufacturing Support Systems Investigation: Conclusions

The conclusions of the study offer valuable insights into the interactions among ADHD-symptomatic persons and various workplace technological interventions in manufacturing settings, revealing several factors that appear to influence production efficiency, quality, cognitive load, and system usability. Notably, individuals with higher ADHD symptoms demonstrated higher production rates without a corresponding increase in error rates, suggesting they can excel in environments that match their unique strengths. This finding underscores the potential to optimize workplace roles to better align with the capabilities of individual workers, in this case, those with ADHD symptoms.

This dissertation also highlighted the impact of different support systems on cognitive load, with advanced technologies combined with a Lean tool. In particular, the *combination* of Lean+I4.0 showed a significant reduction in mental workload, as reported by participants. This suggests that integrating multiple systems can have a greater impact than the systems used independently, which could lead to enhanced productivity and reduced burnout among workers. The impacts of the combined use of tools appear to be synergistic; further investigation into other potential interactions of assistive technologies is recommended.

Moreover, treatments utilizing I4.0 sensor systems scored higher on usability scales, indicating that these advanced tools are perceived as more user-friendly compared to traditional methods like PWI and the Lean tool (check piece) alone. This points to the

potential benefits of employing modern sensor technologies in improving the user experience, leading to better work performance and satisfaction.

Regarding script comparisons, the study found no significant differences in error rates between quality-focused (QI) and performance-focused (PI) scripts, but PI scripts did lead to higher production rates. This illustrates that productivity increases do not necessarily come at the cost of quality. This opens an interesting area to investigate the impact of scripts on performance and quality outcomes. The results also suggest that QI scripts could also be refined to potentially improve usability and acceptance. While usability and acceptance were not considered independent variables in this investigation, future work could investigate their impact on productivity and quality.

This investigation concludes with recommendations for exploring customized training and strategic implementation of technologies to maximize productivity and accommodate diverse cognitive needs, particularly for those with ADHD. These insights are crucial for designing inclusive workplace environments that not only cater to a broad spectrum of workers but also harness the unique strengths of neurodiverse populations to improve overall workplace efficiency and psychosocial well-being.

6.2.2 Manufacturing Support Systems Investigation: Limitations

In this study, participants were tasked with producing cars under different experimental conditions, focusing on either quality (QI) or performance (PI). One notable observation is that participants were working very slowly and focusing primarily on quality, producing fewer cars. This led to fewer data points and, consequently, fewer possibilities for errors, which could impact the overall analysis of error rates and performance.

A significant limitation of this study is the experimental design and the relatively small number of participants exhibiting the higher end of ADHD symptoms. This limited representation of individuals with higher ADHD symptomatology restricts the ability to generalize the findings to a broader ADHD population.

The study utilized a randomized assignment of participants to treatment orders without prior knowledge of their ADHD status. While this approach helps avoid bias, it led to somewhat uneven distributions of ADHD participants across different treatment

conditions. Such variability could impact the study's findings, introducing noise that might obscure the actual effects of the treatments.

Another limitation is the lack of information regarding the participants' ADHD diagnosis status and medication treatment status. This omission means that potential influences of medication or the severity of ADHD symptoms were not controlled, which could affect the outcomes related to performance and error rates.

Expanding this study to investigate the effects of workplace support systems on other neurodiverse populations, such as individuals with autism, could provide valuable insights into the broader applicability of these systems. The current study's focus on ADHD symptoms highlights significant interactions between neurodiversity and usability perceptions. However, it does not account for other neurodiverse conditions that could similarly impact participants' experiences and performance.

Additionally, the study's design did not consider potential coexisting conditions among participants, such as fatigue, illness, or other mental health issues, which could confound the results. Understanding the intersection of multiple neurodiverse conditions and external factors is essential for developing inclusive and effective support systems. Future research could include a more comprehensive assessment of participants' health and neurodiversity status to control for these variables, helping to ensure that findings reflect the nuanced realities of diverse workplaces. This approach would help tailor workplace support systems to meet the varied needs of all employees, fostering a more inclusive and supportive work environment.

Additionally, the study's small sample size, mainly when divided into the QI and PI groups and ADHD classifications, limits the generalizability of the findings. With only 26 participants in the QI group and 24 in the PI group, the statistical power to detect differences and draw definitive conclusions is reduced. This relatively small sample size also increases the likelihood that chance variations could affect the distribution of participants with significant ADHD symptoms, leading to potential biases in the results.

Despite these limitations, the randomized assignment of participants was an attempt to distribute individuals across treatment orders evenly, ensuring a balance in the study design. However, future studies could aim to balance the groups more effectively based on ADHD symptomology. Identifying participants' ADHD diagnosis and/or

symptomology status beforehand and then stratifying the random assignment process can help maintain balance and provide more accurate comparisons between treatment conditions.

Another limitation of this study is the composition of the sample, which was primarily drawn from college students. This group may not represent typical manufacturing workers, who may differ significantly in education, age, and other demographic factors. College students might possess different cognitive abilities, familiarity with technology, and problem-solving skills compared to a more diverse manufacturing workforce. Similarly, manufacturing workers may possess experiences and training that may make them more suited for manufacturing processes and work. These differences could influence how participants interact with the experimental conditions and interpret usability measures, potentially skewing the results.

In conclusion, while the study provides valuable insights into the effects of ADHD symptoms and workplace support systems on performance and usability, addressing the highlighted limitations could enhance future studies' ability to detect important differences in various populations and suggest means of accommodating those different populations.

6.2.3 Manufacturing Support Systems Investigation: Recommendations

Based on the conclusions drawn from the study on the effects of various treatments on production, quality, cognitive load, and usability in the context of ADHD symptoms, several actionable recommendations can be made for human factors practitioners, manufacturing engineers, managers, and workers. These suggestions are aimed at improving workplace support systems to enhance both the performance and well-being of neurotypical and ADHD, as well as neurotypical, workers in manual assembly tasks:

6.2.3.1 Recommendations for Human Factors Practitioners

- Customize Work Environments: Design workplace environments that accommodate diverse cognitive profiles. Utilize findings such as those on

cognitive load and usability to optimize task design, ensuring that systems reduce mental strain and enhance productivity.

- Integrate Advanced Technologies Thoughtfully: Employ advanced technologies like I4.0 sensor systems and Lean tools that have been shown to improve usability and reduce cognitive load. Work to integrate these technologies into the workplace to complement existing workflows without adding unnecessary complexity. Be sure to look for combinations of interventions that may have synergistic benefits.
- Investigate Cognitive Load Over Time: For example, does the cognitive workload of a particular technological intervention change over time? Answering the question: Does the increased load decrease over time as the workers acclimate to the technology?

6.2.3.2 Recommendations for Manufacturing Engineers

- Leverage Technology for Quality Improvement: Implement technologies such as vision inspection systems and Lean tools, which have been demonstrated to enhance product quality significantly. Consider the specific needs and capabilities of ADHD workers when integrating such technologies, as they can differ in how they perceive and interact with technological aids. Empirically investigate individual and combinations of technologies for benefits and potential drawbacks.
- Continuous Improvement of Work Systems: Use the insights from studies on tool-assisted support systems and lean methods to continuously refine and improve work processes and tools, enhancing the efficiency and quality of the outputs.
- Investigate Individual Differences: Consider individual differences for implementation of improvements and changes to workplace support systems. Some changes may have conflicting effects on different workers, as some may benefit some and harm others. Technology that is intended to help a particular population should be investigated to ensure it does not negatively impact the performance of other populations.

6.2.3.3 Recommendations for Managers

- Training and Support: Develop training programs that are tailored to the unique needs of all workers, including those with ADHD and other neurodiverse conditions. Training should focus on familiarizing workers with new tools and technologies and reinforcing the benefits of practice and task familiarity.
- Performance and Quality Metrics: Encourage a balanced focus on both performance and quality by setting clear, achievable goals that consider the strengths of workers with ADHD, such as their ability to work quickly without sacrificing the quality of their output.
- Strategic Implementation of Work Instructions and Motivational Statements: Build awareness in your team of the potential impact of motivational statements and work instructions, as how instructions are conveyed can potentially impact productivity and quality.

6.2.3.4 Recommendations for Workers

- Engage with New Technologies: Actively engage with and provide feedback on new technologies and support systems. Worker input is crucial in assessing the effectiveness of these systems and can lead to adjustments that make them more user-friendly and effective.
- Self-Advocacy and Communication: Communicate personal needs and preferences for workplace accommodations and support. Workers, especially those with ADHD, should feel empowered to discuss how certain conditions affect their work and what adjustments could help enhance their performance.

6.2.3.5 General Recommendations

- Foster an Inclusive Workplace Culture: Cultivate a workplace culture that recognizes and values diversity in cognitive styles and abilities. An inclusive culture can encourage all employees to perform to their best capabilities, ensuring that the workplace is supportive and accommodating to everyone's needs.
- Monitor and Evaluate: Regularly monitor the effectiveness of implemented changes and remain open to continuous improvements. Use performance data and

worker feedback to guide workplace adjustments and technology implementations.

By implementing these recommendations, practitioners, engineers, managers, and workers can collectively enhance the efficacy and inclusiveness of manufacturing environments, ultimately leading to improved productivity, reduced errors, and a healthier, more engaged workforce.

6.2.4 Manufacturing Support Systems Investigation: Future Investigation Recommendations

Considering the limitations observed in the current study, several recommendations emerge to guide future research in the domain of workplace support systems, particularly for neurodiverse populations such as those with ADHD. These recommendations aim to refine research methodologies, enhance the reliability and applicability of findings, and ultimately contribute to developing more inclusive and supportive workplace environments. By addressing these key areas, future studies can overcome the identified challenges and provide deeper insights into the complex dynamics of neurodiversity in the workplace. The following suggestions are intended to guide researchers in expanding their investigations' scope, accuracy, and impact in this increasingly important field.

- Increase Sample Size and Diversity: Future studies could increase the sample size and target population to improve the generalizability and reduce potential biases. This allows for a more robust analysis that accurately reflects the population. Ideally, participants should include actual manufacturing workers from varied demographic and employment backgrounds. This would enhance the applicability of findings to real-world settings.
- Detailed Screening for ADHD and Other Neurodiverse Conditions: Implement a comprehensive screening process to accurately assess participants' ADHD status, medication treatment, and any coexisting conditions. This would help control for potential confounders related to the severity of ADHD symptoms and their management, providing a clearer understanding of their impact on performance and error rates.

- Stratified Randomization: To ensure even distribution across different treatment conditions, use stratified randomization based on ADHD status or other relevant factors. This approach would help maintain balance and allow for more accurate group comparisons.
- Extend Research to Other Neurodiverse Conditions: Expanding the focus to include other neurodiverse conditions, such as autism spectrum disorder, could offer insights into how various workplace support systems affect a broader range of neurodiverse populations. This could help in designing more inclusive and effective support systems.
- Consideration of Coexisting Conditions: Future studies could include assessing external factors such as fatigue, mental health issues, or physical health conditions that could affect participants' performance. Understanding the intersection of these factors with neurodiversity is important for creating supportive work environments.
- Longitudinal and Multi-Session Studies: Consider designing studies that track participants over extended periods and/or across multiple sessions. This would shed light on how performance and error rates evolve over time and under varying conditions, providing deeper insights into the effects of workplace interventions.
- Use of More Detailed Usability and Cognitive Load Measures: Employing comprehensive tools to measure usability and cognitive load can help capture subtle differences in how participants interact with workplace technologies. This could aid in better understanding the specific needs of neurodiverse employees.
- Incorporate Realistic Workplace Tasks and Environments: More realistically simulating manufacturing tasks and environments could increase the operational fidelity and subsequent ecological validity of the findings. This could include varying and increasing the complexity of tasks or using actual workplace settings.
- Qualitative Feedback: Incorporate qualitative feedback mechanisms to capture participants' personal experiences and perceptions beyond quantitative measures. This could provide richer data on the usability and acceptability of different interventions. For example, talk about protocols, focus groups, and structured post-experiment interviewing.

- Investigate Trust in Automation: Future research should explore the impact of trust in automation on workers' performance and cognitive load. Understanding how trust levels influence the adoption and effective use of automated tools in manufacturing settings can provide insights into designing more user-friendly and reliable systems. This could involve assessing workers' perceptions of automation reliability, transparency, and overall trustworthiness, as well as identifying factors that enhance or undermine trust in these technologies.

These recommendations aim to address the limitations identified in the study, thereby enhancing the rigor and relevance of future research in workplace support systems for neurodiverse populations.

6.3 Workplace Psychosocial Survey

This study investigates the prevalence of attention deficit hyperactivity disorder (ADHD) among U.S. workers, with a specific focus on the manufacturing sector, and examines the relationship between ADHD symptoms, self-efficacy, social anxiety, and workplace support systems. Utilizing an online survey conducted via Qualtrics, the study gathered data from 249 participants across various employment sectors. The survey aimed to evaluate ADHD symptomatology using the ADHD Adult Self-Report Scale (ASRS v1.1), assess self-efficacy through the Global Perceived Self-Efficacy Scale (GPSES), measure social anxiety using the Liebowitz Social Anxiety Scale (LSAS), and capture perceptions of workplace support systems.

6.3.1 Workplace Psychosocial Survey: Conclusions

This study sheds light on the correlation between ADHD symptoms, self-reported ADHD diagnoses, and various demographic and workplace factors. It reveals significant differences in ADHD symptom reporting and diagnosis rates across employment sectors, emphasizing the necessity for targeted awareness and diagnostic efforts in specific fields.

A key takeaway is that individuals self-reporting an ADHD diagnosis show notably higher ADHD symptoms, as measured by the ASRS v1.1, compared to those without such a diagnosis. This disparity is evident in both the number and severity of

symptoms, supporting the credibility of self-reported ADHD diagnoses in reflecting actual symptomatology. The use of prescribed ADHD medication does appear to positively impact (reduce) symptoms of those who self-report ADHD diagnosis. The ramification is that persons with treated ADHD may outwardly display fewer (or less pronounced) of the common symptoms of ADHD, thus potentially differentially impacting interactions with others and work outcomes.

Contrary to expectations, the likelihood of being diagnosed with ADHD among adults does appear to vary between different employment sectors. However, relatively small sample sizes and the subsequent wide confidence intervals suggest further research is needed to determine the prevalence in various work sectors. Retail was found to have the highest rates and education showed the lowest. Other higher sectors included healthcare and 'transportation and warehousing'. The manufacturing and government sectors were in the lower range for self-diagnosis of ADHD. The reasons for the differences in reporting were not part of this study, but it is speculated there may be barriers to reporting in certain industries.

The analysis also showed significant variations in the likelihood of having significant ADHD symptoms reported but not self-reporting ADHD diagnosis among different employment sectors. Notably, individuals in the Transportation and Warehousing sector are six times more likely to have apparent undiagnosed ADHD compared to those in Manufacturing, and the odds for Government workers are five times that of Manufacturing workers. This pattern underscores the complex nature of ADHD diagnosis across different employment sectors, suggesting a nuanced landscape where certain sectors may face higher risks or challenges in diagnosing ADHD.

Logistic regression analysis reveals the power of the ASRS 6 symptom levels to associate with the diagnosis of ADHD. Higher numbers of significant symptoms (3, 4, 5, and 6) were indicative of self-reported ADHD diagnosis.

Furthermore, the research highlights ADHD's impact on self-efficacy and social anxiety. Individuals with self-reported ADHD diagnosis and/or high levels of symptoms reported higher social anxiety and lower self-efficacy. These findings suggest that ADHD significantly affects psychological well-being and self-perception, potentially impacting professional and personal lives.

The study also investigates workplace support satisfaction, finding no significant differences between adults with and without a self-reported ADHD diagnosis. This indicates that a self-reported ADHD diagnosis does not necessarily affect satisfaction with workplace support, suggesting other factors may play a more important role in shaping these perceptions.

In summary, this research highlights the complexity of ADHD, varying significantly across demographic and occupational contexts. The findings emphasize the potential need for targeted diagnostic and support strategies tailored to specific sectors and underscore ADHD's possible profound impact on individuals' psychological well-being and professional lives. Future research could explore these sector-specific factors and develop interventions to better support individuals with ADHD in various occupational environments.

6.3.2 Workplace Psychosocial Survey: Limitations

Despite their ability to gather input from more participants than in-person studies, surveys have several limitations that can affect their ability to provide comprehensive insights (Andrade, 2020). Some of the standard limitations of surveys and specific limitations of this study include the following:

Limited Access to Manufacturing Facilities: Many manufacturing facilities declined to distribute the survey due to concerns about the sensitive information being collected. Additionally, manufacturing-focused Facebook groups often refused to post the survey flyer, fearing it might be fraudulent or spam. This limited direct access to operational manufacturing employees for survey distribution.

Inability to Describe the Population: Defining the population with a social media-distributed survey is challenging, making it difficult to generalize the results (Andrade, 2020).

Self-Selection Bias: The survey, advertised as a psychosocial survey on workplace stress and anxiety, likely attracted respondents with pre-existing interests or experiences related to these issues (Andrade, 2020). Individuals currently working or those familiar with stress and anxiety, either personally or through others, may have been more inclined to participate, possibly resulting in a sample that overrepresents certain

aspects of the population.

Sampling Bias: Online surveys inherently select participants who have computer and internet access and social media accounts, potentially skewing the pool of potential respondents (Menon & Muraleedharan, 2020).

Fraudulent Responses: Fraudulent responses in web-based surveys have increased significantly recently (Levi et al., 2022). Despite implementing methods to detect suspected bot activity, the survey still experienced significant fraudulent responses, including bots that adapted to evade detection (Storozuk et al., 2020). While multiple screening methods were employed to uphold the quality of the final responses, it is possible that some fraudulent responses were not identified.

Removal of Quality Data: The screening methods used to filter out fraudulent responses may have inadvertently removed valid responses. This could particularly impact the study's focus on participants with ADHD, who may display inattentiveness—a trait that might have led to their responses being incorrectly filtered out (Teitcher et al., 2015).

Self-Report Bias: Reliance on self-reported data can introduce bias due to social desirability, memory recall issues, and other factors, potentially skewing the results.

Response Bias: The framing of questions can influence responses, leading to potential misunderstandings or misinterpretations by the respondents. Participants brought up the question about self-medication as being particularly misleading.

Cross-Sectional Nature: The survey captures data at a single point in time, limiting the ability to make causal inferences or understand changes over time.

Limited Depth: The use of validated metrics and the absence of in-depth interviews or extensive free-response questions limit the richness of the data collected. While the survey included three open-response questions, the overall depth of information remains somewhat constrained.

Ethical Concerns: Participants' concerns about the confidentiality of their responses, particularly on sensitive topics like psychosocial research, may deter them from participating.

Survey Fatigue: Lengthy or repetitive surveys can lead to fatigue, potentially affecting the quality of responses. The survey, which took 10-12 minutes to complete,

was on the borderline of causing fatigue, with some quality check questions potentially missed due to this issue.

These limitations highlight the challenges in conducting psychosocial survey research and underscore the importance of robust methods to mitigate these issues.

6.3.3 Workplace Psychosocial Survey: Recommendations

Based on the findings from this research, several actionable recommendations can be made for human factors practitioners, individuals experiencing workplace stress and anxiety, and those managing employees with ADHD symptomology. These recommendations aim to enhance the identification, support, and management of ADHD and related stress and anxiety in the workplace.

6.3.3.1 For Human Factors Practitioners

1. Conduct Workplace Workshops and Training:

Regular workshops and training sessions for employees and management can raise awareness about ADHD, reduce stigma, and promote effective coping strategies. These sessions could cover recognizing ADHD symptoms, effective communication, and creating supportive work environments.

2. Implement Comprehensive Screening and Diagnosis Programs:

Practitioners could develop and offer screening programs for workers interested in determining whether they have ADHD within workplaces, particularly in sectors identified as having higher prevalence rates, such as Healthcare and Retail. Regular screenings can help in early identification and timely intervention, reducing the long-term impact of ADHD on job performance and well-being.

3. Provide Tailored Mental Health Services:

Mental health professionals could offer tailored services that address the specific needs of employees with ADHD. In addition to pharmaceutical treatments, these services might include cognitive-behavioral therapy (CBT), mindfulness-based stress reduction (MBSR), and other therapeutic approaches that have proven effective in managing ADHD symptoms and related anxiety.

6.3.3.2 For Individuals Experiencing Workplace Stress and Anxiety

1. Seek Professional Help:

Individuals experiencing stress and anxiety should seek help from mental health professionals who can provide accurate diagnoses and appropriate treatment plans. Early intervention can significantly improve outcomes. The effective treatment of ADHD may help reduce anxiety and improve self-efficacy.

2. Practice Self-Care and Stress Management Techniques:

Engaging in regular physical activity, practicing mindfulness, and using relaxation techniques can help manage stress and anxiety. Maintaining a healthy work-life balance and setting realistic goals can also reduce work-related stress.

3. Utilize Workplace Support Systems:

Employees should utilize available workplace support systems, such as employee assistance programs (EAPs), counseling services, and support groups. These resources can provide emotional support and practical advice for managing stress and anxiety.

4. Communicate with Employers:

Open communication with employers about ADHD and related challenges can lead to better understanding and development of helpful accommodations. Employees should feel empowered (understandably there could be circumstances that they do not) to discuss their needs and seek adjustments to help them perform their duties effectively.

6.3.3.3 For Managers and Employers

1. Foster an Inclusive and Psychologically Safe Work Environment:

Creating an inclusive work environment that supports mental health is essential. Employers should promote a culture of acceptance and understanding where employees feel safe to disclose their conditions without fear of stigma or discrimination.

2. Provide Reasonable Accommodations:

Employers should provide reasonable accommodations for employees with ADHD. These might include flexible work schedules, modifications to the work environment, and access to assistive technologies. These adjustments may help employees better manage their symptoms and improve their productivity.

3. Train Management on ADHD and Mental Health:

Training programs for managers and HR professionals can equip them with the knowledge and skills to support employees with ADHD and related stress and anxiety. Topics might include recognizing symptoms, providing accommodations, and fostering a supportive work culture.

4. Implement Employee Wellness Programs:

Employee wellness programs that include mental health components can be beneficial. These programs might offer resources such as stress management workshops, mental health screenings, and access to fitness and wellness activities.

5. Regularly Evaluate Workplace Policies:

Employers should regularly review and update workplace policies to help verify that they are inclusive and supportive of employees with ADHD and other mental health conditions. This includes ensuring policies comply with legal requirements and reflect best practices in mental health support.

Conclusion:

The research underscores the importance of addressing ADHD and related stress and anxiety in the workplace. By implementing comprehensive screening and tailored mental health services, fostering an inclusive work environment, and providing reasonable accommodations, practitioners, and employers can significantly improve the well-being and productivity of employees with ADHD. Individuals experiencing workplace stress and anxiety should seek professional help, practice self-care, and utilize available support systems. Through these collective efforts, workplaces can become more supportive and conducive to the success and well-being of all employees.

6.3.4 Workplace Psychosocial Survey: Future Investigation Recommendations

The findings from these studies provide a foundation for understanding the prevalence and impact of ADHD across various employment sectors. However, several areas warrant further investigation: additional sector-specific research, longitudinal studies, and the effectiveness of intervention strategies.

6.3.4.1 Sector-Specific Factors

The significant variability in ADHD prevalence and diagnosis rates across

different employment sectors suggests that sector-specific factors may influence the recognition and management of ADHD symptoms. Future studies should investigate the unique characteristics of retail, healthcare, government, manufacturing, education, and transportation and warehousing sectors. For instance, qualitative research methods, including interviews and focus groups with employees and healthcare providers within these sectors, include the identification of potential barriers to ADHD diagnosis and treatment.

Quantitative studies should also examine environmental and occupational stressors unique to each sector, such as job demands, work environment, and access to mental health resources. By understanding these factors, researchers can identify potential barriers to ADHD diagnosis and management and develop targeted strategies to address them. Additionally, comparing sectors can help identify protective factors that might mitigate ADHD symptoms.

6.3.4.2 Longitudinal Studies

While this study provides a snapshot of ADHD prevalence and its impact, longitudinal studies are necessary to understand the long-term effects of ADHD in various employment sectors. Tracking individuals over time can reveal how ADHD symptoms evolve and how they impact career progression, job performance, and overall well-being. Longitudinal data can also help identify critical periods for intervention and support, thereby improving outcomes for individuals with ADHD.

These studies could include periodic assessments of ADHD symptoms, self-efficacy, social anxiety, and satisfaction with workplace support systems. By examining changes over time, researchers can identify patterns and predictors of positive or negative outcomes, which can inform the development of more effective support programs.

6.3.4.3 Intervention Strategies

Given the significant impact of ADHD on self-efficacy and social anxiety, as well as the variability in diagnosis rates across sectors, there may be a need for tailored intervention strategies. Future research could focus on designing and evaluating interventions that address the specific needs of workers in high-prevalence sectors. For

example, training programs for managers and HR professionals in the relatively high prevalence sectors can increase awareness and improve the identification and support of employees with ADHD.

Moreover, workplace accommodations and support programs could be developed and tested for their effectiveness in improving job performance and well-being among employees with ADHD. These programs might include flexible work arrangements, modifications to the physical work environment, and access to mental health resources. Implementing and evaluating such interventions can provide evidence-based guidelines for employers to create more inclusive and supportive workplaces.

In sectors where undiagnosed ADHD is more prevalent, efforts could focus on increasing access to diagnostic services and reducing the stigma associated with mental health issues. Mobile health units, telehealth services, and workplace mental health campaigns can effectively reach employees who may not seek traditional healthcare services.

6.3.4.4 Data Expansion and Refinement

Expanding current studies to specifically recruit ADHD participants and place them into blinded and stratified experimental designs could enhance the robustness of the data set and increase the generalizability of future study results.

Researchers should consider expanding the dataset to include more diverse populations and employment sectors to build on the current findings. Increasing the sample size and diversity will enhance the generalizability of the results and allow for more nuanced analyses. Additionally, refining data collection methods to help guarantee high quality and accuracy is essential. Using validated tools and standardized procedures can minimize the risk of data inconsistencies and improve the reliability of the findings.

Collaborating with industry partners and professional organizations can facilitate access to more representative samples. These collaborations can also provide practical insights and resources for implementing and evaluating workplace interventions.

6.3.4.5 Conclusion

Future investigations could clarify this study's results by exploring sector-specific

factors, conducting longitudinal research, and developing targeted intervention strategies. By focusing on these areas, researchers can deepen their understanding of ADHD in the workplace, improve support for affected individuals, and ultimately enhance the career outcomes and overall quality of their lives. Addressing the unique needs of workers in sectors with high ADHD prevalence and tailoring interventions accordingly could be important for fostering inclusive and supportive work environments.

7.0 References

7.1 Author and Collaborator Publications and Presentations

7.1.1 Literature Review

Ballard, V. (2023c, July 12). How do Industrial Engineers Support Sustainability? [Educational Session]. Minority Introduction to Engineering Camp, Brown-Kopel.

Ballard, V. (2023d, August 17). Unlocking Potential: Redefining Workspaces through Inclusivity and Innovative Universal Design [Webinar]. Cintas Ergonomics Corporate Conference, Cintas Ergo Competition 2023.

Ballard, V. (2023e, August 18). How do you Engineer Together? [Table Talk]. Student Welcome Student Browse, Auburn University, Gavin Gardens, Auburn, AL.

Ballard, V. (2023f, September 19). Unlocking Potential: Redefining Workspaces through Inclusivity and Innovative Universal Design. [Keynote Speaker]. CINTAS Ergonomics Competition Innovation Webinar Series, Webinar.

Ballard, V. (2022f). Impacts of Workers with Attention Deficit Hyperactivity Disorder. Written for PSYC 7700, Dr. Jesse Michel, Auburn University Course.

Ballard, V., & Pantazes, R. (2023, October 26). DEI Colloquium: Neurodiversity [Seminar]. Auburn College of Engineering Faculty DEI Colloquium, Auburn University, Auburn, AL.

Ballard, V., & Pantazes, R. (2024a, February 15). Engineer Together Day: Neurodiversity [Seminar]. Engineer Together Day, Faculty and Staff Seminar, Auburn University, Auburn, AL.

7.1.2 Pilot Study: Augmented Reality Effects on Performance and Quality

Ballard, V. (2022a, September 21). Augmented Reality in Manufacturing: A help or a hindrance? [Session Presentation]. IISE Lean Six Sigma Data Science Conference, Atlanta, GA.

Ballard, V. (2022b, September 21). Evaluation of an Augmented Reality System in Tiger Motors Lean Education Center [Poster Presentation]. IISE Lean Six Sigma Data Science Conference, Atlanta, GA.

Ballard, V. (2022c, October 11). Tiger Motors Lean Education Center, Lean | Human Factors | Ergonomics | Safety | Technology [Poster Presentation]. HFES 66th International Annual Meeting, Atlanta, GA.

Ballard, V. (2022d, October 21). Augmented Reality in Manufacturing: A help or a hindrance? [Poster Presentation]. Graduate Engineering Research Showcase, Auburn University, Auburn, AL.

7.1.3 Experiment 1: Manufacturing Technology Support Investigation-Assessing the Effects of Augmented Reality Technology on ADHD

Workers

Ballard, V. (2023g, October 12). Assessing the Cognitive Load and Learning of ADHD Workers in Manual Assembly Manufacturing Tasks With and Without Augmentation [Poster Presentation]. Graduate Engineering Research Showcase, Auburn University, Auburn, AL.

Ballard, V., O'Leary, D., & Sesek, R. F. (2024, March 26). The Role of Technology in Enhancing Workplace Ergonomics for Neurodiverse Employees: A Performance and Safety Perspective [Poster Presentation]. Applied Ergonomics Conference 2024, Applied Ergonomics Conference, Louisville, KY.

O'Leary, D. J. (In Press). Augmented vs. Traditional Instruction in Manufacturing Assembly: An Affordance-Based, Multi-Modal Assessment of Learning, Recall, and Retention [PhD Dissertation]. Auburn University.

7.1.4 Experiment 2: Manufacturing Workplace Support Investigation- Assessing Effects of Technology Used in Improving Quality and Performance

Ballard, V. (2024c, March 25). Enhancing Ergonomics: Technology's Role in Neurodiverse Workers' Health, Performance, and Safety [Standard Presentation]. Applied Ergonomics Conference 2024, Applied Ergonomics Conference, Louisville, KY.

Hossain, M. M., Ballard, V. L., O'Leary, D., Purdy, G., & Sesek, R. F. (2024). Exploring the Integration Effect of Lean and Industry 4.0: A Case Study. TBA.

Hossain, M. M., & Purdy, G. (2023). Integration of Industry 4.0 into Lean Production systems: A systematic literature review. Manufacturing Letters, 51st SME North American Manufacturing Research Conference (NAMRC 51, 2023).

Hossain, Md. M. (2024). Integration of Lean and Industry 4.0 for Smart Manufacturing [PhD Dissertation]. Auburn University.

7.2 Dissertation Sources

Adamis, D., Flynn, C., Wrigley, M., Gavin, B., & McNicholas, F. (2022). ADHD in Adults: A Systematic Review and Meta-Analysis of Prevalence Studies in Outpatient Psychiatric Clinics. *Journal of Attention Disorders*, *26*(12), 1523–1534. https://doi.org/10.1177/10870547221085503

Adamou, M., Arif, M., Asherson, P., Aw, T.-C., Bolea, B., Coghill, D., Guðjónsson, G., Halmøy, A., Hodgkins, P., Müller, U., Pitts, M., Trakoli, A., Williams, N., & Young, S. (2013). Occupational issues of adults with ADHD. *BMC Psychiatry*, *13*, 59. https://doi.org/10.1186/1471-244X-13-59

Adler, L. A., Faraone, S. V., Sarocco, P., Atkins, N., & Khachatryan, A. (2019). Establishing US norms for the Adult ADHD Self-Report Scale (ASRS-v1.1) and characterising symptom burden among adults with self-reported ADHD. *International Journal of Clinical Practice*, *73*(1), e13260. https://doi.org/10.1111/ijcp.13260

Adler, L. A., Spencer, T., Faraone, S. V., Kessler, R. C., Howes, M. J., Biederman, J., & Secnik, K. (2006). Validity of Pilot Adult ADHD Self- Report Scale (ASRS) to

Rate Adult ADHD Symptoms. *Annals of Clinical Psychiatry*, *18*(3), 145–148. https://doi.org/10.1080/10401230600801077

Adult ADHD Self-Report Scale (ASRS). (2021, September 15). *NovoPsych*. https://novopsych.com.au/assessments/diagnosis/adult-adhd-self-report-scale-asrs/

Afsharian, A., Dollard, M. F., Glozier, N., Morris, R. W., Bailey, T. S., Nguyen, H., & Crispin, C. (2023). Work-related psychosocial and physical paths to future musculoskeletal disorders (MSDs). *Safety Science*, *164*, 106177. https://doi.org/10.1016/j.ssci.2023.106177

Al-Yateem, N., Slewa-Younan, S., Halimi, A., Saeed, S. A., Tliti, D., Mohammad, M., Ridwan, M., Zeidan, R., Hammash, M. H., Ahmed, F. R., Dias, J. M., Rahman, S. A., Subu, M. A., Hijazi, H., Yeganeh, F., Momani, A., Zandi, M., & Mottershead, R. (2023). Prevalence of Undiagnosed Attention Deficit Hyperactivity Disorder (ADHD) Symptoms in the Young Adult Population of the United Arab Emirates: A National Cross-Sectional Study. *Journal of Epidemiology and Global Health*. https://doi.org/10.1007/s44197-023-00167-4

Andrade, C. (2020). The Limitations of Online Surveys. *Indian Journal of Psychological Medicine*, *42*(6), 575–576. https://doi.org/10.1177/0253717620957496

Andreasson, R., Lindblom, J., & Thorvald, P. (2017). Interruptions in the wild: Portraying the handling of interruptions in manufacturing from a distributed cognition lens. *Cognition, Technology & Work*, *19*(1), 85–108. https://doi.org/10.1007/s10111-016-0399-6

Atici-Ulusu, H., Ikiz, Y. D., Taskapilioglu, O., & Gunduz, T. (2021). Effects of augmented reality glasses on the cognitive load of assembly operators in the automotive industry. *International Journal of Computer Integrated Manufacturing*, *34*(5), 487–499. https://doi.org/10.1080/0951192X.2021.1901314

Ayano, G., Tsegay, L., Gizachew, Y., Necho, M., Yohannes, K., Abraha, M., Demelash, S., Anbesaw, T., & Alati, R. (2023). Prevalence of attention deficit hyperactivity disorder in adults: Umbrella review of evidence generated across the globe. *Psychiatry Research*, *328*, 115449. https://doi.org/10.1016/j.psychres.2023.115449

Baker, S. L., Heinrichs, N., Kim, H.-J., & Hofmann, S. G. (2002). The liebowitz social anxiety scale as a self-report instrument: A preliminary psychometric analysis. *Behaviour Research and Therapy*, *40*(6), 701–715. https://doi.org/10.1016/s0005-7967(01)00060-2

Ballard, V., & Pantazes, R. (2024, February 28). *Neurodiversity* [Lecture]. Occupational Safety and Ergonomics Seminar Course, Auburn University, Auburn, AL.

Barajas-Bustillos, M. A., Maldonado-Macías, A. A., Serrano-Rosa, M. A., Hernandez-Arellano, J. L., Llamas-Alonso, L., & Balderrama-Armendariz, O. (2023). Impact of experience on the sensitivity, acceptability, and intrusive of two subjective mental workload techniques: The NASA TLX and workload profile. *Work*, *75*(4), 1265–1275. https://doi.org/10.3233/WOR-211324

Baudin, M. (2007). *Working with Machines: The Nuts and Bolts of Lean Operations with Jidoka*. CRC Press.

Beard, C., Rodriguez, B. F., Moitra, E., Sibrava, N. J., Bjornsson, A., Weisberg, R. B., & Keller, M. B. (2011). Psychometric Properties of the Liebowitz Social Anxiety Scale (LSAS) in a Longitudinal Study of African Americans with Anxiety

Disorders. *Journal of Anxiety Disorders*, *25*(5), 722–726. https://doi.org/10.1016/j.janxdis.2011.03.009

Biederman, J., Mick, E., Fried, R., Aleardi, M., Potter, A., & Herzig, K. (2005). A Simulated Workplace Experience for Nonmedicated Adults With and Without ADHD. *Psychiatric Services*, *56*(12), 1617–1620. https://doi.org/10.1176/appi.ps.56.12.1617

Birren, J. E. (Ed.). (2007). Research Design and Methods—Cronbach's alpha. In *Encylopedia of Gerntology* (2nd ed.). https://www-sciencedirect-com.spot.lib.auburn.edu/topics/nursing-and-health-professions/cronbach-alpha-coefficient

Bjerrum, M. B., Pedersen, P. U., & Larsen, P. (2017). Living with symptoms of attention deficit hyperactivity disorder in adulthood: A systematic review of qualitative evidence. *JBI Database of Systematic Reviews and Implementation Reports*, *15*(4), 1080–1153. https://doi.org/10.11124/JBISRIR-2017-003357

Bommer, S. C. (2016). *A Theoretical Framework for Evaluating Mental Workload Resources in Human Systems Design for Manufacturing Operations*. Wright State University.

Bommer, S. C., & Fendley, M. (2018). A theoretical framework for evaluating mental workload resources in human systems design for manufacturing operations. *International Journal of Industrial Ergonomics*, *63*, 7–17. https://doi.org/10.1016/j.ergon.2016.10.007

Bottani, E., & Vignali, G. (2019). Augmented reality technology in the manufacturing industry: A review of the last decade. *IISE Transactions*, *51*(3), Article 3. https://doi.org/10.1080/24725854.2018.1493244

Breslin, F. C., Lay, A. M., Jetha, A., & Smith, P. (2018). Examining occupational health and safety vulnerability among Canadian workers with disabilities. *Disability & Rehabilitation*, *40*(18), 2138–2143.

Breslin, F. C., & Pole, J. D. (2009). Work Injury Risk Among Young People With Learning Disabilities and Attention-Deficit/Hyperactivity Disorder in Canada. *American Journal of Public Health*, *99*(8), 1423–1430. https://doi.org/10.2105/AJPH.2008.140855

Calvallari, J., & Nobrega, S. (2021). *Total Worker Health for Occupational Safety and Health Professionals Course*. http://www.uml.edu/cphnew

CDC. (2021, September 28). *Attention-Deficit / Hyperactivity Disorder (ADHD)*. Centers for Disease Control and Prevention. https://go.usa.gov/xRAsU

Chan, W. P., Hanks, G., Sakr, M., Zhang, H., Zuo, T., Van der Loos, H. F. M., & Croft, E. (2022). *Design and Evaluation of an Augmented Reality Head-Mounted Display Interface for Human Robot Teams Collaborating in Physically Shared Manufacturing Tasks* (arXiv:2203.08343). arXiv. https://doi.org/10.48550/arXiv.2203.08343

Chapman, R. (2021). Neurodiversity and the Social Ecology of Mental Functions. *Perspectives on Psychological Science : A Journal of the Association for Psychological Science*, *16*(6), 1360–1372. https://doi.org/10.1177/1745691620959833

Choomlucksana, J., & Doolen, T. L. (2017). An exploratory investigation of teaching innovations and learning factors in a lean manufacturing systems engineering

course. *European Journal of Engineering Education*, *42*(6), 829–843. https://doi.org/10.1080/03043797.2016.1226780
Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Lawrence Erlbaum Associates.
Cohen, R. A. (2011). Yerkes–Dodson Law. In J. S. Kreutzer, J. DeLuca, & B. Caplan (Eds.), *Encyclopedia of Clinical Neuropsychology* (pp. 2737–2738). Springer. https://doi.org/10.1007/978-0-387-79948-3_1340
Conklin, T. (2019). *The 5 Principles of Human Performance: A contemporary update of the building blocks of Human Performance for the new view of safety*. Pre-Accident Investigation Media.
Cronbach, L. J. (1951). Coefficient alpha and the internal structure of tests. *Psychometrika*, *16*, 297–334.
Das, D., Cherbuin, N., Butterworth, P., Anstey, K. J., & Easteal, S. (2012). A Population-Based Study of Attention Deficit/Hyperactivity Disorder Symptoms and Associated Impairment in Middle-Aged Adults. *PLOS ONE*, *7*(2), e31500. https://doi.org/10.1371/journal.pone.0031500
Dekker, S. (2014). *Safety differently: Human factors for a new era*. CRC Press.
Dekker, S. (2016). Safety Differently: Human Factors for a New Era. *Collegiate Aviation Review*, *34*(2), 107.
Dolan, J. (2020, June 3). *5 Ways Augmented Reality Can Increase Manufacturing Productivity*. ROKIN. https://www.rokin.tech/post/5-ways-augmented-reality-can-increase-manufacturing-productivity
Doyle, N., & McDowall, A. (2021). Diamond in the rough? An "empty review" of research into "neurodiversity" and a road map for developing the inclusion agenda. *Equality, Diversity and Inclusion: An International Journal*, *41*(3), 352–382. https://doi.org/10.1108/EDI-06-2020-0172
Duffy, T., & Romero, M. (2024, July 2). *Promoting Neurodiversity Through MBSE and Other Technical Approaches*. 34th Annual INCOSE International Symposium, Dublin, Ireland.
Dwyer, P. (2022). The Neurodiversity Approach(es): What Are They and What Do They Mean for Researchers? *Human Development*, *66*(2), 73–92. https://doi.org/10.1159/000523723
Egger, J., & Masood, T. (2020). Augmented reality in support of intelligent manufacturing – A systematic literature review. *Computers & Industrial Engineering*, *140*, 106195. https://doi.org/10.1016/j.cie.2019.106195
Elia, V., Gnoni, M. G., & Lanzilotto, A. (2016). Evaluating the application of augmented reality devices in manufacturing from a process point of view: An AHP based model. *Expert Systems with Applications*, *63*, 187–197. https://doi.org/10.1016/j.eswa.2016.07.006
Erboz, G. (2017). *How To Define Industry 4.0: Main Pillars Of Industry 4.0*.
Fabiano, G. A., Hulme, K. F., Sodano, S. M., Caserta, A., Hulme, K., Stephan, G., & Smyth, A. C. (2018). An Evaluation of Occupational Behavior in Individuals with and without Attention Deficit/Hyperactivity Disorder. *Human Performance*, *31*(3), 165–178. https://doi.org/10.1080/08959285.2018.1489809
Faheem, M., Akram, W., Akram, H., Khan, M. A., Siddiqui, F. A., & Majeed, I. (2022). Gender-based differences in prevalence and effects of ADHD in adults: A

systematic review. *Asian Journal of Psychiatry*, *75*. https://doi.org/10.1016/j.ajp.2022.103205

Frazier, T. W., Youngstrom, E. A., Glutting, J. J., & Watkins, M. W. (2007). ADHD and Achievement: Meta-Analysis of the Child, Adolescent, and Adult Literatures and a Concomitant Study with College Students. *Journal of Learning Disabilities*, *40*(1), 49–65.

Fried, R., Surman, C., Hammerness, P., Petty, C., Faraone, S., Hyder, L., Westerberg, D., Small, J., Corkum, L., Claudat, K., & Biederman, J. (2012). A controlled study of a simulated workplace laboratory for adults with attention deficit hyperactivity disorder. *Psychiatry Research*, *200*(2–3), 949–956. https://doi.org/10.1016/j.psychres.2012.04.020

Funk, J., & Schmidt, L. (2021). *Evaluation of an Augmented Reality Instruction for a Complex Assembly Task—Comparison of a Smartphone-Based Augmented Reality Instruction with a Conventional Paper Instruction for the Teach-in Phase in Manual Assembly*. https://doi.org/10.1515/icom-2021-0005

Gattullo, M., Scurati, G. W., Fiorentino, M., Uva, A. E., Ferrise, F., & Bordegoni, M. (2019). Towards augmented reality manuals for industry 4.0: A methodology. *Robotics and Computer-Integrated Manufacturing*, *56*, 276–286. https://doi.org/10.1016/j.rcim.2018.10.001

Gémes, K., Björkenstam, E., Rahman, S., Gustafsson, K., Taipale, Tanskanen, A., Ekselius, L., Mittendorfer-Rutz, E., & Helgesson, M. (2022). Occupational Branch and Labor Market Marginalization among Young Employees with Adult Onset of Attention Deficit Hyperactivity Disorder—A Population-Based Matched Cohort Study. *International Journal of Environmental Research and Public Health*, *19*(7254), 7254–7254. https://doi.org/10.3390/ijerph19127254

Gilman, L. (2006, October 6). How to Succeed in Business with ADHD. *ADDitude*. https://www.additudemag.com/adhd-entrepreneur-stories-jetblue-kinkos-jupitermedia/

Gordon, C. T., & Fabiano, G. A. (2019). The Transition of Youth with ADHD into the Workforce: Review and Future Directions. *Clinical Child & Family Psychology Review*, *22*(3), 316–347. https://doi.org/10.1007/s10567-019-00274-4

Halbesleben, J. R. B., Wheeler, A. R., & Shanine, K. K. (2013). The moderating role of attention-deficit/hyperactivity disorder in the work engagement–performance process. *Journal of Occupational Health Psychology*, *18*, 132–143. https://doi.org/10.1037/a0031978

Hallowell, E. M. (2005). Overloaded Circuits: Why Smart People Underperform. *Harvard Business Review*, *83*(1), 54–62.

Hallowell M.D, E. M., & Ratey M.D, J. J. (2021). *ADHD 2.0: New Science and Essential Strategies for Thriving with Distraction--from Childhood through Adulthood*. Ballantine Books.

Hart, S. G. (2016). *Nasa-Task Load Index (NASA-TLX); 20 Years Later*. https://doi.org/10.1177/154193120605000909

Heitz, R. P. (2014). The speed-accuracy tradeoff: History, physiology, methodology, and behavior. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00150

Helgesson, M., Björkenstam, E., Rahman, S., Gustafsson, K., Taipale, H., Tanskanen, A., Ekselius, L., & Mittendorfer-Rutz, E. (2023). Labour market marginalisation in

young adults diagnosed with attention-deficit hyperactivity disorder (ADHD): A population-based longitudinal cohort study in Sweden. *Psychological Medicine*, *53*(4), 1224–1232. https://doi.org/10.1017/S0033291721002701

Herbert, B., Wigley, G., Ens, B., & Billinghurst, M. (2022). Cognitive load considerations for Augmented Reality in network security training. *Computers & Graphics*, *102*, 566–591. https://doi.org/10.1016/j.cag.2021.09.001

Hines, J. L., King, T. S., & Curry, W. J. (2012). The Adult ADHD Self-Report Scale for Screening for Adult Attention Deficit–Hyperactivity Disorder (ADHD). *The Journal of the American Board of Family Medicine*, *25*(6), 847–853. https://doi.org/10.3122/jabfm.2012.06.120065

Ho, P. T., Albajez, J. A., Santolaria, J., & Yagüe-Fabra, J. A. (2022). Study of Augmented Reality Based Manufacturing for Further Integration of Quality Control 4.0: A Systematic Literature Review. *Applied Sciences*, *12*(4), Article 4. https://doi.org/10.3390/app12041961

Hodge, V., & Austin, J. (2004). A Survey of Outlier Detection Methodologies. *Artificial Intelligence Review*, *22*(2), 85–126. https://doi.org/10.1023/B:AIRE.0000045502.10941.a9

Hoedt, S., Claeys, A., Van Landeghem, H., & Cottyn, J. (2017). The evaluation of an elementary virtual training system for manual assembly. *International Journal of Production Research*, *55*(24), 7496–7508. https://doi.org/10.1080/00207543.2017.1374572

Hollan, J., Hutchins, E., & Kirsh, D. (n.d.). Distributed cognition: Toward a new foundation for human-computer interaction research. ACM Trans. Comput. Hum. Interact. *AMC Trans.Comput. Hum. Interact.*, *7*, 174–196. https://doi.org/doi: 10.1145/353485.353487

Hossain, M. M., Ballard, V. L., O'Leary, D., Purdy, G., & Sesek, R. F. (In Press). Exploring the Integration Effect of Lean and Industry 4.0: A Case Study. *TBA*.

Hossain, M. M., & Purdy, G. (2023). Integration of Industry 4.0 into Lean Production systems: A systematic literature review. *Manufacturing Letters*, *51st SME North American Manufacturing Research Conference (NAMRC 51, 2023)*.

Hossain, Md. M. (2024). *Integration of Lean and Industry 4.0 for Smart Manufacturing* [PhD Dissertation]. Auburn University.

Javaid, M., Haleem, A., Singh, R. P., Rab, S., & Suman, R. (2022). Exploring impact and features of machine vision for progressive industry 4.0 culture. *Sensors International*, *3*, 100132. https://doi.org/10.1016/j.sintl.2021.100132

Jia, J. (2009). A Machine Vision Application for Industrial Assembly Inspection. *2009 Second International Conference on Machine Vision*, 172–176. https://doi.org/10.1109/ICMV.2009.51

Johansson, G., Hofsten, C., & Jansson, G. (n.d.). Event perception. *Annual Review of Psychology*, *31*, 27–63. https://doi.org/10.1146/annurev.ps.31.020180.000331

Kaplan, A. D., Cruit, J., Endsley, M., Beers, S. M., Sawyer, B. D., & Hancock, P. A. (2020). The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis. *HUMAN FACTORS*. https://doi.org/10.1177/0018720820904229

Keshav Kolla, S. S. V., Sanchez, A., & Plapper, P. (2021). Comparing software frameworks of Augmented Reality solutions for manufacturing. *Procedia*

Manufacturing, *55*, 312–318. https://doi.org/10.1016/j.promfg.2021.10.044
Kessler, R. C., Adler, L. A., Gruber, M. J., Sarawate, C. A., Spencer, T., & Van Brunt, D. L. (2007). Validity of the World Health Organization Adult ADHD Self-Report Scale (ASRS) Screener in a representative sample of health plan members. *International Journal of Methods in Psychiatric Research*, *16*(2), 52–65. https://doi.org/10.1002/mpr.208
Kessler, R. C., Adler, L., Ames, M., Barkley, R. A., Birnbaum, H., Greenberg, P., Johnston, J. A., Spencer, T., & ??st??n, T. B. (2005). The Prevalence and Effects of Adult Attention Deficit/Hyperactivity Disorder on Work Performance in a Nationally Representative Sample of Workers: *Journal of Occupational and Environmental Medicine*, *47*(6), 565–572. https://doi.org/10.1097/01.jom.0000166863.33541.39
Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M. J., Jin, R., Secnik, K., Spencer, T., Ustun, T. B., & Walters, E. E. (2005). The World Health Organization adult ADHD self-report scale (ASRS): A short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256. https://doi.org/10.1017/S0033291704002892
Kessler, R. C., Lane, M., Stang, P. E., & Brunt, D. L. V. (2009). The prevalence and workplace costs of adult attention deficit hyperactivity disorder in a large manufacturing firm. *Psychological Medicine*, *39*(1), 137–147. https://doi.org/10.1017/S0033291708003309
Khan, M. H., Grabarski, M. K., Ali, M., & Buckmaster, S. (2022). Insights into Creating and Managing an Inclusive Neurodiverse Workplace for Positive Outcomes: A Multistaged Theoretical Framework. *Group & Organization Management*, 10596011221133583. https://doi.org/10.1177/10596011221133583
Kia, K., Hwang, J., Kim, I.-S., Ishak, H., & Kim, J. H. (2021). The effects of target size and error rate on the cognitive demand and stress during augmented reality interactions. *APPLIED ERGONOMICS*, *97*, 103502. https://doi.org/10.1016/j.apergo.2021.103502
Klug, B. (2017). An Overview of the System Usability Scale in Library Website and System Usability Testing. *Weave: Journal of Library User Experience*, *1*(6). https://doi.org/10.3998/weave.12535642.0001.602
Kumar, N., & Lee, S. C. (2022). Human-machine interface in smart factory: A systematic literature review. *Technological Forecasting and Social Change*, *174*, 121284. https://doi.org/10.1016/j.techfore.2021.121284
Küpper, T., Haavik, J., Drexler, H., Ramos-Quiroga, J. A., Wermelskirchen, D., Prutz, C., & Schauble, B. (2012). The negative impact of attention-deficit/hyperactivity disorder on occupational health in adults and adolescents. *International Archives of Occupational and Environmental Health*, *85*(8), 837–847. https://doi.org/10.1007/s00420-012-0794-0
Laviola, E., Gattullo, M., Evangelista, A., Fiorentino, M., & Uva, A. E. (2023). In-situ or side-by-side? A user study on augmented reality maintenance instructions in blind areas. *Computers in Industry*, *144*, N.PAG-N.PAG. https://doi.org/10.1016/j.compind.2022.103795
LeFevre-Levy, R., Melson-Silimon, A., Harmata, R., Hulett, A. L., & Carter, N. T. (2022). Neurodiversity in the Workplace: Considering Neuroatypicality as a Form

of Diversity. *In Press*.
Levi, R., Ridberg, R., Akers, M., & Seligman, H. (2022). Survey fraud and the integrity of web-based survey research. *American Journal of Health Promotion*, *36*(1), 18–20. https://doi.org/10.1177/08901171211037531
Lewis, J. R. (2018). The System Usability Scale: Past, Present, and Future. *International Journal of Human–Computer Interaction*, *34*(7), 577–590. https://doi.org/10.1080/10447318.2018.1455307
Lewis, J. R., & Sauro, J. (2018). Item Benchmarks for the System Usability Scale—JUX. *JUX - The Journal of User Experience*, *13*(3), 158–167.
Liebowitz, M. R. (1987). *Liebowitz Social Anxiety Scale*. Psychology Tools. https://psychology-tools.com/liebowitz-social-anxiety-scale/
Lindblom, J., & Thorvald, P. (2017). Manufacturing in the wild – viewing human-based assembly through the lens of distributed cognition. *Production & Manufacturing Research*, *5*(1), 57–80. https://doi.org/10.1080/21693277.2017.1322540
Longo, L., Wickens, C. D., Hancock, G., & Hancock, P. A. (2022). Human Mental Workload: A Survey and a Novel Inclusive Definition. *Frontiers in Psychology*, *13*. https://www.frontiersin.org/articles/10.3389/fpsyg.2022.883321
Lorenz, M., Knopp, S., & Klimant, P. (2018). Industrial Augmented Reality: Requirements for an Augmented Reality Maintenance Worker Support System. *2018 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 151–153. https://doi.org/10.1109/ISMAR-Adjunct.2018.00055
Lovreglio, R. (2018, June 5). *A Review of Augmented Reality Applications for Building Evacuation*.
Malik, A. A., & Bilberg, A. (2019). Human centered Lean automation in assembly. *Procedia CIRP*, *81*, 659–664. https://doi.org/10.1016/j.procir.2019.03.172
Manghisi, V. M., Martellotta, F., Evangelista, A., Giliberti, C., Mariconte, R., Diano, M., Galasso, V., & Uva, A. E. (2022). Investigating the Effects on User Performance and Perceived Workload of Environmental Noise in Immersive Virtual Reality. *2022 IEEE International Conference on Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE), Metrology for Extended Reality, Artificial Intelligence and Neural Engineering (MetroXRAINE), 2022 IEEE International Conference On*, 46–51. https://doi.org/10.1109/MetroXRAINE54828.2022.9967541
Mark, G., Czerwinski, M., & Iqbal, S. T. (2018). Effects of individual differences in blocking workplace distractions. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–12.
Masood, T., & Egger, J. (2020). Adopting augmented reality in the age of industrial digitalisation. *Computers in Industry*, *115*, 103112. https://doi.org/10.1016/j.compind.2019.07.002
McConner, CDE, PhD, M. "MJ." (2023, June 28). *Neurodiversity in the Workplace*.
Mennin, D. S., Fresco, D. M., Heimberg, R. G., Schneier, F. R., Davies, S. O., & Liebowitz, M. R. (2002). Screening for social anxiety disorder in the clinical setting: Using the Liebowitz Social Anxiety Scale. *Journal of Anxiety Disorders*, *16*(6), 661–673. https://doi.org/10.1016/S0887-6185(02)00134-2
Menon, V., & Muraleedharan, A. (2020). Internet-based surveys: Relevance, methodological considerations and troubleshooting strategies. *General*

Psychiatry, *33*(5), e100264. https://doi.org/10.1136/gpsych-2020-100264
Miles, R. (2012). An Introduction to the Kinect Sensor | Microsoft Press Store. In *Start Here! Learn the Kinect API* (1st ed., p. 272). Pearson, Microsoft Press. https://www.microsoftpressstore.com/articles/article.aspx?p=2201646
Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2022). Manufacturing personnel task allocation taking into consideration skills and remote guidance based on augmented reality and intelligent decision making. *International Journal of Computer Integrated Manufacturing*, *0*(0), 1–16. https://doi.org/10.1080/0951192X.2022.2078513
Mourtzis, D., Siatras, V., & Angelopoulos, J. (2020). Real-Time Remote Maintenance Support Based on Augmented Reality (AR). *Applied Sciences*, *10*(5), Article 5. https://doi.org/10.3390/app10051855
Nagata, M., Nagata, T., Inoue, A., Mori, K., & Matsuda, S. (2019a). Effect Modification by Attention Deficit Hyperactivity Disorder (ADHD) Symptoms on the Association of Psychosocial Work Environments With Psychological Distress and Work Engagement. *Frontiers in Psychiatry*, *10*, 166. https://doi.org/10.3389/fpsyt.2019.00166
Nagata, M., Nagata, T., Inoue, A., Mori, K., & Matsuda, S. (2019b). Effect Modification by Attention Deficit Hyperactivity Disorder (ADHD) Symptoms on the Association of Psychosocial Work Environments With Psychological Distress and Work Engagement. *Frontiers in Psychiatry*, *10*, 166. https://doi.org/10.3389/fpsyt.2019.00166
National Safety Council. (2023a, July 19). *Industry Profiles*. Injury Facts. https://injuryfacts.nsc.org/work/industry-incidence-rates/industry-profiles/
National Safety Council. (2023b, July 19). *Work Injury Costs*. NSC Injury Facts. https://injuryfacts.nsc.org/work/costs/work-injury-costs/
Nyden, A., Niklasson, L., Stahlberg, O., Anckarsater, H., Wentz, E., Rastam, M., & Gillberg, C. (2010). Adults with Autism Spectrum Disorders and ADHD Neuropsychological Aspects. *Research in Developmental Disabilities: A Multidisciplinary Journal*, *31*(6), 1659–1668. https://doi.org/10.1016/j.ridd.2010.04.010
O'Leary, D. J. (In Press). *Augmented vs. Traditional Instruction in Manufacturing Assembly: An Affordance-Based, Multi-Modal Assessment of Learning, Recall, and Retention* [Dissertation]. Auburn University.
Oscarsson, M., Nelson, M., Rozental, A., Ginsberg, Y., Carlbring, P., & Jönsson, F. (2022). Stress and work-related mental illness among working adults with ADHD: A qualitative study. *BMC Psychiatry*, *22*(1), 1–11. https://doi.org/10.1186/s12888-022-04409-w
Pignoni, G., & Komandur, S. (2019). *Development of a Quantitative Evaluation Tool of Cognitive Workload in Field Studies Through Eye Tracking* (pp. 106–122). https://doi.org/10.1007/978-3-030-22507-0_9
Qeshmy, D. E., Makdisi, J., Ribeiro da Silva, E. H. D., & Angelis, J. (2019). Managing Human Errors: Augmented Reality systems as a tool in the quality journey. *Procedia Manufacturing*, *28*, 24–30. https://doi.org/10.1016/j.promfg.2018.12.005
Qualtrics. (2024). *Fraud Detection*. https://www.qualtrics.com/support/survey-

platform/survey-module/survey-checker/fraud-detection/
Ramsay, J. R. (2010). Career counseling and workplace support. In *Nonmedication treatments for adult ADHD: Evaluating impact on daily functioning and well-being.* (2009-08919-004; pp. 77–90). American Psychological Association. https://doi.org/10.1037/12056-004
Rasmussen, J. (1983). Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *IEEE Transactions on Systems, Man, and Cybernetics*, *SMC-13*(3), 257–266. IEEE Transactions on Systems, Man, and Cybernetics. https://doi.org/10.1109/TSMC.1983.6313160
Reljić, V., Milenković, I., Dudić, S., Šulc, J., & Bajči, B. (2021). Augmented Reality Applications in Industry 4.0 Environment. *Applied Sciences*, *11*(12), Article 12. https://doi.org/10.3390/app11125592
Ren, Z., Fang, F., Yan, N., & Wu, Y. (2022). State of the Art in Defect Detection Based on Machine Vision. *International Journal of Precision Engineering and Manufacturing-Green Technology*, *9*(2), 661–691. https://doi.org/10.1007/s40684-021-00343-6
Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2020). Impacts of Industry 4.0 technologies on Lean principles. *International Journal of Production Research*, *58*(6), Article 6. https://doi.org/10.1080/00207543.2019.1672902
Rytwinski, N. K., Fresco, D. M., Heimberg, R. G., Coles, M. E., Liebowitz, M. R., Cissell, S., Stein, M. B., & Hofmann, S. G. (2009). Screening for social anxiety disorder with the self-report version of the Liebowitz Social Anxiety Scale. *Depression & Anxiety (1091-4269)*, *26*(1), 34–38. https://doi.org/10.1002/da.20503
Saurin, T. A., Ribeiro, J. L. D., & Vidor, G. (2012). A framework for assessing poka-yoke devices. *Journal of Manufacturing Systems*, *31*(3), Article 3. https://doi.org/10.1016/j.jmsy.2012.04.001
Schreiber, J. E., Possin, K. L., Girard, J. M., & Rey-Casserly, C. (2014). Executive Function in Children with Attention Deficit/Hyperactivity Disorder: The NIH EXAMINER Battery. *Journal of the International Neuropsychological Society*, *20*(1), 41–51. https://doi.org/10.1017/S1355617713001100
Schwarzer, R. (2012). *The General Self-Efficacy Scale (GSE)*. 1–4.
Scurati, G. W., Gattullo, M., Fiorentino, M., Ferrise, F., Bordegoni, M., & Uva, A. E. (2018). Converting maintenance actions into standard symbols for Augmented Reality applications in Industry 4.0. *Computers in Industry*, *98*, 68–79. https://doi.org/10.1016/j.compind.2018.02.001
Simon, H. (1978). Information-processing theory of human problem solving. In *Handbook of learning and cognitive processes* (pp. 271–295).
So, P. (2020, December 15). *NASA TLX Task Load Index*. NASA TLX Task Load Index. https://humansystems.arc.nasa.gov/groups/TLX/tlxpaperpencil.php
Stanton, K., Forbes, M. K., & Zimmerman, M. (2018). Distinct dimensions defining the Adult ADHD Self-Report Scale: Implications for assessing inattentive and hyperactive/impulsive symptoms. *Psychological Assessment*, *30*(12), 1549–1559. https://doi.org/10.1037/pas0000604
Stanton, N. (1995). Ecological ergonomics: Understanding human action in context. *Contemporary Ergonomics*, *165*, 62.

Stork, S., & Schubö, A. (2010a). Cognition in Manual Assembly. *KI - Künstliche Intelligenz*, *24*(4), 305–309. https://doi.org/10.1007/s13218-010-0054-y

Stork, S., & Schubö, A. (2010b). Human cognition in manual assembly: Theories and applications. *Advanced Engineering Informatics*, *24*(3), 320–328. https://doi.org/10.1016/j.aei.2010.05.010

Storozuk, A., Ashley, M., Delage, V., & Maloney, E. A. (2020). Got Bots? Practical Recommendations to Protect Online Survey Data from Bot Attacks. *The Quantataive Methods for Psychology*, *16*(5), 472–481.

Suzuki, T., Wada, K., Nakazato, M., Ohtani, T., Yamazaki, M., & Ikeda, S. (2023). Associations Between Adult Attention-Deficit/Hyperactivity Disorder (ADHD) Traits and Sociodemographic Characteristics in Japanese Workers. *Neuropsychiatric Disease and Treatment*, *19*, 759–773. https://doi.org/10.2147/NDT.S398478

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, *12*(2), 257–285. https://doi.org/10.1016/0364-0213(88)90023-7

Sweller, J. (2011). CHAPTER TWO - Cognitive Load Theory. In J. P. Mestre & B. H. Ross (Eds.), *Psychology of Learning and Motivation* (Vol. 55, pp. 37–76). Academic Press. https://doi.org/10.1016/B978-0-12-387691-1.00002-8

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*. https://doi.org/doi: 10.5116/ijme.4dfb.8dfd

Teitcher, J. E. F., Bockting, W. O., Bauermeister, J. A., Hoefer, C. J., Miner, M. H., & Klitzman, R. L. (2015). Detecting, preventing, and responding to "fraudsters" in internet research: Ethics and tradeoffs. *The Journal of Law, Medicine & Ethics: A Journal of the American Society of Law, Medicine & Ethics*, *43*(1), 116–133. https://doi.org/10.1111/jlme.12200

Thorvald, P., Lindblom, J., & Andreasson, R. (2019). On the development of a method for cognitive load assessment in manufacturing. *Robotics and Computer-Integrated Manufacturing*, *59*, 252–266. https://doi.org/10.1016/j.rcim.2019.04.012

Torres, Y., Nadeau, S., & Landau, K. (2021). Evaluation of Fatigue and Workload among Workers Conducting Complex Manual Assembly in Manufacturing. *IISE Transactions on Occupational Ergonomics and Human Factors*, *9*(1), 49–63.

Uva, A. E., Gattullo, M., Manghisi, V. M., Spagnulo, D., Cascella, G. L., & Fiorentino, M. (2018). Evaluating the effectiveness of spatial augmented reality in smart manufacturing: A solution for manual working stations. *The International Journal of Advanced Manufacturing Technology*, *94*(1), 509–521. https://doi.org/10.1007/s00170-017-0846-4

UX Principles that include Cognitive Accessibility. (2022). https://www.ab11y.com/articles/ux-principles-that-include-cognitive-accessibility/

van Lopik, K., Sinclair, M., Sharpe, R., Conway, P., & West, A. (2020). Developing augmented reality capabilities for industry 4.0 small enterprises: Lessons learnt from a content authoring case study. *Computers in Industry*, *117*, 103208. https://doi.org/10.1016/j.compind.2020.103208

Vanneste, P., Huang, Y., Park, J. Y., Cornillie, F., Decloedt, B., & Van den Noortgate, W. (2020). Cognitive support for assembly operations by means of augmented

reality: An exploratory study. *International Journal of Human-Computer Studies*, *143*, 102480. https://doi.org/10.1016/j.ijhcs.2020.102480

Vélaz, Y., Rodríguez Arce, J., Gutiérrez, T., Lozano-Rodero, A., & Suescun, A. (2014). The Influence of Interaction Technology on the Learning of Assembly Tasks Using Virtual Reality. *Journal of Computing and Information Science in Engineering*, *14*(041007). https://doi.org/10.1115/1.4028588

Volmer, B., Baumeister, J., Von Itzstein, S., Bornkessel-Schlesewsky, I., Schlesewsky, M., Billinghurst, M., & Thomas, B. H. (2018). A Comparison of Predictive Spatial Augmented Reality Cues for Procedural Tasks. *IEEE Transactions on Visualization and Computer Graphics*, *24*(11), 2846–2856. IEEE Transactions on Visualization and Computer Graphics. https://doi.org/10.1109/TVCG.2018.2868587

Vygotsky, L. S. (1980). *Mind in Society: Development of Higher Psychological Processes* (M. Cole, V. John-Steiner, S. Scribner, & E. Souberman, Eds.). Harvard University Press.

Waite, R., Buchanan, T., & Leahy, M. (2022a). Assessing ADHD Symptoms among Young Adults in the University with the ASRS v1.1: Examining Associations with Social Anxiety and Self-Efficacy. *International Journal of Disability, Development & Education*, *69*(5), 1631–1644. https://doi.org/10.1080/1034912X.2020.1825643

Waite, R., Buchanan, T., & Leahy, M. (2022b). Assessing ADHD Symptoms among Young Adults in the University with the ASRS v1.1: Examining Associations with Social Anxiety and Self-Efficacy. *International Journal of Disability, Development and Education*, *69*(5), 1631–1644. https://doi.org/10.1080/1034912X.2020.1825643

Wang, C.-H., Lo, W.-J., & Wang, M.-J. J. (2022). Usability evaluation of augmented reality-based maintenance instruction system. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *32*(3), 239–255. https://doi.org/10.1002/hfm.20942

Wang, Z., Bai, X., Zhang, S., Billinghurst, M., He, W., Wang, P., Lan, W., Min, H., & Chen, Y. (2022). A comprehensive review of augmented reality-based instruction in manual assembly, training and repair. *Robotics and Computer-Integrated Manufacturing*, *78*, 102407. https://doi.org/10.1016/j.rcim.2022.102407

Weber, C., Krieger, B., Häne, E., Yarker, J., & McDowall, A. (2021). Physical workplace adjustments to support neurodivergent workers: A systematic review. *Applied Psychology*, *n/a*(n/a). https://doi.org/10.1111/apps.12431

What is Poka-Yoke? Mistake & Error Proofing | ASQ. (2022, June 17). https://asq.org/quality-resources/mistake-proofing

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159–177. https://doi.org/10.1080/14639220210123806

Wickens, C. D., & Carswell, C. M. (2021). Information processing. *Handbook of Human Factors and Ergonomics*, 114–158.

Widjajanto, S., Purba, H. H., & Jaqin, S. C. (2020). Novel POKA-YOKE approaching toward industry-4.0: A literature review. *Operational Research in Engineering Sciences: Theory and Applications*, *3*(3), Article 3.

https://doi.org/10.31181/oresta20303065w
Womack, J. P. (2007). *The machine that changed the world: The story of lean production--Toyota's secret weapon in the global car wars that is revolutionizing world industry* (Auburn RBD Library (2nd Floor) HD 9710 .J32 W66 2007; 1st Free Press trade pbk. ed.). Free Press.
Yang, Y., Karreman, J., & de Jong, M. (2020). Comparing the Effects of Paper and Mobile Augmented Reality Instructions to Guide Assembly Tasks. *2020 IEEE International Professional Communication Conference (ProComm), Professional Communication Conference (ProComm), 2020 IEEE International*, 96–104. https://doi.org/10.1109/ProComm48883.2020.00021
Yiyuan, Z., Tangwen, Y., Dayong, D., & Shan, F. (2011). Using NASA-TLX to evaluate the flight deck design in Design Phase of Aircraft. *Procedia Engineering*, *17*, 77–83. https://doi.org/10.1016/j.proeng.2011.10.010
Young, M. S., & Stanton, N. A. (2002). Malleable attentional resources theory: A new explanation for the effects of mental underload on performance. *Human Factors*, *44*(3), 365–375. https://doi.org/10.1518/0018720024497709
Zajonc, R. B. (1984). The interaction of affect and cognition. *Approaches Emotion*, *239*, 246.
Zaloshnja, E., Miller, T. R., & Waehrer, G. (2006). The impact of occupational injury reduction on the U.S. economy. *American Journal of Industrial Medicine*, *49*(9), 719–727. https://doi.org/10.1002/ajim.20353
Zandin, K. B. (2002). *M.O.S.T.(R) – Work Measurement Systems* (3rd ed.). CRC Press.

Appendix A: Standardized Assessment Tools and Questionnaires

A.1 NASA Task Load Index (NASA TLX)

Task Loading Index, p1 / 2

Participant #: _____ **Invest / Treat:** _____ **Date:** _____

Sources of Workload

Consider the following definitions:

Title	Range	Description
Mental Demand	Low / High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low / High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experiment (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

For each of the following pairs, circle the word that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

Effort or **Performance**	**Temporal Demand** or **Frustration**	**Physical Demand** or **Performance**	**Temporal Demand** or **Mental Demand**	**Mental Demand** or **Physical Demand**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**	**Frustration** or **Effort**	**Performance** or **Mental Demand**	**Effort** or **Physical Demand**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**	**Performance** or **Temporal Demand**	**Mental Demand** or **Effort**	**Frustration** or **Mental Demand**

Task Loading Index, p2 / 2

Participant #: _____ Invest / Treat: _____ Date: _____

Workload Rating Sheet

For each of the following 6 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

1. How mentally demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

2. How physically demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

3. How hurried or rushed was the pace of the task?

1	2	3	4	5	6	7
Very Low						Very High

4. How successful were you in accomplishing what you were asked to do?

1	2	3	4	5	6	7
Perfect						Failure

5. How hard did you have to work to accomplish your level of performance?

1	2	3	4	5	6	7
Very Low						Very High

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1	2	3	4	5	6	7
Very Low						Very High

A.2 Adult ADHD Self-Report Scale (ASRS-V1.1)

Behavioral Control Survey

Participant #: _____ **Date:** _____

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					

A.3 System Usability Scale (SUS)

System Usability Scale

Participant #: _____ **Invest / Treat:** _____ **Date:** _____

For each of the following 10 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

		Strongly Agree				Strongly Disagree
1	I think that I would like to use this system frequently.	1	2	3	4	5
2	I found the system unnecessarily complex.	1	2	3	4	5
3	I thought the system was easy to use.	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5	I found the various functions in this system were well integrated.	1	2	3	4	5
6	I thought there was too much inconsistency in this system.	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8	I found the system very cumbersome to use.	1	2	3	4	5
9	I felt very confident using the system.	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

A.4 Liebowitz Social Anxiety Scale (LSAS)

Below, the full LSAS scale is pictured. The survey asked participants a portion of these questions (2, 5, 6, 8, 10, 15, 16, 18). Each question was scaled for the following:

- How anxious or fearful do you feel in the situation?
- How often do you avoid the situation?

Liebowitz Social Anxiety Scale Liebowitz MR. Social Phobia. Mod Probl Pharmacopsychiatry 1987;22:141-173

Pt Name:		Pt ID #:
Date:	Clinic #:	Assessment point:

Fear or Anxiety:
0 = None
1 = Mild
2 = Moderate
3 = Severe

Avoidance:
0 = Never (0%)
1 = Occasionally (1—33%)
2 = Often (33—67%)
3 = Usually (67—100%)

	Fear or Anxiety	Avoidance	
1. Telephoning in public. (P)			1.
2. Participating in small groups. (P)			2.
3. Eating in public places. (P)			3.
4. Drinking with others in public places. (P)			4.
5. Talking to people in authority. (S)			5.
6. Acting, performing or giving a talk in front of an audience. (P)			6.
7. Going to a party. (S)			7.
8. Working while being observed. (P)			8.
9. Writing while being observed. (P)			9.
10. Calling someone you don't know very well. (S)			10.
11. Talking with people you don't know very well. (S)			11.
12. Meeting strangers. (S)			12.
13. Urinating in a public bathroom. (P)			13.
14. Entering a room when others are already seated. (P)			14.
15. Being the center of attention. (S)			*15.*
16. Speaking up at a meeting. (P)			16.
17. Taking a test. (P)			17.
18. Expressing a disagreement or disapproval to people you don't know very well. (S)			18.
19. Looking at people you don't know very well in the eyes. (S)			19.
20. Giving a report to a group. (P)			20.
21. Trying to pick up someone. (P)			21.
22. Returning goods to a store. (S)			22.
23. Giving a party. (S)			23.
24. Resisting a high pressure salesperson. (S)			24.

A.5 General Self-Efficacy Scale (GPSES)

The full GPSES is shown below. A subset of questions was used in the survey (4, 5, 7, 8, 10). Participants are asked to "Indicate the extent to which each item applies to you".

General Self-Efficacy Scale (GSE)

	Not at all true	Hardly true	Moderately true	Exactly true
1. I can always manage to solve difficult problems if I try hard enough	☐	☐	☐	☐
2. If someone opposes me, I can find the means and ways to get what I want.	☐	☐	☐	☐
3. It is easy for me to stick to my aims and accomplish my goals.	☐	☐	☐	☐
4. I am confident that I could deal efficiently with unexpected events.	☐	☐	☐	☐
5. Thanks to my resourcefulness, I know how to handle unforeseen situations.	☐	☐	☐	☐
6. I can solve most problems if I invest the necessary effort.	☐	☐	☐	☐
7. I can remain calm when facing difficulties because I can rely on my coping abilities.	☐	☐	☐	☐
8. When I am confronted with a problem, I can usually find several solutions.	☐	☐	☐	☐
9. If I am in trouble, I can usually think of a solution	☐	☐	☐	☐
10. I can usually handle whatever comes my way.	☐	☐	☐	☐

Appendix B: Workplace Technology Support Investigation (Chapter 3) Supplements

B.1 Pilot Study Augmented Reality Effects on Performance and Quality

A pilot study comparing the use of the PBAR and PWI with a small number of students and faculty informed the use of the technology for in-person and online classroom use. However, the insights from the pilot study also informed the experimental design of future human subjects' research in this space.

As a Teaching Assistant in the Tiger Motors Lean Education Center, I conducted a pilot study, which was submitted to the Auburn University Human Research Protection Program with the following description:

> We wish to evaluate the implementation strategies of the Light Guide Augmented Reality System (a projection and camera system) to determine the best method to incorporate this technology into our curriculum for the campus and online courses. This system is used to train people on how to build the Lego™ cars at that station by projecting lights onto the work area to indicate the location and order of the parts to be assembled. This and similar devices are in common use in industry and we want to familiarize students with this technology in laboratory exercises. This does not fundamentally change the physical nature of the tasks students perform in these labs (i.e., building lego cars). (Appendix E.1)

The response from Sally Headley, Manager, Human Research Protection Program, was as follows:

> Based on information shared during yesterday's telephone conversation and confirmed in your email (below), the described activities meet the criteria for a determination of Not Human Subjects Research (NHSR). No further action is required by the AU IRB. (Appendix E.1)

B.11 Pilot Study: Participants and Procedure

The pilot study involved current Lean Teaching Assistants and Faculty ("participants") building the SUV model of LEGO® car at the eighth station of the assembly line. Eight participants, aged 22 to 65, were invited for this investigation, which was classified as "Not Human Subjects Research (NHSR)" by the Auburn University

Human Research Protection Program on June 17, 2022 (Appendix E.1).

Each participant was introduced to the station and allowed to familiarize themselves with the posted paper instructions and parts locations. Participants built ten cars using Paper Work Instructions only (PWI) and ten cars using both the PWI and the Projection-Based Augmented Reality (PBAR) system, with the order of treatments randomized.

The PBAR system projects the assembly steps onto the workstation, indicating the parts' locations in the bins with lights and highlighting where to place the parts on the assembly. In training mode, used for this experiment, participants must click “next” or step on a floor pedal to advance to the next step. In production mode, the system auto-advances based on sensing part placement.

Participants were observed completing the task, with errors noted and completion times recorded. Qualitative notes were taken on participant comments, compliance with work instructions, difficulties encountered, and frequency of referencing the posted instructions. Completion time was measured with a stopwatch, and errors were noted through visual analysis after task completion.

B.12 Pilot Study: Research Question

Does the use of Projection-Based Augmented Reality (PBAR) for manufacturing station support affect productivity, quality, and compliance with work instructions compared to traditional PWI in a classroom-simulated manufacturing environment?

B.1.3 Pilot Study: Specific Aims

The pilot study investigated how a projection-based AR system can be best implemented into Tiger Motors to standardize procedures and reduce mistakes without negatively impacting throughput.

B.1.4 Pilot Study: Hypotheses

a. Expect a quality increase for PBAR compared to PWI.
b. Expect an increase in production time for PBAR compared to PWI.
c. Expect increased compliance with standard procedure with PBAR

compared with PWI.

B.1.5 Pilot Study: Variables

The study assessed the implementation of the PBAR system by measuring the time required to complete vehicle assembly at station eight, the number of errors, and the qualitative recording of comments and behaviors. Completion time was measured with a stopwatch, and errors were noted through visual analysis after task completion.

B.1.6 Pilot Study: Results

Without separating the order of treatments (PWI only first or PBAR first), there was a significant difference in the time required to complete one vehicle: PWI only averaged 63 seconds, while PBAR averaged 74 seconds. Figure 13 presents a boxplot showing the distribution of completion times for each guidance method.

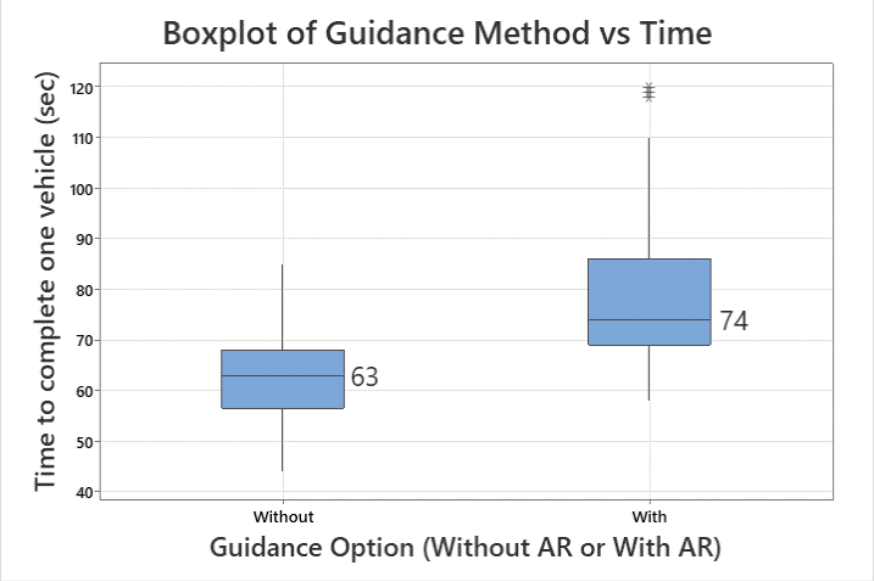


Figure 68: Pilot Study: Boxplot of Guidance Method vs Time

B.1.6.1 Completion Time

All participants took longer to complete the assembly with the PBAR system compared to PWI, regardless of whether they used PBAR first or second. On average, participants using the PBAR system took 11 seconds longer than when using PWI. The

range of completion times was also greater with PBAR (60 seconds) compared to PWI (45 seconds).

B.1.6.2 Error Rates

The number of errors made during assembly was significantly lower with the PBAR system (quality increased). Participants using PWI made up to six errors per car out of sixteen parts. In contrast, participants using PBAR made almost no errors, except for three cars where additional parts were placed due to incomplete station resets. The most common errors with PWI involved misplacement of similarly shaped and colored pieces, which were difficult to distinguish in the paper instructions. Figure 14 shows a dot plot of the number of correctly placed parts per car for each guidance method.

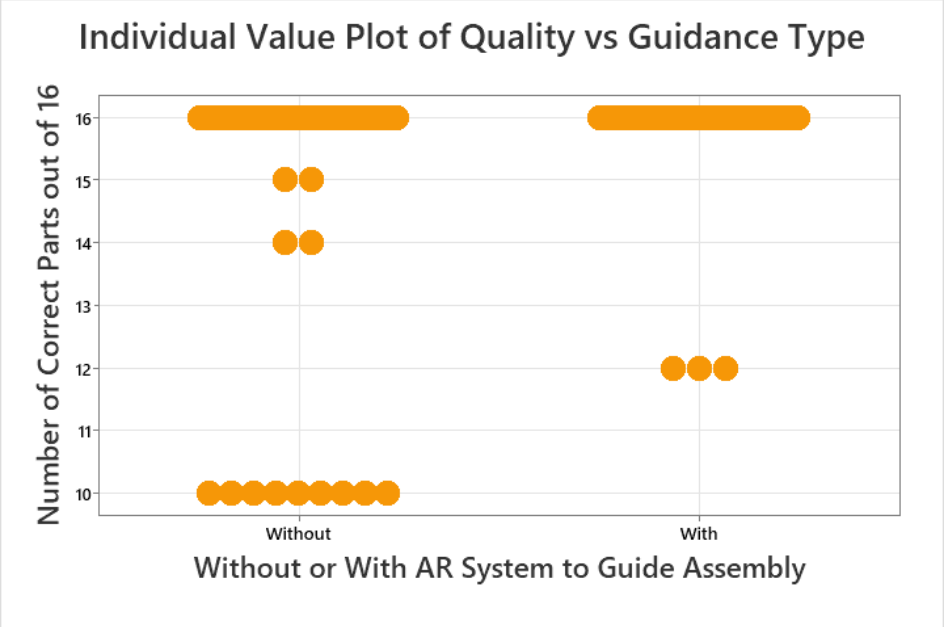


Figure 69: Pilot Study: Dot pot of Individual Plot of Quality vs Guidance Type.

Dividing the groups by which treatment they did first, there were no statistical differences in whether the participants did the AR treatment first or second in the outcomes for the AR treatments ($p = 0.717$). However, with the PWI treatment, there was a very significant difference if the participant did the PBAR first or second when doing the PWI treatment. The quality of their AR trial was significantly improved if the participant had undergone the AR treatment first. The average quality measure went from 14.12 parts/16 correct on average if they did the PWI first to 15.85 parts/16 correct on

average if they did the AR first. This statistically significant result was significant at the $p<0.001$ level, confirmed group differences by the Tukey Pairwise Comparison and Fisher LSD.

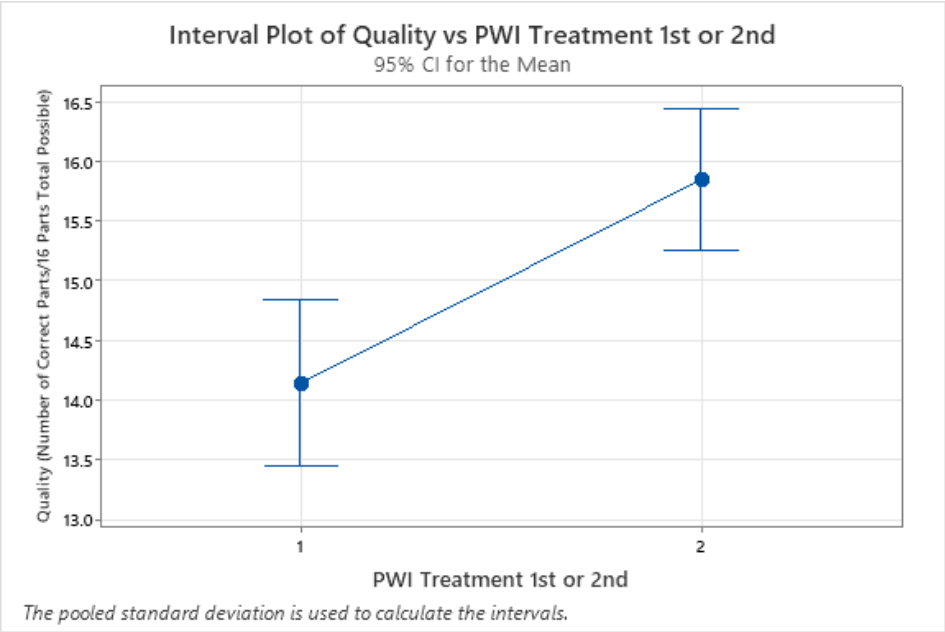


Figure 70: Interval Plot of Quality vs PWI Treatment Order

B.1.6.3 Compliance

Compliance with the standard order of steps was notably higher with PBAR. All participants followed the prescribed order of steps with PBAR, whereas, with PWI, participants frequently deviated from the standard sequence.

B.1.6.4 Participant Feedback

Participants expressed frustration with the PBAR system due to its slower operation and occasional technical issues. This frustration was more pronounced among older participants. Qualitative feedback highlighted difficulties with the AR system's responsiveness and the added cognitive load of managing the system interface.

B.1.6.5 Qualitative Observations

- Greater Time with AR: Every participant took longer to complete the 16 steps with the AR system compared to PWI, regardless of the order in which they used the methods.
- Compliance Improvement: The AR system led to greater compliance with the standard order of steps during assembly.
- Quality Improvement: The AR system significantly improved assembly quality, reducing the number of mistakes, although it introduced a new error type in some cases.
- Frustration with AR: Operators expressed frustration with the AR system's slower pace and occasional operational issues. This was particularly notable among older participants.

B.1.7 Pilot Study: Conclusions

The purpose of the pilot study was to determine the efficacy of the PBAR system in a simulated manufacturing environment for use in classroom activities, both in-person and online. The findings revealed significant improvements in compliance with work instructions and assembly quality when using the PBAR system compared to traditional PWI. The quality improvements were also shown to carry over from the PBAR system to the PWI treatment if the PBAR system came first in the treatment order. However, the use of PBAR also resulted in longer completion times and introduced a new type of error.

B.1.7.1 Key Conclusions

- Enhanced Compliance: PBAR effectively improved compliance with the prescribed assembly steps, ensuring that all participants followed the standard order. This indicates that AR systems can be valuable tools for standardizing procedures in training environments.
- Improved Quality: The reduction in assembly errors with PBAR suggests that AR systems can enhance the accuracy of tasks involving complex or similar-looking components. This finding is particularly relevant for industrial applications where precision is critical.

- Increased Completion Time: The longer completion times observed with PBAR highlight a trade-off between quality and productivity. While AR systems can improve task accuracy and compliance, they may also introduce delays due to the need for users to interact with the system interface. This trade-off needs to be carefully managed in real-world applications.
- Usability Challenges: The frustration expressed by participants, particularly older ones, underscores the importance of designing user-friendly AR systems. Future iterations of the PBAR system should focus on improving responsiveness and reducing the cognitive load associated with its use. Training programs should also account for varying levels of user familiarity with technology.
- New Error Types: The introduction of a new error type with PBAR, where participants placed additional parts due to incomplete station resets, suggests that AR systems may require specific procedural adjustments to prevent such issues. This finding highlights the need for thorough testing and refinement of AR-based training protocols.

B.1.7.2 Recommendations for Future Research

- Time Management: To account for the variability in participant performance, future studies should consider limiting the duration of trials rather than the number of assemblies completed. This approach can help plan experimental sessions that remain within a manageable timeframe.
- Participant Training: Providing additional training on the use of AR systems may help mitigate usability challenges and reduce frustration among users. Tailored training programs can address the specific needs of different user groups, including older participants.
- Expanded Study: Conducting a larger-scale study with a more diverse participant pool may provide more comprehensive insights into the efficacy of AR systems in training environments. Such studies could

explore the impact of factors such as participant age, familiarity with technology, and task complexity on the effectiveness of AR systems.

- Technological Improvements: Ongoing development and refinement of AR systems are essential to address usability issues and enhance system performance. Future iterations of the PBAR system should explore methods for improving responsiveness, reducing setup time, and minimizing potential sources of error.

In conclusion, the pilot study demonstrated that PBAR has the potential to significantly enhance training in simulated manufacturing environments by improving compliance and assembly quality. However, the observed increase in completion time and usability challenges must be addressed to realize the benefits of AR technology fully. These findings provide valuable guidance for the design and implementation of AR-based training programs and highlight the importance of user-centered design in developing practical educational tools.

B.2 Manufacturing Technology Support Script

Written by Dan O'Leary with input from Victoria Ballard

The Effects of Augmented Instruction on Manufacturing Assembly Training

Recruiting Procedures

send copy of consent document to eligible participants after screening call with appt information

For both investigations a total of between 70 and 100 subjects will be recruited from the Auburn University community. Between 40 and 60 of those will participate in the first investigation, and 30 to 40 in the second. Potential participants in the first investigation will be screened for exclusion based on the following: 1. Under 18 years of age 2. Prone to motion sickness 3. Prior experience with head-mounted or projected AR systems 4. Prior experience building cars in the Lean Lab as part of INSY 5800/6800 or otherwise. Note that third item does not exclude those having experience with Virtual Reality headsets like the Occulus Rift, which are much more commonly available than AR devices. For the second investigation, any volunteer 18 or older will qualify. A shared screening form will be used for both investigations, and candidates will be assigned to one or both investigation(s) accordingly. Active recruiting efforts will focus on freshman and sophomore engineering students in Industrial & Systems Engineering (ISE), as they are accessible and are likely to meet all requirements.

Students and Faculty will be recruited using flyers distributed around the Auburn University campus. Additionally, ISE students will be recruited via in-class announcements and the distribution of emails. Copies of each are included in Appendix B. Interested participants will be instructed to contact the PI for more information. In the call that follows, the PI will: 1. Briefly explain the investigation, recapping and elaborating on the recruiting materials 2. Explain the exclusion criteria and identify relevant issues for the candidate 3. Set expectations for participant involvement, including time commitment and tasks 4. Answer any questions the candidate has regarding participation in the investigation If the candidate is ready and willing to proceed, their information will be collected using the Subject Recruitment Data Sheet provided in Appendix C. They will be assigned a unique participant ID, the investigation(s) most appropriate for their exclusions, and a date and time for data collection. If interest in either investigation exceeds capacity, additional participants will be thanked for their interest and informed that enrollment is limited. They will be given the option to remain “waitlisted” if additional participants or follow-up studies are required.

- give eligible candidates the option to participate in both investigations
  - schedule both times at intake if so; separate by at least 1 week, I1 first, followed by I2 (note may influence results at pizza party)

Create a schedule of available times with assigned staff. Assign treatments from the [[Random Treatments]] list to those time slots. Schedule qualifying participants to those

time slots based on their availability. In the event of a drop-out or no-show, reallocate skipped treatments to later appointments in order to maintain balance.

Protocol Procedures

Loadout

Checklist

- ☐ batteries
- ☐ memory cards
- ☐ consent forms in lock box
- ☐ packets prepared for each participant
  - ☐ surveys, IC, folder
  - ☐ trial card for each participant
  - ☐ fill out forms with part, date, etc. information
  - ☐ procedure script for assigned trial
- ☐ run details label for overhead folder, etc.
- ☐ snacks and water

0. Initial Setup

Checklist

- ☐ place, reset timers
- ☐ turn on cameras
- ☐ wipe down surfaces and devices
- ☐ streaming setup
- ☐ fixture set up and aligned
- ☐ move pedal out of way
- ☐ double check all 14 prebuilt cars
- ☐ reset station: table setup, bin placement
- ☐ check HL align / tracking
- ☐ secondary review of all checklists
- ☐ stow check piece and starting piece
- ☐ door signage up
- ☐ red and green trays at stations 6-8
- ☐ result tray at station 9
- ☐ photos of setup before each trial, stations 7-9
- ☐ check LG system
- ☐ confirm bin part counts sufficient for 10 cars

- ☐ part 65 x 10
- ☐ part 75 x 10
- ☐ part 59 x 40
- ☐ part 74 x 20
- ☐ part 67 x 20
- ☐ part 88 x 20
- ☐ part 3 x 10
- ☐ part 1 x 30

1. Intake

1. Participant is greeted and ushered into the conference room.
2. Participant is offered drink / snacks.
3. Participant is talked through the consent document. After any questions they have are answered, the participant is asked to acknowledge their understanding and acceptance of it, initial each page, and sign.
4. Participant is assigned to the "next up" treatment from a randomized list constructed before the first trial.
5. Assistant remains in the room while the participant reads the NASA TLX instructions and completes a trial run of that survey. Afterwards, the assistant leaves the room while the participant provides basic demographic information and completes the Behavior Control Survey.
6. Participant is briefed on emergency procedures.
7. Any questions?
8. Participant is offered the opportunity to use the restroom before the experiment commences.
9. Once the research team has signaled their readiness, the participant is escorted to the work cell.

don't discuss details of experiment

Checklist

- ☐ signed consent forms in lock box
- ☐ initial surveys in participant folder
- ☐ secondary review of all checklists
- ☐ check and sign all forms

2. Orientation

Before orientation begins, ensure that the side camera is recording.

> [!quote] Welcome to the Tiger Motors Lean Education Center, affectionately called the Lean Lab or LEGO Lab. As you can see, we use LEGO bricks to simulate a manufacturing environment. The simulation consists of 15 stations that build two

models of LEGO cars from zero parts put together to fully assembled. The work content at each station is designed to be the same for each, approximately 60 seconds per station. This means a fully completed car comes off the line every 60 seconds, just like a full-size car manufacturer such as Toyota. The only difference is a full-size car has thousands of stations instead of 15. When we run this simulation, we impress upon the operators that it is equally important to build quality cars (with no errors) and make them quickly, so the whole line is not held up. The target for the station you are working on today is one quality car per minute.

Checklist

- ☐ secondary review of all checklists

Demonstrations

Questions are allowed throughout this process.

- limit discussion during demonstrations
  - participants free to talk aloud if they wish? not encouraged
  - researchers can answer questions
  - researchers should not prompt or instruct the participants
  - limit dialog, avoid making it conversational
- don't explain the bin order
- pwi on the table

3. Intro (WS7, All)

[!quote] Before you start the experiment we need to introduce you to the process. Here at work station 7 we will demonstrate basic assembly of the Model T, an SUV style car. The each work station shares key features: work surface, part bins, and paper work instructions.

Manufacturing traditionally uses paper work instructions like these. Normally they will be hanging above the bins, but we have it taken it down for easy reference. A sequence of steps is depicted by the arrows. For each step, new pieces are shown in the correct color. Details for the corresponding parts, including the part number and required quantity, are given with an image of the part. At the bottom of the page, you will find a map of the part numbers and bin locations.

I will now demonstrate a few assembly steps. Find the bin containing part number 34. Collect two pieces and affix them to the model as shown. Repeat this process for parts 32, 64, and 89. Once complete, put the car in the green tray.

There are a few other important rules. First, don't chase dropped parts. Just continue working. You are allowed to correct any errors that you notice before a car is placed in the green tray. If the car breaks in a way that requires rework at a prior station, put it in the red tray and begin a new car. If any other issue prevents

you from working, notify the observer and follow their instructions. Otherwise, we can only observe once the experiment begins.

Do you have any questions?

Move the participant to work station 8 and read the section for their assigned treatment.

4A. Paper Work Instructions Demonstration (PWI)

[!quote] We are interested in learning how augmented instructions affect the way that people learn manufacturing assembly processes. For this experiment you will be a member of our control group, using paper work instructions. Those instructions are normally posted above the bins, as you see here at work station 8.

Proceed to donning the HL2.

4B. Projected AR Demonstration (PAR)

Start the LightGuide in production run mode.

[!quote] We are interested in learning how augmented instructions affect the way that people learn manufacturing assembly processes. For this experiment, work instructions projected by the overhead system will guide you through the assembly process at work station 8. Please watch as I demonstrate the system.

Put your hand over the projected SUV "button" to select that option. Next, place the model in the fixture as directed. It must remain in the fixture throughout assembly. The system projects X, Y, and Z onto the work station, along with instructions for the next step. An arrow points to the appropriate bin, which is illuminated green. Grab the parts as directed. The system should automatically advance to the next step, telling you where to place them on the model. The system should automatically advance after each step. If not, or if you need to go back, use the green and red buttons to manually step through the instructions. If you reach into the wrong bin, the system will use red illumination to signal the error.

4C. Head-Mounted Augmented Reality Demonstration (HMDAR)

- how to use the appropriate forward and back triggers
- how the system signals instructions and feedback related to part bin and placement
- model must remain in the fixture
- consider possibility of technical problems and develop mitigation plan
  - HL problems
- HL training?!?!

4D. Head-Mounted Mixed Reality Demonstration (HMDMR)

- the model can be freely manipulated during assembly

5. HoloLens

> [!quote] For the duration of the experiment you will be wearing a head-mounted augmented reality system made by Microsoft, the HoloLens2. Not all participants will utilize it for the assembly tasks, but everyone wears it to control for any effect it might have on your results, and to allow us to record the entire session from your point of view. The entire procedure will also be recorded by a second camera, which is positioned to only capture the work area.

Begin streaming HL2 video. Help the participant put the HL2 on and adjust it. Confirm that the streaming is working correctly.

Checklist

- ☐ participant wearing HL2
- ☐ check video stream
- ☐ secondary review of all checklists

6. Practice

Instruct the participant to complete the first 4 steps of the assembly process using their treatment. Questions are still allowed.

7. Phase 1 - Learning

The hypotheses are then tested in two phases. The first compares the effects of instructional media on the speed (task completion time) and accuracy (number and type of corrected and uncorrected errors) with which participants perform each repetition of the task. These measures are tracked for each assembly completed in the 10-minute session, allowing us to assess learning rates.

In the first phase, participants will be asked to complete the assembly process for as many cars as they can, while learning the steps and limiting the number of errors produced. This phase will be conducted with the support of the assigned IMT and will last 10 minutes. Observations will be recorded on Data Collection Sheet #1. During that time, we expect that each participant will produce between 3 and 6 cars, based on prior performance data and the 60-second takt time for which the instructions were designed. (10 mins)

Participants will not be allowed to ask questions during either data collection phase of the experiment.

- Instructions: participants asked to accurately complete as many cars as they can while learning the steps and limiting the number of errors produced. They are free to correct any errors that they recognize. They have 10 minutes and will use the assigned treatment. No questions are allowed during this phase and no further instruction will be provided unless there are technical issues.
- Support: member(s) of the research team will facilitate the flow of work pieces into the station 7 out-box and out of the station 8. Completed cars will be placed on the results table. At the completion of the task an overhead photo of the results table

will be taken with info card to associate it with the part #, treatment, and investigation / phase.

- Oversight: the PI for this investigation will observe the participant's activity remotely, making notes on the process. Primary data collection will be completed later through analysis of the video recordings.
  - Looking for…
  - Problem / response strategy
- PWI in rack for this and subsequent phases on WS8
- blue taped fixture properly placed for all but treat 4 - velcro
- cars will move from green box of WS7 to work space in WS8 to green box in WS8
  - research assistant will manage flow, adding / removing
- completed cars go into tray, overhead group photo at end of each run, with label containing run details
- stated goal: learn the process while building the highest number of correct cars
- once completed, state you completed X cars out of the 10 expected for this task?

Checklist

- ☐ monitor video
- ☐ take picture of completed cars
- ☐ secondary review of all checklists

8. Intermission and Reset

During a short break to reset the workstation, the participant will complete the NASA TLX and System Usability Survey for the assigned treatment.

- assistant out of room during surveys
- offer drink, snack, restroom

Checklist

- ☐ secondary review of all checklists

9. Phase 2 - Recall

During the second phase, participants repeat the task four times in the control condition while the same measures are observed. Their results in each phase will be analyzed to compare transfer effectiveness between treatments.

In the second phase each participant will build 4 more cars using only paper work instructions. Their stated goal will be to deliver error-free results quickly, while referencing the instructions only when necessary. Observations will be recorded on Data Collection Sheet #2. (5-10 mins)

Participants will not be allowed to ask questions during either data collection phase of the experiment.

- Instructions: participants are asked to accurately complete 4 cars using only the PWI. Their stated goal is to deliver error-free results quickly while referencing the PWI only when necessary.
- Support: same as I1P1
- Oversight: same as I1P1

Checklist

- ☐ monitor video
- ☐ take picture of completed cars
- ☐ secondary review of all checklists

10. Debriefing

Once the experiment is concluded, each participant will complete an exit survey that incorporates the NASA TLX and System Usability Scale instruments for PWI. When the surveys are completed a research associate will solicit any additional general feedback, ask if the participant experienced any injury or discomfort, and invite them to attend a follow-up session for more in-depth exploration of the HoloLens2. Their responses will be recorded on the exit survey. (5-10 mins)

During the debriefing all participants will be asked if they were injured or experienced any discomfort during their trials. The debriefing also serves to keep each participant under our supervision long enough to ensure no lingering or delayed effects.

- Participants are ushered back into the conference room where their outgoing paperwork is administered by a member of the research team. Scripts for each of the following instruments are followed.
  - NASA-TLX
  - SUS
- assistant out of room during surveys
- The researcher asks questions from the general info page and records the participant's responses.
- The researcher thanks the participant for their time and escorts them to the exit.

Checklist

- ☐ secondary review of all checklists

Reset Between Participants

Checklist

- ☐ restock / check bin levels should be ok returning parts
- ☐ reset / swap cameras between parts?
- ☐ check battery levels
- ☐ check available memory
- ☐ turn off cameras

- ☐ wipe down surfaces and devices
- ☐ offload video?
- ☐ tear down / reset cars
- ☐ double check all prebuilt cars
- ☐ cycle HL2 hardware and charge
- ☐ secondary review of all checklists

End of Day

- ☐ power down mouse and projector, leave computer running
- ☐ clean up
- ☐ lights off
- ☐ doors shut and locked
- ☐ put correct PWI back in place
- ☐ starting pieces back on tables
- ☐ put check piece back out - back the way we found it

Staff Training / Emergency Procedures

Additionally, all participant activities will be supervised and monitored for relevant symptoms. If any participant experiences dizziness or related vestibular issues, or any other significant but unexpected side-effect, we will suspend the experiment, remove the HMD, have them sit and offer drinking water while assessing the situation. If escalation is required, the emergency plan and contact list is included in Appendix D.

Remaining Prep

- ☐ pre-record all instructions
- ☐ staff prepped?
- ☐ document standards
  - ☐ station setup
  - ☐ streaming setup: HL2 pc - stream settings: low res, record locally, don't render on screen
- ☐ pizza party?
- ☐ update [[Random Treatments]]
  - ☒ tabular output
  - ☐ add part number?
  - ☒ add summary stats
  - ☒ revise blocking approach?
  - ☒ discuss blocking with Sesek
  - ☐ add variance level at each trial

    - ☐ output to markdown
- ☐ filename conventions?
- ☐ form change - number intake forms (order for parts)

B.3 Additional ADHD Metrics Summaries

B.3.1 ASRS6 Significant Symptom Prevalence

The ASRS 6-question sub-scale (ASRS6) revealed varying levels of significant symptoms among the participants. The ASRS6 is known for its high specificity and selectivity in identifying self-reported ADHD in adults (Kessler, Adler, Ames, Demler, et al., 2005). Symptoms are considered significant if they meet the threshold for each question, either “Sometimes” or “Often,” depending on the question.

In the sample, 11.3% of participants reported no significant symptoms, and another 11.3% reported one significant symptom. The highest percentage of participants (25.8%) reported two significant symptoms. Those with three and four significant symptoms each comprised 19.3% of the sample. Participants reporting five significant symptoms made up 9.7%, and a few participants (3.2%) reported all six significant

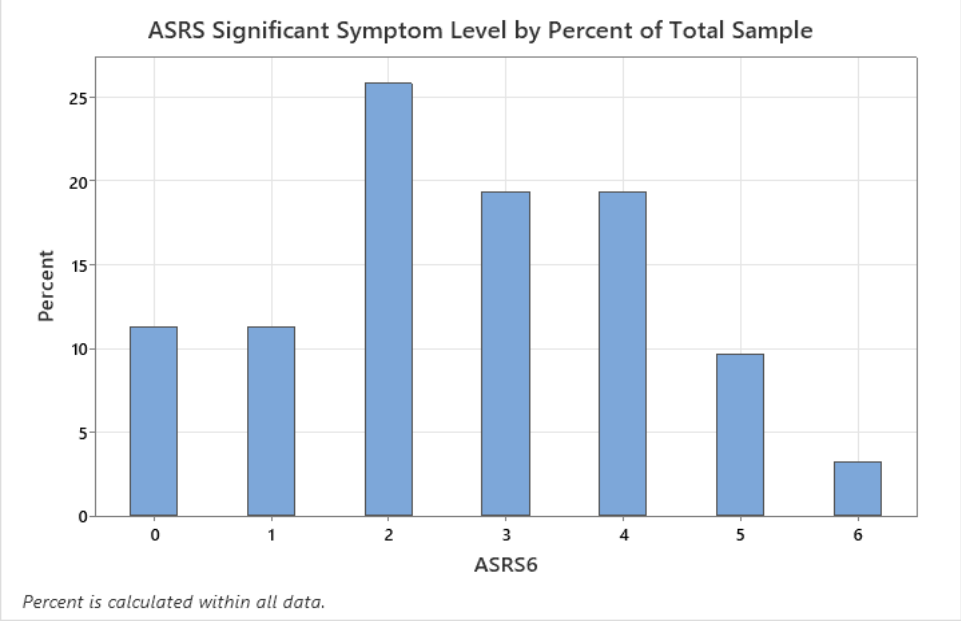


Figure 71: ASRS6 Symptom Level by Percent of Total Sample

symptoms. The bar graph below illustrates this trend. Participants with four or more symptoms are considered highly likely to have ADHD and would typically be referred for further diagnosis in a clinical setting. In this sample, 32.2% of participants reported

four or more significant symptoms.

B.3.2 ADHD6 Levels (Low, Med, High)

The study categorized ADHD levels based on the number of significant symptoms from the ASRS6. Participants with low ADHD levels (0-1 symptoms), characterized as unlikely to have ADHD, comprised 22.6% of the sample. Those with medium ADHD levels (2-3 symptoms), considered possible ADHD, were more prevalent, making up 45.2% of the sample. Participants with high ADHD levels (4-6 symptoms), considered likely to have ADHD, accounted for 32.3% of the sample. This is a higher likely prevalence of ADHD compared to the general US population, but not unlike what has been reported in other studies of US university students (Waite et al., 2022a).

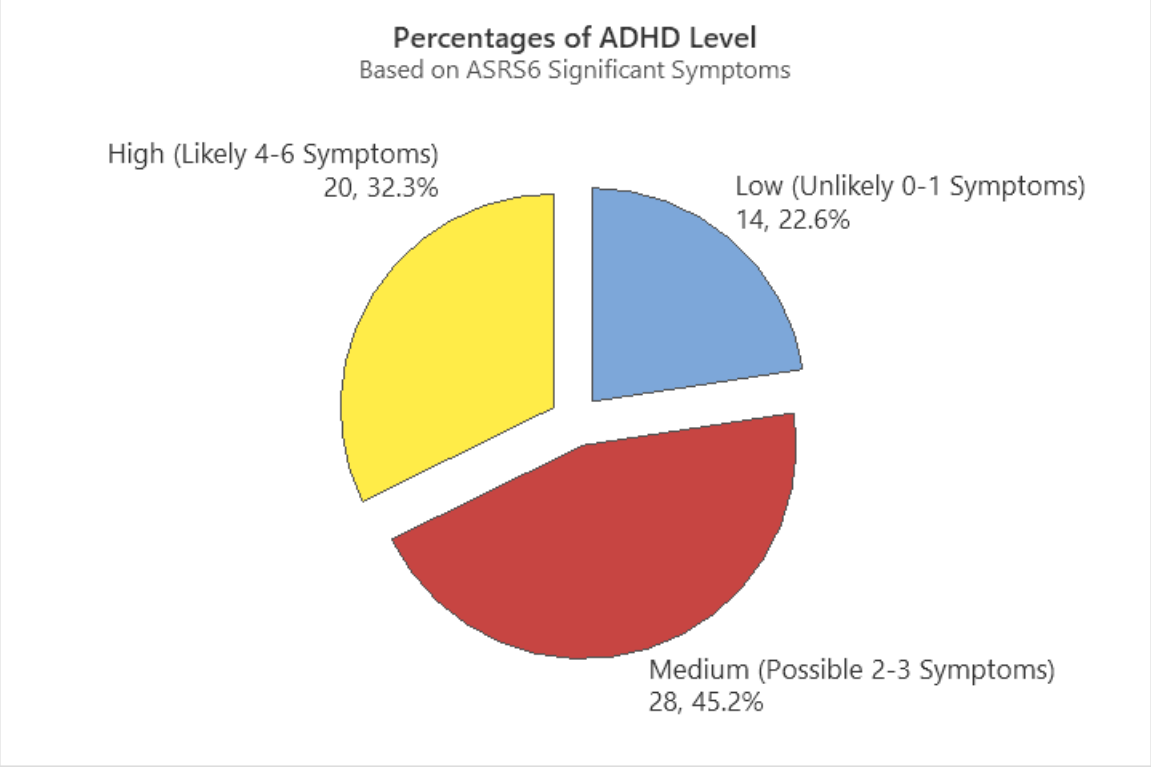


Figure 72: ASRS6 Percentages of ADHD Level (Low, Medium, High)

B.3.3 ASRS6 Total Points Category

The ASRS6 Total Points category is calculated by adding the values for each of the first six questions in the ASRS. This total points score has shown a high correlation with clinician-diagnosed ADHD, especially in the highest category (Kessler et al., 2007). Kessler reports a ratio of 25:1 for clinician-diagnosed cases to non-cases in the 18-24 points range and 10:1 in the 14-17 points range (Kessler et al., 2007).

When examining the ASRS6 Total Points category in this study, 25.8% of the sample fell into the high negative category (0-9 points). The low negative category (10-13 points) included half of the sample at 50.0%. A smaller percentage of the sample (17.7%) fell into the low positive category (14-17 points). The high positive category (18-24 points) included only 6.5% of the sample.

The positive categories combined accounted for 24.2% of the sample, which is lower than the symptom-based categories. This discrepancy places some participants with

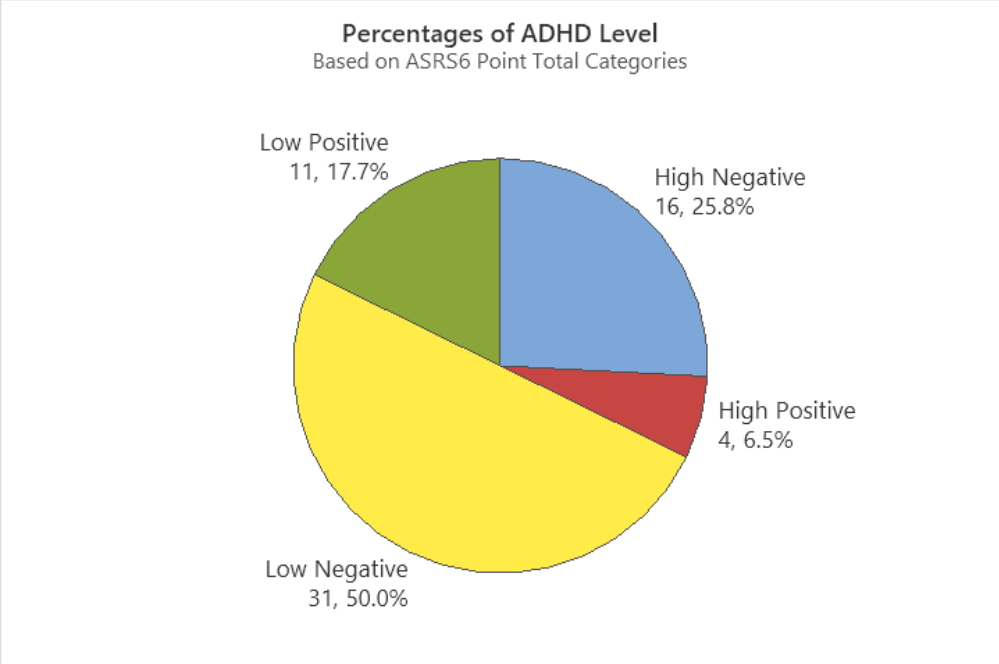


Figure 73: ASRS6 Point Total: Percentages of ADHD Level

four significant symptoms in the “Low Positive” group based on their total points. This factor is illustrated in the following figure.

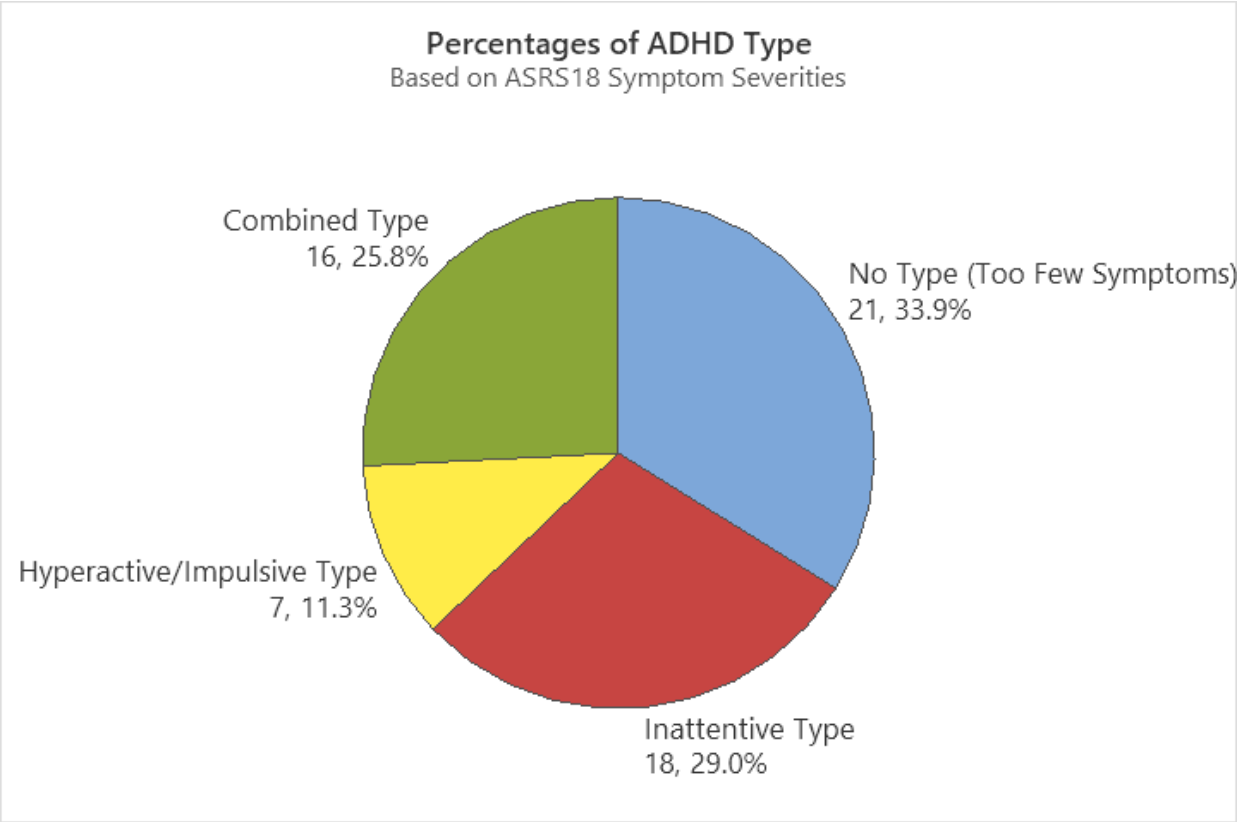


Figure 74: Percentages of ADHD Type based on the ASRS18 Symptom Severity

B.3.4 ADHD Types

Analyzing the specific questions where each participant exhibited significant levels, previous research has classified types of ADHD based on these questions (K. Stanton et al., 2018). A threshold level was chosen for this classification: having four or more significant symptoms in a category was classified as significant. This classification level aligned with the number of participants showing medium to high levels of symptoms in other categories.

Regarding ADHD types based on ASRS 18-question severities, the sample had a substantially higher percentage of participants with inattentive ADHD (29%). A smaller percentage of participants had hyperactive/impulsive ADHD (11.3%). The combined ADHD type was observed in 25.8% of the sample. Additionally, a third of the

participants (33.9%) were classified as having no ADHD type. The following figure shows the proportion of ADHD Types for the whole data set.

B.3.5 Treatment Distribution for ADHD Symptom-Reporting Subjects

To reduce bias, participant ADHD symptom reporting was not scored until after the investigation. As such, participants were randomly assigned treatment groups independent of ADHD status. As a result, the distribution of participants with various levels of reported symptoms is not evenly distributed within the treatments, with the two excluded participants removed (reasoning discussed in the next section on Data Screening and Cleaning). The distribution for the severe ADHD symptom reporting, based on the ASRS six-point scale of three or more severe symptoms and four or more severe symptoms, is shown in the table below.

Table 33: Manufacturing Technology Support Investigation: Breakdown of Participant Treatments

Treatment	All participants	Number of ADHD (Symptoms 3+) Participants	Number of ADHD (Symptoms 4+) Participants
PWI	16	8	7
PBAR	15	7	3
HMAR	15	9	5
EHMAR	15	8	5

Although there were fewer participants with ADHD in some treatments, the random assignment of participants is a key strength of this study as it minimizes the risk of selection bias. The assignment process did not reveal which participants had significant ADHD symptoms, preserving the integrity of the experimental design and preventing any preconceived notions from affecting the results.

Another noteworthy aspect is the relatively even distribution of participants with significant ADHD symptoms across most treatments, especially in the group with three or more symptoms. This balance helps guarantee that the findings are not

disproportionately influenced by any particular treatment, allowing for a more comprehensive understanding of the effects of the different treatments.

B.4 Additional Descriptive Statistics

Using Minitab, descriptive statistics, including mean, standard deviation, minimum, and maximum, were calculated for each of the three categories of metrics.

B.4.1 Summary Tables: Performance and Quality Metrics

First, the performance and quality metrics are presented. The table below contains values for both **Total Built in Training** (the number of complete cars built in each ten-minute trial) and **Average Defects in Training** and **Average Defects in Recall** (calculated by dividing the total number of errors made by the total number of complete cars built) for each of the four treatments. **Participants Making 8 or More Cars During Training** is a count of how many participants made 8 or more cars during training divided by how many participants are in that group. **Participants Making Uncorrected Errors Training** and **Participants Making Uncorrected Errors Recall** is similar; it is a count of how many participants in that group made any uncorrected errors divided by the number of participants in that group.

The table below summarizes these metrics for each of the four treatments that participants performed. Each participant underwent one treatment for training and one recall session with only the PWI.

Table 34: Performance and Quality Metrics Summary Statistics and ANOVA Analysis by Treatment

	PWI N = 16				PBAR N = 15				HMAR N = 15				EHMAR N = 15				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Total Built Training	6.9	2.2	3	11	6.0	1.2	4	8	3.7	0.9	3	5	3.6	1.1	2	6	0.000
Participants Making 8 or More Cars in Training	0.44	0.51	0	1	0.14	0.36	0	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.001
Participants Making Uncorrected Errors Training	0.94	0.25	0	1	0.60	0.51	0	1	0.33	0.49	0	1	0.33	0.49	0	1	0.001
Average Defects Training	6.0	3.3	0.0	12.0	1.0	1.5	0.0	4.2	0.7	1.3	0.0	3.7	0.9	1.4	0.0	3.3	0.000
Total Errors Recall	20.9	13.2	0.0	44.0	3.1	5.2	0.0	18.0	4.5	12.6	0.0	49.0	5.1	8.7	0.0	30.0	0.000
Average Defects Recall	5.2	3.3	0.0	11.0	0.8	1.3	0.0	4.5	1.1	3.2	0.0	12.3	1.3	2.2	0.0	7.5	0.000
Participants Making Uncorrected Errors Recall	0.88	0.34	0	1	0.40	0.51	0	1	0.27	0.46	0	1	0.33	0.49	0	1	0.001

Table 35: Total Number of Cars Training vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	124.3	50.41%	124.3	41.436	19.31	0.000
Error	57	122.3	49.59%	122.3	2.145		
Total	60	246.6	100.00%				

Table 36: Training Participants Making 8+ Cars vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	1.998	26.12%	1.998	0.6661	6.60	0.001
Error	56	5.652	73.88%	5.652	0.1009		
Total	59	7.650	100.00%				

Table 37: Training Participant Errors vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	3.845	25.55%	3.845	1.2817	6.52	0.001
Error	57	11.204	74.45%	11.204	0.1966		
Total	60	15.049	100.00%				

Table 38: Training Average Errors per Car vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	316.5	55.95%	316.5	105.494	24.14	0.000
Error	57	249.1	44.05%	249.1	4.371		
Total	60	565.6	100.00%				

Table 39: Recall Uncorrected Errors vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	3319	34.56%	3319	1106.3	10.03	0.000
Error	57	6285	65.44%	6285	110.3		
Total	60	9604	100.00%				

Table 40: Recall Average Errors Per Car vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	207.4	34.56%	207.4	69.146	10.03	0.000
Error	57	392.8	65.44%	392.8	6.892		
Total	60	600.3	100.00%				

Table 41: Recall Participants Making Errors vs. Treatment: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	3.596	23.64%	3.596	1.1988	5.88	0.001
Error	57	11.617	76.36%	11.617	0.2038		
Total	60	15.213	100.00%				

The ANOVA results reveal statistically significant differences between treatment groups regarding performance and quality metrics, with all metrics showing p-values < 0.001. For production rate (number of cars built), the Control (PWI) and PBAR treatments resulted in nearly twice as many cars on average compared to head-mounted AR systems. Specifically, 43% of Control participants built eight or more cars, while none of the head-mounted AR participants reached this threshold. PBAR participants performed better than head-mounted AR participants but worse than the Control group, with 14% reaching eight or more cars.

In terms of error rates, significant differences were observed between the treatments. The Control group's average error rate during training was six times higher than that of those using AR technologies. During the Recall trial, participants trained with AR made nearly five times fewer errors than those trained with the Control method. The percentage of participants making errors in the Recall trial was as follows: PWI = 87.5%, PBAR = 40%, HMAR = 26.7%, and EHMAR = 33.3%. Although the AR tools were not

statistically different from each other in reducing errors, they were significantly different from the Control group, demonstrating the effectiveness of AR technologies in reducing errors during the Recall trial.

B.4.2 Performance and Quality Metrics: ADHD Symptom Reporting and Treatment Impact

The summary statistics are provided below for each of the metrics.

Table 42: Performance and Quality Metrics Summary Statistics by ASRS6 Level

	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Total Built Training	4.9	2.0	2	8	5.3	2.1	3	11	4.9	2.0	3	10
Participants Making 8 or More Cars in Training	0.15	0.38	0	1	0.14	0.36	0	1	0.16	.37	0	1
Participants Making Uncorrected Errors Training	0.64	0.50	0	1	0.50	0.51	0	1	0.58	0.51	0	1
Average Defects Training	2.5	2.5	0.0	7.0	2.1	3.2	0.0	11.3	2.3	3.3	0.0	12.0
Total Errors Recall	10.4	11.6	0.0	30.0	9.1	14.8	0.0	49.0	6.6	10.2	0.0	30.0
Average Defects Recall	2.6	2.9	0.0	7.5	2.3	3.7	0.0	12.3	1.7	2.5	0.0	7.5
Participants Making Uncorrected Errors Recall	0.57	0.51	0	1	0.46	0.51	0	1	0.42	0.51	0	1

Table 43: Performance and Quality Metrics Summary Statistics by ASRS18 ADHD Type

	No ADHD Type N = 21				ADHD Inattentive Type N = 17				ADHD Hyperactive/Impulsive Type N = 7				ADHD Combined Type N = 16			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Total Built Training	5.0	1.9	2	8	4.9	2.1	3	10	6.1	3.0	3	11	4.9	1.6	3	8
Participants Making 8 or More Cars in Training	0.1	0.4	0	1	0.2	0.4	0	1	0.3	0.5	0	1	0.1	0.3	0	1
Participants Making Uncorrected Errors Training	0.6	0.5	0	1	0.5	0.5	0	1	0.4	0.5	0	1	0.6	0.5	0	1
Average Defects Training	2.4	2.9	0	10	2.6	4.1	0	12	1.0	1.9	0	5	2.1	2.5	0	8
Total Errors Recall	10.6	12.1	0	40	8.4	14.4	0	44	2.3	3.9	0	8	9.1	13.8	0	49
Average Defects Recall	2.7	3.0	0	10	2.1	3.6	0	11	0.6	1.0	0	2	2.3	3.5	0	12.5
Participants Making Uncorrected Errors Recall	0.6	0.5	0	1	0.4	0.5	0	1	0.3	0.5	0	1	0.5	0.5	0	1

B.4.3 Summary Tables: System Usability Scale (SUS) Metrics

The SUS metrics are summarized using the same descriptive statistics and table organization as in the previous section. The initial metric is the SUS score calculated from the instrument administered to the participants. To enable comparison between different systems and participants, the scores are normalized. The Control Normalized SUS indicates whether the treatment SUS is higher or lower than the control (PWI), with positive values for higher scores and negative for lower. No values are given for the PWI treatment for this metric; since the calculations of the metric are based on this value, all the values would be zero. The Normalized SUS, presented as a decimal percent (0-1), is derived from a normal curve with a mean of 65 and a standard deviation of 12.5. The table

below provides a summary of these values.

The following table summarizes these metrics for each of the four treatments that participants performed; each participant did one treatment for training and one recall session with only the PWI.

The following table summarizes these metrics for the three levels of ASRS6 based on the number of significant ADHD symptoms. The categories for the levels are Low/Unlikely (0-1 significant symptoms), Medium/Possible (2-3 significant symptoms), and High/Likely (4-6 significant symptoms).

Following the ADHD Level table is the ASRS18 ADHD Type summary. The ASRS18 Type uses all 18 questions of the ASRS to determine the likelihood of the type of ADHD based on having four or more significant symptoms in symptoms characteristic of the types of ADHD. If the participant has four or more symptoms in both types(Inattentive and Hyperactive/Impulsive), they are categorized as "Combined Type."

Table 44: System Usability Scale (SUS) Metrics Summary Statistics by Treatment

	PWI N = 16				PBAR N = 15				HMAR N = 15				EHMAR N = 15			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
SUS - Training	72.5	16.0	37.5	92.5	71.5	13.8	35.0	85.0	67.7	16.8	37.5	97.5	61.3	20.6	7.5	87.5
Control Normalized SUS - Training	-7.8	15.5	-42.3	34.6	3.0	46.0	-56.3	138.5	-13.6	24.8	-57.1	28.6	-15.3	31.5	-90.9	28.6
Normalized SUS - Training	0.617	0.346	.007	0.975	0.613	0.305	0.004	0.913	0.517	0.319	0.007	0.991	0.412	.358	0.000	0.941

	PWI N = 16				PBAR N = 15				HMAR N = 15				EHMAR N = 15			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
SUS-Recall	78.8	13.4	52.5	100.0	75.7	18.2	32.5	97.5	80.0	11.0	62.5	97.5	75.7	15.4	35.0	90.0

Table 45: System Usability Scale (SUS) Metrics Summary Statistics by ASRS6 Level

	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
SUS - Training	75.5	22.8	7.5	97.5	70.6	12.4	37.5	87.5	61.8	17.4	35.0	92.5
Control Normalized SUS - Training	-2.1	31.6	-90.9	39.1	-1.0	34.8	-45.5	138.5	-23.9	18.9	57.1	0.0
Normalized SUS - Training	0.674	0.339	0.000	0.991	0.577	0.284	0.007	0.941	0.390	0.363	0.004	0.975
SUS - Recall	76.6	16.5	35.0	97.5	75.2	15.1	32.5	97.5	81.7	11.4	52.5	100.0

Table 46: System Usability Scale (SUS) Metrics Summary Statistics by ASRS18 ADHD Type

	No ADHD Type N = 21				ADHD Inattentive Type N = 17				ADHD Hyperactive/Impulsive Type N = 7				ADHD Combined Type N = 16			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
SUS -Training	69.9	20.1	7.5	97.5	67.5	13.5	47.5	90.0	73.6	14.8	45.0	87.5	64.8	17.9	35.0	92.5
Control Normalized SUS - Training	-7.3	27.2	-90.9	39.1	-2.9	41.3	-45.7	138.5	-10.4	25.6	-45.5	34.6	-14.8	27.6	-57.1	54.5
Normalized SUS - Training	0.605	0.327	0.000	0.991	0.492	0.328	0.51	0.961	0.651	.320	0.033	0.941	0.461	0.362	0.004	0.975
SUS - Recall	77.3	14.8	35	97.5	74.6	16.3	32.5	90.0	83.9	10.8	65.0	97.5	78.3	13.6	55.0	100.0

B.4.4 Summary Tables: Cognitive Load (NASA TLX) Metrics

The cognitive load (or mental workload) of the participants is estimated from the self-reported NASA TLX completed after each treatment, assessing workload across six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The NASA TLX has been analyzed in various ways, as described previously. This study investigates several metrics, including participant-specific normalized values (Control Normalized TLX) and global study normalized values (Min-Max Normalized TLX). Additionally, raw weighted TLX, unweighted NASA TLX scores, and six weighted sub-scores are presented in the table below.

The following table summarizes these metrics for each of the four treatments that participants performed; each participant did one treatment for training and one recall session with only the PWI.

The following table summarizes these metrics for the three levels of ASRS6 based on the number of significant ADHD symptoms. The categories for the levels are Low/Unlikely (0-1 significant symptoms), Medium/Possible (2-3 significant symptoms), and High/Likely (4-6 significant symptoms).

Following the ADHD Level table is the ASRS18 ADHD Type summary. The ASRS18 Type uses all 18 questions of the ASRS to determine the likelihood of the type of ADHD based on having four or more significant symptoms in symptoms characteristic of the types of ADHD. If the participant has four or more symptoms in both types(Inattentive and Hyperactive/Impulsive), they are categorized as “Combined Type.”

Table 47: NASA TLX Metrics Summary Statistics by Treatment

Training	PWI N = 16				PBAR N = 15				HMAR N = 15				EHMAR N = 15			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Control Normalized TLX	108.9	138.4	0.0	415.2	25.0	43.9	-17.4	145.1	51.9	58.8	-41.4	176.5	36.7	56.5	-54.8	148.7
Min-Max TLX	57.4	12.6	38.5	84.8	58.8	18.7	34.8	100.8	57.2	18.5	27.1	85.7	58.4	22.0	5.7	94.3
Weighted TLX	57.7	10.3	42.3	80.0	58.8	15.2	39.3	92.3	57.5	15.0	33.0	80.7	58.5	17.9	15.7	87.7
Unweighted TLX	50.0	9.3	30.8	70.0	51.4	14.4	31.7	79.2	49.2	10.5	26.7	65.0	50.2	17.8	16.7	78.3
Mental Demand TLX	7.8	6.4	0.3	25.0	6.3	7.4	0.0	22.7	8.0	7.1	1.0	28.3	10.0	8.8	0.0	26.7
Physical Demand TLX	1.4	3.3	0.0	13.0	3.0	5.6	0.0	16.0	0.7	1.6	0.0	5.3	2.0	4.1	0.0	12.0
Temporal TLX	15.1	6.8	1.7	24.0	17.1	4.7	11.0	16.7	20.9	6.1	7.6	30.0	16.6	8.7	0.0	30.0
Performance TLX	13.0	7.2	1.7	31.7	13.1	5.8	5.0	24.0	12.4	7.9	4.0	33.3	10.1	7.8	1.3	25.0
Effort TLX	7.9	5.5	1.0	20.0	6.8	5.0	0.0	16.0	5.0	5.2	1.3	22.7	8.6	6.9	1.3	24.0
Frustration TLX	12.5	8.9	0.0	25.0	12.5	8.9	0.0	31.7	10.4	8.1	0.0	24.0	11.3	10.3	0.0	33.3

Table 48: NASA TLX Metrics Summary Statistics by ASRS6 Level

Training	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Control Normalized TLX	50.1	66.0	-54.8	148.7	35.8	79.8	-41.4	406.1	92.4	108.3	-1.5	415.2
Min-Max TLX	55.7	25.8	5.7	100.0	57.8	14.9	27.1	85.7	59.8	14.9	29.8	78.3
Weighted TLX	56.3	20.9	15.7	92.3	58.0	12.1	33..0	80.7	59.7	12.1	35.2	74.7
Unweighted TLX	50.1	19.2	16.7	79.2	50.1	11.5	26.7	70.0	50.3	9.9	31.5	68.3
Mental Demand TLX	7.2	7.4	0.0	22.7	6.4	4.8	0.0	18.7	10.9	9.6	1.0	28.3
Physical Demand TLX	1.8	3.6	0.0	11.3	1.7	4.1	0.0	16.0	1.8	4.0	0.0	13.0

Training	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Temporal TLX	14.2	8.4	0.0	28.3	19.2	5.9	6.0	30.0	17.2	6.6	1.7	30.0
Performance TLX	12.4	7.8	1.3	24.0	12.3	7.3	1.7	33.3	11.9	6.8	3.0	31.7
Effort TLX	8.9	6.8	1.7	24.0	6.8	5.9	0.0	22.7	6.1	6.5	1.3	17.0
Frustration TLX	11.7	9.8	0.0	33.3	11.6	8.3	0.0	31.7	11.7	9.4	0.0	31.7

Table 49: NASA TLX Metrics Summary Statistics by ASRS18 ADHD Type

Training	No ADHD Type N = 21				ADHD Inattentive Type N = 17				ADHD Hyperactive/Impulsive Type N = 7				ADHD Combined Type N = 16			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Control Normalized TLX	59.0	98.7	-54.8	406.1	40.5	48.4	-17.4	176.5	15.7	32.7	-41.4	56.2	92.3	118.1	-3.1	415.2
Min-Max TLX	56.0	22.6	5.7	100.0	61.6	13.5	38.5	82.4	50.8	17.5	27.1	68.4	59.8	14.2	29.8	85.7
Weighted TLX	56.5	18.4	15.7	92.3	61.1	10.9	42.3	78.0	52.3	14.2	33.0	66.7	59.7	11.6	35.2	80.7
Unweighted TLX	49.2	17.3	16.7	79.2	52.2	9.8	31.5	68.3	44.2	11.5	26.7	56.7	52.0	9.6	36.7	70.0
Mental Demand TLX	7.1	6.9	0.0	22.7	8.9	8.0	1.0	28.3	4.4	4.0	0.0	11.3	10.1	8.0	1.0	25.0
Physical Demand TLX	2.1	4.2	0.0	14.0	2.0	4.7	0.0	16.0	1.0	1.4	0.0	3.3	1.3	3.4	0.0	13.0
Temporal TLX	16.4	8.7	0.0	30.0	18.7	5.2	7.3	28.3	20.1	4.0	14.0	26.7	16.1	6.9	1.7	30.0
Performance TLX	11.0	7.1	1.3	24.0	12.1	7.0	3.0	31.7	12.1	8.2	1.7	25.0	13.9	7.2	4.0	33.3
Effort TLX	7.9	6.0	1.0	24.0	7.9	6.8	0.0	22.7	5.3	5.2	1.3	15.0	5.9	4.1	1.7	17.0
Frustration TLX	11.9	10.3	0.0	33.3	11.6	9.3	0.0	31.7	9.4	6.8	0.0	16.0	12.5	7.6	0.0	23.3

B.4.5 Reliability of Measures

Cronbach's alpha is a measure of internal consistency, which assesses how closely related a set of items are as a group (Birren, 2007). It is based on the average inter-item correlation and the number of items in the scale. Cronbach's alpha is used to evaluate the reliability of a psychometric instrument, ensuring that the items consistently reflect the construct being measured. High values (typically above 0.7) indicate good internal consistency (Cronbach, 1951; Tavakol & Dennick, 2011). This metric is chosen to test the reliability of measures like NASA TLX, SUS, and ASRS to confirm that the items within each scale reliably assess the intended dimensions of cognitive load, usability, and ADHD symptoms, respectively. By confirming high internal consistency, researchers can be confident that their instruments produce stable and consistent results across different samples and settings. In Minitab, this is performed by using this menu sequence (Stat>Multivariate Analysis>Item Analysis, then selecting all the questions that input into the measure – such as all six subscales of the NASA TLX).

The Cronbach's alpha values for the three validated measures used in this investigation are as follows:

1. NASA TLX: The average Cronbach's alpha across the treatments is 0.79. This high value indicates excellent internal consistency, suggesting that the six subscales of the NASA TLX reliably measure the overall cognitive load.

2. SUS: The Cronbach's alpha for the SUS is 0.79. However, the SUS questions must be analyzed half at a time, with the similar direction questions analyzed together. Otherwise, the contradictory alternating scale confuses this statistical measure and causes a falsely low value. This high value indicates excellent internal consistency, suggesting that the ten questions of the SUS reliably measure the overall system usability. (Cronbach, 1951).

3. ASRS v1.1: The Cronbach's alpha for the ASRS v1.1 is 0.81, which falls within the ideal range. This indicates good internal consistency, meaning the items on the ASRS v1.1 reliably assess ADHD symptoms.

These Cronbach's alpha values indicate that the SUS, NASA TLX, and ASRS v1.1 have good to excellent internal consistency. These results support the continued use of these measures in assessing cognitive load, usability, and ADHD symptoms in similar research contexts.

B.5 Hypothesis Testing Analyses

B.5.1 Productivity-Related Hypotheses

H1: ADHD symptom levels will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

A one-way ANOVA was conducted to determine if ADHD symptom levels (ASRS6 Low, Medium, High) significantly affect production speed across different treatments. To investigate this hypothesis, first, the combined effects of the treatments over the ASRS6 Levels were tested. The results are shown in the table below, which are insignificant for both performance metrics.

Table 50: Performance Metrics by ASRS6 Level ANOVA

	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Total Built Training	4.9	2.0	2	8	5.3	2.1	3	11	4.9	2.0	3	10	0.844
Parti. Making 8 or More Cars in Train.	0.15	0.38	0	1	0.14	0.36	0	1	0.16	.37	0	1	0.990

Table 51: All Treatments, Participants Making 8+ Cars in Training: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.00281	0.001403	0.01	0.990
Error	57	7.64719	0.134161		
Total	59	7.65000			

The next step is to divide the treatments by the ASRS6 ADHD Levels. The sample sizes of each division are shown below, indicating sufficient participants in each classification for comparison.

Table 52: Sample Size (N) for each ASRS6 Level and Treatment

	N			
Metric	Low	Med	High	Total
PWI	2	7	7	16
PBAR	5	3	7	15
HMAR	3	8	4	15
EHMAR	4	6	5	15

Summary statistics and ANOVA results for the 95% CI, 2-sided test are shown below. No significant differences were found in the number of cars built by each ADHD symptom level for each treatment. However, PWI and PBAR show larger differences compared to the head-mounted AR treatments, though not significantly.

Table 53: Total Built in Training by ASRS6 Level and Treatment ANOVA

	ASRS6 – Low (Unlikely)				ASRS6- Medium (Possible)				ASRS6-High (Likely)				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
PWI	5.00	1.41	4	6	8.14	1.46	7	11	6.14	2.54	3	10	0.107
PBAR	6.80	1.30	5	8	5.57	0.79	5	7	5.67	1.53	4	7	0.191
HMAR	3.67	1.55	3	5	4.00	0.93	3	5	3.25	0.50	3	4	0.408
EHMAR	3.25	1.26	2	5	3.33	0.82	3	5	4.2	1.1	3	6	0.317

Table 54: PBAR Treatment, Total Built in Training by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	4.819	2.410	1.90	0.191
Error	12	15.181	1.265		
Total	14	20.000			

The hypothesis is supported, with the results indicating no significant differences in production speed across ADHD symptom levels for each treatment. The ANOVA p-values show that the variations in the number of cars built during training were not statistically significant among the different ADHD symptom levels for each treatment. Notably, while the Control (PWI) and PBAR treatments showed more considerable differences compared to the head-mounted AR treatments, these differences were not significant.

This lack of significant difference suggests that ADHD symptom levels do not significantly impact production speed across the various AR treatments tested. However, further investigation with larger sample sizes could provide more insight into the potential differences between the control (PWI) and PBAR treatments compared to the other AR treatments.

H_2: ADHD Type will not significantly affect production speed across different treatments (PBAR, HMAR, EHMAR, and PWI).

A one-way ANOVA was conducted to determine if ADHD types (None, Inattentive, Hyperactive/Impulsive, Combined) significantly affect production speed across different treatments individually. The results are summarized below:

Table 55: Total Built in Training by ASRS18 ADHD Type and Treatment ANOVA

	No ADHD Type				ADHD Inattentive Type				ADHD Hyperactive/Impulsive Type				ADHD Combined Type				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
PWI	6.25	1.71	4	8	7.4	2.19	4	10	10.00	1.41	9	11	5.6	1.95	3	8	0.092
PBAR	6.67	1.21	5	8	5.00	0.00	5	5	6.00	1.41	5	7	5.60	1.14	4	7	0.300
HMAR	4.00	1.00	3	5	3.60	0.89	3	5	5.00	-	5	5	3.25	0.5	3	4	0.301
EHMAR	3.17	0.93	2	5	3.80	0.84	3	5	3.00	0.00	3	3	5.00	1.41	4	6	0.137

Table 56: PWI Treatment, Total Built in Training by ASRS18 Type: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Type (1=I,2=H/I,3=C)	3	30.60	10.200	2.71	0.092
Error	12	45.15	3.763		
Total	15	75.75			

The sample sizes for each division of ADHD type and treatment are shown below, ensuring adequate representation in each category.

Table 57: Total Built in Training by ASRS18 ADHD Type and Treatment ANOVA

	N				
Metric	None	I	H/I	C	Total
PWI	4	5	2	5	16
PBAR	6	2	2	5	15
HMAR	5	5	1	4	15
EHMAR	6	5	2	2	15

The hypothesis is supported, with the results indicating no significant differences in production speed across ADHD types for each treatment. The ANOVA p-values show that variations in the number of cars built during training were not statistically significant among the different ADHD types for each treatment. Although the differences in mean values suggest some variability, these differences were not significant.

This lack of significant difference suggests that ADHD type does not significantly impact production speed across the various AR treatments tested. However, it is important to note that the n values for this analysis are very low, limiting the strength and generalizability of these conclusions. The small sample sizes reduce the power of the analysis, increasing the risk of Type II errors (failing to detect a difference when one exists). Therefore, while the current results do not show significant differences, further investigation with larger sample sizes is necessary to provide more detailed insights into the potential differences between treatments and ADHD types.

H3: ADHD symptom levels will not significantly affect production speed across all treatments (PBAR, HMAR, EHMAR, and PWI).

The findings of a hypothesis test conducted to investigate the impact of ADHD symptom levels on production speed across four treatments, PBAR, HMAR, EHMAR, and PWI, are included below. The hypothesis was tested using a two-way ANOVA analysis, which examined the effects of ASRS6 ADHD symptom levels (categorized as low, medium, and high likelihood of ADHD) and treatments (PBAR, HMAR, EHMAR, and PWI) on production speed. The analysis was conducted using Minitab statistical software. (Menus: Stat > ANOVA > General Linear Model > Fit General Linear Model > response variable: Number of Cars Produced in Training > Response: two categorical

variables, ADHD Level and Treatment > Factors> “Model” button> Add interaction term to main effects in terms in the model)

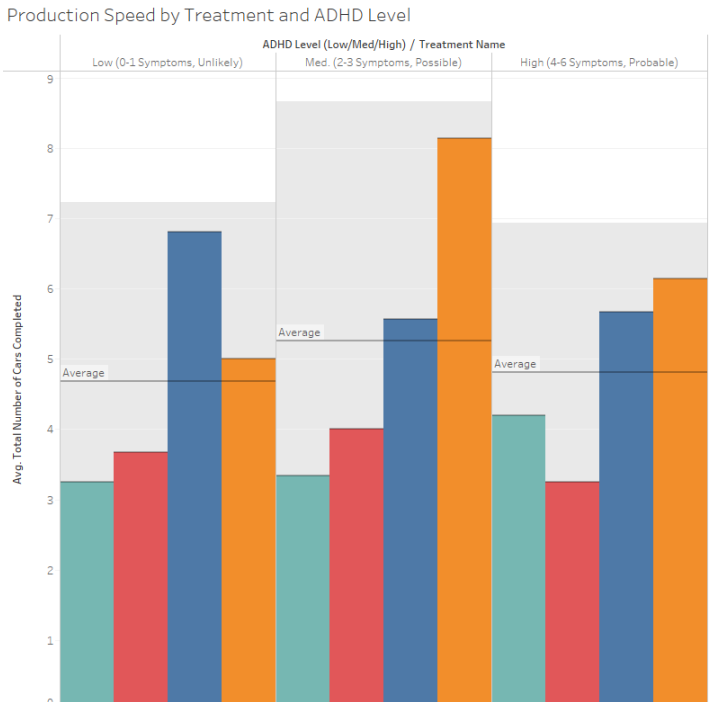


Figure 75: Production Speed by Treatment and ADHD Level

A summary of the relevant results from the two-way ANOVA analysis is presented in the table below:

Table 58: Summary of Results of Two-Way-ANOVA Number of Cars Built in Training by ADHD Level x Treatment

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	3.776	1.888	1.01	0.370
Treatment Name	3	88.180	29.393	15.79	0.000
ADHD Level (Low/Med/High)*Treatment Name	6	28.101	4.683	2.52	0.033
Error	49	91.195	1.861		
Total	60	246.590			

The results of the two-way ANOVA analysis provide evidence to reject the null hypothesis (H3) that ADHD symptom levels do not significantly affect production speed across all treatments.

Table 59: H3 GLM Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	4.919	0.190	25.92	0.000	
ADHD Level (Low/Med/High)					
0	-0.239	0.293	-0.82	0.417	1.50
1	0.343	0.242	1.42	0.162	1.43
Treatment Name					
EHMAR	-1.324	0.316	-4.19	0.000	1.66
HMAR	-1.280	0.331	-3.87	0.000	1.82
PBAR	1.094	0.325	3.36	0.002	1.76
ADHD Level (Low/Med/High)*Treatment Name					
0 EHMAR	-0.105	0.477	-0.22	0.827	2.16
0 HMAR	0.267	0.512	0.52	0.604	2.22
0 PBAR	1.027	0.467	2.20	0.033	1.89
1 EHMAR	-0.604	0.417	-1.45	0.154	2.33
1 HMAR	0.018	0.413	0.04	0.966	2.36
1 PBAR	-0.785	0.415	-1.89	0.065	2.20

Specifically:

ADHD Symptom Level: The main effect of ADHD symptom levels alone did not significantly influence production speed ($p = 0.370$). However, when considering the interaction between ADHD symptom levels and treatments, a statistically significant effect was observed ($p = 0.033$). This indicates that the impact of ADHD symptom levels on production speed varies depending on the treatment administered.

Treatment: The main effect of treatment was found to be statistically significant ($p < 0.001$), indicating that different treatments significantly affect production speed. Further analysis revealed significant interactions between treatments and ADHD symptom levels, suggesting differential treatment responses across different levels of ADHD severity.

Upon closer examination of the interactions between ADHD symptom levels and treatments, several specific conclusions emerge:

ADHD Low (Low Likelihood of ADHD): None of the interactions with treatments were statistically significant. This suggests that treatment efficacy in terms of improving production speed remains consistent across individuals with a low likelihood of ADHD.

ADHD Medium (Medium Likelihood of ADHD): Treatment PBAR shows a statistically significant positive effect on production speed at this ADHD level, indicating potential benefits of PBAR treatment for individuals with a medium likelihood of

ADHD. However, other treatments do not exhibit significant interactions, implying inconsistent treatment responses across this subgroup.

ADHD High (High Likelihood of ADHD): Treatment PBAR demonstrates a significant positive effect on production speed, suggesting potential benefits for individuals with a high likelihood of ADHD. Conversely, Treatments EHMAR and HMAR show significant negative effects, indicating that these treatments may be less effective or even detrimental to production speed for individuals with a high likelihood of ADHD. Treatment PWI does not show a significant interaction effect at this ADHD level.

In conclusion, the findings of this analysis reject the null hypothesis (H3) and indicate that ADHD symptom levels significantly affect production speed across treatments. While the severity of ADHD symptoms alone may not directly impact production speed, the interaction between ADHD symptom levels and treatments plays an important role in determining treatment efficacy. Tailoring treatment approaches based on individual ADHD symptom levels may be essential to optimize production speed outcomes.

Further research is warranted to explore the mechanisms underlying treatment responses across varying ADHD symptom levels, ultimately informing personalized interventions for individuals with ADHD.

H_4: Participants using PWI will report higher production speed compared to those using all other AR treatments regardless of ADHD symptom levels.

The findings of the hypothesis test that was conducted to examine whether participants using the PWI treatment report higher production speed compared to those using all other treatments, regardless of their ADHD symptom levels.

The hypothesis was tested using a two-way ANOVA analysis, which examined the effects of ADHD symptom levels (categorized as low, medium, and high likelihood of ADHD) and the treatment PWI and all others (coded as 1 for PWI treatment and 0 for all other treatments) on production speed (Number of Cars Built in Training). The analysis was conducted using Minitab statistical software.

A summary of the relevant results from the two-way ANOVA analysis is

presented in the table below:

Table 60: Summary of Results of Two-Way-ANOVA Number of Cars Built in Training by ADHD Level x PWI vs all other Treatments and GLM Coefficients

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	14.58	7.289	2.63	0.081
Treatment PWI and All others	1	34.45	34.446	12.44	0.001
ADHD Level (Low/Med/High)*Treatment PWI and All others	2	19.96	9.981	3.60	0.034
Error	55	152.30	2.769		
Total	60	246.59			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	5.450	0.277	19.65	0.000
ADHD Level (Low/Med/High)				
0	-0.534	0.460	-1.16	0.251
1	0.788	0.348	2.27	0.027
Treatment PWI and All others				
0	-0.978	0.277	-3.53	0.001
ADHD Level (Low/Med/High)*Treatment PWI and All others				
0 0	0.895	0.460	1.95	0.057
1 0	-0.927	0.348	-2.67	0.010
1 0	1.99			

The results of the two-way ANOVA analysis provide evidence to fail to reject the hypothesis (H4) that participants using PWI report higher production speed compared to those using all other treatments, dependent on their ADHD symptom levels.

Specifically:

ADHD Symptom Level: The main effect of ADHD symptom levels alone did not significantly influence production speed ($p = 0.081$). However, when considering the interaction between ADHD symptom levels and the treatment PWI and all others, a statistically significant effect was observed ($p = 0.034$). This indicates that the impact of ADHD symptom levels on production speed varies depending on whether participants are using PWI versus all other treatments.

Treatment PWI and All Others AR Treatments: The main effect of treatment PWI and all others were found to be statistically significant ($p = 0.001$), indicating that participants using PWI reported higher production speed compared to those using all other treatments.

Upon closer examination of the interactions between ADHD symptom levels and the treatment PWI and all others, the following specific conclusions emerge:

ADHD Level Low (Low Likelihood of ADHD): The interaction between ADHD Low Level and Treatment PWI and all others did not reach statistical significance, suggesting that the difference in production speed between PWI and all other treatments is not significant for individuals with a low likelihood of ADHD.

ADHD Level Medium (Medium Likelihood of ADHD): The interaction between ADHD Medium Level and Treatment PWI and all other treatments did not reach statistical significance, indicating that the difference in production speed between PWI and all other treatments is not significant for individuals with a medium likelihood of ADHD.

ADHD Level High (High Likelihood of ADHD): The interaction between ADHD High Level and Treatment PWI and all others was statistically significant ($p = 0.034$). This suggests that individuals with a high likelihood of ADHD using PWI had higher production speeds compared to those using all other treatments. ADHD High Level participants produced almost a full car more than other participants, on average.

In conclusion, the findings of this analysis support the hypothesis (H4) and indicate that participants using PWI report higher production speed compared to those using all other treatments, regardless of their ADHD symptom levels. While the severity of ADHD symptoms alone may not directly impact production speed, the interaction between ADHD symptom levels and treatment PWI and all others plays a role in determining production speed outcomes.

Further research is warranted to explore the mechanisms underlying the observed treatment effects across varying ADHD symptom levels, ultimately informing personalized interventions for individuals with ADHD.

B.5.2 Quality-Related Hypotheses

H_5: ADHD symptom levels will not significantly impact production quality across different treatments (PBAR, HMAR, EHMAR, and PWI).

An initial analysis of this hypothesis investigates each treatment separately with regard to differences by ASRS6 Level of ADHD symptoms.

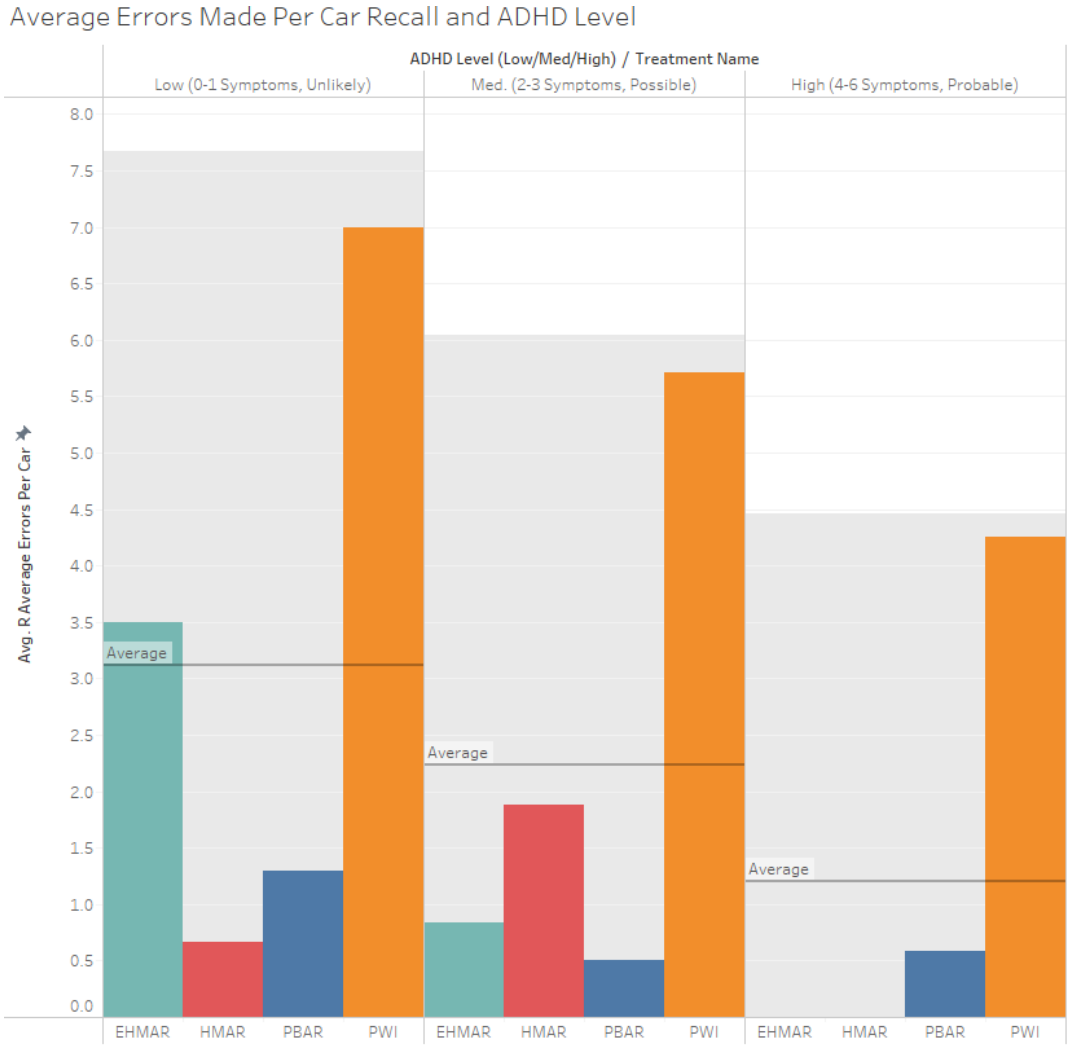


Figure 76: Average Errors Made Per Car During Recall by ADHD Level

The results of the one-way ANOVA analysis and descriptive statistics are shown in the table below.

Table 61: Average Errors per Car Recall by ASRS6 Level and Training Treatment ANOVA

	ASRS6 – Low (Unlikely)				ASRS6- Medium (Possible)				ASRS6-High (Likely)				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
PWI	7.00	0.00	7	7.0	5.71	4.27	0	11.0	4.25	2.56	0	7.5	0.544
PBAR	1.30	1.99	0	4.5	0.50	0.87	0	2.0	0.58	0.81	0	1.5	0.585
HMAR	0.67	1.16	0	2.0	1.88	4.25	0	12.3	0.00	0.00	0	0.0	0.634
EHMAR	3.50	3.08	0	7.5	0.83	1.33	0	3.0	0.00	0.00	0	0.00	0.031

Table 62: EHMAR Treatment Average Errors Per Car During Recall by ASRS 6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	29.10	14.550	4.68	0.031
Error	12	37.33	3.111		
Total	14	66.43			

The one-way ANOVA results show that ADHD symptom levels significantly impact production quality for the EHMAR treatment (p = 0.031). The post-hoc comparisons indicate that the average errors per car for the low ADHD symptom level group (mean = 3.50) were significantly higher compared to the medium (mean = 0.833) and high (mean = 0.000) symptom level groups. Interestingly, though, the EHMAR resulted in higher error rates for both the ADHD Low (mean = 2.50) and Medium groups (mean = 0.83) than the same groups for the PBAR treatment (Low mean = 1.30, Medium mean = 0.50). The Tukey Pairwise Comparison results for EHMAR and ADHD Levels are below.

Table 63: For Recall Average Error Rate Results, EHMAR by ADHD Level: Grouping Information Using the Tukey Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping	
0	4	3.50	A	
1	6	0.833	A	B
2	5	0.000000		B

Means that do not share a letter are significantly different.

An additional Two-Way ANOVA was also done to test this hypothesis. This was tested in Minitab, examining the effects of ADHD symptom levels (categorized as low, medium, and high likelihood of ADHD) and treatments (EHMAR, HMAR, PBAR, PWI) on production quality (Recall Average Errors Per Car).

Table 64: Summary of Results of Two-Way-ANOVA Average Errors per Car during Recall by ADHD Level x Treatments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	27.08	13.540	1.97	0.150
Treatment Name	3	193.55	64.518	9.38	0.000
ADHD Level (Low/Med/High)*Treatment Name	6	22.53	3.755	0.55	0.770
Error	49	336.90	6.875		
Total	60	600.27			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.185	0.365	5.99	0.000	
ADHD Level (Low/Med/High)					
0	0.931	0.563	1.65	0.104	1.50
1	0.045	0.465	0.10	0.922	1.43
Treatment Name					
EHMAR	-0.741	0.607	-1.22	0.228	1.66
HMAR	-1.338	0.635	-2.11	0.040	1.82
PBAR	-1.391	0.626	-2.22	0.031	1.76
ADHD Level (Low/Med/High)*Treatment Name					
0 EHMAR	1.124	0.916	1.23	0.226	2.16
0 HMAR	-1.112	0.985	-1.13	0.264	2.22
0 PBAR	-0.426	0.897	-0.47	0.637	1.89
1 EHMAR	-0.657	0.801	-0.82	0.417	2.33
1 HMAR	0.982	0.793	1.24	0.222	2.36
1 PBAR	-0.340	0.799	-0.43	0.672	2.20

The results of the two-way ANOVA analysis do not provide sufficient evidence to reject the null hypothesis (H5), indicating that ADHD symptom levels do not significantly impact production quality across different treatments. However, the analysis revealed some notable findings:

ADHD Symptom Level: The main effect of ADHD symptom levels did not reach statistical significance ($p = 0.150$), suggesting that production quality, as measured by average errors per car, is not significantly influenced by ADHD symptom levels alone. Despite not being significant, the following graph illustrates a slight downward trend (fewer errors means improved quality) as the ADHD symptom level increases.

Treatment: The main effect of treatment was statistically significant ($p < 0.001$), indicating that the type of treatment significantly affects production quality.

Interaction Between ADHD Symptom Level and Treatment: The interaction effect was not statistically significant ($p = 0.770$), suggesting that the impact of ADHD

symptom levels on production quality does not vary significantly across different treatments.

In conclusion, the findings of this analysis indicate that ADHD symptom levels do significantly impact production quality across different treatments. The statistical improvement in the quality of the EHMAR treatment for the highest ADHD level. Also, the treatment type itself significantly affects production quality, with a large effect size. As ADHD symptoms increase, there is a general trend for improvement. Further research is warranted to explore the underlying mechanisms and inform personalized interventions for individuals with ADHD.

H_6: Participants with higher ADHD symptom levels will show greater improvement in production quality using AR technologies (PBAR, HMAR, EHMAR) compared to traditional Paper Work Instructions (PWI).

The hypothesis test was conducted to examine whether participants using the PWI treatment report higher production quality (measured by Average Defects per Car in Recall) compared to those using all other treatments, regardless of their ADHD symptom levels.

The hypothesis was tested using a two-way ANOVA analysis, which examined the effects of ADHD symptom levels (categorized as low, medium, and high likelihood of ADHD) and the treatment PWI and all others (coded as 1 for PWI treatment and 0 for all other AR treatments) on higher production quality (measured by Average Defects per Car in Recall). The analysis was conducted using Minitab statistical software.

A summary of the relevant results from the two-way ANOVA analysis is presented in the table below:

Table 65: H6 Summary of Results of Two-Way-ANOVA Average Defects per Car in Recall by ADHD Level x PWI vs all other Treatments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	28.763	14.381	2.19	0.122
Treatment PWI and All others	1	191.114	191.114	29.04	0.000
ADHD Level (Low/Med/High)*Treatment PWI and Others	2	1.407	0.704	0.11	0.899
Error	55	362.001	6.582		
Total	60	600.270			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value
Constant	3.351	0.428	7.84	0.000
ADHD Level (Low/Med/High)				
0	1.087	0.709	1.53	0.131
1	0.066	0.536	0.12	0.902
Treatment PWI and All others				
0	-2.304	0.428	-5.39	0.000
ADHD Level (Low/Med/High)*Treatment PWI and All others				
0 0	-0.258	0.709	-0.36	0.717
1 0	0.006	0.536	0.01	0.990

The results of the two-way ANOVA analysis reject the hypothesis (H_6) that participants with higher ADHD symptom levels will not show greater improvement in production quality using AR technologies (PBAR, HMAR, EHMAR) compared to traditional Paper Work Instructions (PWI).

Specifically:

ADHD Symptom Level: The main effect of ADHD symptom levels alone did not significantly influence production quality ($p = 0.122$). Also, when considering the interaction between ADHD symptom levels and the treatment PWI and all others, no statistically significant effect was observed ($p = 0.899$). This indicates the lack of impact of ADHD symptom levels on production quality between PWI and the other AR treatments.

Treatment PWI and All Others AR Treatments: The main effect of treatment PWI and all others were found to be statistically significant ($p < 0.001$), and the coefficients of the regression equation indicate that participants using AR technologies reported higher production quality compared to those using PWI.

In conclusion, the findings of this analysis support the rejection of the hypothesis (H_6) and indicate that the ADHD level of participants using AR Technologies does not report higher production quality compared to those using all other treatments and ADHD levels. While the severity of ADHD symptoms alone may not directly impact production quality, the AR technologies did so significantly.

H7: Participants using EHMAR will report higher production quality compared to those using the other treatments, regardless of ADHD symptom levels.

The purpose of this hypothesis test was to examine the effects of using Enhanced Head-Mounted Augmented Reality (EHMAR) on production quality in a simulated manufacturing environment. Specifically, the hypothesis (H_7) tested was that participants using EHMAR would report higher production quality compared to those using other treatments, regardless of ADHD symptom levels. This study employed a Two-Way ANOVA to analyze the average number of errors per car produced in the Recall phase, with ADHD level (Low/Med/High) and treatment type (EHMAR vs. all other treatments) as factors. The factors included ADHD levels (Low/Med/High) with three levels (0, 1, 2) and treatment types (EHMAR vs. all other treatments) with two levels (0 = All other treatments, 1 = EHMAR treatment). The analysis included the main effects and interaction effects between the factors. The factor coding for the model was (-1, 0, +1).

Table 66: H7 Summary of Results of Two-Way-ANOVA Average Defects per Car in Recall by ADHD Level x EHMAR vs all other Treatments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	19.937	9.969	0.99	0.378
EHMAR vs Others	1	9.579	9.579	0.95	0.334
ADHD Level (Low/Med/High)*EHMAR vs Others	2	23.055	11.527	1.15	0.326
Error	55	553.527	10.064		
Total	60	600.270			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.915	0.483	3.97	0.000	
ADHD Level (Low/Med/High)					
0	0.960	0.726	1.32	0.192	1.71
1	-0.169	0.641	-0.26	0.793	1.86
EHMAR vs Others					
0	0.471	0.483	0.98	0.334	1.05
ADHD Level (Low/Med/High)*EHMAR vs Others					
0 0	-1.096	0.726	-1.51	0.137	1.72
1 0	0.442	0.641	0.69	0.493	1.89

The results of the ANOVA do not support the hypothesis that participants using EHMAR report higher production quality compared to those using other treatments, regardless of ADHD symptom levels. The analysis showed no significant main effects or interaction effects for ADHD levels and treatment types on the average number of errors

per car. The low R-squared values and lack of significant findings suggest that other factors not included in the model may influence production quality or that the effect of EHMAR is not as pronounced as hypothesized.

B.5.3 Cognitive Load Related Hypotheses

H_8: ADHD symptom levels will significantly impact Cognitive Load, as measured by the NASA TLX, across different treatments (PBAR, HMAR, EHMAR, and PWI).

A two-way ANOVA was performed to evaluate the effects of ADHD level (Low/Medium/High) and treatment (EHMAR, HMAR, PBAR, PWI) on the weighted TLX. The study included three levels of ADHD and four different treatments, with 60 total observations. Factor coding was set to (-1, 0, +1), and one row was unused in the analysis.

Table 67: General Linear Model: Weighted TLX vs ADHD Level and Treatment, Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	93.2	0.76%	49.3	24.66	0.10	0.902
Treatment	3	35.7	0.29%	85.7	28.57	0.12	0.948
ADHD Level (Low/Med/High)*Treatment	6	615.6	5.03%	615.6	102.60	0.43	0.856
Error	48	11488.1	93.91%	11488.1	239.34		
Total	59	12232.6	100.00%				

The two-way ANOVA did not find significant effects of ADHD levels, treatment type, or their interaction on weighted TLX scores. The minimal variance explained by the model and the lack of significant findings suggest high variability in the data.

These findings underscore the need for further research with larger sample sizes or alternative methodologies to more definitively determine the effects of ADHD levels and treatments on cognitive load. The observed trends, while not statistically significant, provide potential insights for future studies aimed at optimizing task performance for individuals with ADHD.

The additional analyses look at each treatment separately and by TLX Metric with all sub-scores and each sub-score individually. Significant or approaching significant results are discussed after each table. These analyses are located in Appendix B.5.

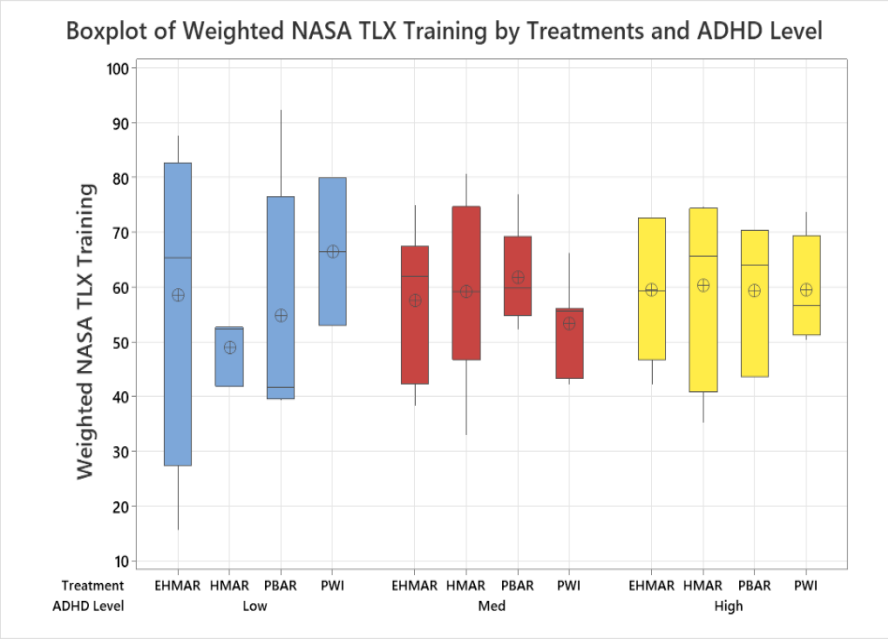


Figure 77: Weighted NASA TLX Training by Treatment and ADHD Level

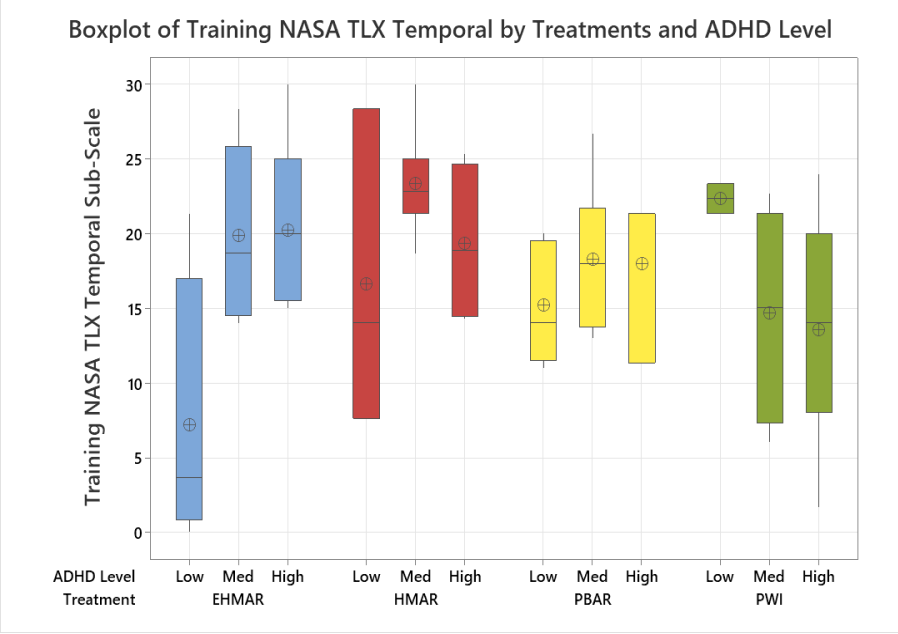


Figure 78: Training NASA TLX **Temporal** by Treatment and ADHD Level

There was considerable variability within each group for most metrics, but only one metric showed a statistically significant difference between ADHD levels. Significant results are summarized below.

Temporal TLX

- The ANOVA showed a significant effect ($p = 0.026$).
- Tukey's post-hoc test indicated that the Low ADHD group had significantly lower Temporal TLX scores compared to both the Medium and High ADHD groups.
- This suggests that individuals with higher ADHD levels experienced significantly higher temporal demand in the HMAR treatment compared to those with low ADHD levels.

The one-way ANOVA revealed a significant difference in Temporal TLX scores across ADHD levels during the HMAR treatment. Participants with higher ADHD levels experienced significantly greater temporal demand compared to those with low ADHD levels. While other metrics did not show significant differences, the trends observed in Mental Demand TLX suggest that individuals with higher ADHD levels may face increased cognitive challenges in augmented reality settings.

H_8 PWI Cognitive Load

Table 68: PWI – Cognitive Load Metrics by ASRS6 Levels -Descriptive Statistics and ANOVA Results

	ASRS6 – Low (Unlikely) N = 2				ASRS6- Medium (Possible) N = 7				ASRS6-High (Likely) N = 7				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Control Normalized TLX	45.9	12.6	37.1	54.8	79.9	144.8	0.0	406.1	156.0	148.3	44.4	415.2	0.496
Min-Max TLX	68.2	23.5	51.6	84.8	52.2	10.2	38.5	68.0	59.6	11.3	48.4	77.1	0.251
Weighted TLX	66.5	19.1	53.0	80.0	53.5	83.	42.3	66.3	49.5	12.4	30.8	70.0	0.251

	ASRS6 – Low (Unlikely) N = 2				ASRS6- Medium (Possible) N = 7				ASRS6-High (Likely) N = 7				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Unweighted TLX	54.6	12.4	45.8	63.3	49.5	12.4	30.8	70.0	49.2	5.4	40.8	57.5	0.780
Mental Demand TLX	9.0	8.0	3.3	14.7	6.5	4.6	0.3	14.3	8.8	8.1	1.0	25.0	0.789
Physical Demand TLX	0.0	0.0	0.0	0.0	0.8	1.3	0.0	2.7	2.4	4.9	0.0	13.0	0.564
Temporal TLX	22.3	1.4	21.3	23.3	14.7	6.3	6.0	22.7	13.5	7.3	1.7	24.0	0.276
Performance TLX	14.3	13.7	4.7	24.0	11.5	5.6	1.7	20.0	14.1	7.8	10.0	31.7	0.788
Effort TLX	5.8	2.1	4.3	7.3	8.5	6.8	1.0	20.0	7.9	5.2	3.0	17.0	0.848
Frustration TLX	15.0	12.7	6.0	24.0	11.5	8.5	0.0	25.0	12.8	9.7	0.0	23.3	0.894

No statistically significant differences were found. While there appear to be some general trends, the standard deviations were large enough to indicate that larger samples could provide a different result.

The variability in scores, particularly in the Control Normalized TLX and the Physical Demand TLX, was higher in the Medium and High ADHD groups. This indicates a more diverse range of experiences and responses to the PWI treatment among participants with higher ADHD levels.

H_8 PBAR Cognitive Load

Table 69: PBAR – Cognitive Load Metrics by ASRS6 Levels -Descriptive Statistics and ANOVA Results

	ASRS6 – Low (Unlikely) N = 5				ASRS6- Medium (Possible) N = 7				ASRS6-High (Likely) N = 3				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Control Normalized TLX	45.6	62.0	-8.5	145.1	4.8	26.0	-17.4	56.2	30.9	28.6	-1.5	52.9	0.323
Min-Max TLX	53.9	28.0	34.8	100.0	62.6	11.0	50.8	81.2	59.4	17.1	40.2	73.0	0.772
Weighted TLX	54.8	22.8	39.3	92.3	61.9	8.9	52.3	77.0	59.3	13.9	43.7	70.3	0.772
Unweighte d TLX	46.7	21.0	31.7	79.2	54.7	8.7	44.2	69.2	52.5	13.6	40.8	67.5	0.681
Mental Demand TLX	5.7	9.5	0.0	22.7	4.9	4.1	0.0	11.3	10.0	10.2	1.7	21.3	0.643
Physical Demand TLX	1.9	4.0	0.0	9.0	5.0	7.8	0.0	16.0	0.7	1.2	0.0	2.0	0.523
Temporal TLX	15.2	4.1	11.0	20.0	18.3	4.9	13.0	26.7	18.0	5.8	11.3	21.3	0.554
Performanc e TLX	13.5	8.3	5.0	24.0	12.8	3.4	8.7	16.7	13.1	7.4	8.3	21.7	0.983
Effort TLX	9.3	5.4	2.3	16.0	5.7	5.5	0.0	15.0	4.9	0.5	4.3	5.3	0.405
Frustration TLX	9.1	7.9	0.0	20.0	15.2	10.0	5.0	31.7	12.7	9.4	2.7	21.3	0.571

There was considerable variability within each group for the Control Normalized TLX scores, but no statistically significant differences were found between the ADHD levels. Although no statistically significant differences were observed, the Control Normalized TLX scores indicated that participants with Low ADHD levels experienced the highest cognitive load. In contrast, those with Medium ADHD levels experienced the lowest. The Mental Demand TLX scores were notably higher for the High ADHD group, suggesting that participants with higher ADHD levels perceived a greater mental demand during the PBAR treatment. Physical Demand TLX scores varied widely, with the Medium ADHD group reporting the highest scores, indicating variability in physical demand perceptions across ADHD levels.

The one-way ANOVA did not reveal significant differences in NASA TLX scores

and its subscales across ADHD levels during the PBAR treatment. However, the observed trends suggest that participants with Low ADHD levels experienced higher cognitive load overall, while those with High ADHD levels reported higher mental sub-scale demand.

H_8 HMAR – Cognitive Load

Table 70: HMAR – Cognitive Load Metrics by ASRS6 Levels -Descriptive Statistics and ANOVA Results

	ASRS6 – Low (Unlikely) N = 3				ASRS6- Medium (Possible) N = 8				ASRS6-High (Likely) N = 4				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Control Normalized TLX	58.2	64.5	-6.4	122.5	23.8	37.0	-41.4	64.4	103.4	66.9	37.0	176.5	0.074
Min-Max TLX	46.7	7.5	38.0	51.2	59.4	19.6	27.1	85.7	60.6	22.7	29.8	78.3	0.578
Weighted TLX	49.0	6.1	41.9	52.7	59.3	16.0	33.0	80.7	60.3	18.4	35.2	74.7	0.578
Unweighte d TLX	45.6	6.3	38.3	50.0	48.8	12.5	26.7	65.0	52.7	9.4	43.3	60.8	0.694
Mental Demand TLX	7.4	6.8	3.0	15.2	6.3	3.9	1.0	14.0	11.8	12.0	2.0	28.3	0.482
Physical Demand TLX	0.3	0.5	0.0	1.0	0.8	1.9	0.0	5.3	1.0	1.9	0.0	3.8	0.889
Temporal TLX	16.7	10.6	7.6	28.3	23.4	3.4	18.7	30.0	19.3	5.5	14.3	25.3	0.224
Performanc e TLX	13.4	5.7	9.5	20.0	10.8	10.0	4.0	33.3	14.9	4.4	11.0	20.0	0.704
Effort TLX	4.1	3.9	1.7	8.6	6.0	6.8	1.3	22.7	3.6	1.6	1.9	5.3	0.750
Frustration TLX	7.1	6.7	0.0	13.3	12.1	8.8	0.0	24.0	9.7	8.7	0.0	18.0	0.680

Table 71: HMAR, Control Normalized TLX: Fisher Pairwise Comparisons, Grouping Information Using the Fisher LSD Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping	
2	4	103.4	A	
0	3	58.2	A	B
1	8	23.8		B

Means that do not share a letter are significantly different.

Table 72: Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	-34.4	34.6	(-109.8, 41.0)	-0.99	0.339
2 - 0	45.2	39.0	(-39.9, 130.2)	1.16	0.270
2 - 1	79.6	31.3	(11.4, 147.8)	2.54	0.026

Simultaneous confidence level = 88.44%

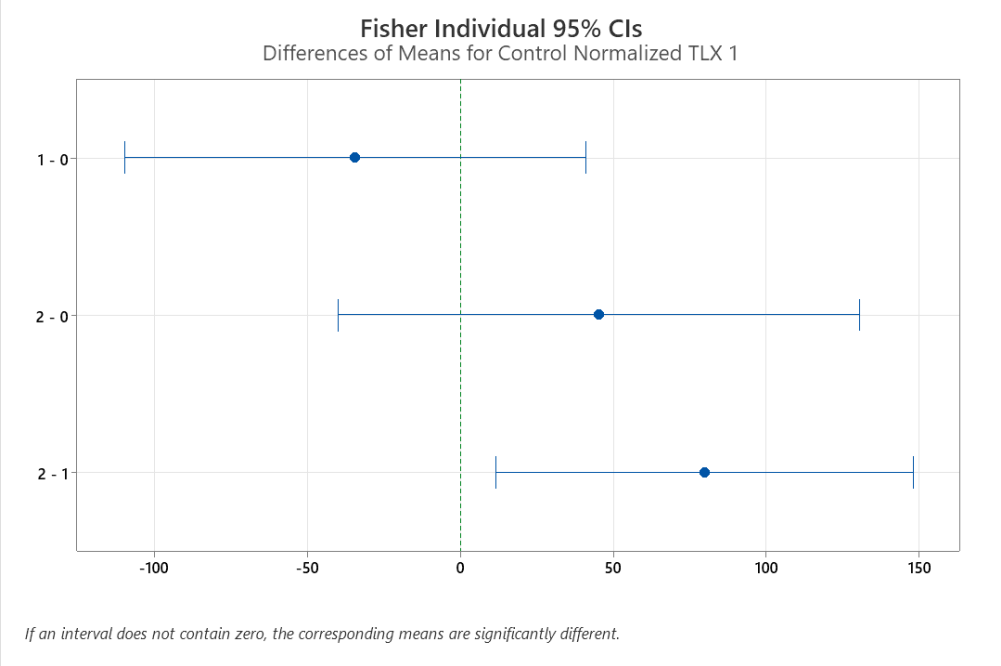


Figure 79: Fisher Individual 95% CIs Plot

The Control Normalized TLX, Min-Max TLX, Weighted TLX, and Unweighted TLX scores were higher for the High ADHD group compared to the Low and Medium ADHD groups, though these differences were not statistically significant. Notable differences between the metrics and subscales are summarized below.

Control Normalized TLX:

- Mean scores: Low ADHD (58.2), Medium ADHD (23.8), High ADHD (103.4).

- The differences approached significance (p = 0.074), indicating a possible trend where the High ADHD group experienced higher cognitive load.).

Frustration TLX:

- Mean scores lowest for Low ADHD (7.1), highest for Medium ADHD (12.1), and in between for High ADHD (9.7).
- The differences were not statistically significant (p = 0.680).

The Control Normalized TLX scores indicated a possible trend: Participants with High ADHD levels experienced higher cognitive load compared to those with Medium and Low ADHD levels. Fisher pairwise comparisons confirmed a significant difference between the Control Normalized TLX Medium and High ADHD groups, suggesting that the HMAR treatment imposed a substantially greater cognitive load on participants with higher ADHD levels. This relationship will be investigated further in the next hypothesis test.

Despite the lack of significant differences in most subscales, the trend in the Control Normalized TLX and Mental Demand TLX suggests that higher ADHD levels may be associated with increased cognitive and mental demands in augmented reality settings.

The one-way ANOVA revealed a difference approaching significance in Control Normalized TLX scores across ADHD levels during the HMAR treatment (p = 0.074). Participants with higher ADHD levels appeared to experience greater cognitive load compared to those with medium ADHD levels. While most subscale differences were not statistically significant, the trends observed suggest that individuals with higher ADHD levels may face increased cognitive and mental demands in augmented reality environments.

H_8 EHMAR – Cognitive Load

Table 73: EHMAR – Cognitive Load Metrics by ASRS6 Levels -Descriptive Statistics and ANOVA Results

	ASRS6 – Low (Unlikely) N = 4				ASRS6- Medium (Possible) N = 6				ASRS6-High (Likely) N = 5				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
Control Normalized TLX	51.6	104.1	-54.8	148.7	31.3	34.7	-9.7	84.0	31.2	35.4	6.7	93.5	0.848
Min-Max TLX	58.4	37.5	5.7	94.3	57.4	17.1	33.6	78.7	59.8	16.4	38.5	75.8	0.986
Weighted TLX	58.5	30.5	15.7	87.7	57.7	13.9	38.3	75.0	59.6	13.4	42.3	72.7	0.986
Unweighted TLX	55.4	28.9	16.7	78.3	47.8	13.3	30.0	64.2	48.8	15.0	31.5	68.3	0.809
Mental Demand TLX	8.1	7.7	1.3	17.1	8.1	7.0	0.0	18.7	13.8	11.7	2.0	26.7	0.528
Physical Demand TLX	3.6	5.2	0.0	11.3	0.6	1.4	0.0	3.3	2.4	5.4	0.0	12.0	0.529
Temporal TLX	7.2	9.6	0.0	21.3	19.9	5.8	14.0	28.3	20.2	5.9	15.0	30.0	0.026
Performance TLX	9.1	8.4	1.3	20.0	14.4	8.7	2.7	25.0	5.6	2.9	3.0	10.0	0.166
Effort TLX	13.7	9.3	5.0	24.0	7.1	5.0	1.3	14.0	6.4	6.0	1.3	16.0	0.243
Frustration TLX	16.8	13.1	2.0	33.3	7.6	5.5	0.3	17.7	11.2	12.4	0.0	31.7	0.410

Table 74: EHMAR, Temporal TLX: Grouping Information Using the Tukey Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping
2	5	20.20	A
1	6	19.89	A
0	4	7.17	B

Means that do not share a letter are significantly different.

H9: The Weighted NASA TLX scores after Recall will vary between participants using the EHMAR treatment for training and those using other treatments, with the differences influenced by the levels of ADHD symptoms.

A two-way ANOVA was conducted to examine the effects of ADHD level (Low/Medium/High) and treatment (EHMAR and all others) on the Weighted NASA TLX after recall. The analysis involved three levels of ADHD and two groups of treatments, with a total of 60 observations. The factor coding was set to (-1, 0, +1), and

one row was unused in the analysis due to missing TLX scores.

Table 75: Summary of Results of Two-Way-ANOVA Weighted NASA TLX in Recall by ADHD Level x EHMAR vs all other Treatments

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	498.2	249.1	1.26	0.292
EHMAR vs Others	1	411.6	411.6	2.08	0.155
ADHD Level (Low/Med/High)*EHMAR vs Others	2	690.7	345.3	1.75	0.184
Error	54	10665.3	197.5		
Total	59	13340.9			

ADHD Level: The effect of the ADHD level on the control normalized TLX was not statistically significant ($p = 0.292$). The levels of ADHD explained 12.57% of the total variance.

Treatment: The effect of treatment on the control normalized TLX was also not statistically significant ($F(1,54) = 2.08$, $p = 0.155$). The treatments explained 2.31% of the total variance.

ADHD Level * Treatment: The interaction between ADHD level and treatment was not significant ($F(2,54) = 1.75$,$p = 0.184$), contributing 5.18% to the total variance.

Although the ADHD Level, Treatment, and their interaction terms did not reach statistical significance, the p-values for Treatment and the interaction term are

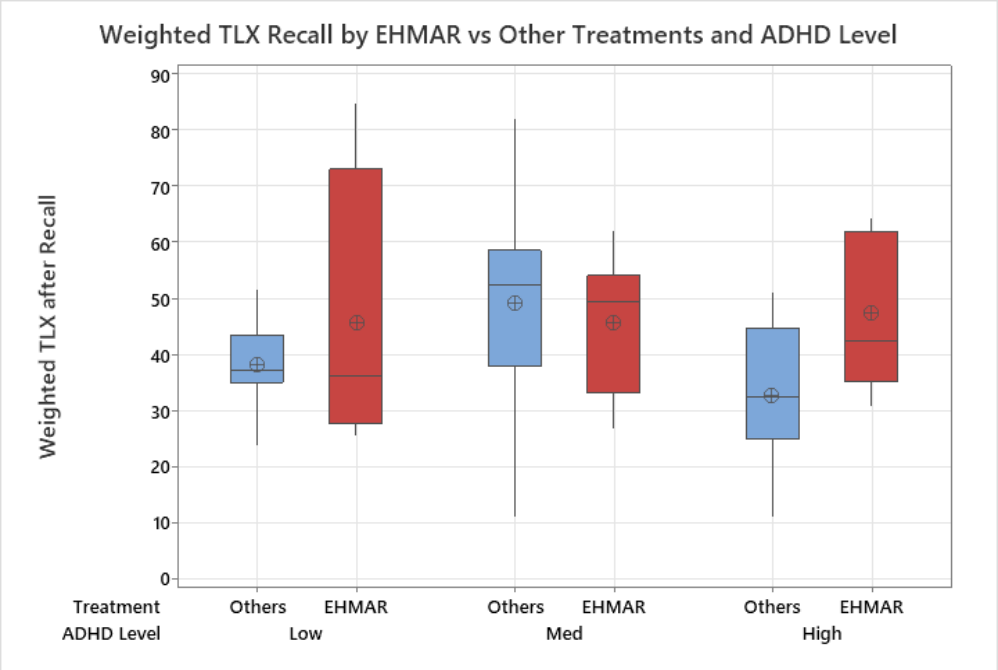


Figure 80: Weighted TLX Recall EHMAR vs Other Treatments and ADHD Level

approaching significance, suggesting that there might be some relationship worth further investigation.

The model explains 20.06% of the variance in Weighted TLX 2 scores (R^2), indicating that these factors alone cannot explain a large portion of the variability.

Overall, these results suggest a complex relationship between ADHD levels, treatment types, and cognitive load, warranting further exploration, particularly considering the approaching significant findings for the treatment and interaction effects.

H_{10}: The Control Normalized NASA TLX Training differs among the levels of ADHD Symptoms.

The Control Normalized TLX score was calculated by taking the TLX score for

the Control (the Recall session using PWI), subtracting it from the treatment-weighted TLX score, and then dividing it by the Control TLX value. This normalization method mitigates individual variability, allowing more accurate treatment comparisons. Positive scores indicate a higher cognitive load in the treatment compared to the control, while negative scores indicate a lower cognitive load. The descriptive statistics for this metric are summarized by treatment in the table below.

Table 76: Descriptive Statistics of Control Normalized TLX by ASRS6 ADHD Level and Treatment

	ASRS6 – Low (Unlikely)				ASRS6- Medium (Possible)				ASRS6-High (Likely)				2-sided 95% CI
Treatment	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
PWI	45.9	12.6	37.1	54.8	79.9	144.8	0.0	406.1	156.0	148.3	44.4	415.2	0.496
PBAR	45.6	62.0	-8.5	145.1	4.8	26.0	-17.4	56.2	30.9	28.6	-1.5	52.9	0.323
HMAR	58.2	64.5	-6.4	122.5	23.8	37.0	-41.4	64.4	103.4	66.9	37.0	176.5	0.074
EHMAR	51.6	104.1	-54.8	148.7	31.3	34.7	-9.7	84.0	31.2	35.4	6.7	93.5	0.848

Table 77: HMAR Treatment, Control Normalized NASA TLX Training by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	17045	8523	3.26	0.074
Error	12	31335	2611		
Total	14	48380			

In the PWI treatment for the training session, participants' NASA TLX scores were consistently higher than those recorded during the PWI Recall session, however not significant. The recall session was not time-limited, unlike the training session, which included time pressure. This difference likely explains the universally positive values for this treatment since time pressure is added to the cognitive load of the task. Additionally, a trend was observed where the cognitive load increased with higher ADHD levels, suggesting that time pressure may have a greater impact on participants with ADHD. Although this trend was not statistically significant, it is noteworthy and suggests a potential area for future research.

Table 78: Descriptive Statistics of Control Normalized TLX Training by ASRS6 ADHD

Level

	ASRS6 – Low (Unlikely) N = 14				ASRS6- Medium (Possible) N = 28				ASRS6-High (Likely) N = 19				One-Way ANOVA p-value
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
Control Normalized TLX Training	50.1	66.0	-54.8	148.7	35.8	79.8	-41.4	406.1	92.4	108.3	-1.5	415.2	0.099

Table 79: All Treatments, Control Normalized TLX Training by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	36552	18276	2.41	0.099
Error	57	433023	7597		
Total	59	469575			

An intriguing trend emerges when analyzing the data by ADHD level. For participants with Low and Medium ADHD levels across all four treatments, the minimum values of the Control Normalized TLX scores were negative, indicating a reduction in cognitive load compared to the PWI Recall session. Conversely, for the High ADHD level group, the minimum values were predominantly positive, suggesting an increase in cognitive load for these participants in all treatments. The PBAR treatment had a very small negative minimum (-1.5) from one participant, which is an exception. This trend is visible in the figure below, with the highest level of ADHD on the right in yellow.

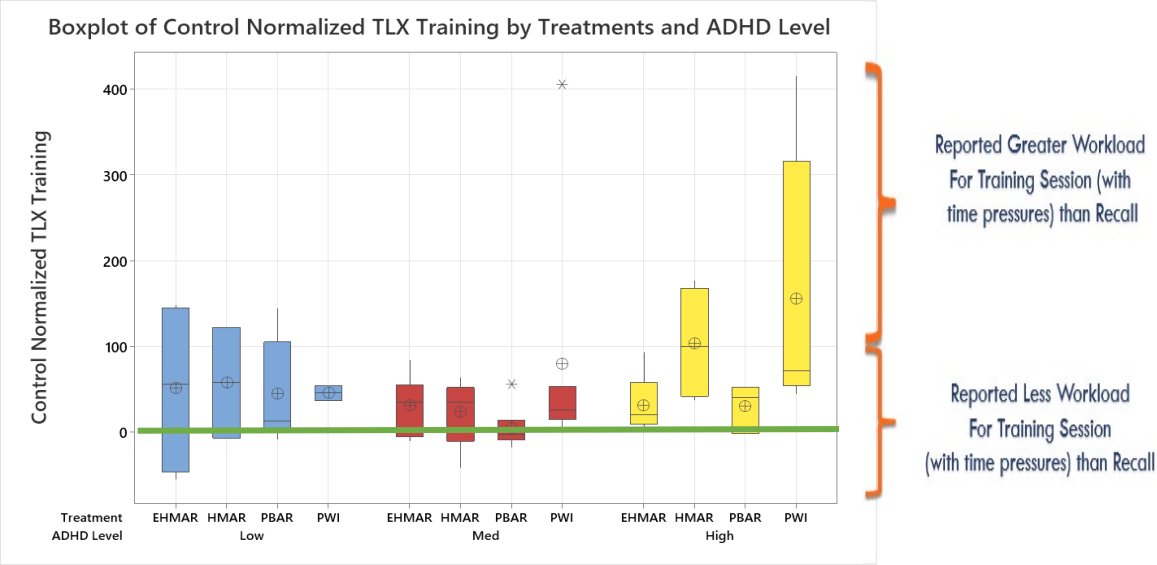


Figure 81: Control Normalized NASA TLX Training by ADHD L

The Fisher Pairwise Comparison shows a significant difference between the medium and high groups as seen below.

Table 80: Control Normal TLX Training by ADHD Level: Fisher Pairwise Comparisons, Grouping Information Using the Fisher LSD Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping	
2	19	92.4	A	
0	14	50.1	A	B
1	27	35.8		B

Means that do not share a letter are significantly different.

Table 81: Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	-14.3	28.7	(-71.7, 43.2)	-0.50	0.621
2 - 0	42.3	30.7	(-19.2, 103.8)	1.38	0.174
2 - 1	56.6	26.1	(4.3, 108.8)	2.17	0.034

Simultaneous confidence level = 87.92%

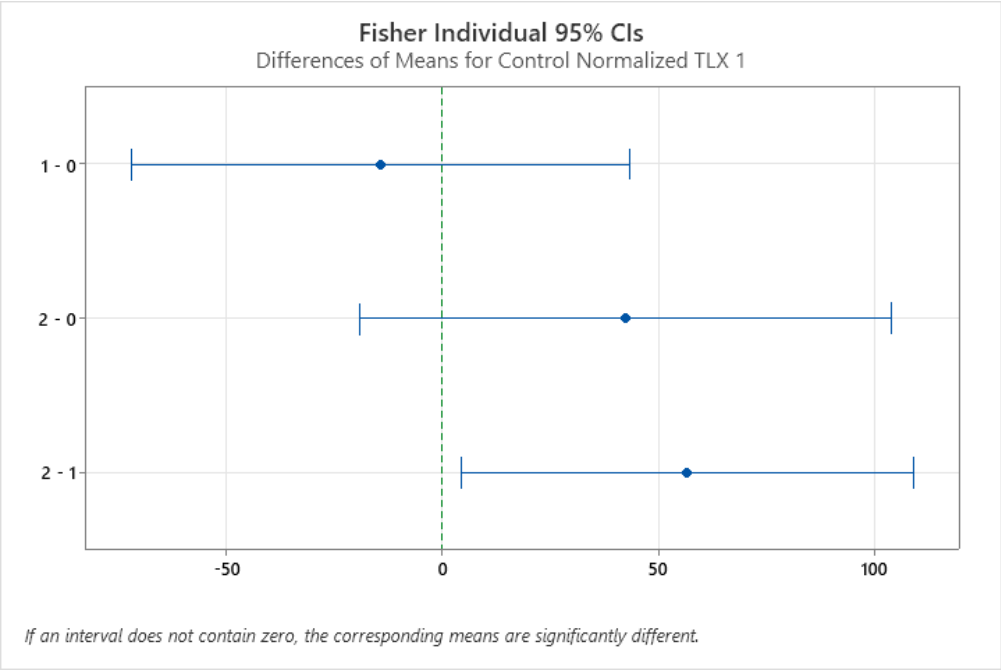


Figure 82: Fisher Individual 95% CI Plot

This trend, though not statistically significant overall, approaches significance ($p = 0.099$) and suggests that participants with higher ADHD levels may perceive increased cognitive load across different treatments compared to those with lower ADHD levels.

B.5.4 Usability (SUS) Related Hypotheses

H_{11}: System Usability Scale Ratings differ among the levels of ADHD Symptoms

The hypothesis test H_{11} aimed to determine whether System Usability Scale (SUS) ratings differ among various levels of ADHD symptoms. This analysis considered three groups based on ADHD symptom levels: low, medium, and high. The data were gathered during different phases, including training and recall, and the results were analyzed using ANOVA, two-tailed, $\alpha = 0.05$, 95% CI. Descriptive statistics and results are found in the graph, table, and analysis below.

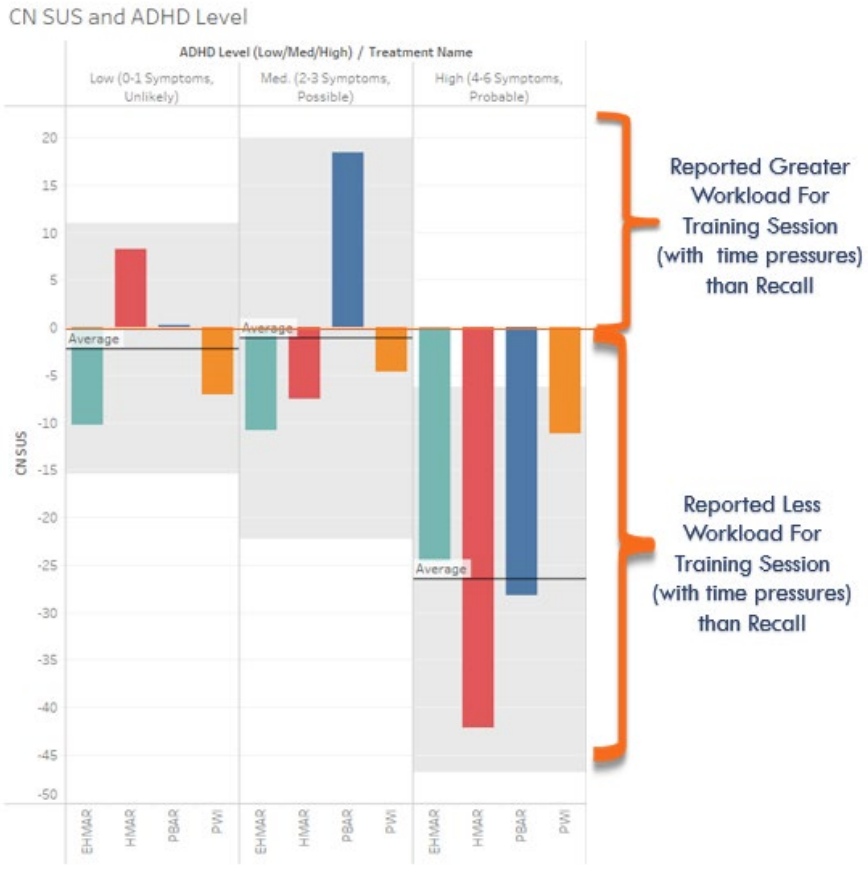


Figure 83: Control Normalized SUS by ADHD Level

Table 82: H_{11} SUS by ASRS6 Level for Training and Recall: Hypothesis Test Results

		ADHD Low N = 14				ADHD Medium N = 28				ADHD High N = 19				Statistical Test Two-tailed $\alpha = 0.05$
Metric	Phase	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value
SUS	Training	72.5	22.8	7.5	97.5	70.6	12.4	37.5	84.5	61.8	17.4	35.0	92.5	0.131
Control Normalized SUS		-2.1	31.6	-90.9	39.1	-1.0	34.8	-45.5	138.5	-23.9	18.9	-57.1	0.0	0.030
Normalized SUS		0.7	0.3	0.0	1.0	0.6	0.3	0.0	0.9	0.4	0.4	0.0	1.0	0.039

		ADHD Low N = 14				ADHD Medium N = 28				ADHD High N = 19				Statistical Test Two-tailed α = 0.05
Metric	Phase	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value
SUS	Recall	76.6	16.5	35.0	97.5	75.2	15.1	32.5	97.5	81.7	11.4	52.5	100.0	0.308

Table 83: Control Normalized SUS by ASRS6 Level for Training: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	6668	3333.9	3.71	0.030
Error	58	52101	898.3		
Total	60	58769			

During the training phase, the SUS p-value for this phase was 0.131, indicating no statistically significant difference in SUS scores among the three ADHD levels during training.

The training control normalized SUS scores provided more insight. The high ADHD group had a notably lower mean of -23.9, with a standard deviation of 18.9 and a range from -57.1 to 0. The p-value for the control normalized SUS was 0.030, indicating a statistically significant difference among the ADHD levels.

Fisher pairwise comparisons for the control normalized SUS scores indicated significant differences. The high ADHD group (mean: -23.95) significantly differed from both the low (-2.11) and medium (-1.03) ADHD groups. Specifically, the differences in means between the high ADHD group and the low and medium ADHD groups were -21.8 and -22.92, respectively, with adjusted p-values of 0.043 and 0.013, indicating

statistically significant differences.

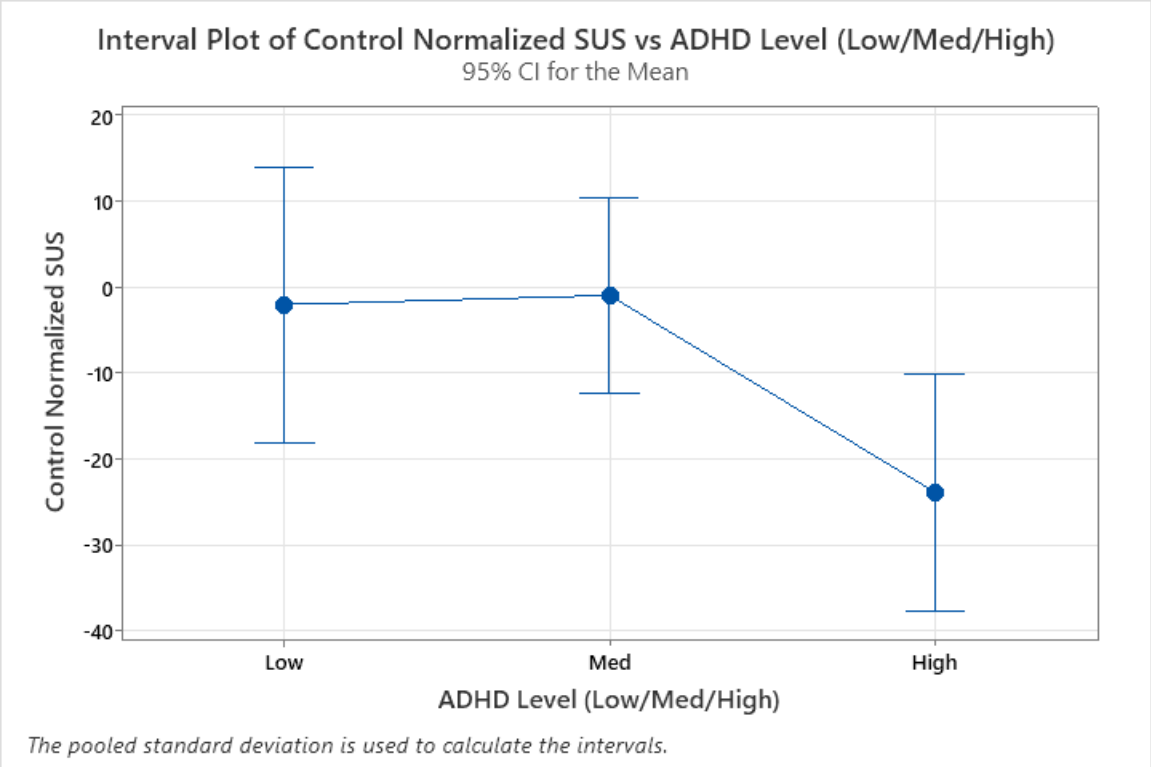


Figure 84: Interval Plot of Control Normalized SUS vs ADHD Level

Table 84: Control Normalized SUS vs. ADHD Level: Fisher Pairwise Comparisons

Grouping Information Using the Fisher LSD Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping
1	28	-1.03	A
0	14	-2.11	A
2	19	-23.95	B

Means that do not share a letter are significantly different.

Table 85: Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	1.07	9.81	(-18.56, 20.71)	0.11	0.913
2 - 0	-21.8	10.6	(-43.0, -0.7)	-2.07	0.043
2 - 1	-22.92	8.91	(-40.75, -5.08)	-2.57	0.013

Simultaneous confidence level = 87.91%

The normalized SUS scores also revealed significant differences. The normalized SUS scores for the High ADHD symptom group were significantly lower than those for the other two groups. The p-value for the normalized SUS was 0.039, further supporting the presence of significant differences among the ADHD symptom levels.

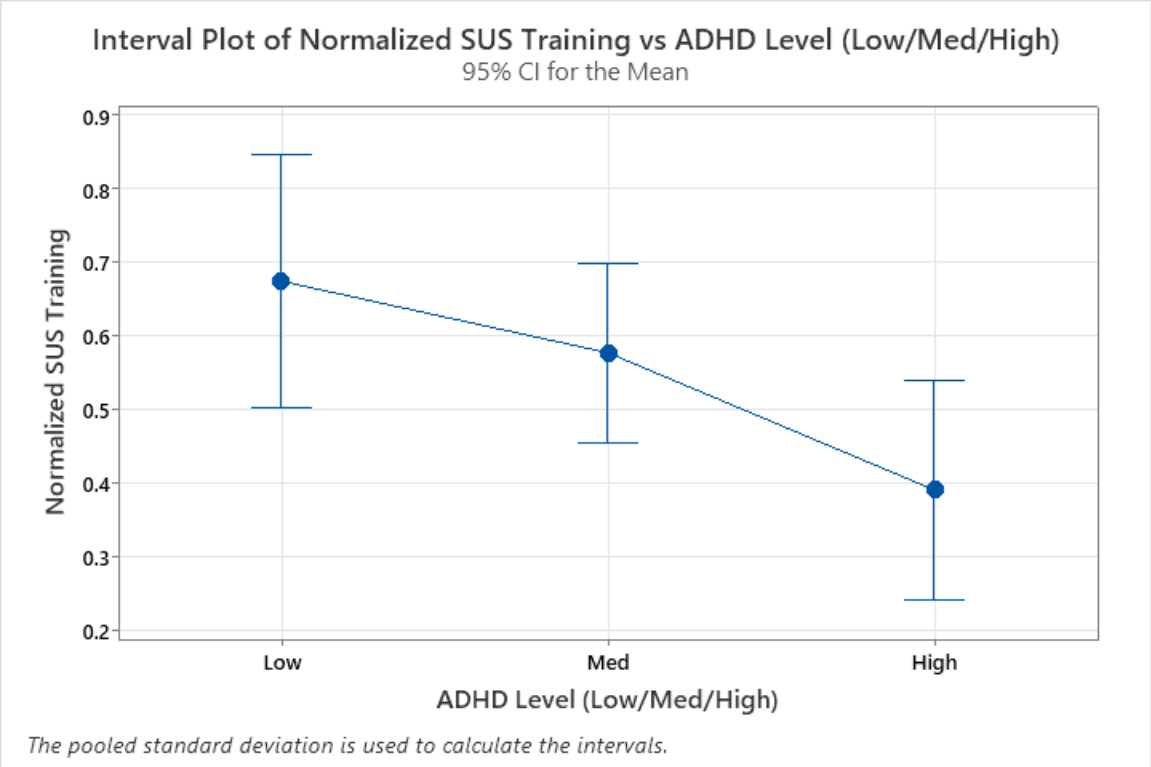


Figure 85: Interval Plot of Normalized SUS Training vs ADHD Level

During the recall phase, the participants rated the traditional paper work without a time limit; the mean SUS scores were slightly higher, with the low ADHD group scoring 76.6 (SD: 16.5), the medium ADHD group 75.2 (SD: 15.1), and the high ADHD group the highest at 81.7 (SD: 11.4). However, the p-value for this phase was 0.308, indicating no significant differences in recall SUS scores among the ADHD levels.

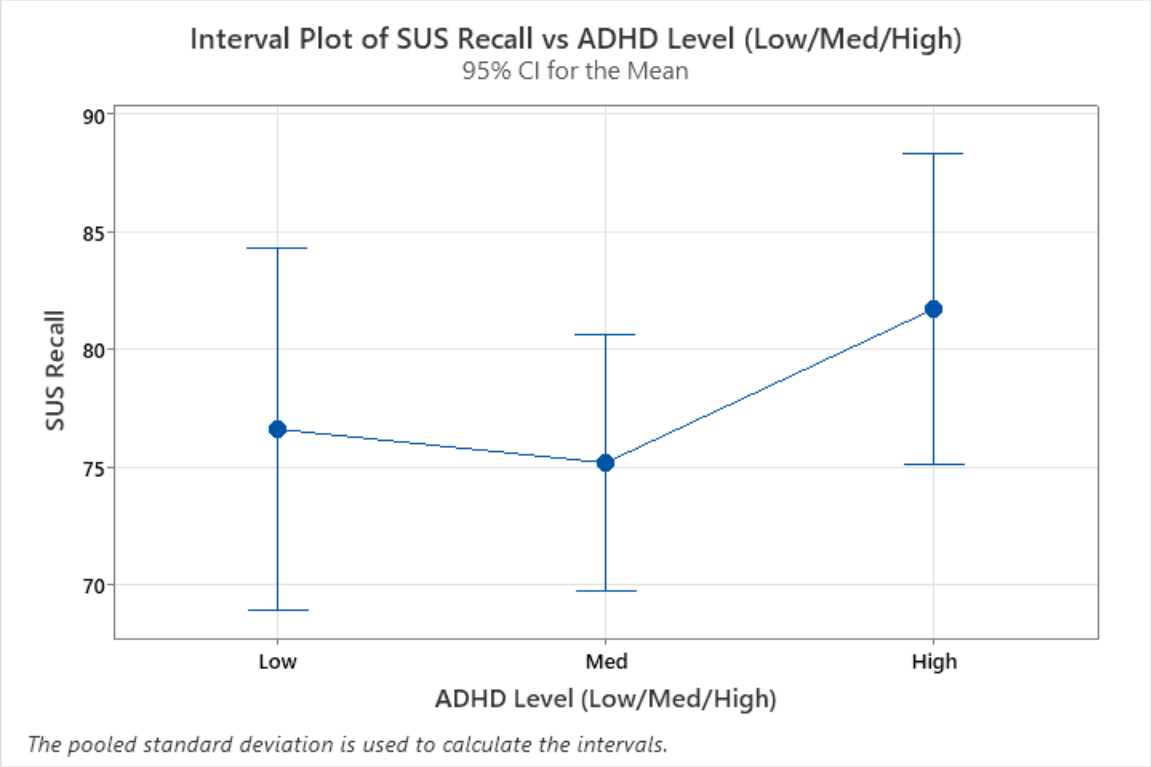


Figure 86: Interval Plot of SUS Recall vs ADHD Level

In conclusion, the hypothesis test results indicate significant differences in System Usability Scale ratings among different levels of ADHD symptoms. The control normalized SUS scores and the normalized SUS scores both showed statistically significant differences, particularly highlighting that individuals with high ADHD symptoms tend to have lower SUS ratings. This suggests that ADHD symptom level influences perceived system usability, with higher symptoms correlating with lower usability ratings. These findings underscore the importance of considering ADHD symptom levels in usability assessments and potentially tailoring user interfaces to accommodate users with higher ADHD symptoms for better usability outcomes.

H_{12}: ADHD symptom levels will not significantly affect the Control Normalized System Usability Scale (SUS) scores within each treatment (PBAR, HMAR, EHMAR, and PWI).

The hypothesis test H_{12} aimed to investigate whether ADHD symptom levels

significantly affect the Control Normalized System Usability Scale (SUS) scores within each treatment type, including PBAR, HMAR, EHMAR, and PWI. The ANOVA analysis was conducted with participants categorized into three groups based on their ADHD symptoms: low (unlikely), medium (possible), and high (likely).

The descriptive statistics of each of the treatments by ADHD Level are summarized in the table below.

Table 86: Control Normalized SUS Training by ASRS6 Level and Treatment ANOVA Results

	ASRS6 – Low (Unlikely)				ASRS6- Medium (Possible)				ASRS6-High (Likely)				2-sided 95% CI
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	ANOVA p-value
PWI	-7.1	1.2	-7.9	-6.3	-4.7	22.4	-42.3	34.6	-11.2	8.5	-24.2	0.0	0.758
PBAR	0.2	26.1	-26.5	39.1	18.4	59.2	-28.2	138.5	-28.2	25.0	-56.3	-8.3	0.361
HMAR	8.3	17.7	-3.7	28.6	-7.5	15.4	-25.7	16.0	-42.2	15.4	-25.7	16.0	0.006
EHMAR	-10.3	54.7	-90.9	28.6	-10.8	25.9	-45.5	21.1	-24.6	14.8	-36.1	0.0	0.748

Table 87: HMAR, Control Normalized SUS by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	5006	2503.1	8.28	0.006
Error	12	3628	302.3		
Total	14	8634			

The ANOVA results for each treatment provided insights into the impact of ADHD symptom levels on Control Normalized SUS scores. For the PWI treatment, the mean Control Normalized SUS scores decreased as the ADHD level increased; though not statistically significant, the p-value was 0.758. Similarly, the PBAR treatment showed means of 0.2, 18.4, and -28.2 for the low, medium, and high ADHD groups, respectively, with a p-value of 0.361. Again, this indicated no significant differences in SUS scores based on ADHD levels. The EHMAR treatment showed mean SUS scores of -10.3 for the low ADHD group, -10.8 for the medium group, and -24.6 for the high group, with a p-value of 0.748, indicating no significant differences.

In contrast, the HMAR treatment revealed significant differences. The low ADHD group had a mean SUS score of 8.3, the medium group was -7.5, and the high group was -42.2. The p-value for the ANOVA was 0.006, indicating a statistically significant

difference in Control Normalized SUS scores among the ADHD levels for this treatment. This shows the same general trend of decreasing SUS Control Normalized scores as ADHD symptom levels increase.

The Fisher pairwise comparisons for the HMAR treatment further elucidated these findings. The high ADHD group's mean SUS score (-42.2) significantly differed from both the low (8.3) and medium (-7.53) groups. The differences in means were -50.5 and -34.7, respectively, with adjusted p-values of 0.003 and 0.007, confirming significant differences.

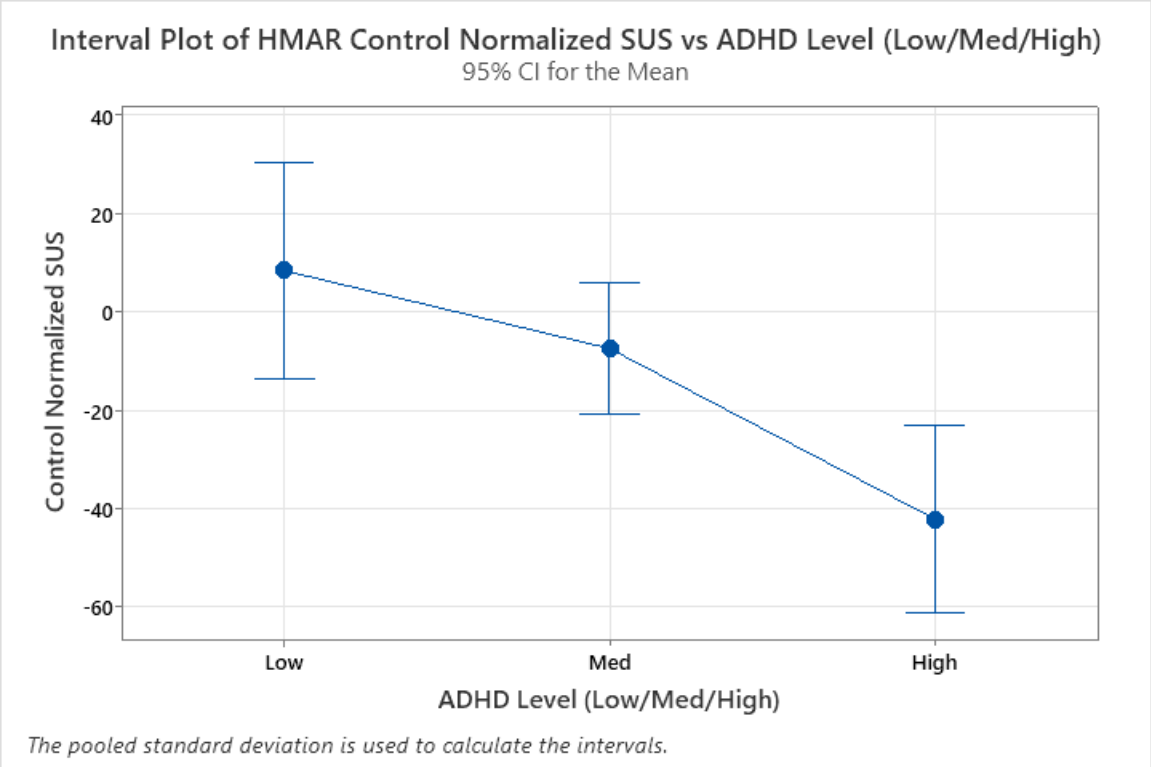


Figure 87: Interval Plot of HMAR Control Normalized SUS vs ADHD Level

Table 88: HMAR, Control Normalized SUS: Fisher Pairwise Comparisons

Grouping Information Using the Fisher LSD Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping
0	3	8.3	A
1	8	-7.53	A
2	4	-42.2	B

Means that do not share a letter are significantly different.

Table 89: Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	-15.8	11.8	(-41.5, 9.8)	-1.34	0.204
2 - 0	-50.5	13.3	(-79.4, -21.6)	-3.80	0.003
2 - 1	-34.7	10.6	(-57.9, -11.5)	-3.26	0.007

Simultaneous confidence level = 88.44%

In conclusion, the hypothesis that ADHD symptom levels would not significantly affect the Control Normalized SUS scores was not entirely supported. While the PWI, PBAR, and EHMAR treatments showed no significant differences in SUS scores among ADHD levels, the HMAR treatment did exhibit significant differences. Specifically, participants with high ADHD symptoms had significantly lower usability ratings compared to those with low and medium symptoms.

H_{13}: The SUS scores for each ADHD symptom level will be different between treatments (PBAR, HMAR, EHMAR, and PWI).

The hypothesis test H_{13} aimed to determine if System Usability Scale (SUS) scores differ between treatments (PBAR, HMAR, EHMAR, and PWI) for each ADHD symptom level. This analysis involved using a General Linear Model (GLM)/ Two-Way ANOVA to explore the interaction between ADHD levels and treatment types, focusing on their combined effect on SUS scores.

Table 90: Summary of Results of Two-Way-ANOVA SUS in Training by ADHD Level x Treatments

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value
ADHD Level (Low/Med/High)	2	1191	6.78%	1649	824.6	3.09
Treatment Name	3	1272	7.24%	1336	445.2	1.67
ADHD Level (Low/Med/High)*Treatment Name	6	2024	11.53%	2024	337.3	1.26
Error	49	13072	74.45%	13072	266.8	
Total	60	17559	100.00%			

Source	P-Value
ADHD Level (Low/Med/High)	0.054
Treatment Name	0.186
ADHD Level (Low/Med/High)*Treatment Name	0.291
Error	
Total	

Significant findings included the coefficient for the EHMAR treatment, which was -7.67 with a p-value of 0.048, indicating that EHMAR had a significantly lower SUS score compared to other treatments. Additionally, the interaction term between low ADHD level and EHMAR treatment was -12.62, with a p-value of 0.032, indicating a significant negative impact on SUS scores for low ADHD participants using EHMAR.

The interesting finding was the near-significant effect of ADHD levels on SUS scores, as the p-value of 0.054 for ADHD levels approached the threshold for significance. This suggests that while inconclusive, there is a potential trend worth further investigation. Additionally, the medium ADHD level had a coefficient of 2.19 with a p-value of 0.454, indicating no significant impact on SUS scores. However, the low ADHD level showed a more considerable effect with a coefficient of 5.79 and a p-value of 0.105, approaching significance.

Equation 1: Regression Equation

SUS Training = 68.25 + 5.79 ADHD Level (Low/Med/High)_0 + 2.19 ADHD Level (Low/Med/High)_1
- 7.98 ADHD Level (Low/Med/High)_2 - 7.67 Treatment Name_EHMAR
- 0.09 Treatment Name_HMAR + 1.42 Treatment Name_PBAR
+ 6.33 Treatment Name_PWI - 12.62 ADHD Level (Low/Med/High)*Treatment Name_0
EHMAR + 10.22 ADHD Level (Low/Med/High)*Treatment Name_0 HMAR
+ 1.53 ADHD Level (Low/Med/High)*Treatment Name_0 PBAR
+ 0.88 ADHD Level (Low/Med/High)*Treatment Name_0 PWI
+ 2.23 ADHD Level (Low/Med/High)*Treatment Name_1 EHMAR
- 0.03 ADHD Level (Low/Med/High)*Treatment Name_1 HMAR
+ 1.00 ADHD Level (Low/Med/High)*Treatment Name_1 PBAR
- 3.20 ADHD Level (Low/Med/High)*Treatment Name_1 PWI
+ 10.39 ADHD Level (Low/Med/High)*Treatment Name_2 EHMAR
- 10.18 ADHD Level (Low/Med/High)*Treatment Name_2 HMAR
- 2.53 ADHD Level (Low/Med/High)*Treatment Name_2 PBAR
+ 2.32 ADHD Level (Low/Med/High)*Treatment Name_2 PWI

Upon additional analysis, the model summary indicates a low R^2 of 25.5% and a very low predicted R^2 of 0.0%, indicating a minimal effect size and poor predictive power for new data.

In conclusion, the hypothesis that SUS scores would differ between treatments for each ADHD symptom level was not supported, due to the low effect size of the model. While the overall interaction between ADHD levels and treatments was not statistically significant, the approaching significant findings for ADHD levels suggest that further research is warranted to understand these relationships fully. These results highlight the complexity of how ADHD symptoms and different treatments interact to affect perceived system usability, suggesting the possible need for tailored usability assessments and

interventions.

B.5.5 Covariate Analysis

Multiple regression analyses were performed on the outcomes of the investigations with all the covariates. The following table shows the outcome of one of the analyses. The analyses were performed in Minitab using the “Stat”, “Regression”, “Regression”, “Fit Regression Model” feature, putting the Independent Metrics and variables in the “Responses” and the covariates in either “Continuous predictors” or “Categorical Predictors” depending on the type of variable. Being able to use both continuous and categorical variables in this analysis makes the Regression analysis a better choice for this study of covariates than an ANCOVA, which only calculates based on continuous/numerical variables.

The tables summarize the significant outcomes of the analysis across the metrics for this investigation by treatment. The Durbin-Watson Statistic for this analysis is 2.17, generally considered to indicate no significant autocorrelation (if within the range of 1.5 and 2.5). This statistic helps to check the regression assumptions and the inferences' validity.

The tables below summarize the findings from the other regression analyses for covariates. A separate regression analysis was performed for representative output variables and metrics. The key metrics and outcomes for each treatment are summarized in the following tables. They show each covariate's p-value and 95% percentile confidence interval. Highlighted in orange are significant at the 95% confidence interval, and highlighted in blue are significant at the 90% confidence interval (including the orange values).

Table 91: Covariate Analysis Summary Results

	Total Cars Built Training		Average Defects Training		Average Defects Recall		Weighted NASA TLX Training		SUS Training	
	p-value	(CI)	p-value	(CI)	p-value	(CI)	p-value	(CI)	p-value	(CI)
Constant	0.027	(08.83-12.72)	0.002	(5.27, 21.41)	0.065	(-0.54, 17.62)	0.017	(10.9, 105.7)	0.000	(61.0, 16.3.7)
Age	0.182	(-0.19, 0.04)	0.751	(-0.28, 0.03)	0.873	(-0.19, 0.16)	0.304	(-0.42, 1.31)	0.043	(-2.03, -0.03)
Race (Ref: Asian)										
Black or African-American	0.698	(-4.50, 3.05)	0.921	(-4.21, 5.93)	0.353	(-8.42, 3.09)	0.907	(-29.4, 26.1)	0.773	(-28.0, 37.3)
White	0.998	(-2.99, 3.00)	0.976	(-3.87, 4.27)	0.393	(-6.53, 2.63)	0.685	(-26.5, 17.6)	0.271	(-40.2, 11.6)
More than one race	0.380	(-7.42, 2.89)	0.973	(-7.12, 6.88)	0.832	(-8.71, 7.05)	0.181	(-63.4, 12.4)	0.851	(40.4, 48.7)
LEGO Experience (Ref: Little/No)										
Some experience	0.522	(-1.20, 2.23)	0.861	(-2.18, 2.60)	0.356	(-1.45, 3.09)	0.686	(-15.82, 10.09)	0.585	(-11.07, 19.34)
Lots of experience	0.364	(-1.14, 3.05)	0.147	(-4.92, 0.76)	0.433	(-4.45, 1.95)	0.956	(-15.94, 15.10)	0.803	(-15.86, 20.35)
Expert	0.078	(-0.28, 5.13)	0.823	(-3.27, 4.08)	0.623	(-3.12, 5.15)	0.530	(-26.11, 13.68)	0.786	(-20.3, 26.6)
Gender (Ref: Female)										
Male	0.454	(-1.70, 3.87)	0.258	(-3.52, 0.97)	0.257	(-3.97, 1.09)	0.591	(-8.92, 15.44)	0.899	(-13.41, 15.22)
Other*	0.225	(-1.73, 7.13)	0.001	(4.46, 16.49)	0.006	(3.01, 16.55)	0.555	(-42.2, 23.0)	0.175	(-12.2, 64.4)
School Major (Ref: Business)										
COSAM	0.092	(-0.54, 6.91)	0.324	(-2.57, 7.55)	0.497	(-3.77, 7.62)	0.153	(50.9, 8.3)	0.176	(-10.3, 54.2)
Engineering	0.437	(-1.70, 3.87)	0.201	(-6.21, 1.35)	0.543	(-5.54, 2.96)	0.875	(-27.1, 23.2)	0.573	(-30.8, 17.3)
N/A	0.361	(-2.09, 5.61)	0.751	(-6.05, 4.40)	0.400	(-3.41, 8.35)	0.981	(-30.5, 31.2)	0.382	(-18.7, 47.8)
Birth Country (Ref: Other)										
USA	0.153	(-3.50, .052)	0.398	(-5.29, 4.06)	0.730	(-3.33, 2.36)	0.068	(-0.97, 26.44)	0.577	(-11.61, 20.56)

	Total Cars Built Training		Average Defects Training		Average Defects Recall		Weighted NASA TLX Training		SUS Training	
	p-value	(CI)	p-value	(CI)	p-value	(CI)	p-value	(CI)	p-value	(CI)
Ethnicity (Ref: Hispanic/Latino)										
Not Hispanic or Latino	0.270	(-4.87, 1.41)	0.006	(-10.35, -1.82)	0.240	(-7.63, 1.97)	0.216	(-37.4, 8.8)	0.463	(-37.1, 17.2)
ADHD Level (Ref: Low)										
Medium	0.310	(-0.91, 2.76)	0.971	(-2.44, 2.53)	0.662	(-3.41, 2.19)	0.922	(-14.13, 12.82)	0.978	(-16.06,15.63)
High	0.576	(-1.37, 2.42)	0.838	(-2.31, 2.83)	0.353	(-4.23, 1.55)	0.669	(-10.98, 16.91)	0.740	(-19.05, 13.65)
Language (Ref: English)										
Other	0.685	(-4.14, 2.75)	0.792	(-5.29, 4.06)	0.308	(-7.95, 2.58)	0.387	(-14.4, 36.3)	0.615	(-37.2, 22.3)
Manufacturing (Ref: No Experience)										
One or More Classes	0.549	(-1.16, 2.15)	0.597	(-1.66, 2.84)	0.732	(-2.10, 2.96)	0.253	(-19.16, 5.20)	0.802	(-16.12, 12.54)
Part-time /temp job	0.679	(-1.51, 2.28)	0.050	(-0.00, 5.14)	0.041	(0.13, 5.91)	0.463	(-8.85, 19.05)	0.613	(-20.47, 12.24)
1+ years exp	0.423	(-1.49, 3.48)	0.000	(3.66, 10.42)	0.013	(1.08, 8.68)	0.577	(-13.28, 23.49)	0.681	(-25.9, 17.1)

*Only one person reported a gender other than male or female

Appendix C: Manufacturing Workplace Support Investigation (Chapter 4) Supplements

C.1 Additional Descriptive Statistics

C.1.1 ASRS6 Significant Symptom Prevalence

The ASRS 6 question sub-scale (ASRS6) revealed varying levels of significant symptoms among the participants. The ASRS6 has been statistically proven to have high specificity and selectivity in identifying self-reporting Adults who clinically have ADHD (Kessler, Adler, Ames, Demler, et al., 2005). Symptoms are considered significant if they reach the question threshold, either "Sometimes" or "Often" depending on the question. In the QI group, 15.4% of participants reported no significant symptoms, while 20.8% of the PI group reported the same, leading to a combined total of 18.0%. Participants with one significant symptom accounted for 26.9% in the QI group and 20.8% in the PI group, resulting in an overall percentage of 24.0%. Interestingly, the highest percentage within the QI group was for those with two significant symptoms (34.6%), compared to 20.8% in the PI group. When combined, this amounted to 28.0% of the total sample.

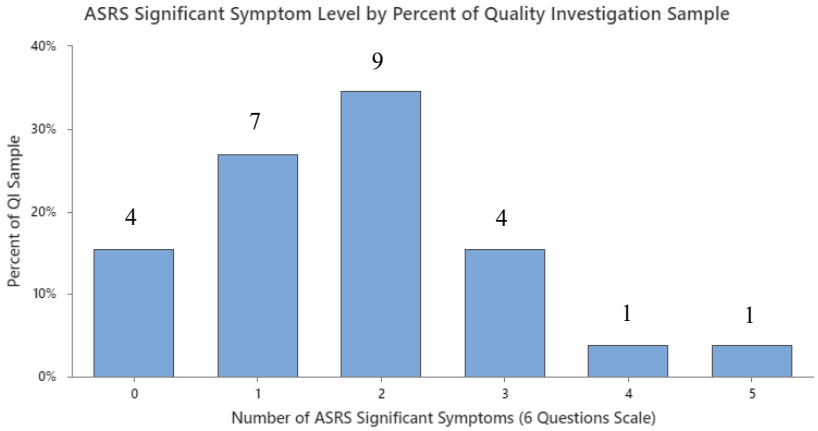


Figure 88: ASRS Significant Symptoms by Percent of Quality Investigation Sample

Participants with three significant symptoms comprised 15.4% of the QI group and 12.5% of the PI group, totaling 14.0%. Those with four significant symptoms were fewer in the QI group (3.9%) compared to the PI group (16.7%), leading to a combined

10.0%. Lastly, participants with five significant symptoms were slightly more in the PI group (8.3%) compared to the QI group (3.9%), with an overall prevalence of 6.0%. No participants in either group reported six significant symptoms. +

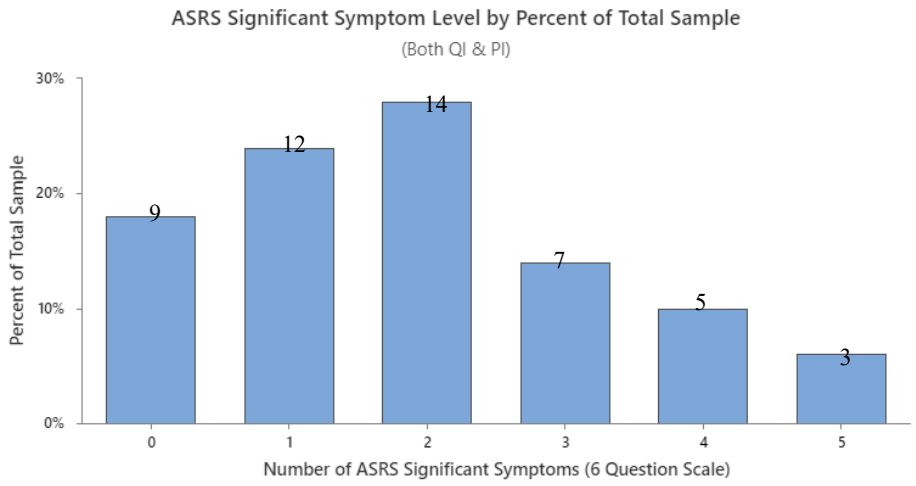


Figure 89: ASRS Significant Symptoms by Percent of Total Sample (QI+PI)

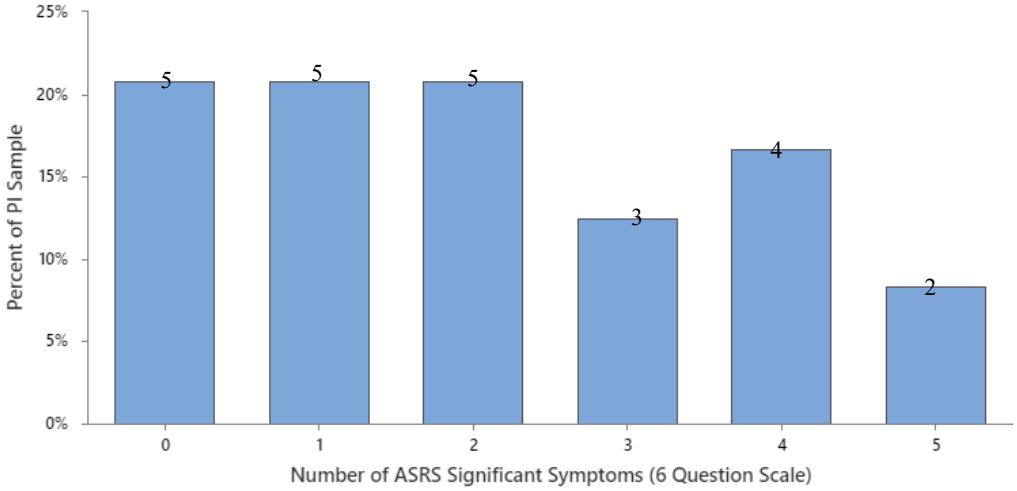


Figure 90: ASRS Significant Symptoms by Percent of Performance Investigation Sample

C.1.2 ASRS6 Levels (Low, Med, High)

The study categorized ADHD levels based on the number of significant symptoms from the ASRS6. The QI group had 42.3% of participants with Low ADHD levels (0-1 symptoms), closely mirrored by the PI group at 41.7%, leading to an overall 42.0%. Medium ADHD levels (2-3 symptoms) were more prevalent in the QI group (50.0%) compared to the PI group (33.3%), resulting in a combined 42.0%. High ADHD levels (4-6 symptoms) were significantly higher in the PI group (25.0%) than in the QI group (7.7%), with an overall prevalence of 16.0%. This factor is illustrated in the following three figures.

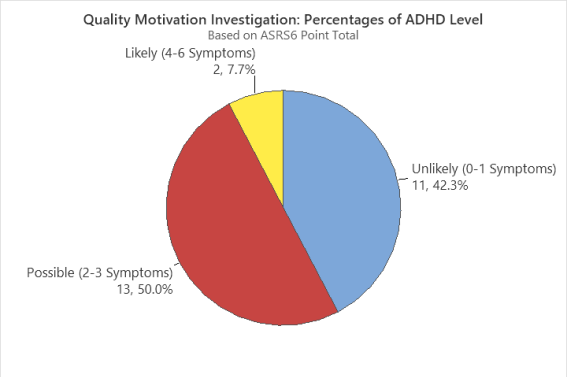


Figure 92: Quality Motivation Investigation: Percentages of ADHD Level based on ASRS6 Number of Significant Symptoms

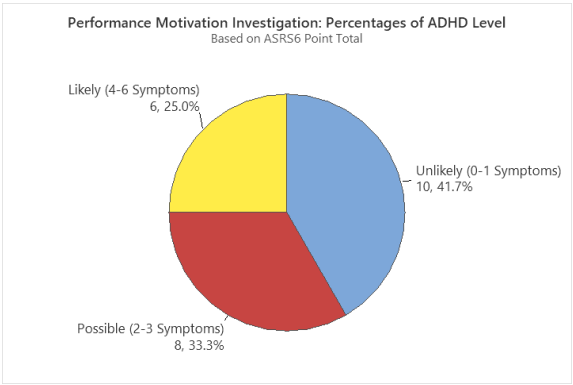


Figure 91: Performance Motivation Investigation: Percentages of ADHD Level based on ASRS6 Number of Significant Symptoms

C.1.3 ASRS6 Total Points Category

The ASRS6 Total Points category is calculated by adding the values for each of the first six questions in the ASRS, thus "Total Points." With particularly the top two levels of this classification, there has been a high correlation between clinician-diagnosed adults and the scale, especially with the highest level (Kessler et al., 2007). Kessler reports a proportion of clinician-diagnosed cases to non-cases of 25:1 for those in the 18-24 group and 10:1 for the 14-17 category (Kessler et al., 2007). When examining the ASRS6 Total Points category, the data showed that 46.2% of the QI group fell into the high negative category (0-9 points), compared to 50.0% of the PI group, resulting in an

overall 48.0%. The low negative category (9-13 points) included 38.5% of the QI group and 33.3% of the PI group, with a combined total of 36.0%. Both groups had a smaller

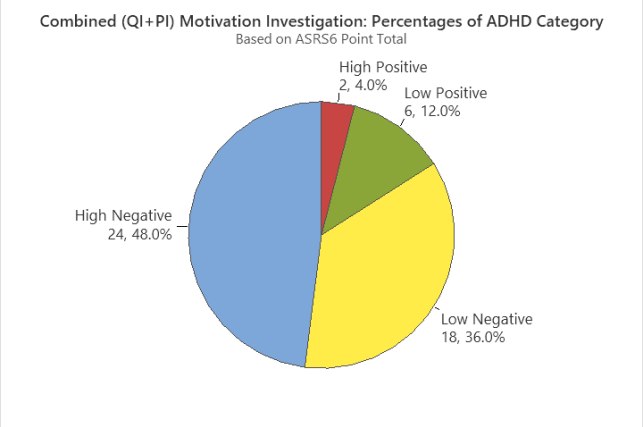


Figure 93: Combined (QI+PI) Motivation Investigation: Percentages of ADHD Category on ASRS6 Total of Points

percentage in the low positive category (14-17 points), with 11.5% for the QI group and 12.5% for the PI group, totaling 12.0%. The high positive category (18-24 points) included only 3.9% of the QI group and 4.2% of the PI group, combining for 4.0%. This factor is illustrated in the following figure.

C.1.4 ADHD Types

Analyzing the specific questions that each participant had significant levels, previous research has set classifications of the type of ADHD based on these questions (K. Stanton et al., 2018). A threshold level had to be determined for this classification; having four significant symptoms or more in a category was classified as significant. This classification level paralleled the number of participants with medium to high levels of symptoms in the other categories.

Regarding ADHD types based on ASRS 18 question severities, the PI group had a substantially higher percentage of participants with inattentive ADHD (62.5%) compared to the QI group (15.4%), leading to a total of 38.0%. Both groups had a small percentage of participants with hyperactive/impulsive ADHD, with 3.9% in the QI group and 4.2% in the PI group, totaling 4.0%. The combined ADHD type was equally represented in both groups, with 7.7% in the QI group and 8.3% in the PI group, leading to an overall 8.0%. Most participants reported no ADHD, with 73.1% in the QI group and 25.0% in the PI group, resulting in 50.0% overall. The following figure shows the proportion of ADHD Types for the whole data set of ADHD-likely participants.

C.1.5 Treatment Order of ADHD+ Subjects

This section investigates the distribution of participants with three or more significant ADHD symptoms across different treatment orders and groups, including Quality Investigation (QI), Performance Investigation (PI), and the combined total sample. The participants were randomly assigned to treatment orders to avoid bias, as

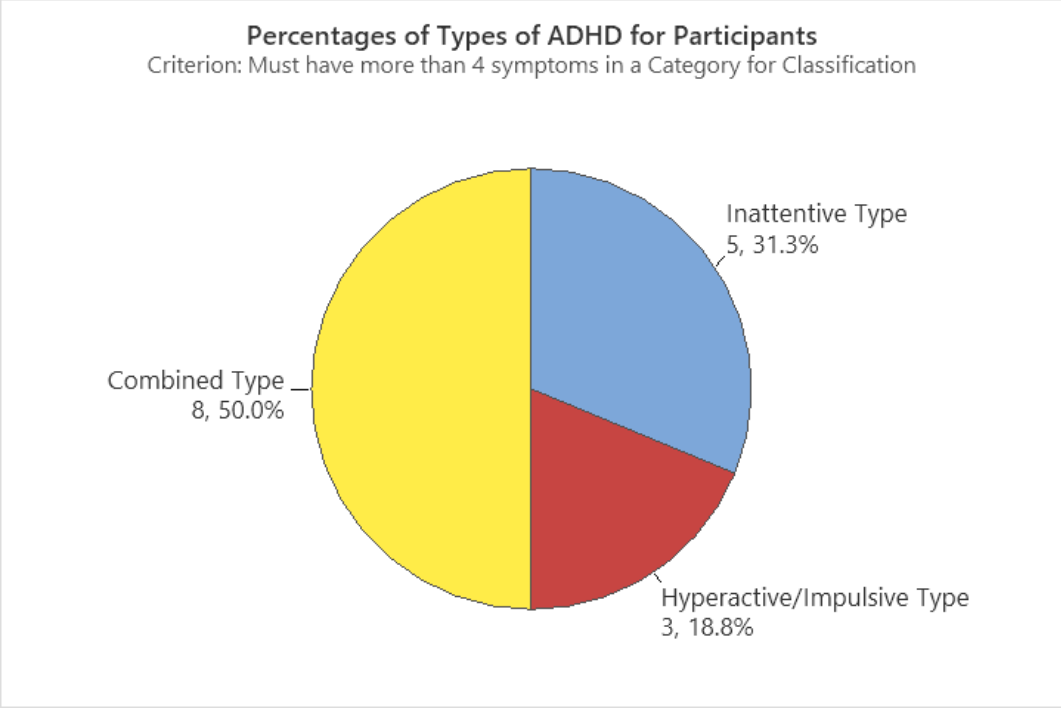


Figure 94: Number of Participants with >3 ADHD Symptoms: Combined (QI+PI) Motivation Investigation: Percentages of ADHD Type based on ASRS18 Symptom Significance

their ADHD status was unknown during the assignment. The summarized data is seen in the table below.

Table 92: ADHD (High Category) Frequency by Treatment Order and Treatment

	Quality Investigation N = 26				Performance Investigation N = 24				Total Sample (Both Investigations) N = 50			
Treatment Order	Control	Lean	I4.0	L+I4.0	Control	Lean	I4.0	L+I4.0	Control	Lean	I4.0	L+I4.0
1	2	2	2	0	1	3	2	3	3	5	5	2
2	2	1	2	1	4	0	3	2	6	1	5	3
3	1	3	0	2	2	4	2	1	3	7	1	4
4	1	0	2	3	2	2	2	3	3	2	4	6

Despite the limitations of missing ADHD participants in some of the treatment orders, the random assignment of participants is a positive aspect of this study, as it reduces the risk of selection bias. By not knowing which participants had significant ADHD symptoms during the assignment process, the study maintains the integrity of its experimental design and avoids preconceived notions influencing the results.

Another positive aspect is the relatively balanced distribution of participants with significant ADHD symptoms across most treatment orders, particularly in the combined total sample. This balance helps guarantee that the findings are not overly skewed by one treatment order or group, providing a more comprehensive understanding of the effects of the different treatments.

C.2 Additional Descriptive Analysis

C.2.1 Descriptive Statistics: Summary Tables

Using Minitab, descriptive statistics were calculated for each metric category, including mean, standard deviation, minimum, and maximum. First, the performance and quality metrics are presented. The table below contains values for Total Built (the number of complete cars built in each ten-minute trial) and Average Defects (calculated by dividing the total number of errors made by the total number of complete cars built) for

each of the four treatments. The values are divided by script (Quality Motivation Script-QI and Performance Motivation Script-PI) and reported in combined form (Combined-CI).

Table 93: Performance and Quality Metrics Summary Statistics

		PWI				Lean				I4.0				L+I4.0			
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Total Built	QI	7.58	1.68	5.00	10.00	7.65	1.67	4.00	11.00	7.69	1.49	4.00	11.00	7.27	1.71	4.00	10.00
	PI	8.83	1.52	6.00	12.00	9.33	1.46	7.00	1300	9.46	1.38	6.00	13.00	9.04	1.65	5.00	13.00
	CI	8.18	1.71	5.00	12.00	8.46	1.78	4.00	13.00	8.54	1.68	4.00	13.00	8.12	1.89	4.00	13.00
Average Defects	QI	0.07	0.20	0.00	1.00	0.06	0.20	0.00	1.00	0.01	0.03	0.00	0.11	0.01	0.06	0.00	0.29
	PI	0.06	0.12	0.00	0.43	0.05	0.12	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	CI	0.07	0.17	0.00	1.00	0.05	0.16	0.00	1.00	0.00	0.02	0.00	0.11	0.01	0.04	0.00	0.29

The SUS metrics are summarized using the same descriptive statistics and table organization as in the previous section. The initial metric is the SUS score directly obtained from participants. To enable comparison between different systems and participants, the scores were normalized. The Control Normalized SUS indicates whether the treatment SUS is higher or lower than the control (PWI), with positive values for higher scores and negative for lower. No values are given for the PWI treatment for this metric; since the metric calculations are based on this value, all the values would be zero. The Normalized SUS, a decimal percent (0-1), is derived from a normal curve with a mean of 65 and a standard deviation of 12.5. The table below provides a summary of these values.

Table 94: System Usability Scale (SUS) Metrics Summary Statistics

		PWI				Lean				I4.0				L+I4.0			
Dep. Var.	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
SUS	QI	35.38	19.97	2.50	77.5	27.60	17.74	2.50	75.00	21.35	18.17	0.00	62.50	26.54	19.81	0.00	65.00
	PI	26.46	16.25	0.00	55	20.83	13.79	0.00	47.50	17.08	12.17	0.00	42.50	27.40	14.07	0.00	47.50
	CI	31.10	18.65	0.00	77.50	24.35	16.17	0.00	75.00	19.30	15.58	0.00	62.50	26.95	17.13	0.00	65.00
Control Normalized SUS	QI	-	-	-	-	6.62	130.91	-83.33	600.00	-34.2	55.0	-100.0	108.3	-16.11	51.64	-100.0	100.00
	PI	-	-	-	-	-1.44	100.42	-100.0	400.00	.32.88	43.02	-100.0	33.33	65.92	250.02	-100.0	1150.0
	CI	-	-	-	-	2.75	116.16	-100.0	600.00	-33.57	49.12	-100.0	108.33	23.26	180.04	-100.0	1150.0

		PWI				Lean				I4.0				L+I4.0			
Dep. Var.	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Normalized SUS	QI	0.083	0.180	0.000	0.776	0.044	.014	0.000	0.712	0.027	0.081	0.000	0.330	0.049	0.111	0.000	0.405
	PI	0.020	0.044	0.000	0.149	.005	.012	0.000	0.051	0.002	0.005	0.000	0.021	0.009	0.014	0.000	0.051
	CI	0.053	0.136	0.000	.776	0.026	0.105	0.000	0.712	0.015	0.059	0.000	0.330	0.030	0.083	0.000	0.405

The participants' cognitive load (or mental workload) is estimated from the self-reported NASA TLX completed after each treatment, assessing workload across six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration. The NASA TLX has been analyzed in various ways, as described previously. This study investigates several metrics, including participant-specific normalized values (Control Normalized TLX) and global study normalized values (Min-Max Normalized TLX). Additionally, raw weighted TLX, unweighted NASA TLX scores, and six weighted sub-scores are presented in the table below.

Table 95: NASA TLX Metrics Summary Statistics

		PWI				Lean				I4.0				L+I4.0			
Dep. Var.	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Control Normalized TLX	QI	-	-	-	-	0.20	15.23	-39.47	38.89	-3.22	20.69	-46.51	30.26	-20.88	22.35	-57.30	36.67
	PI	-	-	-	-	4.67	28.71	-28.07	97.14	3.77	24.13	-49.12	46.81	-15.08	22.41	-41.41	35.09
	CI	-	-	-	-	2.35	22.59	-39.47	97.14	0.14	22.46	-49.12	46.81	-18.10	22.34	-57.30	36.67
Min-Max TLX	QI	58.68	20.21	11.54	94.87	57.89	18.56	2.56	88.46	54.53	20.22	0.00	99.99	37.28	10.67	16.67	57.69
	PI	55.29	20.55	17.95	99.99	55.61	16.54	25.64	96.15	55.87	19.35	10.26	89.74	39.79	11.87	11.54	60.25
	CI	57.05	20.23	11.54	99.99	56.76	17.48	2.56	96.15	55.18	19.62	0.00	99.99	38.48	11.22	11.54	60.25
Weighted TLX	QI	63.59	15.01	28.57	90.48	63.00	13.79	21.90	85.71	60.51	15.02	20.00	94.29	47.69	7.93	32.38	62.86
	PI	61.07	15.26	33.33	94.29	61.61	12.29	39.05	91.43	61.51	14.37	27.62	86.67	49.56	8.82	28.57	64.76
	CI	62.38	15.03	28.57	94.29	62.19	12.98	21.90	91.43	60.99	14.57	20.00	94.29	48.59	8.33	28.57	64.76
Unweighted TLX	QI	57.14	12.44	33.33	80.95	55.77	12.64	21.43	80.95	52.75	12.91	21.43	88.10	56.68	10.75	33.33	83.33
	PI	54.66	12.57	33.33	80.95	55.37	10.83	35.71	83.33	54.96	12.89	30.95	80.95	54.37	10.80	30.95	71.43
	CI	55.95	12.43	33.33	80.95	54.62	11.75	21.43	83.33	53.81	12.82	21.43	88.10	55.57	10.73	30.95	88.33
Mental Demand TLX	QI	12.42	8.22	1.90	33.33	9.63	8.04	0.00	26.67	9.49	7.39	0.00	23.81	3.77	6.29	0.00	23.81
	PI	9.52	7.77	0.00	28.57	8.17	6.30	0.00	23.81	8.21	7.36	0.00	26.67	3.77	5.64	0.00	20.00
	CI	11.03	8.06	0.00	33.33	8.93	7.22	0.00	26.67	8.88	7.33	0.00	26.67	3.77	5.93	0.00	23.81

		PWI				Lean				I4.0				L+I4.0			
Dep. Var.	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Physical Demand TLX	QI	4.10	6.45	0.00	22.86	4.18	6.27	0.00	22.86	3.04	5.92	1.11	23.81	2.8	4.11	0.00	19.05
	PI	5.48	7.60	0.00	23.81	3.53	4.97	0.00	15.24	4.09	6.88	0.00	22.86	3.93	3.89	0.00	11.43
	CI	4.76	6.99	0.00	23.81	3.87	5.63	0.00	22.86	3.54	6.35	0.00	23.81	3.35	4.00	0.00	19.05
Temporal TLX	QI	19.49	9.21	0.00	33.33	21.14	8.09	3.81	33.33	20.15	7.28	0.00	28.57	18.21	7.65	5.71	33.33
	PI	21.31	7.34	3.81	33.33	25.04	7.44	5.71	33.33	23.81	5.90	8.57	33.33	19.76	7.35	0.00	28.57
	CI	20.36	8.33	0.00	33.33	23.01	7.96	3.81	33.33	21.90	6.84	0.00	33.33	18.95	7.47	0.00	33.33
Performance TLX	QI	13.66	7.93	0.00	28.57	12.31	7.21	2.86	23.81	12.81	7.29	1.90	28.57	7.73	4.98	1.90	23.81
	PI	9.64	7.78	0.00	28.57	7.58	5.81	0.00	26.67	8.10	5.80	0.00	23.81	5.32	4.27	0.00	19.05
	CI	11.73	8.04	0.00	28.57	10.04	6.93	0.00	26.67	10.50	6.95	0.00	28.57	6.57	4.76	0.00	23.81
Effort TLX	QI	10.55	5.88	3.81	23.81	12.01	5.26	2.86	22.86	9.45	6.44	0.00	26.67	3.48	2.55	0.00	6.67
	PI	9.80	6.36	0.00	20.00	10.60	6.64	0.00	22.86	11.15	4.94	2.86	22.86	2.98	2.53	0.00	6.67
	CI	10.19	6.07	0.00	23.81	11.33	5.94	0.00	22.86	10.27	5.77	0.00	26.67	3.24	2.53	0.0	6.67
Frustration TLX	QI	3.37	3.745	0.00	14.286	3.74	6.80	0.00	28.57	5.59	7.51	0.00	33.33	11.68	6.68	0.95	23.81
	PI	5.32	7.33	0.00	28.57	6.39	8.19	0.00	28.57	6.15	7.17	0.00	28.57	13.81	7.46	3.81	28.57
	CI	4.31	5.77	0.00	28.57	5.01	7.55	0.00	28.57	5.90	7.28	0.00	33.33	12.70	7.07	0.95	28.57

C.2.2 Reliability of Measures

Cronbach's alpha is a measure of internal consistency, which assesses how closely related a set of items are as a group (Birren, 2007). It is based on the average inter-item correlation and the number of items in the scale. Cronbach's alpha is used to evaluate the reliability of a psychometric instrument, ensuring that the items consistently reflect the measured construct. High values (typically above 0.7) indicate good internal consistency (Cronbach, 1951; Tavakol & Dennick, 2011). This metric was chosen to test the reliability of measures like NASA TLX, SUS, and ASRS to help verify that the items within each scale reliably assess the intended dimensions of cognitive load, usability, and ADHD symptoms, respectively. By confirming high internal consistency, researchers can be confident that their instruments produce stable and consistent results across different samples and settings. In Minitab, this is performed by using the "Stat" menu, "Multivariate Analysis", "Item Analysis", selecting all the questions that input into the measure – such as all six subscales of the NASA TLX.

The Cronbach's alpha values for the three validated measures used in this investigation are as follows:

1. NASA TLX: The average Cronbach's alpha across the treatments is 0.93. This high value indicates excellent internal consistency, suggesting that the six subscales of the NASA TLX reliably measure the overall cognitive load.
2. SUS: The Cronbach's alpha for the SUS is 0.79. However, the SUS questions must be analyzed one half at a time, with similar direction questions analyzed together; otherwise, the contradictory alternating scale confuses this statistical measure and causes a false value. This high value indicates excellent internal consistency, suggesting that the ten questions of the SUS reliably measure the overall system usability (Cronbach, 1951).
3. ASRS v1.1: The Cronbach's alpha for the ASRS v1.1 is 0.78, which falls within the ideal range. This indicates good internal consistency, meaning the items on the ASRS v1.1 reliably assess ADHD symptoms.

These Cronbach's alpha values indicate that the SUS, NASA TLX, and ASRS v1.1 have good to excellent internal consistency. These results support the continued use of these measures in assessing cognitive load, usability, and ADHD symptoms in similar research contexts.

C.3 Qualitative Analysis

Qualitative data were recorded during participant trials and at the end of the study interview. Unusual behaviors, comments made by the participant, and general observations about the participants were recorded. This section is not intended to be a comprehensive account of the observations, but rather a summary of relevant and interesting findings.

C.3.1 Qualitative Data Collection Methodology

Two main types of qualitative data were collected during this experiment. First, observations on participant behaviors, comments, and incidents were recorded during the experiment training and trials. Examples of items recorded are frequency of dropping parts, dropping a car on the ground, general frustration, not following protocol and placing parts on the table to stage them instead of taking them from the parts bin each time.

The second type of qualitative data was collected during the final interview at the very end of the experiment. The participants were asked a series of questions, and notes about their verbal responses were recorded by the researcher. The questions each participant was asked are as follows:

- Any comments on the tools or experiment today?
- What did you think of the vision camera?
- What is your level of trust in the vision camera, in percent?
- What would you say if you learned that 14 out of the 18 parts were programmed into the vision camera?
- Would that change your level of trust in the vision camera?
- What are your thoughts on the check piece?
- Any other comments on the study?

C.3.2 Qualitative Data: General Experiment Comments

Participants reported a positive experience, expressing gratitude for the opportunity to participate. Many favored the vision camera system, though some found its flashing lights annoying. Grabbing and placing the small LEGO pieces quickly posed a challenge for some. Participants in the QI script questioned the feasibility of assembling ten cars. Many expressed curiosity about their error rates since they were not informed

during the experiment. Some example comments: “Assembly was hard to figure out based on the instructions” and “Enjoyed it. It was good. But it was more physically demanding than I thought.”

C.3.3 Qualitative Data: Lean Check Piece Comments

Feedback on the check piece was generally positive. Participants appreciated its utility in ensuring correct assembly. Common sentiments included, “It was helpful to help me be confident that I made it correct,” and “When I saw the check piece after the training, I realized I had made mistakes right away.” Some participants wished they had access to the check piece during training. However, a few felt it was redundant when used with the inspection camera, and some disliked using it after they had learned the assembly process.

C.3.4 Qualitative Data: Vision Camera Comments

The comments about the vision camera and trusting the system were entertaining to observe. The participants expressed a general fondness for the system and its easy use – unless they experienced a false error that frustrated them. False errors happened to a small percentage of the participants, mostly due to not putting the car in the correct position under the camera.

Participants generally reported a high level of trust (between 70% and 100%) when asked about their trust in the camera system. However, when informed that the camera did not check all parts (a detail noted on a card by the camera but overlooked by participants), their reactions were uniformly shocked and speechless. This revelation led to a significant drop in trust levels, even though they liked and depended on the system during the trials. Most participants reported a substantially lower trust percentage afterward.

C.3.5 Qualitative Data: Conclusion

Overall, participants enjoyed the experiment and valued the tools, particularly the vision camera system. However, some usability issues, such as the sensitivity of the vision camera to position, handling small pieces, and understanding assembly

instructions, were noted. The check piece was well-received for its role in ensuring correctness, although its necessity was questioned when combined with the vision camera. Trust in the vision camera was initially high but decreased upon learning about its limitations. Future improvements should address these usability concerns and enhance the reliability of the tools.

C.4: Covariate Analysis Additional Treatment Results

The analyses were performed in Minitab using: Stat > Regression > Regression > Fit Regression Model analysis features, putting the Independent Metrics and variables in the "Responses" and the covariates in either "Continuous predictors" or "Categorical Predictors" depending on the type of variable. Being able to use both continuous and categorical variables in this analysis makes the Regression analysis a better choice for this study of covariates than an ANCOVA, which only calculates based on continuous/numerical variables.

The table below summarizes the significant outcomes of the analyses across the metrics used in this investigation. This regression analyses were done on the combined data set (CI) for the outcome variable Total Number of Cars Built in the PWI treatment. The Durbin-Watson Statistic for this analysis is 2.11, which is generally considered to indicate no significant autocorrelation (if within the range of 1.5 and 2.5). This statistic helps to check the regression assumptions and the inferences' validity.

Table 96: Regression Analysis of Covariates: Total Built in PWI vs. all Covariates

Term	Coef	SE Coef	95% CI	T-Value	P-Value
Constant	32.6	21.6	(-27.5, 92.7)	1.51	0.206
Age (continuous)	-0.541	0.718	(-2.533, 1.451)	-0.75	0.493
Script (Ref: QI)					
PI	1.07	2.39	(-5.57, 7.70)	0.45	0.678
LEGO Experience (Ref: Expert)					
Little/No experience	-6.70	4.79	(-20.01, 6.61)	-1.40	0.235
Lots of experience	-6.90	5.06	(-20.95, 7.15)	-1.36	0.244
Some experience	-4.54	3.78	(-15.03, 5.95)	-1.20	0.296
ADHD Level (Ref: High)					
Low	-1.25	3.88	(-12.02, 9.52)	-0.32	0.764
Med	-0.51	2.06	(-6.24, 5.23)	-0.24	0.819
Gender (Ref: Female)					
Male	-1.23	2.13	(-7.13, 4.68)	-0.58	0.596
School Major (Ref: Business)					

Term	Coef	SE Coef	95% CI	T-Value	P-Value
Engineering	-2.30	2.08	(-8.09, 3.49)	-1.10	0.332
Education	1.1	21.4	(-58.2, 60.5)	0.05	0.961
STEM	-5.58	5.15	(-19.89, 8.73)	-1.08	0.340
N/A	-1.98	5.00	(-15.87, 11.90)	-0.40	0.712
Schooling (Ref: Graduate)					
High School	0.63	3.09	(-7.96, 9.21)	0.20	0.849
Some College	-1.62	2.18	(-7.66, 4.42)	-0.75	0.497
Bachelor	2.70	5.85	(-13.53, 18.93)	0.46	0.668
Race(Ref: Asian)					
Black or African-American	-0.02	4.83	(-13.44, 13.40)	-0.00	0.997
White	-0.94	5.23	(-15.47, 13.59)	-0.18	0.866
More than one race	1.53	8.05	(-20.82, 23.89)	0.19	0.858
Ethnicity (Ref: Hispanic or Lat)					
Not Hispanic or Latino	0.42	2.89	(-7.60, 8.45)	0.15	0.891
Unknown	3.36	5.69	(-12.45, 19.17)	0.59	0.587
Birth Country (Ref: Other)					
USA	-3.97	3.68	(-14.18, 6.24)	-1.08	0.341

Multiple regression analyses were performed on the outcomes of the investigations with all the covariates. The following table shows the outcome of one of the analyses. A summary of the findings from the other regression analyses for covariates is found in the tables below.

A separate regression analysis was performed for each output variable and metric. The key metrics and outcomes for each treatment are summarized in the following table for PWI. The remaining treatments are summarized in Appendix C.4. They show each covariate's p-value and 95% percentile confidence interval. Highlighted in orange are those that are significant at the 95% confidence interval, and highlighted in blue are significant at the 90% confidence interval (including the orange values).

Table 97: Covariate Analysis Summary PWI Treatment

	PWI											
	Total Built		**Ave Defects**		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Constant	0.206	(-27.5, 92.7)	0.398	(-5.18, 2.55)	0.003	(-327.8, -129.8)	0.002	(-468.2, -201.6)	0.094	(-729, 87)	0.45	(-2.456, 1.319)
Age	0.493	(-2.533, 1.451)	0.535	(-0.0969, 0.1593)	0.002	(5.53, 12.10)	0.002	(7.44, 16.28)	0.066	(-1.28, 25.77)	0.378	(-0.0402, 0.0849)
Race (Ref: Asian)												
Black or African American	0.997	(-13.44, 13.40)	0.634	(-0.703, 1.023)	0.07	(-2.82, 41.42)	0.073	(-3.8, 55.8)	0.208	(-41.9, 140.3)	0.731	(-0.366, 0.478)
White	0.866	(-15.47, 13.59)	0.673	(-0.781, 1.088)	0.008	(18.28, 66.18)	0.008	(24.6, 89.1)	0.09	(-19.7, 177.6)	0.633	(-0.372, 0.541)
More than one race	0.858	(-20.82, 23.89)	0.691	(-1.659, 1.216)	0.002	(65.7, 139.4)	0.002	(88.5, 187.7)	0.267	(-81.4, 222.1)	0.852	(-0.652, 0.753)
LEGO Experience (Ref: Expert)												
Lots of experience	0.244	(-20.95, 7.15)	0.388	(-0.588, 1.218)	0.84	(-24.90, 21.41)	0.844	(-33.5, 28.8)	0.989	(-95.9, 94.9)	0.973	(-0.436, 0.447)
Some experience	0.296	(-15.03, 5.95)	0.893	(-0.640, 0.709)	0.54	(-21.47, 13.10)	0.538	(-28.90, 17.64)	0.347	(-98.5, 43.9)	0.611	(-0.395, 0.264)
Little/No experience	0.235	(-20.01, 6.61)	0.292	(-0.483, 1.229)	0.62	(-17.69, 26.18)	0.62	(-23.8, 35.2)	0.969	(-91.7, 89.0)	0.927	(-0.433, 0.403)
Gender (Ref: Female)												
Male	0.596	(-7.13, 4.68)	0.995	(-0.381, 0.379)	0.002	(14.85, 34.33)	0.002	(19.99, 46.21)	0.629	(-32.6, 47.7)	0.689	(-0.2144, 0.1568)
School Major (Ref: Graduate)												

	PWI											
	Total Built		**Ave Defects**		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Education	0.961	(-58.2, 60.5)	0.861	(-4.07, 3.56)	0.006	(-287.7, -92.0)	0.006	(-387.2, -123.9)	0.145	(-665, 141)	0.496	(-2.368, 1.362)
Engineering	0.332	(-8.09, 3.49)	0.335	(-0.225, 0.519)	0.001	(18.85, 37.93)	0.001	(25.37, 51.05)	0.26	(-20.7, 57.9)	0.565	(-0.1408, 0.2228)
STEM	0.34	(-19.89, 8.73)	0.567	(-0.714, 1.127)	0.27	(-12.76, 34.41)	0.272	(-17.2, 46.3)	0.944	(-99.8, 94.6)	0.916	(-0.431, 0.468)
N/A	0.712	(-15.87, 11.90)	0.747	(-0.782, 1.004)	0.003	(31.42, 77.19)	0.003	(42.3, 103.9)	0.763	(-83.3, 105.2)	0.736	(-0.379, 0.493)
Schooling Category (Ref: Masters)												
Bachelor	0.668	(-13.53, 18.93)	0.777	(-1.158, 0.930)	0.818	(-24.38, 29.12)	0.818	(-32.8, 39.2)	0.84	(-101.6, 118.7)	0.977	(-0.516, 0.504)
High School	0.849	(-7.96, 9.21)	0.707	(-0.472, 0.632)	0.012	(7.88, 36.18)	0.012	(10.61, 48.70)	0.687	(-49.2, 67.4)	0.846	(-0.2496, 0.2897)
Some College	0.497	(-7.66, 4.42)	0.525	(-0.291, 0.486)	0.246	(-5.08, 14.82)	0.246	(-6.84, 19.95)	0.891	(-38.8, 43.2)	0.92	(-0.1970, 0.1824)
Birth Country (Ref: Other)												
USA	0.341	(-14.18, 6.24)	0.42	(-0.444, 0.869)	0.062	(-1.29, 32.36)	0.062	(-1.73, 43.56)	0.912	(-72.3, 66.4)	0.544	(-0.244, 0.397)
Ethnicity (Ref: Hispanic/Latino)												
Not Hispanic or Latino	0.891	(-7.60, 8.45)	0.675	(-0.600, 0.432)	.171	(-5.29, 21.16)	0.171	(-7.12, 28.48)	0.739	(-47.5, 61.5)	0.606	(-0.3029, 0.2013)
Unknown	0.587	(-12.45, 19.17)	0.592	(-1.230, 0.803)	0.043	(1.37, 53.47)	0.043	(1.8, 72.0)	0.634	(-127.2, 87.5)	0.599	(-0.599, 0.395)
ADHD Level (Ref: High)												
Medium	0.819	(-6.24, 5.23)	0.467	(-0.262, 0.475)	0.089	(-1.85, 17.05)	0.089	(-2.49, 22.95)	0.329	(-23.4, 54.5)	0.792	(-0.1618, 0.1984)
Low	0.764	(-12.02, 9.52)	0.617	(-0.557, 0.828)	0.049	(-35.57, -0.08)	0.049	(-47.88, -0.10)	0.669	(-61.0, 85.3)	0.961	(-0.345, 0.332)
Script (Ref: QI)												
PI	0.678	(-5.57, 7.70)	0.844	(-0.394, 0.459)	0.795	(-9.84, 12.03)	0.795	(-13.25, 16.19)	0.776	(-50.0, 40.1)	0.681	(-0.1752, 0.2417)

Table 98: Covariate Analysis Summary Lean Treatment

	Lean											
	Total Built		**Ave Defects**		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Constant	0.854	(-43.6, 50.2)	0.091	(-0.73, 6.46)	0.882	(-215.9, 192.7)	0.69	(-317.6, 232.5)	0.588	(-276.3, 179.6)	0.798	(-0.461, 0.378)
Age	0.705	(-1.327, 1.784)	0.131	(-0.2006, 0.0379)	0.379	(-4.36, 9.18)	0.379	(-5.88, 12.36)	0.712	(-6.48, 8.64)	0.945	(-0.01354, 0.01427)
Race (Ref: Asian)												
Black or African American	0.431	(-13.78, 7.18)	0.386	(-1.084, 0.522)	0.336	(-27.7, 63.6)	0.336	(-37.3, 85.6)	0.283	(-28.2, 73.6)	0.519	(-0.0699, 0.1175)
White	0.953	(-11.09, 11.60)	0.328	(-1.219, 0.521)	0.334	(-29.9, 68.9)	0.334	(-40.2, 92.8)	0.21	(-25.5, 84.8)	0.712	(-0.0870, 0.1159)
More than one race	0.948	(-17.89, 17.02)	0.927	(-1.291, 1.385)	0.064	(-6.4, 145.6)	0.064	(-8.6, 196.0)	0.465	(-60.1, 109.5)	0.624	(-0.1262, 0.1858)
LEGO Experience (Ref: Expert)												
Lots of experience	0.306	(-15.60, 6.34)	0.252	(-1.246, 0.436)	0.896	(-45.4, 50.2)	0.896	(-61.1, 67.5)	0.148	(-18.9, 87.7)	0.59	(-0.0774, 0.1187)
Some experience	0.398	(-10.98, 5.40)	0.433	(-0.825, 0.431)	0.869	(-33.4, 37.9)	0.869	(-45.0, 51.0)	0.234	(-19.7, 59.9)	0.858	(-0.0682, 0.0782)
Little/No experience	0.186	(-16.36, 4.43)	0.346	(-1.103, 0.490)	0.37	(-28.8, 61.7)	0.37	(-38.8, 83.1)	0.036	(5.9, 106.9)	0.306	(-0.0537, 0.1322)
Gender (Ref: Female)												
Male	0.714	(-5.27, 3.96)	0.698	(-0.407, 0.301)	0.122	(-5.94, 34.25)	0.122	(-7.99, 46.10)	0.057	(-1.00, 43.84)	0.218	(-0.0196, 0.0629)
School Major (Ref: Graduate)												
Education	0.428	(-61.0, 31.7)	0.519	(-2.65, 4.46)	0.259	(-297.4, 106.3)	0.259	(-400.4, 143.0)	0.709	(-192.7, 257.8)	0.708	(-0.354, 0.474)
Engineering	0.878	(-4.78, 4.25)	0.343	(-0.480, 0.212)	0.609	(-23.61, 15.76)	0.609	(-31.78, 21.21)	0.69	(-25.35, 18.56)	0.667	(-0.0337, 0.0471)
STEM	0.752	(-12.54, 9.81)	0.292	(-1.231, 0.483)	0.957	(-49.7, 47.7)	0.957	(-66.8, 64.2)	0.977	(-53.7, 54.9)	0.91	(-0.1042, 0.0955)
N/A	0.615	(-12.97, 8.71)	0.975	(-0.821, 0.841)	0.228	(-23.0, 71.4)	0.228	(-31.0, 96.1)	0.56	(-64.7, 40.6)	0.539	(-0.0735, 0.1203)

	Lean											
	Total Built		**Ave Defects**		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Schooling Category (Ref: Masters)												
Bachelor	0.262	(-6.72, 18.63)	0.63	(-0.789, 1.154)	0.955	(-54.0, 56.4)	0.955	(-72.7, 75.9)	0.208	(-94.9, 28.3)	0.302	(-0.1616, 0.0650)
Some College	0.715	(-4.05, 5.38)	0.051	(-0.721, 0.002)	0.445	(-26.80, 14.27)	0.445	(-36.08, 19.21)	0.975	(-23.18, 22.64)	0.922	(-0.0437, 0.0406)
High School	0.505	(-4.93, 8.47)	0.785	(-0.460, 0.568)	0.208	(-13.4, 45.0)	0.208	(-18.0, 60.5)	0.653	(-38.3, 26.9)	0.89	(-0.0567, 0.0631)
Birth Country (Ref: Other)												
USA	0.977	(-8.06, 7.88)	0.799	(-0.671, 0.551)	0.628	(-28.2, 41.3)	0.628	(-37.9, 55.5)	0.122	(-66.1, 11.4)	0.557	(-0.0877, 0.0548)
Ethnicity (Ref: Hispanic/Latino)												
Not Hispanic or Latino	0.121	(-1.83, 10.70)	0.586	(-0.583, 0.378)	0.151	(-44.68, 9.89)	0.151	(-60.1, 13.3)	0.732	(-26.4, 34.5)	0.677	(-0.0470, 0.0651)
Unknown	0.552	(-9.46, 15.23)	0.449	(-0.661, 1.232)	0.232	(-26.5, 81.0)	0.232	(-35.6, 109.1)	0.926	(-57.8, 62.1)	0.569	(-0.0857, 0.1350)
ADHD Level (Ref: High)												
Medium	0.454	(-5.81, 3.14)	0.157	(-0.558, 0.128)	0.256	(-10.19, 28.79)	0.256	(-13.72, 38.76)	0.056	(-0.80, 42.69)	0.135	(-0.0131, 0.0669)
Low	0.838	(-9.07, 7.75)	0.183	(-1.018, 0.271)	0.295	(-52.5, 20.7)	0.295	(-70.7, 27.9)	0.1	(-9.5, 72.2)	0.598	(-0.0597, 0.0906)
Script (Ref: QI)												
PI	0.487	(-3.75, 6.61)	0.249	(-0.204, 0.590)	0.52	(-16.84, 28.29)	0.52	(-22.7, 38.1)	0.205	(-38.90, 11.46)	0.408	(-0.0617, 0.0309)

Table 99: Covariate Analysis Summary I4.0 Treatment

	I4.0									
	Total Built		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Constant	0.741	(-32.4, 42.0)	0.129	(-421.7, 78.0)	0.1	(-595, 78)	0.304	(-307.2, 124.2)	0.8	(-0.1861, 0.1529)
Age	0.486	(-0.893, 1.574)	0.104	(-2.03, 14.54)	0.104	(-2.73, 19.57)	0.376	(-4.59, 9.71)	0.932	(-0.00544, 0.00580)
Race (Ref: Asian)										
Black or African American	0.64	(-9.82, 6.80)	0.472	(-39.9, 71.7)	0.472	(-53.7, 96.6)	0.115	(-13.4, 83.0)	0.523	(-0.0283, 0.0474)
White	0.886	(-8.50, 9.49)	0.26	(-31.9, 89.0)	0.26	(-42.9, 119.8)	0.959	(-53.2, 51.1)	0.712	(-0.0352, 0.0468)
More than one race	0.482	(-9.98, 17.70)	0.1	(-21.5, 164.4)	0.1	(-29.0, 221.3)	0.102	(-141.4, 19.1)	0.971	(-0.0622, 0.0639)
LEGO Experience (Ref: Expert)										
Lots of experience	0.178	(-13.82, 3.58)	0.243	(-29.6, 87.2)	0.243	(-39.9, 117.4)	0.088	(-9.6, 91.2)	0.632	(-0.0323, 0.0470)
Some experience	0.129	(-10.97, 2.02)	0.287	(-24.3, 62.9)	0.287	(-32.7, 84.7)	0.592	(-29.8, 45.5)	0.922	(-0.0285, 0.0307)
Little/No experience	0.083	(-15.07, 1.41)	0.303	(-31.8, 78.9)	0.303	(-42.8, 106.2)	0.082	(-7.9, 87.6)	0.332	(-0.0226, 0.0525)
Gender (Ref: Female)										
Male	0.707	(-3.13, 4.19)	0.45	(-17.17, 31.97)	0.45	(-23.1, 43.0)	0.396	(-13.95, 28.47)	0.218	(-0.00790, 0.02544)
School Major (Ref: Graduate)										
Education	0.25	(-54.6, 18.9)	0.124	(-419.7, 74.0)	0.124	(-565, 100)	0.402	(-141.2, 285.0)	0.775	(-0.1490, 0.1859)
Engineering	0.619	(-4.28, 2.89)	0.279	(-13.21, 34.93)	0.279	(-17.8, 47.0)	0.452	(-27.01, 14.55)	0.651	(-0.01346, 0.01920)
STEM	0.279	(-12.86, 4.86)	0.728	(-51.5, 67.5)	0.728	(-69.3, 90.9)	0.583	(-62.4, 40.3)	0.873	(-0.0429, 0.0379)
N/A	0.925	(-8.29, 8.91)	0.218	(-27.4, 88.1)	0.218	(-36.8, 118.6)	0.045	(-101.7, -2.0)	0.497	(-0.0286, 0.0497)

	I4.0									
	Total Built		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Schooling Category (Ref: Masters)										
Bachelor	0.263	(-5.34, 14.76)	0.45	(-47.2, 87.8)	0.45	(-63.5, 118.2)	0.026	(-131.0, -14.5)	0.403	(-0.0612, 0.0304)
Some College	0.589	(-4.53, 2.95)	0.426	(-17.11, 33.12)	0.426	(-23.0, 44.6)	0.058	(-1.17, 42.19)	0.906	(-0.01781, 0.01627)
High School	0.462	(-3.76, 6.87)	0.122	(-10.5, 60.9)	0.122	(-14.2, 81.9)	0.2	(-47.8, 13.8)	0.878	(-0.02279, 0.02565)
Birth Country (Ref: Other)										
USA	0.952	(-6.18, 6.47)	0.255	(-22.2, 62.7)	0.255	(-29.8, 84.5)	0.407	(-24.4, 48.9)	0.56	(-0.0354, 0.0222)
Ethnicity (Ref: Hispanic/Latino)										
Not Hispanic or Latino	0.129	(-1.55, 8.38)	0.354	(-46.0, 20.8)	0.354	(-61.9, 27.9)	0.813	(-26.2, 31.4)	0.634	(-0.01845, 0.02683)
Unknown	0.39	(-6.39, 13.18)	0.72	(-56.6, 74.8)	0.72	(-76.2, 100.7)	0.277	(-82.4, 31.1)	0.518	(-0.0332, 0.0560)
ADHD Level (Ref: High)										
Medium	0.558	(-4.36, 2.73)	0.214	(-11.17, 36.50)	0.214	(-15.0, 49.1)	0.033	(3.19, 44.35)	0.135	(-0.00529, 0.02705)
Low	0.577	(-8.13, 5.21)	0.542	(-55.5, 34.1)	0.542	(-74.7, 45.8)	0.021	(12.7, 90.1)	0.651	(-0.0250, 0.0357)
Script (Ref: QI)										
PI	0.898	(-4.31, 3.91)	0.086	(-5.01, 50.17)	0.086	(-6.7, 67.5)	0.874	(-25.27, 22.37)	0.373	(-0.02548, 0.01197)

Table 100: Covariate Analysis Summary Lean+I4.0 Treatment

	Lean+I4.0									
	Total Built		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Constant	0.788	(-31.5, 38.8)	0.552	(-203.6, 327.8)	0.683	(-301, 414)	0.304	(-307.2, 124.2)	0.501	(-0.369, 0.214)
Age	0.551	(-0.893, 1.440)	0.926	(-9.12, 8.50)	0.926	(-12.28, 11.44)	0.376	(-4.59, 9.71)	0.719	(-0.00831, 0.01099)
Race (Ref: Asian)										
Black or African American	0.929	(-7.59, 8.13)	0.858	(-55.3, 63.4)	0.858	(-74.4, 85.4)	0.115	(-13.4, 83.0)	0.12	(-0.0189, 0.1112)
White	0.699	(-7.24, 9.78)	0.755	(-72.0, 56.5)	0.755	(-96.9, 76.1)	0.959	(-53.2, 51.1)	0.734	(-0.0612, 0.0796)
More than one race	0.79	(-11.75, 14.43)	0.768	(-87.6, 110.1)	0.768	(-117.9, 148.2)	0.102	(-141.4, 19.1)	0.547	(-0.1339, 0.0827)
LEGO Experience (Ref: Expert)										
Lots of experience	0.312	(-11.65, 4.80)	0.362	(-85.1, 39.1)	0.362	(-114.6, 52.6)	0.088	(-9.6, 91.2)	0.337	(-0.0414, 0.0948)
Some experience	0.123	(-10.45, 1.83)	0.452	(-60.3, 32.5)	0.452	(-81.1, 43.7)	0.592	(-29.8, 45.5)	0.694	(-0.0586, 0.0431)
Little/No experience	0.063	(-14.95, 0.64)	0.823	(-63.9, 53.8)	0.823	(-86.0, 72.4)	0.082	(-7.9, 87.6)	0.506	(-0.0476, 0.0814)
Gender (Ref: Female)										
Male	0.431	(-4.55, 2.37)	0.601	(-20.79, 31.47)	0.601	(-28.0, 42.4)	0.396	(-13.95, 28.47)	0.221	(-0.0137, 0.0436)
School Major (Ref: Graduate)										
Education	0.301	(-49.6, 19.9)	0.882	(-277.5, 247.5)	0.882	(-374, 333)	0.402	(-141.2, 285.0)	0.457	(-0.202, 0.373)
Engineering	0.939	(-3.29, 3.49)	0.715	(-21.98, 29.21)	0.715	(-29.6, 39.3)	0.452	(-27.01, 14.55)	0.819	(-0.0305, 0.0256)
STEM	0.843	(-9.02, 7.74)	0.376	(-86.0, 40.6)	0.376	(-115.7, 54.6)	0.583	(-62.4, 40.3)	0.46	(-0.0898, 0.0489)
N/A	0.827	(-8.81, 7.45)	0.606	(-49.0, 73.8)	0.606	(-66.0, 99.3)	0.045	(-101.7, -2.0)	0.629	(-0.0799, 0.0546)

	Lean+I4.0									
	Total Built		**Weighted TLX**		**Min-Max TLX**		**SUS**		**Normalized SUS**	
Schooling Category (Ref: Masters)										
Bachelor	0.295	(-5.38, 13.63)	0.783	(-79.4, 64.2)	0.783	(-106.9, 86.4)	0.026	(-131.0, -14.5)	0.079	(-0.1451, 0.0122)
Some College	0.862	(-3.30, 3.77)	0.328	(-37.41, 16.00)	0.328	(-50.4, 21.5)	0.058	(-1.17, 42.19)	0.124	(-0.0088, 0.0497)
High School	0.721	(-4.33, 5.72)	0.429	(-25.9, 50.0)	0.429	(-34.9, 67.3)	0.2	(-47.8, 13.8)	0.66	(-0.0345, 0.0487)
Birth Country (Ref: Other)										
USA	0.851	(-5.55, 6.41)	0.661	(-37.5, 52.8)	0.661	(-50.4, 71.1)	0.407	(-24.4, 48.9)	0.513	(-0.0367, 0.0622)
Ethnicity (Ref: Hispanic/Latino)										
Not Hispanic or Latino	0.616	(-3.78, 5.62)	0.822	(-32.4, 38.5)	0.822	(-43.6, 51.9)	0.813	(-26.2, 31.4)	0.968	(-0.0395, 0.0383)
Unknown	0.848	(-9.94, 8.57)	0.22	(-33.3, 106.5)	0.22	(-44.9, 143.3)	0.277	(-82.4, 31.1)	0.627	(-0.0911, 0.0621)
ADHD Level (Ref: High)										
Medium	0.287	(-4.84, 1.87)	0.558	(-19.52, 31.17)	0.558	(-26.3, 42.0)	0.033	(3.19, 44.35)	0.122	(-0.0082, 0.0474)
Low	0.838	(-6.80, 5.81)	0.347	(-65.9, 29.4)	0.347	(-88.7, 39.5)	0.021	(12.7, 90.1)	0.152	(-0.0190, 0.0854)
Script (Ref: QI)										
PI	0.146	(-1.36, 6.41)	0.501	(-21.5, 37.1)	0.501	(-29.0, 50.0)	0.874	(-25.27, 22.37)	0.748	(-0.0361, 0.0282)

C.5: Manufacturing Workplace Support Investigation Script

C5.1 Quality Motivation Script

Lean/I 4.0 Research Study Script

Protocol Procedures

Loadout

Checklist

- ☐ batteries
- ☐ memory cards
- ☐ consent forms in lockbox
- ☐ packets prepared for each participant
  - ☐ Informed Consent
  - ☐ Biographical information form
  - ☐ Behavioral Control survey
  - ☐ Practice NASA TLX
  - ☐ Practice Record (4 vehicles)
  - ☐ 4 packets of NASA TLX and SUS Surveys
  - ☐ 4 Trial record forms
  - ☐ Outtake form, comments
  - ☐ fill out forms with I2, treatment, part, date, etc. information
  - ☐ procedure script
- ☐ NASA TLX Instructions
- ☐ Emergency Procedures and COVID-19 screening
- ☐ run details label for overhead folder, etc.
- ☐ snacks and water

0. Initial Setup

Checklist

- ☐ place, reset timers
- ☐ set up and turn on cameras
- ☐ wipe down surfaces and devices
- ☐ double check all 14 prebuilt cars
- ☐ reset station: table setup, bin placement
- ☐ secondary review of all checklists
- ☐ stow check piece and starting piece
- ☐ door signage up
- ☐ red and green trays at stations 10
- ☐ remove supermarket tray of cars
- ☐ finished car tray at station 10
- ☐ photos of setup before each trial, stations 10
- ☐ check Vision system
- ☐ confirm bin part counts sufficient for 10 cars

- ☐ part 30x 20
- ☐ part 65 x 10
- ☐ part 22 x 20
- ☐ part 29 x 20
- ☐ part 16 x 10
- ☐ part 65 x 10
- ☐ part 89 x 20
- ☐ part 79 x 10
- ☐ part 91 x 20
- ☐ part 28 x 20
- ☐ part 15 x 20

Lean/I 4.0 Research Study Script

1. Intake

1. Participant is greeted and ushered into the conference room.
2. Participant is offered drink / snacks.
3. Participant is talked through the consent document. After any questions they have are answered, the participant is asked to acknowledge their understanding and acceptance of it, initial each page, and sign.
4. Participant is assigned to the "next up" treatment from a randomized list constructed before the first trial.
5. Assistant remains in the room while the participant reads the NASA TLX instructions and completes a trial run of that survey. Afterwards, the assistant leaves the room while the participant provides basic demographic information and completes the Behavior Control Survey.
6. Participant is briefed on emergency procedures.
7. Any questions?
8. Participant is offered the opportunity to use the restroom before the experiment commences.
9. Once the research team has signaled their readiness, the participant is escorted to the work cell.

DON'T DISCUSS DETAILS OF THE EXPERIMENT

Checklist

- ☐ signed consent forms in lock box
- ☐ initial surveys in participant folder
- ☐ secondary review of all checklists
- ☐ check and sign all forms

2. Orientation

Before orientation begins, ensure that the side camera is recording.

> [SAY] Welcome to the Tiger Motors Lean Education Center, affectionately called the Lean Lab or LEGO Lab. As you can see, we use LEGO bricks to simulate a manufacturing environment. The simulation consists of 15 stations that build two models of LEGO cars from zero parts put together to fully assembled. The work content at each station is designed to be the same for each, approximately 60 seconds per station. This means a fully completed car comes off the line every 60 seconds, just like a full-size car manufacturer such as Toyota. The only difference is a full-size car has thousands of stations instead of 15. When we run this simulation, we impress upon the operators that it is equally important to build quality cars (with no errors) and make them quickly, so the whole line is not held up. The target for the station you are working on today is one quality car per minute.

Checklist

- ☐ secondary review of all checklists

3. Paper Work Instruction Training (before all treatments)

Questions are allowed throughout this process.

- limit discussion during training
  - participants free to talk aloud if they wish, not encouraged
  - researchers can answer questions
  - researchers should not prompt or instruct the participants
  - limit dialog, avoid making it conversational

Checklist

- ☐ Fit the participant with the head mounted camera
- ☐ Start the cameras
- ☐ Show the Camera the Record Sheet for the Participant Number, Date, Treatment

I. **Paperwork instruction training (for all treatments):**

[SAY]

- Before you start the experiment we need to introduce you to the process.
- Here at work station 10 we will demonstrate basic assembly of the Model T, an SUV style car. The each work station shares key features: work surface, part bins, and paper work instructions. Manufacturing traditionally uses paper work instructions like these.
- A sequence of steps is depicted by the arrows. For each step, new pieces are shown in the correct color. Details for the corresponding parts, including the part number and required quantity, are given with an image of the part. At the bottom of the page, you will find a map of the part numbers and bin locations.

- I will now demonstrate the first assembly step. Find the bin containing part number 30. Collect two pieces and affix them to the model as shown. Once complete, put the car on the black tray in numerical order.
- There are a few other important rules.
    - First, don't chase dropped parts. Just continue working.
    - You are allowed to correct any errors that you notice before a car is placed on the black tray.
    - If the car breaks in a way that requires rework at a prior station, put it in the red tray and begin a new car.
    - If any other issue prevents you from working, notify the observer and follow their instructions.
- **Do you have any questions?**
- Now you will practice building four cars without a timer. Please follow the directions and learn to build the car for this station.
- You may ask questions for clarification during this training period, but not later during the study.

Checklist

- ☐ Stop the cameras
- ☐ Take a picture of the finished training cars from the top and sides, with the record sheet in view
- ☐ Disassemble cars
- ☐ Set up cars for First Trial cars
- ☐ Get the record sheet for first trial ready

4A. Vision Camera instruction training (treatment)

Checklist

- ☐ Start the vision inspection camera
- ☐ Show the Camera the Record Sheet for the Participant Number, Date, Treatment
- ☐ Layout the Inspection Camera Part Reference Card
- ☐ Set out 10 cars
- ☐ Set out timer, set for 10 minutes
- ☐ Get the record sheet for ready

- [SAY] This is the __(first, second..) treatment of four.
- In this treatment you will use this Vision Inspection Camera to check to quality of your car before you put it on the completion tray each time.
- **If the participant has not used the Vision Camera in a trial previously:**
  - This is the camera. We use it for the in-station quality check. The parts locations are programmed into the device to check defects on the top of the model car.
  - After assembling, you need to place your car under the camera. Make sure you correctly put the front and back parts of the car on the device **(the research associate will make a demo)**.
  - After that, on the screen, you will see the readout as NG (not good) or OK (good). If you see any part labeled as NG, you need to track its location and fix it.
  - You can use this sheet to look up the part's location **(the research associate will show it to the participant).**

- Do you have any questions (**the research associate will ensure the participant understands the system**)?
- For this experiment, you are required to use the inspection camera after each car you build and correct any errors that it indicates.
- You are given 10 minutes to make 10 model-Ts. You will try to build as many cars as you can with no mistakes.
- After making a car, put it on the tray, following the numbers on the tray **(the research associate will show the tray with numbers)**.
- Please do not speak during this trial, unless completely necessary.

Checklist

- ☐ Stop the cameras and
- ☐ lead the participant into the conference room for survey completion
- ☐ Take a picture of the finished training cars from the top and sides, with the record sheet in view
- ☐ Disassemble cars
- ☐ Set up cars for next trial cars
- ☐ Get the record sheet for next trial ready

4A. Check Piece instruction training (treatment)

Checklist

- ☐ Start the cameras
- ☐ Show the Camera the Record Sheet for the Participant Number, Date, Treatment
- ☐ Layout the Check Piece
- ☐ Set out 10 cars
- ☐ Set out timer, set for 10 minutes
- ☐ Get the record sheet ready

- [SAY] This is the __(first, second..) treatment of four.
- In this treatment you will use this check piece to check to quality of your car before you put it on the completion tray each time.
- **If the participant has not used the check piece in a trial previously:**
  - This is the check piece. It has been built up to what the model T should look like leaving this station. We use it for the in-station quality check.
  - After assembling, you need to place your car next to the check piece and compare the two cars.
  - If you see any parts different, you need to fix them before placing the finished car on the tray.
- Do you have any questions (**the research associate will ensure the participant understands the system**)?
- For this experiment, you are required to use the check piece after each car you build and correct any errors that you notice.

- You are given 10 minutes to make 10 model-Ts. You will try to build as many cars as you can with no mistakes.
- After making a car, put it on the tray, following the numbers on the tray **(the research associate will show the tray with numbers)**.
- Please do not speak during this trial, unless completely necessary.

Checklist

- ☐ Stop the cameras
- ☐ lead the participant into the conference room for survey completion
- ☐ Take a picture of the finished training cars from the top and sides, with the record sheet in view
- ☐ Disassemble cars
- ☐ Set up cars for the next trial
- ☐ Get the record sheet for next trial ready

4A. Vision Camera and Check Piece instruction training (treatment)

Checklist

- ☐ Start the cameras
- ☐ Show the Camera the Record Sheet for the Participant Number, Date, Treatment
- ☐ Layout the Check Piece
- ☐ Start the Vision Camera
- ☐ Layout the Reference Card
- ☐ Set out 10 cars
- ☐ Set out timer, set for 10 minutes
- ☐ Get the record sheet ready

- [SAY] This is the __(first, second..) treatment of four.
- In this treatment you will use this check piece and the vision camera to check to quality of your car before you put it on the completion tray each time.
- **If the participant has not used the check piece in a trial previously:**
  - This is the check piece. It has been built up to what the model T should look like leaving this station. We use it for the in-station quality check.
  - After assembling, you need to place your car next to the check piece and compare the two cars.
  - If you see any parts different, you need to fix them before placing the finished car on the tray.
- **If the participant has not used the Vision Camera in a trial previously:**
  - In this treatment you will use this Vision Inspection Camera to check to quality of your car before you put it on the completion tray each time.

  - This is the camera. We use it for the in-station quality check. The parts locations are programmed into the device to check defects on the top of the model car.
  - After assembling, you need to place your car under the camera. Make sure you correctly put the front and back parts of the car on the device **(the research associate will make a demo)**.
  - After that, on the screen, you will see the readout as NG (not good) or OK (good). If you see any part labeled as NG, you need to track its location and fix it.
- Do you have any questions (**the research associate will ensure the participant understands the system**)?
- For this experiment, you are required to use the check piece and the vision inspection camera after each car you build and correct any errors that you notice.
- You are given 10 minutes to make 10 model-Ts. You will try to build as many cars as you can with no mistakes.
- After making a car, put it on the tray, following the numbers on the tray **(the research associate will show the tray with numbers)**.
- Please do not speak during this trial, unless completely necessary.

Checklist

- ☐ Stop the cameras
- ☐ lead the participant into the conference room for survey completion
- ☐ Take a picture of the finished training cars from the top and sides, with the record sheet in view
- ☐ Disassemble cars
- ☐ Set up cars for the next trial
- ☐ Get the record sheet for next trial ready

4A. Paper Work Instructions instruction training (treatment)

Checklist

- ☐ Start the cameras
- ☐ Show the Camera the Record Sheet for the Participant Number, Date, Treatment
- ☐ Hide the Check Piece
- ☐Ensure Vision Camera is Off
- ☐ Pick up the Vision Camera Reference Card
- ☐ Set out 10 cars
- ☐ Set out timer, set for 10 minutes
- ☐ Get the record sheet ready

- [SAY] This is the __(first, second..) treatment of four.
- In this treatment you will only use the Work Instructions to check to quality of your car before you put it on the completion tray each time.
- Do you have any questions (**the research associate will ensure the participant understands the system**)?
- For this experiment, you are required to use the Work Instruction to check for errors after each car you build and correct any errors that you notice.
- You are given 10 minutes to make 10 model-Ts. You will try to build as many cars as you can with no mistakes.
- After making a car, put it on the tray, following the numbers on the tray **(the research associate will show the tray with numbers)**.
- Please do not speak during this trial, unless completely necessary.

Checklist

- ☐ Stop the cameras
- ☐ lead the participant into the conference room for survey completion
- ☐ Take a picture of the finished training cars from the top and sides, with the record sheet in view
- ☐ Disassemble cars
- ☐ Set up cars for the next trial
- ☐ Get the record sheet for next trial ready

10. Debriefing

Once each treatment of the experiment is concluded, each participant will complete a survey that incorporates the NASA TLX and System Usability Scale instruments for the treatment.

- Participants are ushered back into the conference room where their survey paperwork is administered by a member of the research team. Scripts for each of the following instruments are followed.
  - NASA-TLX
  - SUS
- assistant out of room during surveys

10. Exit Survey

When the survey is completed a research associate will solicit any additional general feedback, ask if the participant experienced any injury or discomfort, and invite them to attend a follow-up session for more in-depth exploration of the HoloLens2. Their responses will be recorded on the exit survey. (5-10 mins)

During the debriefing all participants will be asked if they were injured or experienced any discomfort during their trials. The debriefing also serves to keep each participant under our supervision long enough to ensure no lingering or delayed effects.

- The researcher asks questions from the general info page and records the participant's responses.
- The researcher thanks the participant for their time and escorts them to the exit.

Reset Between Participants

Checklist

- ☐ restock / check bin levels should be ok returning parts
- ☐ check battery levels
- ☐ check available memory
- ☐ turn off cameras
- ☐ wipe down surfaces and devices
- ☐ offload video?
- ☐ tear down / reset cars
- ☐ double check all prebuilt cars
- ☐ secondary review of all checklists

C5.2 Performance Motivation Script

The Performance Motivation Script is similar to the Quality Motivation Script, with two exceptions.

First, during the treatment instructions, the participant is encouraged to produce as many cars as possible, highlighting that it IS possible to produce more than 10 cars in 10 minutes.

Second, after each trial, based on the participant's performance during that trial, they were told the following statements:

Built 8 or more cars:

<SAY> You have done well making (SAY NUMBER OF CARS) keep up the good work, and continue to try to make 10 cars each time.

Built 6- 7 cars:

<SAY> You are almost there, work faster to make your quota of 10 cars in 10 minutes, so you don’t hold up the manufacturing line.

Built 5 or fewer cars:

<SAY> You are holding up the manufacturing line, your manager is disappointed, you need to build cars much faster and make your quota of 10 cars in ten minutes.

C.6 Hypothesis Analysis

The hypotheses for this investigation are tested for the Quality (QI) and Performance (PI) Motivation Investigations and the Combined (CI) Investigation, as explained previously. All hypotheses (cognitive load, quality, usability, and performance) were tested for groups and sub-groups with ADHD.

4.6.4.1 Performance and Quality Metrics Hypotheses

Visualizing aspects of the data is also helpful to better understanding the trends. In the two figures below, the metric for the Number of Cars Built is graphed in Boxplots, one dividing the treatments by the level of ADHD symptoms, the other dividing the treatments by the motivation script.

The following graphs illustrate the Average Defects Per Car metric for each treatment, segmented by motivation script (left), script and ADHD level (right). Notably, the addition of the I4.0 sensor brought the averages to zero, as seen in the graphs below.

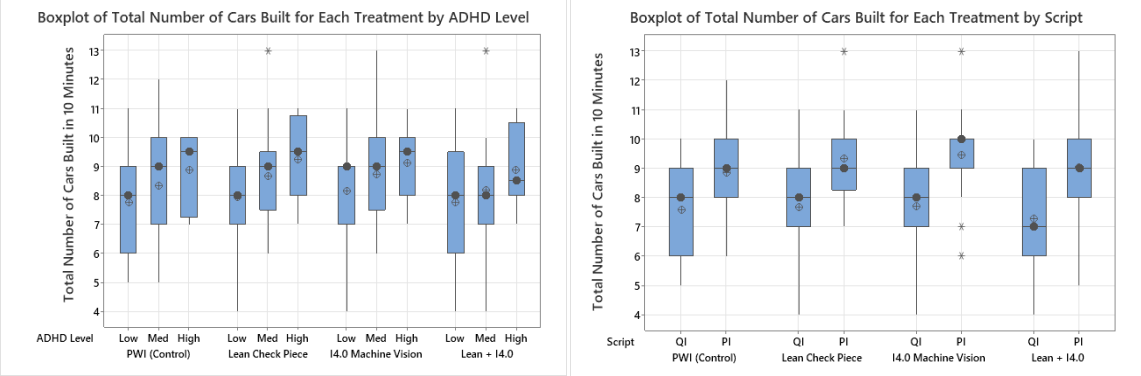


Figure 95: Boxplots of Total Number of Cars Built for Each Treatment. (Left) CI Dataset by ADHD Level (Right) By QI and PI Scripts

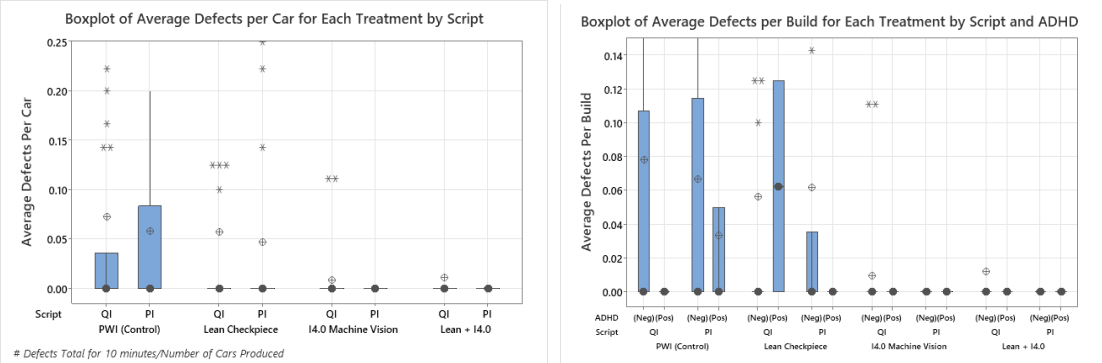


Figure 96: Boxplots of Average Defects per Car for Each Treatment, (left) Segmented by Motivation Script, (right) Segmented by Motivation Script and ADHD Category

H1a: Higher Average Errors Per Car if PWI is first in treatment order, compared to later.

A one-way ANOVA was conducted to test hypothesis H_{1a}, which states that there are higher average errors per car if the PWI treatment is first in the treatment order compared to later orders. The PWI treatment order was coded as 1 for the first treatment and 0 for the second, third, and fourth treatments. The analysis compared the average errors for the PWI treatment across different scripts (QI and PI) and combined data (CI).

The study examined the average defects per car and the number of participants making an error in any treatment. The results are shown in the table below; all tests showed no significant difference between the groups.

Table 101: H_{1a} Hypothesis Test Results

		PWI 1st				PWI 2nd, 3rd, or 4th				Statistical Test two-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average Defects per Car	QI	0.052	0.080	0.00	0.167	0.078	0.228	0.00	1.000	0.783	ANOVA
	PI	0.000	0.000	0.00	0.000	0.078	0.132	0.00	0.429	0.168	
	CI	0.026	0.050	0.00	0.167	0.078	0.186	0.00	1.000	0.347	
Number of Participants Making an Error in any Treatment	QI	0.333	0.516	0	1	0.200	0.410	0	1	0.516	ANOVA
	PI	0.000	0.000	0	0	0.333	0.485	0	1	0.111	
	CI	0.167	0.389	0	1	0.263	0.446	0	1	0.505	

Table 102: CI Dataset, Average Defects per Car: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
TO-PWI 1/0	1	0.02483	1.84%	0.02483	0.02483	0.90	0.347

Error	48	1.32170	98.16%	1.32170	0.02754
Total	49	1.34653	100.00%		

In conclusion, the data did not support the hypothesis that there are higher average errors per car when PWI is the first treatment compared to later orders. The ANOVA results and pairwise comparisons indicated no significant difference in the average number of defects or the proportion of participants making errors based on the treatment order of PWI. These findings suggest that the order in which PWI is administered does not significantly impact the error rates, and any observed differences are likely due to random variation rather than a systematic effect of treatment order.

H_{1b}: Slower production speed (lower Number of Cars per Trial) using tools compared to PWI.

The hypothesis H_{1b}, which posits that production speed is slower (measured as a lower number of cars produced per trial) when using tools compared to PWI, was tested using a one-way ANOVA for each script (QI and PI) and for the combined data (CI).

Table 103: H_{1b} Hypothesis Test Results

		PWI				Other Treatments				Statistical Test two-tailed $\alpha = 0.05$	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average # Cars per Trial	QI	7.577	1.677	5	10	7.538	1.617	4	11	0.917	ANOVA
	PI	8.833	1.523	6	12	9.338	1.503	5	13	0.164	
	CI	8.180	1.711	5	12	8.373	1.782	4	13	0.503	
Number of Participants Making 8 or more cars	QI	0.539	0.508	0	1	0.513	0.503	0	1	0.823	ANOVA
	PI	0.792	0.415	0	1	0.877	0.331	0	1	0.318	
	CI	0.660	0.479	0	1	0.687	0.465	0	1	0.728	

Table 104: CI Dataset, Average Cars per Trial: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	1	1.402	1.402	0.45	0.503
Error	198	616.473	3.114		
Total	199	617.875			

In summary, the one-way ANOVA results across all scripts and the combined data did not provide evidence to support the hypothesis that production speed is slower when using tools than PWI. Therefore, the conclusion is that using tools does not significantly impact the number of cars produced per trial compared to using PWI, and

any observed differences are likely due to random variation rather than a systematic effect of the treatment method.

H_{1c}: Quality increases (lower Average Errors Per Car) with the number of vehicles built, independent of treatment.

A paired t-test was used to compare the average defects per car from the first to the fourth treatment for each participant, assuming that the data set meets the assumptions for a paired t-test due to equal group sizes.

The analysis showed that the average defect rate decreased for all three data sets (QI, PI, and CI). This was supported by descriptive statistics and single-tailed t-test p-values of 0.088 for QI, 0.108 for PI, and 0.032 for CI. The combined data set (CI) reached significance at an alpha level of 0.05, with a 95% confidence interval, while the other two data sets approached significance.

Next, the groups were compared by how many participants made errors in the first trial compared to the fourth trial. The paired t-test for this comparison showed p-values of 0.081 for QI and 0.164 for PI. The combined CI value was significant at $\alpha = 0.05$ for the single-tailed t-test, with a p-value of 0.048. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 105: H_{1c} Hypothesis Test Results

		First Treatment				Last (Fourth) Treatment				Statistical Test Single-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Average Defects Per Car	QI	0.075	0.202	0.00	1.00	0.050	0.198	0.00	1.00	0.088	Paired t-test
	PI	0.041	0.118	0.00	0.500	0.014	0.047	0.00	0.200	0.108	
	CI	0.058	0.167	0.00	1.00	0.033	0.147	0.00	1.00	0.032	
Number of Participants Making Errors	QI	0.269	0.452	0	1	0.115	0.326	0	1	0.081	Paired t-test
	PI	0.125	0.338	0	1	0.083	0.282	0	1	0.164	
	CI	0.200	0.404	0	1	0.100	0.303	0	1	0.048	

Table 106: CI Dataset, Average Defects per Car: Estimation for Paired Difference

Mean	StDev	SE Mean	95% Lower Bound for μ_difference
0.0258	0.0961	0.0136	0.0030

μ_difference: population mean of (Ave Per Car 1st Treatment - Ave Per Car 4th Treatment)

Null hypothesis H_0: μ_difference = 0

Alternative hypothesis	H_1: μ_difference > 0
T-Value	**P-Value**
1.90	0.032

This hypothesis reached statistical significance with the larger combined data set, though not with the smaller script data sets. The data and statistical tests suggest that the quality of the work generally improves as participants build more cars.

H_{1d}: Quality (lower Average Errors per Car) is higher for treatments with vision inspection camera system for the same treatment order.

A paired t-test was used to compare the average defects per car from the first to the fourth treatment for each participant, assuming that the data set meets the assumptions for a paired t-test due to equal group sizes.

Notably, for all participants, the only time errors occurred for the I4.0/Lean+I4.0 treatments was when it was the first treatment. This was not the case for PWI only and Lean only treatment, where errors occurred for at least some participants in every treatment order (e.g., first, second, third, or fourth). The analysis showed that significance generally increased as treatment order increased across all three data sets (QI, PI, and CI). Descriptive statistics and single-tailed t-test p-values supported this. Significant values are highlighted in orange, and nearing significant values are highlighted in blue. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 107: H_{1d} Hypothesis Test Results: Average Defects by Treatment Order (First, Second, Third, Forth) by I4.0 Treatments vs Others (PWI and Lean Treatment)

		I4.0 and Lean+I4.0 Treatment				PWI and Lean Treatment				Statistical Test Single-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Average Defects Per Car (**TO1**)	QI	0.039	0.085	0.00	0.286	0.094	0.275	0.00	1.00	0.178	Paired t-test
	PI	0.000	0.000	0.00	0.00	0.044	0.082	0.00	0.020	0.045	
	CI	0.021	0.063	0.00	0.286	0.070	0.204	0.00	1.00	0.063	
Average Defects Per Car (**TO2**)	QI	0.000	0.000	0.00	0.000	0.019	0.049	0.00	0.143	0.083	Paired t-test
	PI	0.000	0.000	0.00	0.000	0.075	0.150	0.00	0.429	0.055	
	CI	0.000	0.000	0.00	0.000	0.049	0.1130	0.00	0.429	0.023	
Average Defects Per Car (**TO3**)	QI	0.000	0.000	0.00	0.000	0.017	0.038	0.00	0.125	0.073	Paired t-test
	PI	0.000	0.000	0.00	0.000	0.006	0.016	0.00	0.050	0.092	
	CI	0.000	0.000	0.00	0.000	0.012	0.029	0.00	0.125	0.029	
Average Defects Per Car (**TO4**)	QI	0.000	0.000	0.00	0.000	0.055	0.137	0.00	0.500	0.038	Paired t-test
	PI	0.000	0.000	0.00	0.000	0.020	0.039	0.00	0.106	0.089	
	CI	0.000	0.000	0.00	0.000	0.038	0.102	0.00	0.500	0.054	

Table 108: CI Dataset, I4.0 Treatments vs. Others, Treatment Order 2: Estimation for Paired Difference

Mean	StDev	SE Mean	95% Upper Bound for μ_difference
-0.0489	0.1130	0.0231	-0.0093

μ_difference: population mean of (I4.0 and L+I4.0 TO2 Ave Defects - PWI Lean TO2 Ave Defects)

Null hypothesis	H_0: μ_difference = 0
Alternative hypothesis	H_1: μ_difference < 0

T-Value	P-Value
-2.12	0.023

This hypothesis reached statistical significance for each data set (QI, PI, CI) in at least one treatment order, also approaching significance in more than one treatment order. The data and statistical tests suggest that the quality of the work improves significantly more with the use of the I4.0 Machine Vision Inspection Camera than with the PWI and the Lean Check Piece Tool alone.

H_{1e}: Participants with higher number of ADHD symptoms will produce cars at a different rate than those with lower number of symptoms.

A one-way ANOVA was conducted to determine if there were significant differences in the number of cars produced among participants with different levels of ADHD (Low, Medium, High). Given the unequal group sizes and a single factor comparison (ADHD Level of Symptoms), ANOVA was chosen. This assumes independence of observations, normality, and homogeneity of variances. The data set passed the normality test ($p < 0.005$), and the distribution of residuals was consistent across ADHD levels.

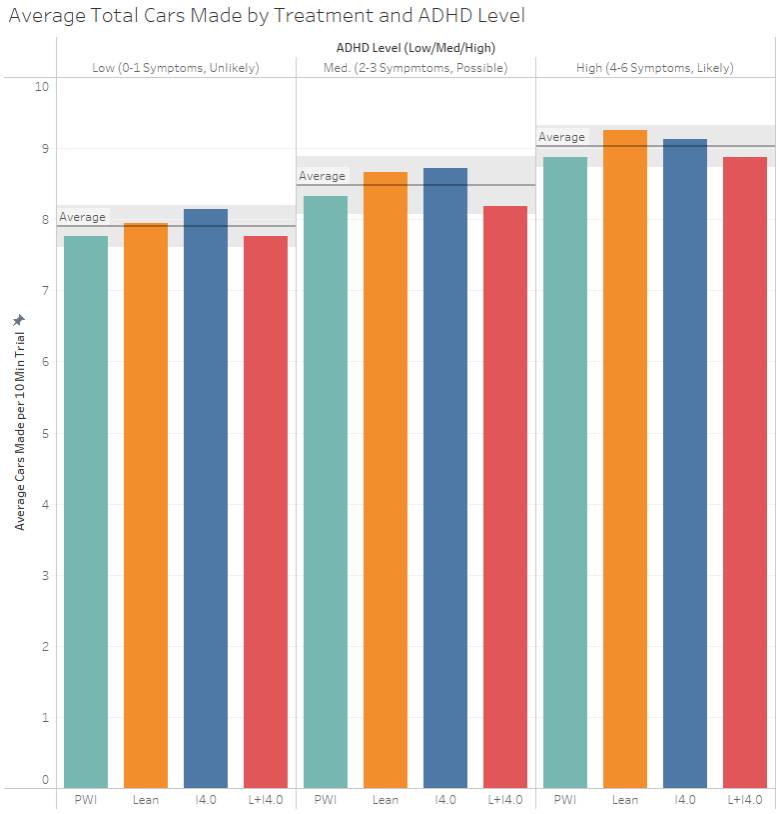


Figure 97: Average Total Cars Made By Treatment vs ADHD Level

Interestingly, the analysis revealed significant differences in production speed across the ADHD levels ($p = 0.005$). Participants with high ADHD levels produced significantly more cars on average (Mean = 9.03, SD = 1.36) compared to those with low ADHD levels (Mean = 7.90, SD = 1.80). The medium ADHD group (Mean = 8.48, SD =

1.72) did not differ significantly from the high ADHD group but was nearing significance compared to the low ADHD group. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 109: H_{1e} Hypothesis Test Results

		ADHD Low				ADHD Medium				ADHD High				Statistical Test Double-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average Cars Produced	QI	7.15	1.8	4	10	7.83	1.49	4	11	7.88	0.83	7	9	0.574	ANOVA
	PI	8.73	1.5	5	11	9.53	1.57	6	13	9.42	1.28	7	11	0.049	
	CI	7.90	1.8	4	11	8.48	1.72	4	13	9.03	1.36	7	11	0.005	

Table 110: CI Dataset, Average Cars Produced by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level	2	32.72	16.358	5.51	0.005
Error	197	585.16	2.970		
Total	199	617.88			

The Tukey and Fisher pairwise comparisons confirmed these findings, showing that the low ADHD group produced significantly fewer cars than the high ADHD group. Below are the results from Minitab of the Tukey analysis, showing the significant difference between the ADHD High and ADHD Low groups for the CI dataset.

Table 111: CI Dataset, Average Cars Produced: Grouping Information Using the Tukey Method and 95% Confidence

ADHD Level	N	Mean	Grouping	
High	32	9.031	A	
Medium	84	8.476	A	B
Low	84	7.905		B

Means that do not share a letter are significantly different.

Table 112: CI Dataset, Average Cars Produced: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
Low - High	-1.126	0.358	(-1.972, -0.281)	-3.15	0.005
Medium - High	-0.555	0.358	(-1.401, 0.291)	-1.55	0.270
Medium - Low	0.571	0.266	(-0.057, 1.200)	2.15	0.083

Individual confidence level = 98.08%

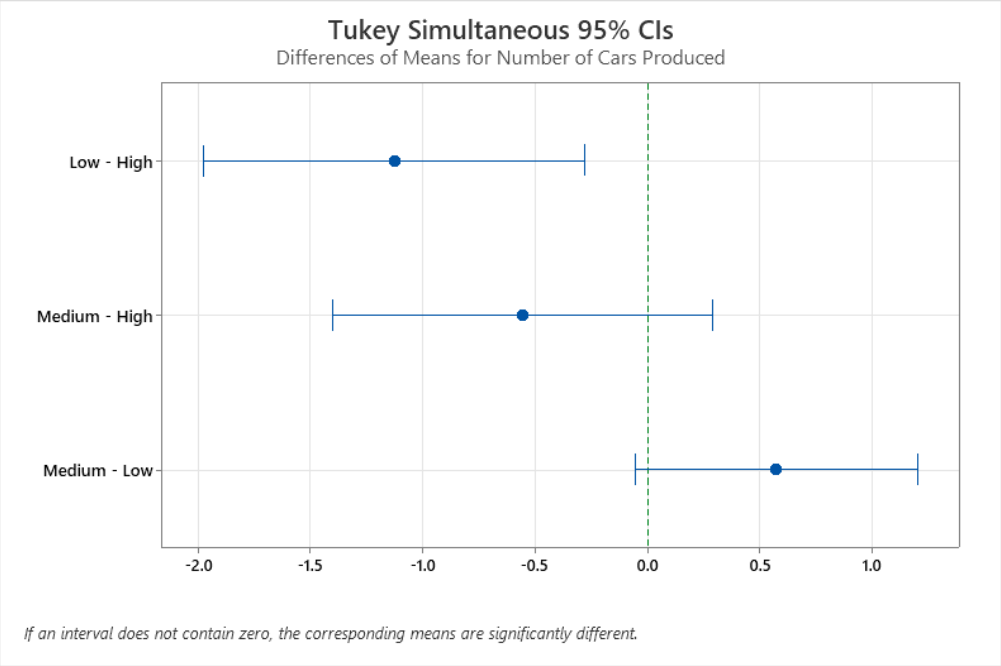


Figure 98: CI Dataset, Average Cars Produced Tukey Simultaneous 95% CIs

The scripts also influenced the differences between workers with different ADHD symptomology. When the workers focused on being slower and on quality (with the QI script), the differences between the groups' production speeds were insignificant. In contrast, with the Performance Motivation script (PI), the increased focus on production rate appeared to influence the workers more if they reported more ADHD symptoms. This interaction should be studied further in future investigations.

These results suggest that higher ADHD levels are associated with higher production speeds. The underlying reasons for this correlation could be explored further in future studies, considering additional factors such as task complexity or environmental influences that may interact with ADHD levels to affect productivity. The data support the hypothesis that ADHD levels can impact production speed, providing valuable insights for optimizing work environments to accommodate individuals with different ADHD levels.

H_{1f}: Participants with higher number of ADHD symptoms will have a different average error rate than those with lower number of symptoms.

A one-way ANOVA tested the average number of errors among participants with different ADHD levels (Low, Medium, High) and the number of participants making errors in any treatment. Given the unequal group sizes and a single factor comparison (ADHD Level of Symptoms), ANOVA was used. This assumes independence of observations, normality, and homogeneity of variances. The data set passed the normality test ($p < 0.005$), and the residual distribution was consistent across ADHD levels.

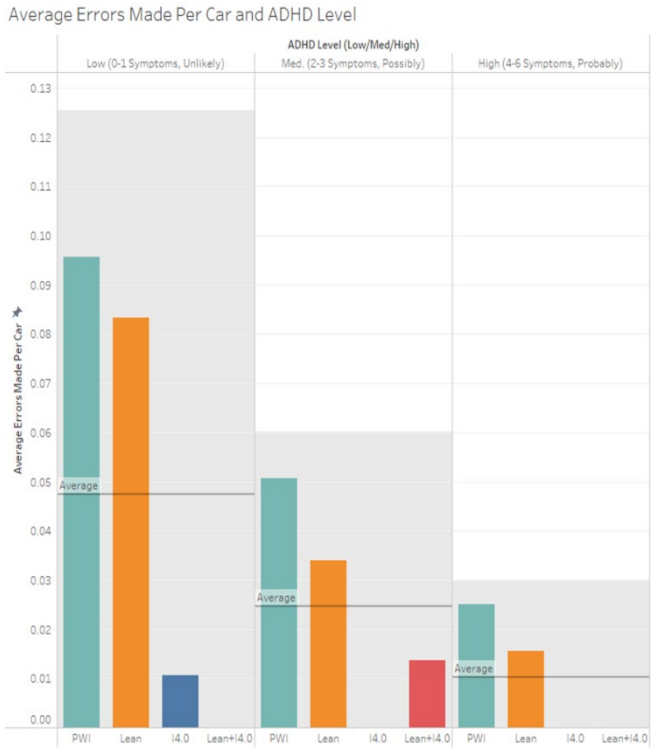


Figure 99: CI Dataset: Average Errors Made Per Car vs ADHD Level

The analysis did not reveal significant differences in the Average Error Rate across ADHD levels ($p = 0.227$). Participants with high ADHD levels produced fewer errors per car on average (Mean = 0.0623, SD = 0.246) compared to those with low ADHD levels (Mean = 0.1190, SD = 0.326). The medium ADHD group (Mean = 0.1786, SD = 0.385) did not differ significantly from the high ADHD or low ADHD groups. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 113: H_{1f} Hypothesis Test Results

		ADHD Low				ADHD Medium				ADHD High				Statistical Test Double tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average Errors Per Car	QI	0.058	0.21	0	1	0.018	0.05	0	0.29	0.02	0.04	0	0.13	0.700	ANOVA
	PI	0.035	0.11	0	0.5	0.018	0.05	0	0.22	0.001	0.04	0	0.20	0.375	
	CI	0.047	0.17	0	1	0.018	0.05	0	0.29	0.010	0.04	0	0.20	0.163	
Number of Participants Making Errors	QI	0.118	0.32	0	1	0.192	0.40	0	1	0.125	0.35	0	1	0.403	ANOVA
	PI	0.125	0.33	0	1	0.156	0.37	0	1	0.042	0.20	0	1	0.560	
	CI	0.121	0.33	0	1	0.180	0.39	0	1	0.063	0.25	0	1	0.227	

Table 114: CI Dataset, Average Errors Per Car by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level	2	0.04978	0.02489	1.83	0.163
Error	197	2.67589	0.01358		
Total	199	2.72567			

The Tukey and Fisher pairwise comparisons confirmed these findings, showing that none of the groups were statistically significantly different. The data fail to support the hypothesis that ADHD levels can impact error rates.

4.6.4.2 Cognitive Load (NASA TLX) Hypotheses

The NASA TLX was administered alongside the SUS after each treatment. Similar to the SUS, the NASA TLX can be analyzed in multiple ways, with the calculations and justifications for the metrics discussed earlier. The figures below present Weighted and Unweighted NASA TLX scores segmented by treatment, script, and ADHD classification.

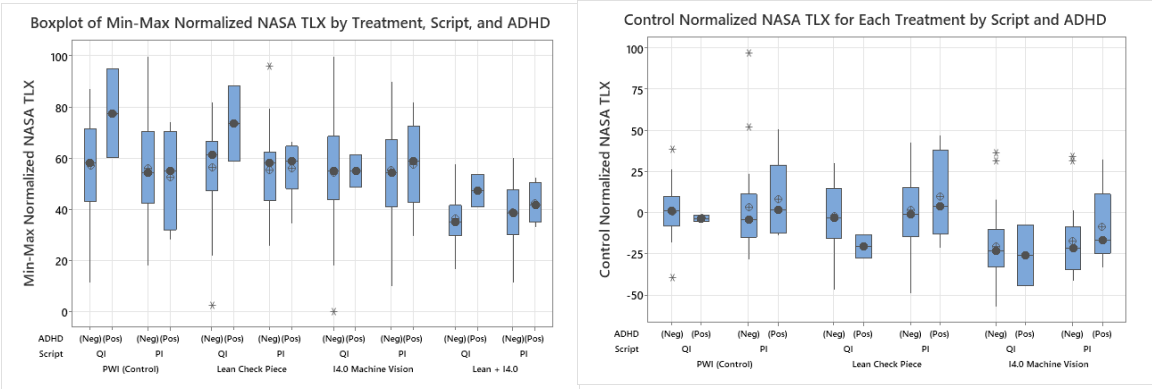


Figure 101: Normalized NASA TLX by Treatment, Script, and ADHD, (left) Min-Max Normalized, (right) Control Normalized.

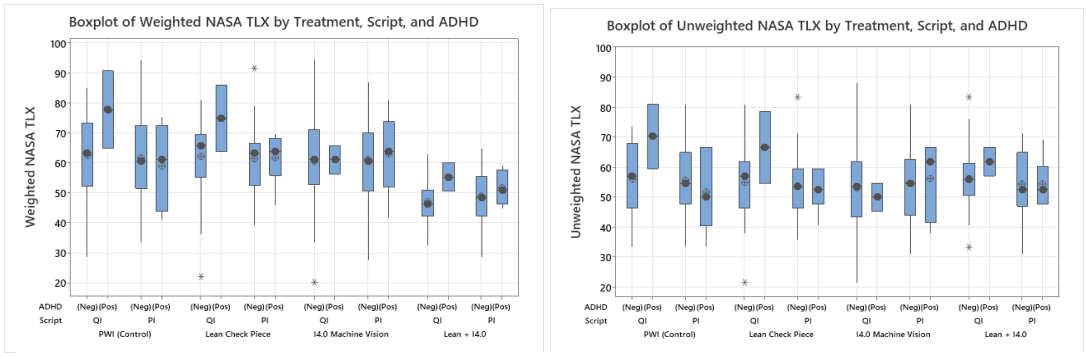


Figure 100: NASA TLX by Treatment, Script, and ADHD, (left) Weighted, (right) Unweighted.

Some slight differences were observed in the graphs. For instance, the Unweighted scores are consistently about ten points lower than the Weighted scores, with some additional outliers.

H_{2a}: Higher cognitive load for control (PWI) than for tools.

A one-way ANOVA was conducted to determine if there were significant differences in the cognitive load, measured by the NASA TLX, among participants using the control (PWI) and other tools (Lean, I4.0, Lean+I4.0). The equal variances assumption was verified, and the analysis showed a significant difference in cognitive load between the control and tool treatments.

Table 115: H_{2a} Hypothesis Test Results

		Control (PWI)				Lean, I4.0, L+I.4.0 Treatments				Statistical Test Double-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Weighted NASA TLX	QI	57.14	12.44	33.3	80.95	57.07	14.18	20	94.2.9	0.981	ANOVA
	PI	54.66	12.57	33.3	80.95	57.43	13.14	27.62	91.43	0.364	
	CI	55.95	12.43	33.3	80.95	57.26	13.64	20	94.29	0.550	
Min-Max NASA TLX	QI	58.68	20.21	11.54	99.99	55.65	19.49	0	99.99	0.499	ANOVA
	PI	55.29	20.55	17.95	99.99	50.42	17.69	10.26	96.15	0.266	
	CI	57.05	20.23	11.54	99.99	50.15	18.37	0	99.99	0.026	

Table 116: CI Dataset, Min-Max NASA TLX vs. Control PWI and All Other Treatments: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	1	1784	1783.8	5.02	0.026
Error	198	70318	355.1		
Total	199	72102			

The analysis revealed that the average weighted NASA TLX scores did not differ significantly across the Quality (QI) script (p = 0.981) and the Performance (PI) script (p = 0.364). However, while the combined data set (CI) mean differences of the weighted NASA TLX were more noticeable, they were not statistically significant (p = 0.550).

When analyzing the Min-Max NASA TLX scores, the QI script showed no significant differences (p = 0.499). The PI script showed no significance (p = 0.266), and the CI dataset revealed a significant difference (p = 0.026). The table below summarizes the descriptive statistics and results of the hypothesis testing.

The Tukey post-hoc test for the Min-Max NASA TLX scores further confirmed these findings. Participants in the PWI treatment reported significantly higher cognitive load compared to those in other treatments (p = 0.026). This result was consistent across different pairwise comparison methods, including Fisher LSD and Dunnett.

The Tukey test showed significant differences in cognitive load between the control (PWI) and other treatments, confirming that the control treatment resulted in a higher cognitive load. The Tukey analysis is shown below:

Table 117: Min-Max NASA TLX Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
PWI	50	57.05	A

Other Treatment	150	50.15	B

Means that do not share a letter are significantly different.

Table 118: Min-Max NASA TLX Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
PWI - Other Treatm	6.90	3.08	(0.83, 12.97)	2.24	0.026

Individual confidence level = 95.00%

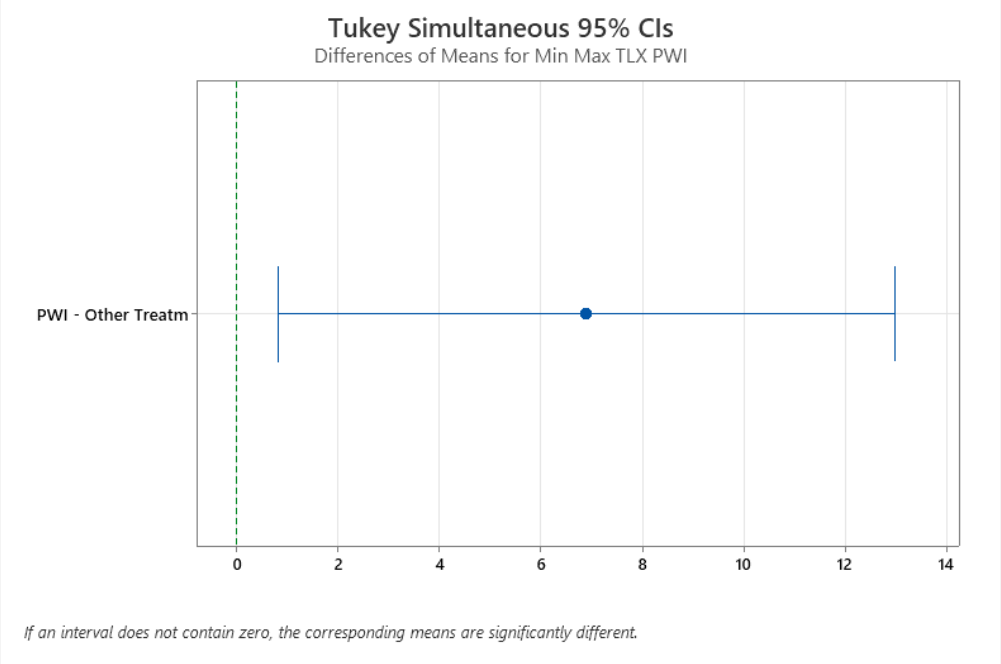


Figure 102: Min-Max TLX Tukey Simultaneous 95% CIs

The ANOVA and subsequent post-hoc tests indicate that participants using the control (PWI) experienced significantly higher cognitive load compared to those using other tools. This suggests that implementing tools like Lean, I4.0, and Lean+I4.0 can effectively reduce cognitive load in manufacturing tasks. These findings align with previous research that reported decreased cognitive load from manufacturing support tools (Atici-Ulusu et al., 2021; Kia et al., 2021). However, some studies have found higher cognitive load associated with workstation support tools (Yang et al., 2020). Future studies should explore this further to optimize tool integration and minimize cognitive demands on workers.

H_{2b}: Cognitive load differs among the four treatments.

A one-way ANOVA was conducted to determine if cognitive load, measured by multiple NASA TLX metrics, differs among the four treatments (Control/PWI, Lean, I4.0, Lean+I4.0). This analysis assumes normality, independence, and homogeneity of variances. The data set passed the normality test, and the residuals were consistently distributed across the treatments.

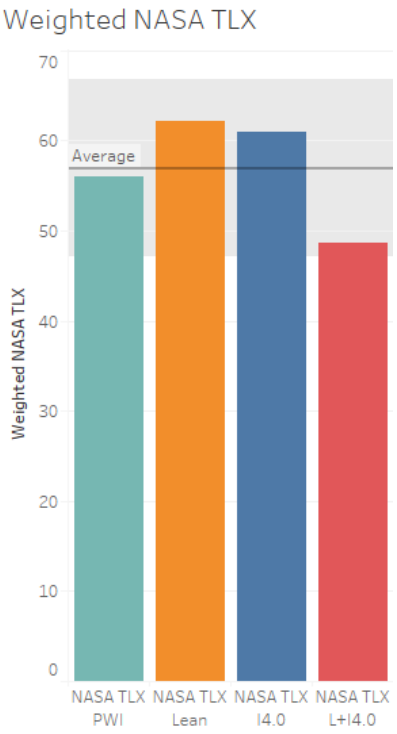


Figure 103: CI Dataset:
Weighted NASA TLX
by Treatment

The analysis revealed significant differences in cognitive load across the four treatments ($p < 0.001$). Participants in the Lean+I4.0 treatment reported significantly lower cognitive load (Mean = 48.59, SD = 8.33) compared to those in the other treatments: Control/PWI (Mean = 62.38, SD = 15.03), Lean (Mean = 62.19, SD = 12.98), and I4.0 (Mean = 60.99, SD = 14.57).

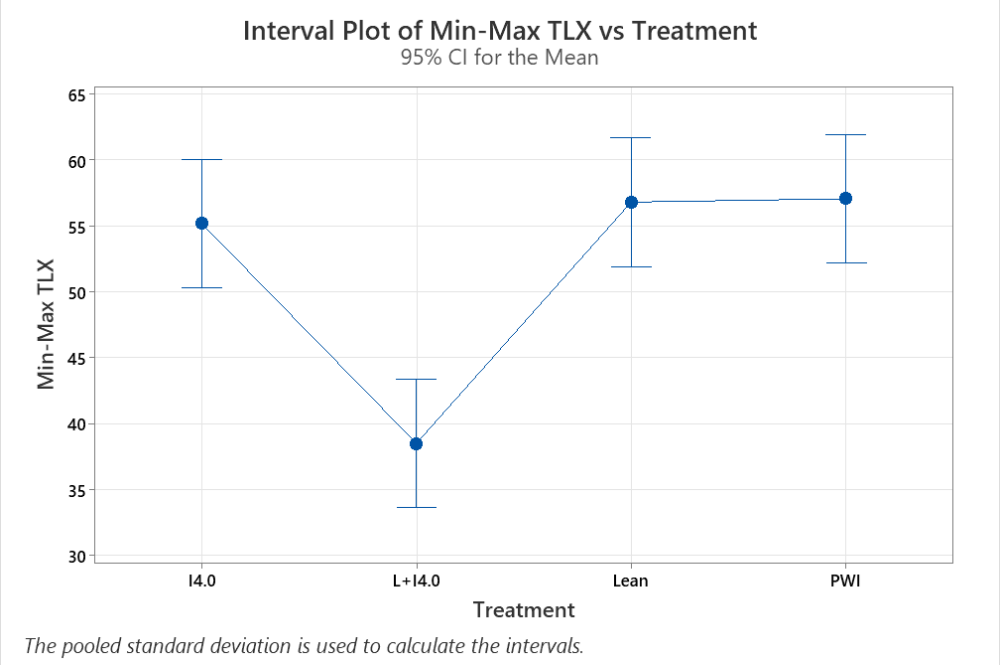


Figure 104: Interval Plot Min-Max Normalized TLX vs. Treatment

The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 119: H_{2b} Hypothesis Test Results (Light-shaded treatments in Tukey group A, Dark-shaded treatment in both A and B, no shading treatment in Tukey group B)

		Control (PWI) Treatment				Lean Treatment			
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Weighted NASA TLX	QI	63.59	15.01	28.57	90.48	63.00	13.79	21.90	85.71
	PI	61.07	15.26	33.33	94.29	61.31	12.29	39.05	91.43
	CI	62.38	15.03	28.57	94.29	62.19	12.98	21.90	91.43
Min-Max NASA TLX	QI	58.68	20.21	11.54	94.87	57.89	18.56	2.56	88.46
	PI	55.29	20.55	17.95	99.99	55.61	16.54	25.64	96.15
	CI	57.05	20.23	11.54	99.99	56.79	17.48	2.56	96.15
Control Normalized NASA TLX	QI	-	-	-	-	0.20	15.23	-39.47	38.89
	PI	-	-	-	-	4.67	28.71	-28.07	97.14
	CI	-	-	-	-	2.23	22.59	-39.47	97.14
Unweighted NASA TLX	QI	57.14	12.44	33.33	80.95	55.77	12.64	21.43	80.95
	PI	54.6	12.57	33.33	80.95	55.37	10.83	35.71	83.33
	CI	55.95	12.43	33.3	80.95	54.62	11.75	21.43	83.33

		Control (PWI) Treatment				Lean Treatment			
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
				3					

		I 4.0 Treatment				Lean+I4.0 Treatment				Statistical Test Single-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Weighted NASA TLX (Continued)	QI	60.51	15.02	20.00	94.29	47.69	7.93	32.38	62.86	0.000	ANOVA
	PI	61.51	14.37	27.62	86.67	49.56	8.82	28.57	64.76	0.003	
	CI	60.99	14.57	20.00	94.29	48.59	8.33	28.57	64.76	0.000	
Min-Max NASA TLX (Continued)	QI	54.53	20.22	0.00	99.99	37.28	10.67	16.67	57.69	0.000	ANOVA
	PI	55.87	19.35	10.26	89.74	39.79	11.87	11.54	60.25	0.003	
	CI	55.18	19.62	0.00	99.99	38.48	11.22	11.54	60.25	0.000	
Cont.Norm NASA TLX (Continued)	QI	-3.22	20.69	-46.51	30.26	-20.88	22.35	-57.30	36.67	0.000	ANOVA
	PI	3.77	24.13	-49.12	46.81	-15.08	22.41	-41.41	34.09	0.008	
	CI	0.14	22.46	-49.12	46.81	-18.10	22.34	-57.30	36.67	0.000	
Unweighted NASA TLX (Continued)	QI	52.75	12.91	21.43	88.10	56.68	10.75	33.33	83.33	0.566	ANOVA
	PI	54.96	12.89	30.95	80.95	54.37	10.80	30.95	71.43	0.970	
	CI	53.81	12.82	21.43	88.10	55.57	10.73	30.95	83.33	0.807	

Table 120: CI Dataset, Weighted NASA TLX vs Treatments: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	6654	2217.9	13.12	0.000
Error	196	33139	169.1		
Total	199	39793			

Comparing the NASA TLX metrics, the results show similar outcomes for the Weighted NASA TLX, Min-Max Normalized TLX, and Control Normalized NASA TLX scores. The Unweighted NASA TLX score was included to highlight its lack of representativeness and show the bigger picture of the cognitive load of the system. However, it will not be included in the remaining hypothesis tests.

The Tukey pairwise comparisons confirmed these findings, indicating that the Lean+I4.0 treatment group experienced significantly lower cognitive load than the other treatment groups. The grouping information showed that Lean+I4.0 treatment is in a separate group (B) compared to Control/PWI, Lean, and I4.0 treatments, which all fell

into group A. The Tukey analysis from Minitab for the Min-Max Normalized NASA TLX analysis, one of the multiple analyses done on this hypothesis, is shown below.

Table 121: Min-Max Normalized NASA TLX Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping	
PWI	50	57.05	A	
Lean	50	56.79	A	
I4.0	50	55.18	A	
L+I4.0	50	38.48		B

Means that do not share a letter are significantly different.

Table 122: Min-Max Normalized NASA TLX Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
L+I4.0 - I4.0	-16.69	3.50	(-25.75, -7.63)	-4.77	0.000
Lean - I4.0	1.62	3.50	(-7.44, 10.67)	0.46	0.967
PWI - I4.0	1.87	3.50	(-7.19, 10.93)	0.53	0.951
Lean - L+I4.0	18.31	3.50	(9.25, 27.37)	5.23	0.000
PWI - L+I4.0	18.56	3.50	(9.50, 27.62)	5.30	0.000
PWI - Lean	0.26	3.50	(-8.80, 9.32)	0.07	1.000

Individual confidence level = 98.96%

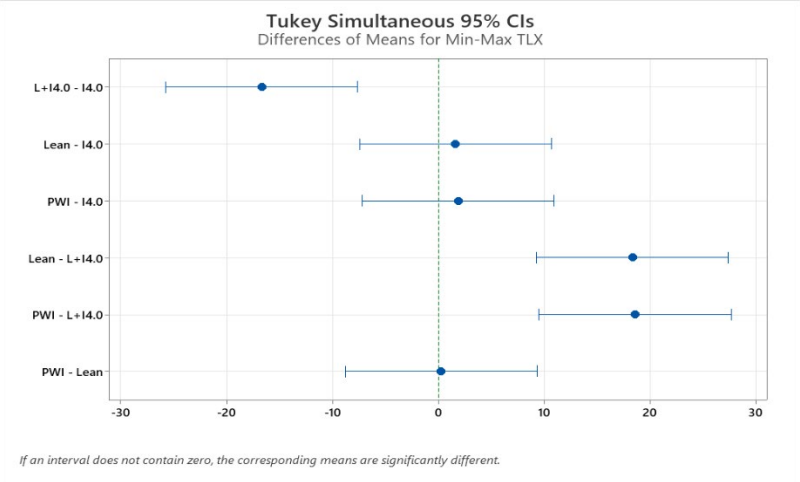


Figure 105: Min-Max Normalized NASA TLX Tukey Simultaneous 95% CIs

These results suggest that combining Lean and I4.0 technologies significantly reduces cognitive load compared to using these tools separately or relying solely on the Control/PWI method. This finding highlights the potential benefits of integrating multiple supportive technologies in reducing cognitive strain in manufacturing tasks. Future

studies should further explore the interaction between these tools to optimize their use in various industrial settings.

$H_{2c:}$ Cognitive load is independent of treatment order.

A one-way ANOVA tested if cognitive load, measured by Weighted and Min-Max Normalized NASA TLX scores, is independent of treatment order. This analysis assumes normality, independence, and homogeneity of variances. The normality test ($p < 0.005$) and residual plots confirmed these assumptions.

The ANOVA showed no significant difference in cognitive load across treatment orders ($p = 0.923$), indicating that treatment order does not impact cognitive load. Tukey and Fisher pairwise comparisons confirmed these findings, with no significant differences between any treatment orders. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 123: H_{2c} Hypothesis Test Results

		First Treatment				Last (Fourth) Treatment				Statistical Test Single-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Weighted NASA TLX	QI	58.50	12.22	36.2	81.0	58.10	17.24	20.0	94.3	0.993	ANOVA
	PI	59.56	10.90	39.1	80.0	57.58	14.89	33.3	94.3	0.993	
	CI	59.01	11.50	36.2	81.0	57.85	15.99	20.0	94.3	0.923	
Min-Max Normalized NASA TLX	QI	51.82	16.45	21.8	82.1	51.28	23.2	0.0	99.9	0.837	ANOVA
	PI	53.26	14.67	23.1	96.2	50.58	20.04	18.0	89.74	0.837	
	CI	52.51	15.48	21.8	82.1	50.95	21.52	0.0	99.9	0.923	

Table 124: CI Dataset, Weighted NASA TLX vs Treatment order: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment Order	3	97.1	32.38	0.16	0.923
Error	196	39695.8	202.53		
Total	199	39793.0			

The Tukey method showed no significant differences among treatment orders, reinforcing that cognitive load is independent of treatment order.

These results suggest that cognitive load does not significantly vary with treatment order, implying that participants' cognitive load remains consistent regardless

of when they encounter a specific treatment.

H_{2d}: Cognitive load from the individual sub-scales will differ between treatments.

This hypothesis is different in that there are six sub-scales, each measuring a different component of cognitive load. Because of this, the results are very different between each factor, instead of each factor representing similar aspects of cognitive load. This necessitates explaining the results on each sub-scale separately. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 125: $H_{4.4.2d}$ Hypothesis Test Results (Light-shaded treatments in Tukey group A, Dark-shaded treatment in both A and B, no shading treatment in Tukey group B)

	Control (PWI) Treatment				Lean Treatment			
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
Mental	11.03	8.06	0.0	33.3	8.93	7.22	0.0	26.7
Physical	4.762	6.99	0.0	23.8	3.87	5.63	0.0	22.9
Temporal	20.36	8.33	0.0	33.3	23.01	7.96	3.8	33.3
Performance	11.73	8.04	0.0	28.6	10.04	6.93	0.0	26.7
Effort	10.19	6.07	0.0	23.8	11.33	5.94	0.0	22.9
Frustration	4.30	5.77	0.0	28.6	5.01	7.55	0.0	28.6

	I 4.0 Treatment				Lean+I4.0 Treatment				Statistical Test Single-tailed α = 0.05	
Metric (Continued)	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Mental	8.88	7.33	0.0	26.7	3.77	5.93	0.0	23.8	0.000	ANOVA
Physical	3.54	6.35	0.0	23.8	3.35	4.00	0.0	19.0	0.636	
Temporal	21.90	6.84	0.0	33.3	18.95	7.47	0.0	33.0	0.048	
Performance	10.50	6.95	0.0	28.6	6.57	4.76	0.0	23.8	0.002	
Effort	10.27	5.77	0.0	26.7	3.24	2.53	0.0	6.7	0.000	
Frustration	5.90	7.28	0.0	33.3	12.70	7.07	1.0	28.6	0.000	

Mental Demand Sub-Scale

The one-way ANOVA analysis was conducted to determine if there were significant differences in mental load among the four treatments (PWI, Lean, I4.0, and Lean+I4.0). The results indicated that the treatments significantly differed in terms of

mental load ($p < 0.001$). The Lean+I4.0 treatment had the lowest mean mental load (Mean = 3.77, SD = 5.93), significantly lower than the other treatments, which did not significantly differ from each other. This suggests that combining Lean and I4.0 technologies effectively reduces the mental sub-scale of cognitive load.

Table 126: CI Dataset, Weighted Mental Demand Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	1430	476.65	9.26	0.000
Error	196	10094	51.50		
Total	199	11524			

Table 127: Mental Demand: Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping
PWI	50	11.03	A
Lean	50	8.93	A
I4.0	50	8.88	A
L+I4.0	50	3.771	B

Means that do not share a letter are significantly different.

Tukey and Fisher's pairwise comparisons confirmed these findings, consistently showing the Lean+I4.0 treatment as significantly different from the others.

Physical Demand Sub-Scale

A one-way ANOVA was conducted to determine if there were significant differences in physical load among the four treatments (PWI, Lean, I4.0, and Lean+I4.0). The results indicated that the treatments did not significantly differ in terms of physical load ($p = 0.636$). The mean physical loads for the treatments were as follows: PWI (Mean = 4.762, SD = 6.985), Lean (Mean = 3.867, SD = 5.634), I4.0 (Mean = 3.543, SD = 6.353), and Lean+I4.0 (Mean = 3.352, SD = 4.005).

Table 128: CI Dataset, Weighted Physical Demand Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	58.50	19.50	0.57	0.636
Error	196	6709.64	34.23		
Total	199	6768.14			

Table 129: Physical Demand: Grouping Information Using the Tukey Method and 95%

Confidence

Treatment	N	Mean	Grouping
PWI	50	4.762	A
Lean	50	3.867	A
I4.0	50	3.543	A
L+I4.0	50	3.352	A

Means that do not share a letter are significantly different.

Tukey and Fisher pairwise comparisons confirmed these findings, showing no significant differences between any pairs of treatments. This suggests that none of the treatments notably reduced or increased physical load compared to the others.

Temporal Demand Sub-Scale

The one-way ANOVA was conducted to analyze the temporal load differences among four treatments (I4.0, Lean+I4.0, Lean, and PWI). The results showed a significant difference in temporal load across the treatments ($p = 0.048$). The mean temporal loads were: I4.0 (Mean = 21.905, SD = 6.841), Lean+I4.0 (Mean = 18.95, SD = 7.47), Lean (Mean = 23.01, SD = 7.96), and PWI (Mean = 20.36, SD = 8.33).

Table 130: CI Dataset, Weighted Temporal Demand Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	472.2	157.39	2.68	0.048
Error	196	11531.1	58.83		
Total	199	12003.2			

Table 131: Temporal Demand: Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping	
Lean	50	23.01	A	
I4.0	50	21.905	A	B
PWI	50	20.36	A	B
L+I4.0	50	18.95		B

Means that do not share a letter are significantly different.

Tukey pairwise comparisons indicated that Lean had a significantly higher temporal load than Lean+I4.0, shown below. These results suggest that the temporal load differs among the treatments, particularly between Lean and Lean+I4.0 treatments, and I4.0 and PWI treatments are similar.

Performance Sub-Scale

The one-way ANOVA analysis was conducted to compare performance scores across four treatments (I4.0, Lean+I4.0, Lean, and PWI). The results showed a significant difference in performance among the treatments ($p = 0.002$). The mean performance scores were: I4.0 (Mean = 10.495, SD = 6.952), Lean+I4.0 (Mean = 6.571, SD = 4.765), Lean (Mean = 10.038, SD = 6.930), and PWI (Mean = 11.73, SD = 8.04).

Table 132: CI Dataset, Weighted Performance Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	733.4	244.48	5.32	0.002
Error	196	9000.3	45.92		
Total	199	9733.7			

Table 133: Performance: Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping	
PWI	50	11.73	A	
I4.0	50	10.495	A	
Lean	50	10.038	A	B
L+I4.0	50	6.571		B

Means that do not share a letter are significantly different.

Tukey pairwise comparisons indicated that Lean+I4.0 had significantly lower performance scores than the other treatments. These results suggest that the performance differed significantly among the treatments, particularly with Lean+I4.0 showing the lowest performance scores (affecting cognitive load the least), PWI, and I4.0 showing the highest performance cognitive load, with Lean in the middle.

Effort Sub-Scale

The one-way ANOVA analysis was conducted to compare effort scores across four treatments (I4.0, Lean+I4.0, Lean, and PWI). The results showed a significant difference in effort among the treatments ($p < 0.001$). The mean effort scores were: I4.0 (Mean = 10.267, SD = 5.773), Lean+I4.0 (Mean = 3.238, SD = 2.531), Lean (Mean = 11.333, SD = 5.944), and PWI (Mean = 10.190, SD = 6.067).

Table 134: CI Dataset, Weighted Effort Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	2071	690.50	24.69	0.000
Error	196	5482	27.97		
Total	199	7553			

Table 135: Effort: Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping	
Lean	50	11.333	A	
I4.0	50	10.267	A	
PWI	50	10.190	A	
L+I4.0	50	3.238		B

Means that do not share a letter are significantly different.

Tukey pairwise comparisons indicated that Lean+I4.0 had significantly lower effort scores than the other treatments, shown below. These results suggest that effort differs significantly among the treatments, with Lean+I4.0 showing the lowest effort scores, distinctive from the other three treatments.

Frustration Sub-Scale

The one-way ANOVA analysis compared frustration levels across four treatments (I4.0, Lean+I4.0, Lean, and PWI) and found significant differences ($p < 0.001$). The mean frustration scores were: I4.0 (Mean = 5.90, SD = 7.28), Lean+I4.0 (Mean = 12.70, SD = 7.07), Lean (Mean = 5.01, SD = 7.55), and PWI (Mean = 4.305, SD = 5.773).

Table 136: CI Dataset, Weighted Frustration Sub-scale vs. Treatment: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Treatment	3	2248	749.48	15.51	0.000
Error	196	9469	48.31		
Total	199	11717			

Table 137: Frustration: Grouping Information Using the Tukey Method and 95% Confidence

Treatment	N	Mean	Grouping	
L+I4.0	50	12.70	A	
I4.0	50	5.90		B
Lean	50	5.01		B
PWI	50	4.305		B

Means that do not share a letter are significantly different.

Tukey pairwise comparisons indicated that Lean+I4.0 had significantly higher frustration scores than the other treatments. These results suggest that frustration levels

differ significantly among the treatments, with Lean+I4.0 showing the highest effect on cognitive load from frustration scores, putting Lean+I4.0 on the opposite side of the cognitive load compared to all other scales.

Sub-Scale Conclusions

The analysis across various NASA TLX sub-scales highlights significant differences in cognitive load among the four treatments: Control/PWI, Lean, I4.0, and Lean+I4.0. Most notably, the Lean+I4.0 treatment consistently showed the lowest cognitive load across most sub-scales, indicating its effectiveness in reducing mental, temporal, effort, and overall weighted cognitive load. This treatment, however, exhibited the highest frustration levels, suggesting a trade-off between different aspects of cognitive load.

For the mental demand sub-scale, the Lean+I4.0 treatment had significantly lower scores than the other treatments, suggesting it effectively reduces mental strain. Physical load did not show significant differences among the treatments, indicating similar physical demands. Temporal load analysis showed that the Lean treatment had a higher temporal load compared to Lean+I4.0, highlighting differences in how these treatments manage time pressure.

Performance scores revealed that Lean+I4.0 significantly reduced perceived performance-related cognitive load compared to the other treatments. The effort sub-scale also showed significantly lower scores for Lean+I4.0, emphasizing its efficiency in reducing perceived effort.

However, the frustration sub-scale presented a contrasting picture, with Lean+I4.0 showing significantly higher frustration levels than the other treatments. This suggests that while Lean+I4.0 reduces various cognitive loads, it might increase frustration due to other factors, such as complexity or usability issues.

Overall, the combination of Lean and I4.0 technologies effectively reduces several cognitive load dimensions. However, it may introduce higher frustration, necessitating further research to optimize its implementation and address potential sources of user frustration.

H_{2e}: Cognitive load differs among the levels of ADHD Symptoms.

A one-way ANOVA was conducted to determine if cognitive load, measured by Weighted and Min-Max Normalized NASA TLX scores, differs among participants with different levels of ADHD (Low, Medium, High). This analysis assumes normality, independence, and homogeneity of variances. The data set passed the normality test ($p < 0.005$), and the residuals were consistently distributed across ADHD levels.

The analysis revealed non-significant differences in cognitive load across ADHD levels ($p = 0.418$). Participants with high ADHD levels had a slightly higher cognitive load (Mean = 60.86, SD = 12.39) compared to those with medium (Mean = 59.02, SD = 15.82) and low ADHD levels (Mean = 57.17, SD = 12.95). The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 138: H_{2e} Hypothesis Test Results

		ADHD Low				ADHD Medium				ADHD High				Statistical Test Double tailed $\alpha = 0.05$	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Weighted NASA TLX	QI	58.27	13.94	28.6	83.8	57.77	15.09	20.0	94.3	67.14	13.92	50.5	90.5	0.233	ANOVA
	PI	55.95	11.82	28.6	80.0	61.07	16.99	27.6	94.3	51.19	15.33	40.9	82.1	0.288	
	CI	57.17	12.95	28.6	83.8	59.02	15.82	20.0	94.3	60.86	12.39	40.9	90.5	0.418	
Min-Max Normalized NASA TLX	QI	51.51	18.76	11.5	85.9	50.8	20.31	0.0	99.9	63.46	18.74	41.0	94.9	0.233	ANOVA
	PI	48.39	15.91	11.5	80.8	55.29	22.87	10.3	99.9	52.19	15.33	28.2	82.1	0.288	
	CI	50.03	17.43	11.5	85.9	52.53	51.29	0.0	99.9	55.00	16.68	28.2	94.9	0.418	

Table 139: CI Dataset, Weighted NASA TLX, ADHD level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	351.1	175.6	0.88	0.418
Error	197	39441.8	200.2		
Total	199	39793.0			

The Tukey and Fisher pairwise comparisons confirmed these findings, showing no statistically significant differences between any ADHD level groups. The results suggest that cognitive load, as measured by the NASA TLX, does not significantly vary with ADHD levels, as indicated by non-significant p-values in all pairwise comparisons.

These results indicate that ADHD levels do not significantly impact cognitive

load, though participants with higher ADHD levels tended to report slightly higher cognitive loads. This finding could inform future studies by suggesting that ADHD levels alone do not predict variations in cognitive load, and other factors may need to be considered to understand cognitive load differences better. The data fails to support the hypothesis that ADHD levels significantly impact cognitive load.

4.6.4.3 Usability (SUS) Hypotheses

4.6.4.3.1 SUS Introduction and Outlier Analysis

Next, participant feedback on the treatments was examined through the System Usability Scale (SUS). After each treatment, participants completed the SUS, which measures usability. Responses varied widely, with a high standard deviation across all treatments, scripts, and ADHD classifications.

When comparing the descriptive statistics for the SUS metrics in this section, recall how each of the SUS metrics is calculated. (Covered in Section 4.6.1.2: Data Screening, Processing, and Cleaning) SUS is the direct output of the SUS instrument, with a range of 0-100. The Normalized SUS is normalized to a normal curve with an average of 65 and a standard deviation of 12.5, and the range is 0 to infinity; the smaller the numbers are because many of the SUS results from the study were well below the normalized mean of 65, they have also been grouped by this normalization. The Control Normalized SUS is calculated by referencing each individual's SUS score for the Control (PWI) treatment; thus, the value for the PWI treatment for this metric is zero since it is referencing itself. For the Control Normalized SUS scale, negative values indicate lower usability compared to the control (Paper Work Instructions). Most participants rated the workstation support systems (the three treatments) as less usable than the control, despite the treatments significantly reducing errors. This discrepancy may be due to participants not being informed about their errors; many believed they made no errors when they actually had. Awareness of how the treatments improved their work quality could potentially enhance usability ratings, a factor not explored in this study but recommended for future research.

The Control Normalized SUS is particularly susceptible to outliers if the participants rank the Control (PWI) at an extreme level, then it affects the scores of the other scales. The Outlier test highlighted a few results, which led to an investigation of the causes of the outliers; see the graph below. Participant 2001 ranked PWI at a scale of 22.5, which caused a problem of falsely inflating the other scales outside of the range of all other scales for the other treatments. These data points were changed from falsely high values to 100, which is the limit of the scale. This follows the technique outlined by Victoria Hodge in A Survey of Outlier Detection Methodologies (Hodge & Austin, 2004).

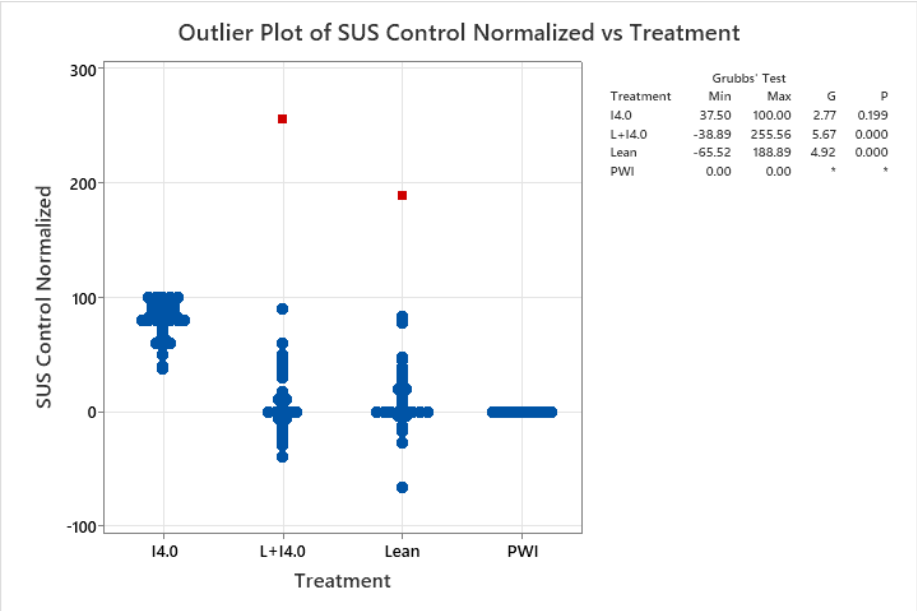


Figure 106: Outlier Plot of Control Normalized SUS vs. Treatment

H_{3a}: Higher SUS for treatments with I4.0 sensor – machine vision inspection system.

The analysis aimed to test the hypothesis (H_{3a}) that treatments utilizing Industry 4.0 (I4.0) machine vision inspection systems would result in higher System Usability Scale (SUS) scores compared to other treatments. The hypothesis was evaluated using a two-tailed ANOVA, with an $\alpha = 0.05$, across different scripts: QI, PI, and CI. The analysis was conducted using ANOVA tests to determine the statistical significance of

the differences in mean SUS scores between treatments with I4.0 and those without. The Tukey method was employed to provide grouping information with 95% confidence.

The results indicated a statistically significant difference in the SUS scores for QI between the I4.0 treatment (mean = 76.1, SD = 19.0) and the other treatments (mean = 68.5, SD = 19.1), with a p-value of 0.046. Similarly, for the Control Normalized SUS in the QI script, the I4.0 treatment group had a mean of 21.8 (SD = 37.6). In contrast, the other treatment group had a mean of 8.3 (SD = 21.9), yielding a significant p-value of 0.027. Additionally, the CI script showed a significant difference in Control Normalized SUS scores (p = 0.025), with the I4.0 group outperforming the other treatment group. The descriptive statistics for each SUS metric and the two test groups are shown in the table below.

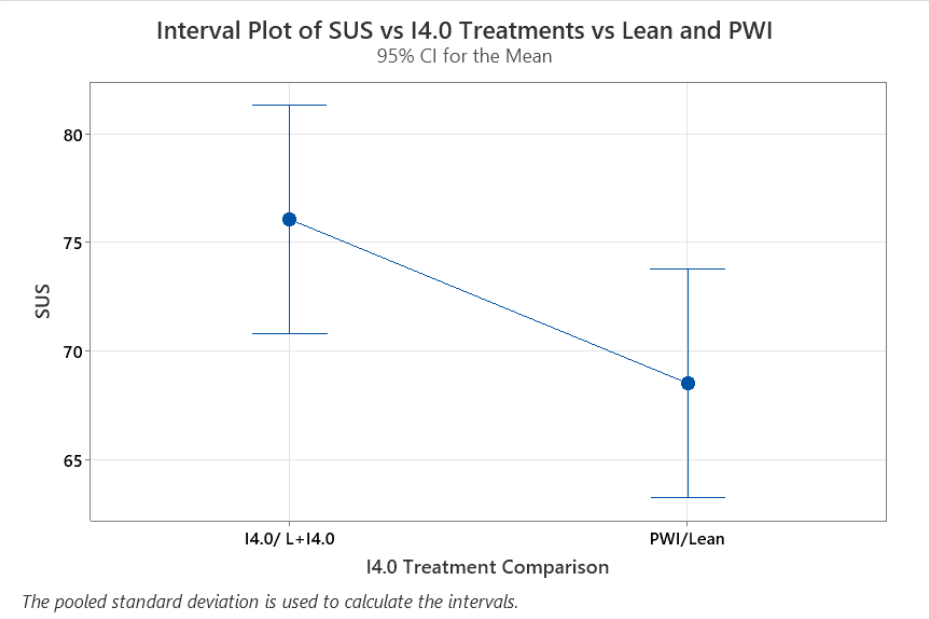
Table 140: H_{3a} SUS vs I4.0 Treatments vs Others Hypothesis Test Results

		I4.0/Lean+I4.0				PWI/Lean Treatment				Statistical Test Two-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
SUS	QI	76.1	19.0	35.0	100.0	68.5	19.1	22.5	97.5	0.046	ANOVA
	PI	77.8	14.0	58.5	100.0	76.4	15.2	45.0	10.00	0.638	
	CI	76.9	16.7	35.0	100.0	72.3	17.7	22.5	100.0	0.060	
Normalized SUS	QI	0.7	0.4	0.0	1.0	0.5	0.4	0.0	1.0	0.061	ANOVA
	PI	0.7	0.3	0.1	1.0	0.7	0.3	0.0	1.0	0.742	
	CI	0.7	0.3	0.0	1.0	0.6	0.4	0.0	1.0	0.098	
Control Normalized SUS	QI	21.8	37.6	-46.4	126.7	8.3	21.9	-65.5	100.00	0.027	ANOVA
	PI	9.7	28.3	-38.9	122.2	5.7	19.5	-26.7	83.3	0.421	
	CI	16.0	33.9	-46.4	126.7	7.0	20.7	-65.5	100.0	0.025	

Table 141: CI Database, CN SUS, I4.0 Treatments vs Others: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
I4.0 Treat Compare	1	4029	4028.8	5.11	0.025
Error	198	156049	788.1		
Total	199	160078			

The figure below shows the interval plot of the data for the two groups for the SUS metric for the combined data set. This clearly shows the increased SUS score average for the treatments that used the I4.0 inspection camera technology.



The analysis provides support for the hypothesis that I4.0 machine vision inspection systems enhance the usability of treatments, as evidenced by higher SUS scores in the QI script data set and significant differences in Control Normalized SUS scores for both QI and CI data sets. While some data sets, such as PI, did not show significant differences, the overall trend suggests a positive impact of I4.0 technologies on usability. The approaching significant results for CI and Normalized SUS in QI further indicate potential areas where the benefits of I4.0 could be more pronounced with larger sample sizes or refined methodologies. Overall, the findings affirm the usability advantages of integrating I4.0 technologies in relevant treatments.

H_{3b}: The SUS score for PWI will be different for treatment orders of 2 or greater compared to the SUS score for PWI in order 1.

The study aimed to test the hypothesis (H_{3b}) that the System Usability Scale (SUS) score for Procedural Impact (PWI) would differ between treatment orders of 2 or greater and treatment orders of 1. This hypothesis was evaluated using a two-tailed ANOVA, with an $\alpha = 0.05$.

Table 142: H_{3b} Hypothesis Test Results

		PWI Treatment Order 1 QI(N=6) PI (N=6) CI(N=12)				PWI Treatment Order 2+ QI(N=20) PI (N=18) CI(N=38)				Statistical Test Two-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
SUS	QI	65.0	22.0	37.5	92.5	64.5	19.9	22.5	97.5	0.958	ANOVA
	PI	81.7	14.1	62.5	100.0	70.8	16.4	45.0	100.0	0.162	
	CI	73.3	19.7	37.5	100.0	67.5	18.4	22.5	100.0	0.350	
Normalized SUS	QI	0.445	0.443	0.0	0.975	0.446	0.371	0.0	0.991	0.993	ANOVA
	PI	0.766	0.284	0.330	0.995	0.561	0.363	0.033	0.995	0.229	
	CI	0.605	0.393	0.007	0.099	0.502	0.367	0.001	0.994	0.407	
Control Normalized SUS	QI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	ANOVA
	PI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	
	CI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-	

Table 143: CI Dataset, SUS, PWI Treatment Order 1 vs. 2+: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TO PWI 2+	1	310.3	310.3	0.89	0.350
Error	48	16729.2	348.5		
Total	49	17039.5			

The analysis revealed no statistically significant differences in SUS scores between treatment orders one and 2+ across all metrics. The descriptive statistics and results of the ANOVA tests on the SUS metrics are shown in the table below.

H_{3c}: SUS is independent of treatment order

A one-way ANOVA was performed to evaluate whether the System Usability Scale (SUS) scores were independent of treatment order. The study adhered to the assumptions of normality, independence, and homogeneity of variances. The data set passed the normality test, and the residuals were consistently distributed across different treatment orders, thereby validating the analysis.

The analysis did not yield any statistically significant differences in SUS scores between the first and last treatment orders. The results are summarized in the table below.

Table 144: H_{3c} Hypothesis Test Results

		First Treatment QI(N=26) PI (N=24) CI(N=50)				Last (Fourth) Treatment QI(N=26) PI (N=24) CI(N=50)				Statistical Test Two-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
SUS	QI	71.5	19.5	25.0	95.0	71.0	18.3	35.0	97.5	0.772	ANOVA
	PI	78.2	11.3	52.5	100.0	76.8	14.4	55.0	100.0	0.914	
	CI	74.8	16.3	25.0	100.0	73.8	16.7	35.0	100.0	0.958	
Normalized SUS	QI	0.614	0.379	0.000	0.985	0.579	0.352	0.004	0.991	0.890	ANOVA
	PI	0.743	0.257	0.10	0.995	0.669	0.315	0.149	0.995	0.734	

		First Treatment QI(N=26) PI (N=24) CI(N=50)				Last (Fourth) Treatment QI(N=26) PI (N=24) CI(N=50)				Statistical Test Two-tailed α = 0.05	
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
				7							
	CI	0.676	0.329	0.000	0.995	0.622	0.334	0.004	0.995	0.822	
Control Normalized SUS	QI	16.2	41.3	-65.5	123.1	14.2	35.2	-38.5	126.7	0.852	
	PI	10.6	27.2	-17.1	83.3	7.0	20.0	-38.9	65.0	0.748	ANOVA
	CI	13.5	35.0	-65.5	123.1	10.7	28.9	-38.9	126.7	0.950	

Table 145: CI Dataset, SUS by Treatment Order: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TO	3	0.1093	0.03642	0.30	0.822
Error	196	23.4386	0.11958		
Total	199	23.5478			

None of the metrics approached statistical significance, as all p-values were well above the 0.05 threshold. The normalized SUS scores and control normalized SUS scores similarly showed no near-significant results, indicating that treatment order did not impact these scores meaningfully.

The findings support the hypothesis that SUS scores are independent of treatment

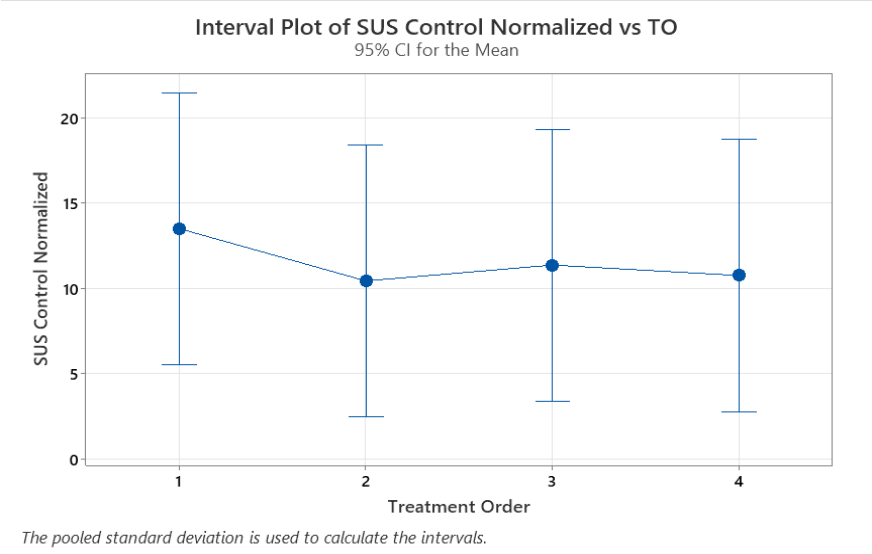


Figure 107: Interval Plot of Control Normalized SUS vs Treatment Order for CI Data Set

order. The absence of statistically significant differences in SUS scores between the treatment orders across both scripts and the combined data set (QI, PI, and CI) indicates

that treatment order does not influence usability perceptions.

H_{3d}: System Usability Scale ratings differ among the levels of ADHD Symptoms.

This study aimed to investigate whether System Usability Scale (SUS) ratings differ among participants with varying levels of ADHD symptoms (Low, Medium, High). A one-way ANOVA was conducted, assuming normality, independence, and homogeneity of variances. The dataset met these assumptions, and the residuals were consistently distributed across the levels of ADHD symptoms.

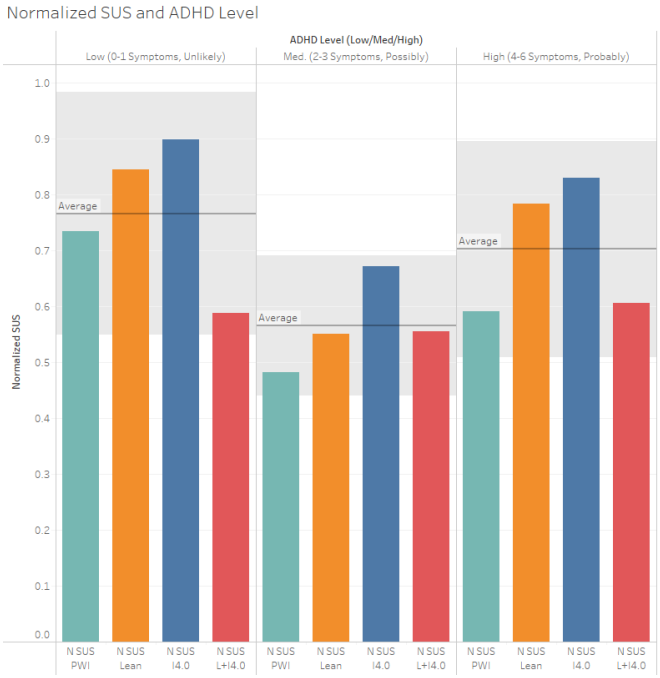


Figure 108: PI Dataset: Normalized SUS by Treatment and ADHD Level

The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 146: H_{3d} Hypothesis Test Results

		ADHD Low QI(N=44) PI (N=40) CI(N=84)				ADHD Medium QI(N=52) PI (N=32) CI(N=84)				ADHD High QI(N=8) PI (N=24) CI(N=32)				p-value
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
SUS	QI	71.3	19.7	22.5	100.0	72.3	19.5	32.5	97.5	77.8	17.0	52.5	100.0	0.686
	PI	79.9	12.3	45.0	100.0	72.2	14.8	50.0	100.0	78.8	16.4	45.0	100.0	0.063
	CI	75.4	17.1	22.5	100.0	72.2	17.8	32.5	100.0	78.5	16.3	45.0	100.0	0.184
Normalized SUS	QI	0.584	0.362	0.000	0.995	0.598	0.386	0.002	0.991	0.668	0.332	0.107	0.995	0.843
	PI	0.766	0.258	0.033	0.995	0.565	0.320	0.075	0.995	0.702	0.338	0.033	0.995	0.021
	CI	0.671	0.328	0.000	0.995	0.586	0.361	0.033	0.995	0.694	0.331	0.033	0.995	0.170
Control Normalized SUS	QI	12.0	31.5	-65.5	100.0	15.4	30.5	-38.5	126.7	29.8	36.2	-10.7	90.5	0.338
	PI	5.9	23.0	-38.9	77.8	7.2	20.6	-26.7	65.0	11.4	30.7	-12.5	122.2	0.680
	CI	9.1	27.8	-65.5	100.0	12.2	27.3	-38.5	126.7	16.0	32.6	-12.5	122.2	0.484

Table 147: PI Dataset, Normalized SUS vs ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.7292	0.36458	4.04	0.021
Error	93	8.3954	0.09027		
Total	95	9.1246			

The one-way ANOVA results revealed a significant difference in the normalized SUS scores for the PI script among the different levels of ADHD symptoms, with a p-value of 0.021. Post-hoc Tukey pairwise comparisons showed that participants with low ADHD symptoms had significantly higher normalized SUS scores for PI (mean = 0.766) compared to those with medium ADHD symptoms (mean = 0.565), with an adjusted p-value of 0.016.

Table 148: Normalized SUS, PI Script: Tukey Pairwise Comparisons: Grouping Information Using the Tukey Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping	
0	40	0.7663	A	
2	24	0.7025	A	B
1	32	0.5654		B

Table 149: Tukey Simultaneous Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	-0.2009	0.0713	(-0.3707, -0.0311)	-2.82	0.016
2 - 0	-0.0638	0.0776	(-0.2486, 0.1211)	-0.82	0.690
2 - 1	0.1371	0.0811	(-0.0562, 0.3304)	1.69	0.214

The study found that SUS ratings for the PI script are significantly affected by the

level of ADHD symptoms, with medium ADHD symptoms correlating with lower usability ratings. This suggests that ADHD symptoms can influence how users perceive the usability of procedural tasks. Although other metrics did not show statistically significant differences, the trends observed in the data indicate that ADHD symptoms may impact usability perceptions in more complex ways than initially anticipated. It is unclear why the medium may be less than the others; these results underscore the importance of considering cognitive factors such as ADHD symptoms in usability studies, as they can provide potentially valuable insights into user experience and system design.

H_{3e}: Individuals with varying levels of ADHD symptoms will rate each treatment differently on the System Usability Scale (SUS).

A one-way ANOVA was conducted to determine if the System Usability Scale (SUS) ratings of each treatment differed among participants with different levels of ADHD symptoms (low, medium, high) for each treatment. This analysis assumes normality, independence, and homogeneity of variances. The data set passed the normality test, and the residuals were consistently distributed across ADHD levels. To test this hypothesis, each treatment is investigated separately below.

Control (PWI) Treatment

The one-way ANOVA did not reveal any statistically significant differences in SUS ratings across ADHD levels. For QI, the mean SUS scores were similar across low (mean = 64.8), medium (mean = 65.0), and high (mean = 61.3) ADHD levels, with a p-value of 0.546. Similarly, the PI and CI metrics showed no significant differences, with p-values of 0.972 and 0.734, respectively. These results suggest that the level of ADHD symptoms did not significantly influence the usability ratings for the Control treatment.

Table 150: H_{3ePWI} Hypothesis Test Results

		ADHD Low QI(N=11) PI (N=10) CI(N=21)				ADHD Medium QI(N=13) PI (N=8) CI(N=21)				ADHD High QI(N=2) PI (N=6) CI(N=8)				p-value
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
SUS	QI	64.8	21.6	22.5	97.5	65.0	20.7	32.5	92.5	61.3	12.4	52.5	70.0	0.546
	PI	77.5	14.0	45.0	90.0	68.8	16.9	50.0	100.0	73.3	19.9	45.0	100.0	0.972
	CI	70.8	19.1	22.5	97.5	66.4	19.0	32.5	100.0	70.3	18.3	45.0	100.0	0.734
Normalized SUS	QI	0.461	0.384	0.000	0.991	0.450	0.408	0.002	0.0975	0.336	0.322	0.107	0.564	0.917
	PI	0.734	0.312	0.033	0.961	0.483	0.356	0.075	0.995	0.591	0.394	0.033	0.995	0.327
	CI	0.591	0.371	0.000	0.991	0.463	0.380	0.002	0.995	0.527	0.374	0.033	0.995	0.545
Control Normalized SUS	QI	-	-	-	-	-	-	-	-	-	-	-	-	N/A
	PI	-	-	-	-	-	-	-	-	-	-	-	-	N/A
	CI	-	-	-	-	-	-	-	-	-	-	-	-	N/A

Table 151: PWI, CI Dataset, Normalized SUS by ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.1730	0.08651	0.61	0.545
Error	47	6.6119	0.14068		
Total	49	6.7849			

Lean Treatment

The one-way ANOVA did not yield any statistically significant differences in SUS ratings across ADHD levels for the Lean treatment. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 152: H_{3eLean} Hypothesis Test Results

		ADHD Low QI(N=11) PI (N=10) CI(N=21)				ADHD Medium QI(N=13) PI (N=8) CI(N=21)				ADHD High QI(N=2) PI (N=6) CI(N=8)				p-value
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
SUS	QI	69.1	20.2	25.0	95.0	74.8	17.1	42.5	97.5	75.0	7.1	70.0	80.0	0.733
	PI	83.5	9.3	72.5	100.00	71.6	15.0	55.0	95.0	82.1	16.2	52.5	100.0	0.159
	CI	76.0	17.3	25.0	100.0	73.6	16.0	42.5	97.5	80.3	14.4	52.5	100.0	0.610
Normalized SUS	QI	0.558	0.359	0.000	0.985	0.649	0.359	0.021	0.991	0.698	0.189	0.564	0.831	0.774
	PI	0.844	0.123	0.641	0.995	0.551	0.345	0.149	0.985	0.783	0.336	0.107	0.995	0.086
	CI	0.694	0.304	0.000	0.995	0.611	0.348	0.021	0.991	0.762	0.296	0.107	0.995	0.488
Control Normalized SUS	QI	12.1	40.2	-65.5	100.0	19.1	18.5	-5.4	46.7	23.8	13.5	14.3	33.3	0.795
	PI	11.4	26.0	-17.1	77.8	6.9	23.6	-26.7	47.8	17.1	34.8	-12.5	47.8	0.796
	CI	11.8	33.3	-65.5	100.0	14.5	20.9	-26.7	47.8	18.8	30.0	-12.5	83.3	0.833

Table 153: Lean, PI Dataset, Normalized SUS vs ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.4045	0.20224	2.77	0.086
Error	21	1.5330	0.07300		
Total	23	1.9375			

For the Normalized SUS metric, PI, again, approaching significance, this time close enough to show a statistical difference in the Fisher Pairwise Comparison for low and medium levels of ADHD symptoms. See the results of the Fisher analysis below.

Table 154: Normalized SUS, PI script, Fisher Pairwise Comparisons Grouping Information Using the Fisher LSD Method and 95% Confidence

ADHD Level (Low/Med/High)	N	Mean	Grouping	
0	10	0.8444	A	
2	6	0.783	A	B
1	8	0.551		B

Means that do not share a letter are significantly different.

Table 155: Normalized SUS, PI script, Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
1 - 0	-0.294	0.128	(-0.560, -0.027)	-2.29	0.032
2 - 0	-0.061	0.140	(-0.351, 0.229)	-0.44	0.665
2 - 1	0.232	0.146	(-0.071, 0.536)	1.59	0.126

Simultaneous confidence level = 88.16%

The findings indicate that System Usability Scale (SUS) ratings for the Lean

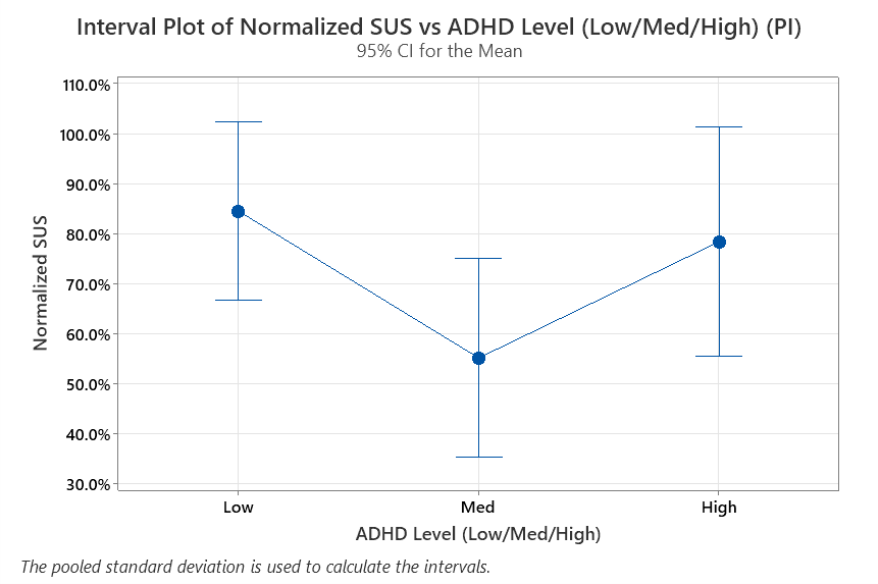


Figure 109: Lean: Interval Plot of Normalized SUS vs ADHD Level (PI)

treatment do not significantly differ among participants with varying levels of ADHD symptoms. Although no statistically significant differences were found across the metrics (QI, PI, CI), the trends observed in the Normalized SUS scores suggest that individuals with medium ADHD symptoms may rate the usability of the Lean treatment less favorably, though the confidence intervals are large.

I 4.0 Treatment

The I4.0 treatment did not yield statistically significant results but exhibited trends worth noting. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 156: $H_{3eI4.0}$ Hypothesis Test Results

		ADHD Low QI(N=11) PI (N=10) CI(N=21)				ADHD Medium QI(N=13) PI (N=8) CI(N=21)				ADHD High QI(N=2) PI (N=6) CI(N=8)				p-value
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
SUS	QI	77.5	20.5	37.5	100.0	77.3	17.2	40.0	97.5	93.8	5.3	90.0	97.5	0.492
	PI	85.8	7.0	80.0	100.0	76.9	13.7	60.0	100.0	86.3	15.6	57.5	100.0	0.235
	CI	81.4	15.8	37.5	100.0	77.1	15.6	40.0	100.0	88.1	13.8	57.5	100.0	0.231
Normalized SUS	QI	0.688	0.381	0.007	0.995	0.688	0.341	0.013	0.991	0.976	0.021	0.961	0.991	0.548
	PI	0.898	0.063	0.831	0.995	0.672	0.278	0.261	0.995	0.829	0.310	0.200	0.995	0.126
	CI	0.788	0.293	0.007	0.995	0.682	0.311	0.013	0.995	0.866	0.271	0.200	0.995	0.278
Control Normalized SUS	QI	20.0	36.9	-46.4	100.0	29.6	49.6	-38.5	126.7	55.4	22.7	-38.5	126.7	0.563
	PI	14.4	24.9	-5.9	77.8	15.9	28.7	-7.1	65.0	25.5	48.5	-4.2	122.2	0.798
	CI	17.3	31.1	-46.4	100.0	24.4	42.6	-38.5	126.7	33.0	44.1	-4.2	122.2	0.602

Table 157: I4.0, PI Dataset, Normalized SUS vs ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.2308	0.11542	2.29	0.126
Error	21	1.0593	0.05044		
Total	23	1.2902			

For the I4.0 treatment, no statistically significant differences were found.

Lean+I4.0 Treatment

The one-way ANOVA did not reveal any statistically significant differences in SUS ratings across ADHD levels for the Lean+I4.0 treatment. None of the metrics approached statistical significance, as all p-values were well above the 0.05 threshold.

This indicates a consistent lack of significant variation in SUS ratings across different levels of ADHD symptoms for the Lean+I4.0 treatment. The table below summarizes the descriptive statistics and results of the hypothesis testing.

Table 158: $H_{3eL+I4.0}$ Hypothesis Test Results

		ADHD Low QI(N=11) PI (N=10) CI(N=21)				ADHD Medium QI(N=13) PI (N=8) CI(N=21)				ADHD High QI(N=2) PI (N=6) CI(N=8)				p-value
Metric	Invest.	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
SUS	QI	73.9	16.7	40.0	97.5	71.9	22.7	35.0	97.5	81.3	26.5	62.5	100.0	0.834
	PI	73.0	14.7	55.0	100.0	71.6	15.5	52.5	100.0	73.3	13.6	57.5	90.0	0.969
	CI	73.5	15.4	40.0	100.0	71.8	19.8	35.0	100.0	75.3	15.7	57.5	100.0	0.880
Normalized SUS	QI	0.630	0.330	0.013	0.991	0.606	0.433	0.004	0.991	0.662	0.470	0.330	0.995	0.977
	PI	0.589	0.332	0.149	0.995	0.556	0.330	0.107	0.995	0.606	0.327	0.200	0.961	0.957
	CI	0.610	0.323	0.013	0.995	0.587	0.389	0.004	0.995	0.620	0.330	0.200	0.995	0.965
Control Normalized SUS	QI	15.8	32.5	-17.9	100.0	12.7	25.3	-23.8	60.0	39.9	71.6	-10.7	90.5	0.540
	PI	-2.3	27.8	-.38.9	44.4	5.8	18.6	-9.1	50.0	2.8	16.1	-12.5	33.3	0.746
	CI	7.2	31.0	-38.9	100.0	10.1	22.7	-23.8	60.0	12.1	34.8	-12.5	90.5	0.903

Table 159: L+I4.0, CI Dataset, Normalized SUS vs ASRS6 Level: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ADHD Level (Low/Med/High)	2	0.00892	0.004458	0.04	0.965
Error	47	5.88054	0.125118		
Total	49	5.88945			

The findings indicate that System Usability Scale (SUS) ratings for the Lean+I4.0 treatment do not significantly differ among participants with varying levels of ADHD symptoms.

Summary of H_{3e} Analysis

The analyses revealed no differences in the influences of ADHD levels on SUS ratings across different treatments. There is a lack of statistical power to support the hypothesis.

4.6.4.4 Comparative Analysis – QI and PI Investigations Comparisons Hypotheses

$H_{4.a}$: Lower Average Errors in QI compared to PI.

A one-way ANOVA was conducted to determine if there were significant differences in the average errors in QI compared to PI. This analysis assumes

independence of observations, normality, and homogeneity of variances. The data set passed the normality test, and the distribution of residuals was consistent across error types.

The analysis revealed no significant differences in average defects per car between QI (Mean = 0.037, SD = 0.145) and PI (Mean = 0.026, SD = 0.087), with a p-value of 0.525. Additionally, there were no significant differences in the percentage of participants making errors between datasets QI (Mean = 0.135, SD = 0.343) and PI (Mean = 0.104, SD = 0.307), with a p-value of 0.510.

Table 160: H_{4a} Hypothesis Test Results

	QI				PI				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average Defects per Car	0.037	0.145	0.00	1.00	0.026	0.087	0.00	0.500	0.525	ANOVA
Participants Making an Error	0.135	0.343	0.00	1.00	0.104	0.307	0.00	1.00	0.510	

Table 161: QI vs PI Scripts by Average Defects per Car: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Script	1	0.00595	0.005946	0.41	0.525
Error	198	2.89735	0.014633		
Total	199	2.90330			

These results suggest that the average number of errors and the proportion of participants making errors do not significantly differ between QI and PI datasets, failing to support the hypothesis that lower average errors would be observed in QI compared to PI.

$H_{4.b}$: More cars produced per trial in PI than in QI.

A one-way ANOVA was conducted to determine if there were significant differences in the number of cars produced per trial between QI and PI. This analysis assumes independence of observations, normality, and homogeneity of variances. The data set passed the normality test, and the distribution of residuals was consistent across error types.

The analysis revealed significant differences in the average number of cars produced per trial between QI (Mean = 7.548, SD = 1.624) and PI (Mean = 9.167, SD = 1.506), with a p-value of <0.001. Additionally, there were significant differences in the percentage of participants making eight or more cars between QI (Mean = 0.519, SD = 0.502) and PI (Mean = 0.854, SD = 0.355), with a p-value of <0.001.

Table 162: H_{4b} Hypothesis Test Results

	QI				PI				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Average # Cars per Trial	7.548	1.624	4	11	9.167	1.506	5	13	0.000	ANOVA
Making 8+ Cars	0.519	0.502	0	1	0.854	0.355	0	1	0.000	

Table 163: QI vs PI, Average Number of Cars Per Trial: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Script	1	130.8	130.782	53.16	0.000
Error	198	487.1	2.460		
Total	199	617.9			

These results suggest that more cars are produced per trial in PI than in QI, supporting the hypothesis that PI leads to higher production rates. The Tukey pairwise comparisons confirmed these findings, showing that PI has a significantly higher production rate than QI. This indicates that the performance motivation script (PI) effectively increases production speed compared to the quality-focused script (QI). Future research could explore the factors contributing to this difference, such as task design, scripting of studies, participant motivation, and environmental influences.

$H_{4.c}$: SUS index is expected to be the same for QI and PI.

A one-way ANOVA was conducted to determine if there were significant differences in the System Usability Scale (SUS) scores between QI and PI treatments. This analysis assumes independence of observations, normality, and homogeneity of variances. The data set passed the normality test, and the distribution of residuals was consistent across error types.

Table 164: $H_{4.4.4c}$ Hypothesis Test Results

	QI N=104				PI N=96				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
SUS	72.3	19.3	22.5	100.0	77.1	14.6	45.0	100.0	0.051	ANOVA
Normalized SUS	0.598	0.369	0.000	0.995	0.683	0.310	0.033	0.995	0.078	
Control Normalized SUS	15.0	31.4	-65.5	126.7	7.7	24.3	-38.9	122.2	0.067	

Table 165: QI vs PI, Normalized SUS: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Script	1	0.3672	0.3672	3.14	0.078
Error	198	23.1807	0.1171		
Total	199	23.5478			

The interval plot shows no significant differences, with overlapping large error bars. These results suggest that the overall SUS scores do not differ significantly between QI and PI.

$H_{4.d}$: NASA TLX is expected to be the same for both QI and PI.

Hypothesis $H_{4.d}$ posits that the NASA Task Load Index (NASA TLX) scores will be the same for both the Quality Inspection (QI) and Performance Inspection (PI) scripts. A one-way ANOVA was conducted to test this hypothesis to compare the NASA TLX scores between the two groups. The results, summarized in the table below, reveal that there were no significant differences in any of the NASA TLX metrics between the QI and PI groups.

Table 166: H_{4d} Hypothesis Test Results

	QI				PI				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
Weighted NASA TLX	58.70	14.59	20.00	94.29	58.36	13.71	27.62	94.29	0.867	ANOVA
Min-Max NASA TLX	52.09	19.64	0.00	99.99	51.64	18.45	10.26	99.99	0.867	
Control Normalized NASA TLX	-5.97	18.92	-57.30	38.89	-1.66	22.94	-49.12	97.14	0.147	
Unweighte	55.59	12.16	21.43	88.10	54.34	11.64	30.95	83.33	0.461	

	QI				PI				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test Max
d NASA TLX										

Table 167: QI vs PI, Control Normalized NASA TLX: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Script	1	928.1	928.1	2.12	0.147
Error	198	86862.2	438.7		
Total	199	87790.3			

The grouping information using the Tukey Method and 95% confidence level confirmed these findings, as the means for both QI and PI groups did not share a letter, reinforcing that there are no significant differences between the groups.

Grouping Information Using the Tukey Method and 95% Confidence

Script	N	Mean	Grouping
QI	104	58.70	A
PI	96	58.36	A

Means that do not share a letter are significantly different.

In conclusion, the analysis supports the hypothesis that the NASA TLX scores do not significantly differ between the QI and PI scripts. This suggests that participants experienced similar levels of perceived workload regardless of the script used. This finding is important as it indicates that the type of script, whether focused on quality or performance, does not appear to impact the perceived task load on participants.

Appendix D: Workplace Support Structures and ADHD (Chapter 5) Prevalence Survey Supplements

D.1 Descriptive Statistical Analysis

The remainder of this analysis will focus exclusively on the High-Quality dataset. This decision is based on the need to guarantee that the survey responses analyzed are most likely to be genuine human responses, not generated by bots, and provided by individuals who carefully read and accurately responded to the quality check questions. This approach enhances the validity of the analysis in answering the research questions for this survey. Future studies could explore other aspects of this dataset, but such analyses are beyond the scope of this current study.

D.1.1 Descriptive Statistics

Analyzing sample-wide general statistics and trends is helpful for understanding the overarching patterns and characteristics within a study population. This approach allows researchers to identify commonalities and differences that inform broader conclusions and insights. By examining metrics such as social anxiety levels, self-efficacy, and ADHD symptoms, alongside demographic factors and coping strategies, one can gain a more nuanced view of the group's experiences and behaviors. This holistic perspective is a first step for developing targeted interventions, informing policy decisions, and advancing understanding of the factors that influence mental health and well-being in diverse populations.

First, analyzing the metrics summary statistics, seen in the table below, one sees that the mean LSAS (Liebowitz Social Anxiety Scale) total points is 23.5, with a standard deviation of 9.5, ranging from 4 to 49 points. This indicates a moderate level of social anxiety within the group. The GPSES (Generalized Perceived Self-Efficacy Scale) mean score is 15.9, with a relatively low standard deviation of 3.2, and scores ranging from 5 to 20. This suggests a generally high level of perceived self-efficacy among participants. The ASRS (Adult ADHD Self-Report Scale) shows a higher variability with a mean of 54.1 and a standard deviation of 12.6, ranging from 12 to 84 points, indicating a wide

range of ADHD symptoms within the group.

Table 168: Metrics Summary Statistics

Metric	Mean	St. Dev	Min	Max
LSAS Total Points	23.5	9.5	4	49
GPSES Total Points	15.9	3.2	5	20
ASRS Total Points	54.1	12.6	12	84

The overall population statistics for the main outcomes of the survey are summarized in the table below.

Table 169: Sample Characteristics Summary Table

Characteristics	Descriptor	N	Percent
ADHD Medical Diagnosis	Yes	64	25.70
	No	185	74.3
ADHD Family Diagnosis	Yes	51	27.72
	No	133	72.28
ADHD Self Diagnosis	Definitely Not	59	31.89
	Probably Not	60	32.43
	Might/Might Not	33	17.84
	Probably Yes	25	13.51
	Definitely Yes	8	4.32
ADHD Prescription Medicated	No	108	56.84
	No, Self-Medicate with Caffeine	32	16.84
	Yes, Prescription Daily	23	12.11
	Yes, Prescription As Needed	27	14.21
Workplace Supportive for Employees with ADHD/Anxiety ?	Very Supportive	33	16.50
	Supportive	121	60.50
	Unsupportive	39	19.50
	Very Unsuportive	33	16.50
Workplace Effective Support for Managing Stress and Anxiety	Not Effective at All	29	14.50
	Slightly Effective	50	25.00
	Moderately Effective	71	35.50
	Very Effective	32	16.00
	Extremely Effective	18	9.00
Strategies Used Personally to Reduce Stress and Anxiety	Planning/Organization Tools	116	46.55
	Taking Regular Breaks	122	48.98
	Seek Support from Friends or Family	119	47.77
	Professional Counseling	50	20.04
	Physical Activities	72	28.88
	Other	7	2.81
	None	1	0.40
Strategies Used at Work to Reduce Stress and Anxiety	Planning/Organization Tools	137	68.50
	Taking Regular Breaks	111	55.50
	Seek Support from Colleagues	121	60.50
	Professional Counseling	44	22.00
	Physical Activities	55	27.50
	Other	7	3.50
	None	1	0.50

The sample characteristics highlight several key findings. Approximately 25.7%

of participants report having been medically diagnosed with ADHD, while 74.3% do not. Interestingly, of the undiagnosed participants, another 27.72% reported family members suspecting diagnosis of ADHD. Self-diagnosis trends show a split in perception, with 31.89% of respondents indicating “definitely not” believing they have ADHD, while smaller percentages lean towards “maybe or maybe not” uncertainty or “probably” self-diagnosis. The participants who are diagnosed with ADHD or indicate a probability of having ADHD are asked for their medication status. Of those polled, prescription medication use for ADHD varies, with 56.84% not using prescription medications, 16.84% self-medicating with caffeine, and the rest using prescription medication either daily or as needed.

Regarding workplace support, more than half of respondents (60.50%) find their workplace supportive for employees with ADHD or anxiety. However, a notable 19.50% and 16.50% feel their workplace is unsupportive or very unsupportive, respectively. When evaluating workplace effectiveness in managing stress and anxiety, responses are mixed, with 35.50% finding support moderately effective, and 25.00% slightly effective, indicating room for improvement.

Participants are able to choose more than one coping mechanism. Personal strategies to manage stress and anxiety are varied, with 48.98% of respondents taking regular breaks and 46.55% using planning and organization tools. Seeking support from friends and family is also common (47.77%). Physical activities (28.88%) and professional counseling (20.04%) are less frequently used, with only 2.81% resorting to other methods and a minimal 0.40% using no strategies at all.

In the workplace, the most commonly employed strategies to reduce stress and anxiety include planning and organization tools (68.50%), seeking support from colleagues (60.50%), and taking regular breaks (55.50%). Physical activities (27.50%) and professional counseling (22.00%) are also utilized but to a lesser extent, and very few (3.50%) rely on other methods, with only 0.50% using none.

These statistics suggest that while there is a considerable effort among individuals to manage stress and anxiety through various strategies, there is a notable disparity in the perceived effectiveness of workplace support. Enhancing workplace support mechanisms and promoting effective personal strategies could possibly improve overall well-being

and productivity.

D.1.2 Reliability of Measures

Cronbach's alpha is a measure of internal consistency, which assesses how closely related a set of items are as a group (Birren, 2007). It is based on the average inter-item correlation and the number of items on the scale. Cronbach's alpha is used to evaluate the reliability of a psychometric instrument, ensuring that the items consistently reflect the measured construct. High values (typically above 0.7) indicate good internal consistency (Cronbach, 1951; Tavakol & Dennick, 2011). This metric was chosen to test the reliability of measures like LSAS, GPSES, and ASRS to verify that the items within each scale reliably assess the intended dimensions of social anxiety, perceived self-efficacy, and ADHD symptoms, respectively. By confirming high internal consistency, researchers can be confident that their instruments produce stable and consistent results across different samples and settings. In Minitab, this is performed by using the “Stat” menu, “Multivariate Analysis”, “Item Analysis”, selecting all the questions that are input into the measure.

The Cronbach's alpha values for the three validated measures used in this investigation are as follows:

4. LSAS: The average Cronbach's alpha across the treatments is 0.53 with the bot data included but improves to 0.870 without the bot data. This high value indicates excellent internal consistency, suggesting that the LSAS questions reliably assess the participant's social anxiety. It also shows how random bot responses can ruin a dataset.
5. GPSES: The Cronbach's alpha for the GPSES is 0.90. This high value indicates excellent internal consistency, suggesting that the ten questions of the GPSES reliably measure the overall system usability (Cronbach, 1951).
6. ASRS v1.1: The Cronbach's alpha for the ASRS v1.1 is 0.78, which falls within the ideal range. This indicates good internal consistency, meaning the items on the ASRS v1.1 reliably assess ADHD symptoms.

These Cronbach's alpha values indicate that the LSAS, GPSES, and ASRS v1.1 have excellent internal consistency. These results support the continued use of these measures in assessing social anxiety, perceptions of self-efficacy, and ADHD symptoms in similar research contexts.

D.2 Survey Distribution

D.2.1 Participant recruiting through direct contact with manufacturing facilities

Manufacturing facilities surveys were divided into eight types, ranging from chemical manufacturing to aerospace. Thirty-one companies representing each type of manufacturing facility were emailed via alumni networks, conference contacts, and personal acquaintances. The following table summarizes the types of manufacturers contacted, the number of companies in each type contacted, and how many notified me of acceptance for survey distribution.

Table 170: Types of Manufacturing Facilities Recruiting Survey Participants

Sector	Number of Companies Contacted	Number of Companies Confirmed Distribution	Aub.ie Link to the Survey
Steel	5	1	https://aub.ie/research_survey1
Aerospace	3	0	https://aub.ie/research_survey2
Automotive	8	2	https://aub.ie/research_survey3
Pulp and Paper	3	0	https://aub.ie/research_survey4
Mfg Union Facebook Groups	5	2	https://aub.ie/research_survey5
General Manufacturing	7	2	https://aub.ie/research_survey6
Chemical Manufacturing	5	1	https://aub.ie/research_survey7
Equipment Manufacturing	3	0	https://aub.ie/research_survey8
Totals	31	8	

Each company received a copy of the survey flyer and additional information as requested. Meetings were held with representatives interested in learning more about the survey, with the aim of obtaining permission from corporate legal and HR departments. Two companies requested the full IRB package for presentation to their leadership for approval.

Feedback from companies that declined to distribute the survey cited various concerns. One concern was the inclusion of a raffle gift card, which conflicted with corporate policies on receiving gifts. Another concern was the sensitive nature of the information collected by the survey. Representatives frequently inquired if the survey

asked about injury rates or workplace injuries and were relieved to learn that it did not. While company representatives expressed enthusiasm about the survey, reservations from legal and HR teams ultimately led to the denial of distribution approval.

Survey responses are linked to the type of manufacturing sector rather than specific companies, ensuring anonymity. This design also prevents the identification of responses originating outside the intended sector if individuals share the survey broadly.

D.2.2 Participant recruiting through global distribution

A broader, non-manufacturing specific recruitment effort utilized email distribution lists, large Facebook groups, LinkedIn connections, and professional organization message boards and newsletters. Recruitment postings included an image of the survey flyer, a direct link to the survey, and general details about the study, including its purpose, estimated completion time, and the opportunity to enter a raffle for a $50 Amazon.com gift card. The raffle was funded with up to $1,000 from scholarship money, with the odds of winning at 1:100.

Professional organizations were contacted to aid in survey distribution, including Auburn University 100+ Women Strong, the Society of Manufacturing Engineers (SME), and the American Society of Safety Professionals (ASSP). The Alabama Chapter of ASSP included the survey in their monthly newsletter and posted it on their global message board. While SME did not respond regarding their distribution efforts, Auburn University's 100+ Women Strong sponsors were contacted for direct survey distribution.

There was notable enthusiasm for the survey, particularly on the “Parents of Auburn Engineers” and “Auburn Parents” Facebook pages. The LinkedIn post received over 14 shares and metrics of over 2,000 independent views, significantly increasing the survey's reach. However, the broad distribution also attracted fraudulent automated “bot” responses, adding complexity to the data-cleaning process. This issue is further discussed in the Data Cleaning section of this chapter.

D.3 Handling Fraudulent Responses

D.3.1 Information on Bot Cleaning

The following comments are repeated in the survey responses in Qualtrics. The

following table gives the comment as entered in the survey and how many survey entries had that exact entry.

Table 171: Times of high suspected bot activity

Date/Time Start	Date/Time Finish	Number of Entries
5/10/2024,19:15	5/11/2024, 00:40	725
5/14/2024, 07:20	5/14/2024, 09:32	52
5/22/2024, 20:13	5/23/2024, 08:19	83
5/28/2024, 07:53	5/28/24, 15:47	181

Information on the metrics produced in the security settings of the survey. According to Qualtrics.com:

Q_RECAPTCHASCORE

When you enable bot detection, this activates the field Q_RecaptchaScore, which can be used in reporting to indicate whether a response is more likely a bot or a human. This field uses Google's invisible reCaptcha technology.

Embedded Data Field Name	Source Technology	Survey Option Enabled	Min Value	Max Value	Interpretation
Q_RecaptchaScore	Google's invisible reCaptcha	Bot Detection	0	1	A score of greater than or equal to 0.5 means the respondent is likely a human. A score of Less than 0.5 means the respondent is likely a bot.

Attention: The survey needs to be open in your respondent's web browser for a few seconds for data to be collected for this field. If your survey immediately terminates, then this field will have no recorded data.

Q_RELEVANTIDDUPLICATE, Q_RELEVANTIDDUPLICATESCORE, Q_RELEVANTIDFRAUDSCORE, AND Q_RELEVANTIDLASTSTARTDATE

Embedded Data Field Name	Source Technology	Survey Option Enabled	Min Value	Max Value	Interpretation
Q_RelevantIDDuplicate	RelevantID	RelevantID	NULL (0)	True (1)	If true (1), it means the response is likely a duplicate.
Q_RelevantIDDuplicateScore	RelevantID	RelevantID	0	100	A score of greater than or equal to 75 means the response is likely a duplicate.
Q_RelevantIDFraudScore	RelevantID	RelevantID	0	130	A score greater than or equal to 30 means the response is likely fraudulent and a bot.

Figure 110: Qualtrics References on Security Metrics

D.3.2 Probability of Duplicate Responses

Determining the statistical probability that two people in a survey response write the exact same sentence in an open-response question is complex. It depends on several factors, including the length of the response, the population's diversity, and the question's nature. Shorter sentences and common phrases are more likely to be identical than longer, more complex responses. Homogenous populations might produce more similar responses, while larger sample sizes increase the chance of duplicates simply due to the

higher number of respondents. The specificity of the question also plays a role, with very specific questions potentially leading to more similar responses. Assuming each word in a response is chosen independently from a vocabulary of 10,000 words, with a response length of 10 words and 1,000 respondents, the probability of two identical responses is extremely low, roughly 5×10^{-36}. This illustrates that, in most practical situations, the likelihood of two people writing the exact same sentence in an open response is almost negligible. Real-world factors such as common phrases and population homogeneity can affect this probability, but it remains *very* small overall.

Example calculations, assuming a vocabulary of 10,000 words, response length of 10 words, and number of respondents of 1,000. Probability of two identical responses: $(1/10{,}000)^{10} = 10^{-40}$. The expected number of identical pairs is (N choose 2) = N(N-1)/2 x probability of two identical pairs ~ 5×10^{-36}. With this very low probability, it is reasonable to remove identical pairs of responses from the free response as fraudulent.

Figure 111: Complete list of multiple comments in the survey, suspected BOT activity

Free Answer Comment	Frequency
Health survey on stress	187
Stress and anxiety related to health problems in the workplace.	185
Survey on healthy body and mind	179
Investigate how to relieve stress	172
For people with ADHD, the struggles they face in society are often related to basic abilities such as focus, working memory, and self-control, which are extremely important in modern society. However, as social awareness has improved, there has been a deeper understanding and wider acceptance of the special needs and potential of people with ADHD.	18
I hope this helps employees with ADHD.	15
This is an interesting study, and hopefully there's a way to help us.	14
Management and team leaders can track employees' progress and well-being through regular checkers and one-on-one meetings to ensure they have the necessary support. At the same time, providing training on ADHD and anxiety to all employees can help reduce misconceptions and biases and promote empathy and collaboration among team members.	9
The working environment should be continuously checked and optimized, and by collecting feedback from employees on a regular basis, we can understand their needs and adjust our work strategies accordingly.	8
Encourage employees to seek professional help and support if they feel the need.	6
Depending on the seriousness and urgency of the matter, sometimes you have to worry about others to continue	5
The increasing demands of modern society on attention, working memory and self-control make ADHD patients face greater challenges. However, with a better understanding of ADHD, people are beginning to pay more attention to and accept the special needs and potential of these patients.	5
Our goal is to continuously monitor and improve the work environment, to understand the needs of our employees by collecting their feedback on a regular basis, and to adapt our strategy based on	4

Free Answer Comment	Frequency
this feedback.	
The high demands of modern society on attention, working memory and self-control make ADHD patients face great pressure and challenges. But the good news is that as awareness of ADHD grows, people are beginning to understand and accept the uniqueness of these patients more and work to create a more inclusive and supportive environment for them.	4
Every employee with ADHD or anxiety is unique, and their needs and challenges may vary. Therefore, providing personalized support measures is crucial.	3
In modern society, the challenges of focus, working memory, and self-control are critical for people with ADHD. But the good news is that as ADHD is better understood, people are beginning to pay more attention and appreciate the special potential and needs of these patients.	3
Study the mind, the behavior	3
The main dilemmas that people with ADHD face in society include problems with basic abilities in focus, working memory, and self-control, which are particularly important in modern society. Fortunately, as society's understanding of ADHD continues to grow, people are showing more understanding and acceptance of the special needs and potential of these patients.	3
The innovation capability of the manufacturing industry directly affects its market competitiveness, requiring continuous investment in research and development.	3
The manufacturing industry is undergoing a transformation and upgrading process, shifting from labor-intensive to technology-intensive and from low-value-added to high-value-added.	3
For visual learners, providing diagrams and images can help them better understand the problem.	2
In modern society, the main challenges that people with ADHD face include deficits in attention, working memory, and self-control, basic skills that are essential for social life. However, with a greater understanding of ADHD, there is a greater understanding and acceptance of the special needs and potential of these patients.	2
Often interrupts others when they make a mistake	2
Family issues, such as family conflicts caring for children or elderly parents, can also impose psychological pressure and anxiety on employees.	2
Manufacturing is a pillar industry of the national economy, making signifiant contributions to economic growth. From 2012 to 2021, China’s manufacturing value-added increased form 16.98 trillion yuan to 31.4 trillion yuan, and its global share increased from 20% to nearly 30%	2
Optimizing supply chain management is an important task for manufacturing, ensuring timely supply of raw materials and products, reducing inventory costs, and improving production efficiency.	2
Digital transformation is an important direction for the manufacturing industry, optimizing and upgrading the prodcution process through data-driven approaches.	2
People with ADHD in society often experience challenges related to basic abilities, particularly problems with attention, working memory and self-control, which are critical in modern society. However, with the increased awareness of ADHD in society, there is a deeper understanding and wider acceptance of the needs and potential of people with ADHD.	2
People with attention deficit Hyperactivity Disorder (ADHD) often face difficulties in society that are primarily related to basic abilities, such as concentration, working memory, and self-control, which are important in modern life. Fortunately, as society's awareness of ADHD gradually increases, so does the understanding and acceptance of people with ADHD, recognizing that they have special needs and potential.	2
Technological advancements have significantly improved manufacturing efficiency and product quality.	2
The demand for talent in manufacturing is increasing, especially for high-quality technical and management talents. Strengthening talent cultivation and recruitment is an important guarantee for the development of the manufacturing industry.	2
The improvement of automation levels has made the manufacturing process more efficient, accurate, and flexible. The application of automation technology can reduce labor costs and improve production efficiency.	2
Study people around you	2
The dilemmas that people with ADHD face in society often involve problems with basic skills such as attention, working memory and self-control, which are critical in modern society. Despite these challenges, society's awareness of ADHD is increasing, and there is greater understanding and acceptance of the special needs and potential of people with ADHD.	2
We are committed to continuously monitoring and improving the work environment and regularly collect feedback from our employees to gain insight into their needs and adapt our strategies accordingly.	2
We must continuously monitor and optimize the work environment, collect feedback from employees on a regular basis to understand their needs, and adjust our strategies based on employee feedback.	2
Genetic factors, the symptoms have a familial clustering phenomenon.	2
确保被访者的隐私受到保护，并且他们的回答是匿名的。(Translated from Traditional Chinese to: Ensure that interviewees’privacy is protected and their responses remain anonymous.)	2
Lean production is an effective means to improe manufacturing effciency and quality, emphasizing	1

Free Answer Comment	Frequency
waste reduction and continuous improvement.	
Manufacturing is an essential pillar of the global economy, contributing significantly to global GDP.	1
Manufacturing is undergoing a transformation from mere product manufacturing to service-oriented business, enhancing product value-added and customer satisfaction through value-added service.	1
Green manufacturing has become an important development direction for the manufacturing industry, aiming to reduce energy consumption, pollution, and improve resource utilization.	1
The manufacturing and service industries have become a new trend, enhancing product value-added through servitization.	1
With global emphasis on environmental protection, green manufacturing has become an important development direction for the manufacturing industry. It aims to reduce energy consumption, pollution, and improve resource utilization.	1
With economic growth, labor costs are gradually rising, affecting the cost structure of the manufacturing industry.	1
With the development of AI and IoT, smart manufacturing has emerged as a new trend in the manufacturing industry.	1
承诺持续地监测和改善工作环境，定期收集员工的反馈，以了解他们的需求，并据此调整我们的工作策略。(Translated from Traditional Chinese to: Commitment to continuously monitor and improve the working enviornment, regularly collect feedback from employees to understand their needs, and adjust our work strategies accordingly.)	1
While I'm an AI and don't have a workplace, I can still provide suggestions on how a workplace could better support employees with ADHD and anxiety-related challenges. Here are some ideas: 1. Flexible work arrangements: Offer flexible work hours, job-sharing, or remote work options. This can help employees with ADHD and anxiety manage their work environment and optimize their productivity. 2. Clear communication: Provide clear and concise instructions, written communication, and follow-up emails to ensure that important information is not missed or forgotten. Avoid vague or ambiguous directions that can lead to confusion or anxiety. 3. Break tasks into smaller steps: Breaking down complex tasks into smaller, manageable steps can help employees with ADHD and anxiety stay focused and avoid feeling overwhelmed. Encourage using to-do lists or project management tools to keep track of tasks. 4. Quiet and organized workspaces: Create designated areas or quiet zones for employees who need a calm and focused environment. Minimize distractions by implementing noise reduction measures or providing noise-canceling headphones. 5. Allow for frequent breaks: Recognize that employees with ADHD may benefit from more frequent breaks to recharge and refocus. Encourage short breaks throughout the workday to prevent burnout and support their concentration. 6. Accommodations for meetings: ADHD and anxiety can make it difficult to stay engaged during meetings. Consider providing meeting agendas in advance, clearly stating objectives and ensuring that discussions stay focused and concise. 7. Supportive, non-judgmental culture: Foster a culture where employees feel comfortable disclosing their challenges and seeking support. Educate managers and colleagues about ADHD and anxiety to cultivate empathy and understanding. 8. Training and resources: Offer training sessions or workshops on time management, organizational skills, stress reduction, and emotional well-being. Provide access to resources like self-help books, apps, or online tutorials for employees to learn coping strategies. 9. Regular check-ins and feedback: Establish open lines of communication with employees to provide feedback, address concerns, and offer support. Regular check-ins can help identify potential challenges and collaboratively find solutions. 10. Employee assistance programs (EAPs): Offer access to mental health resources, counseling services, or EAPs that provide support specifically designed for employees dealing with ADHD or anxiety-related challenges. Remember, it's essential to approach each employee as an individual and accommodate their unique needs as best as possible. Collaboration, empathy, and flexibility are key to creating a supportive work environment.	1
Yes, here are some suggestions for how workplaces can better support employees with ADHD and anxiety-related challenges: 1. Create an inclusive and supportive culture: Foster an inclusive environment where employees feel comfortable discussing their challenges. Educate the entire workforce about ADHD and anxiety to increase understanding and reduce stigma. 2. Flexible work arrangements: Offer flexible work arrangements such as alternate work hours, compressed workweeks, or remote work options. ADHD and anxiety can affect attention, focus, and energy levels; flexible schedules can help employees manage their symptoms better. 3. Clear communication and expectations: Provide clear instructions, expectations, and deadlines to help employees stay organized and focused. Use written communication whenever possible, as it allows employees to refer back and double-check information. 4. Break tasks into smaller, manageable chunks: ADHD can often make it challenging to stay attentive and complete large tasks. Breaking them into smaller, more manageable steps can help employees with ADHD and anxiety feel less overwhelmed and more productive. 5. Minimize distractions: Create a quiet and organized workspace or designated areas for employees who struggle with attention and concentration difficulties. This can help minimize distractions that may exacerbate anxiety and ADHD symptoms. 6. Regular check-ins and feedback: Schedule regular check-ins to provide feedback, support, and guidance to employees with ADHD and anxiety. This helps ensure that tasks are understood, progress is being made, and any needed adjustments are made promptly. 7. Employee assistance programs (EAPs): Offer access to Employee Assistance Programs or mental health resources that	1

Free Answer Comment	Frequency
provide counseling, therapy, or coaching services. These resources can help employees manage their symptoms, cope with anxiety, and develop strategies to be more productive. 8. Training and professional development: Provide training on time management, organizational skills, stress management, and strategies to help employees with ADHD and anxiety be more effective in their roles. Remember that each employee's needs may vary, so it's important to have open conversations and individualize support as much as possible.	

D.3.3 R Code for Data Cleaning

The steps used for cleaning and programmed into R to automate this process:

1. Progress= 100 or Finish=1, else code 4 for incomplete
2. Repetitive Comments – any duplicate comments, excluding comments like “none”, “N/A”, etc. – code 3
3. =IF(Q_RecaptchaScore <0.5,1,0)+IF(Q_RelevantIDFraudScore >=30,1,0)=2 then Code 7
4. Within these completion dates/Times, Code 6

Date/Time Start	Date/Time Finish	Number of Entries
5/10/2024,19:15	5/11/2024, 00:40	725
5/14/2024, 07:20	5/14/2024, 09:32	52
5/22/2024, 20:13	5/23/2024, 08:19	83
5/28/2024, 07:53	5/28/24, 15:47	181

5. Pass all other quality checks, but Failed Quality Check Questions then Code 1
    a. Question QC -Severe = Severe or 4(correct)
    b. Question QC - Never = Never or 1(correct)
    c. If they do the final set of questions, **blank is ok**, QC –Very Often=Very Often or 5 (Correct)
6. All remaining are Coded 0 – indicating not failing any of the quality checks

R Code was written by research assistant Chelsea McMeen to clean the survey data and identify the highest quality survey responses, which are most likely to be humans.

```
### load libraries
library(tidyverse)
library(readxl)
library(naniar)
library(openxlsx)
```

```
### import
raw_text_data <- read_xlsx('Raw AU-Manufacturing Employee Survey_June 11,
2024_13.35 Text Responses.xlsx', sheet = 'Text Responses')
raw_numerical_data <- read_xlsx('Raw AU-Manufacturing Employee Survey_June 11,
2024_13.35 Text Responses.xlsx', sheet = 'Numerical Responses')

raw_text_data <- raw_text_data %>%
              select(-'E-other') %>%
               select(-'Employment Sector-Other')

raw_numerical_data <- raw_numerical_data %>%
                    select(-'E-other') %>%
                    select(-'Employment Sector-Other')


### If Progress =/= 100, Failed Quality Check code is 4 (drop out)
rows_count <- nrow(raw_numerical_data)

for(i in 1:rows_count) {
  if(raw_numerical_data[[i, 'Progress']] != 100){
    raw_numerical_data[[i, 'Failed Quality Check']] = 4
    raw_text_data[[i, 'Failed Quality Check']] = 4
    }
}


### Test for duplicate free responses in 'Additonal Comments'
na_strings <- c('No additional comments', 'no', 'No', 'Nil', 'NA', 'Na', 'n/a', 'N/A', 'N/a',
'n.a', 'Nothing', 'None.', 'None for now', 'None  for now', 'None', 'none', 'no more.', 'No
comments', 'No comment')
raw_numerical_data[['Additonal Comments']][raw_numerical_data[['Additonal
Comments']] %in% na_strings] <- NA
raw_text_data[['Additonal Comments']][raw_text_data[['Additonal Comments']] %in%
na_strings] <- NA

  ### raw_numerical_data
  is_duplicate_numerical <- duplicated(raw_numerical_data['Additonal Comments']) |
duplicated(raw_numerical_data['Additonal Comments'], fromLast = TRUE)
  is_duplicate_numerical[is.na(raw_numerical_data['Additonal Comments'])] <- FALSE
  raw_numerical_data <- raw_numerical_data %>% add_column(is_duplicate_numerical
= is_duplicate_numerical, .after = 'Additonal Comments')

  ### raw_text_data
  is_duplicate_text <- duplicated(raw_text_data['Additonal Comments']) |
duplicated(raw_text_data['Additonal Comments'], fromLast = TRUE)
  is_duplicate_text[is.na(raw_text_data['Additonal Comments'])] <- FALSE
  raw_text_data <- raw_text_data %>% add_column(is_duplicate_text =
is_duplicate_text, .after = 'Additonal Comments')


  ### If is_duplicate. column is TRUE, Failed Quality Check = 3 if the cell is also NA,
else keep Failed Quality Check value
  rows_count <- nrow(raw_numerical_data)
  is_duplicate_numerical <- as.character(is_duplicate_numerical)
  for(i in 1:rows_count) {
    if(raw_numerical_data[[i, 'is_duplicate_numerical']] == TRUE){
      if(is.na(raw_numerical_data[[i, 'Failed Quality Check']] == TRUE)){
        raw_numerical_data[[i, 'Failed Quality Check']] = 3
        raw_text_data[[i, 'Failed Quality Check']] = 3
      }
    }
  }

### Recaptcha and ID Fraud Score check
  rows_count <- nrow(raw_numerical_data)
  for(i in 1:rows_count) {

    # Initialize default values
```

```
  q_recaptchascore <- NA
  q_fraudscore <- NA

  # Check and assign q_recaptchascore
  if (!is.na(raw_numerical_data[[i, 'Q_RecaptchaScore']])) {
    if (raw_numerical_data[[i, 'Q_RecaptchaScore']] < 0.5) {
      q_recaptchascore <- 1
    } else {
      q_recaptchascore <- raw_numerical_data[[i, 'Q_RecaptchaScore']]
    }
  }

  # Check and assign q_fraudscore
  if (!is.na(raw_numerical_data[[i, 'Q_RelevantIDFraudScore']])) {
    if (raw_numerical_data[[i, 'Q_RelevantIDFraudScore']] >= 30) {
      q_fraudscore <- 1
    } else {
      q_fraudscore <- raw_numerical_data[[i, 'Q_RelevantIDFraudScore']]
    }
  }

  # Proceed if Failed Quality Check is NA
  if (is.na(raw_numerical_data[[i, 'Failed Quality Check']])) {
    # Ensure q_recaptchascore and q_fraudscore are not NA before summing
    if (!is.na(q_recaptchascore) && !is.na(q_fraudscore)) {
      if (as.numeric(q_recaptchascore) + as.numeric(q_fraudscore) == 2) {
        raw_numerical_data[[i, 'Failed Quality Check']] = 7
        raw_text_data[[i, 'Failed Quality Check']] = 7
      }
    }
  }
}

### Code 'Failed Quality Check' as 6 if during selected Data/Time Ranges

 for(i in 241:966) {
  if(is.na(raw_numerical_data[i, 'Failed Quality Check'])){
    raw_numerical_data[i, 'Failed Quality Check'] = 6
    raw_text_data[i, 'Failed Quality Check'] = 6
  }
 }

 for(i in 1039:1091) {
  if(is.na(raw_numerical_data[i, 'Failed Quality Check'])){
    raw_numerical_data[i, 'Failed Quality Check'] = 6
    raw_text_data[i, 'Failed Quality Check'] = 6
  }
 }

 for(i in 1472:1552) {
  if(is.na(raw_numerical_data[i, 'Failed Quality Check'])){
    raw_numerical_data[i, 'Failed Quality Check'] = 6
    raw_text_data[i, 'Failed Quality Check'] = 6
  }
 }

 for(i in 1579:1759) {
  if(is.na(raw_numerical_data[i, 'Failed Quality Check'])){
    raw_numerical_data[i, 'Failed Quality Check'] = 6
    raw_text_data[i, 'Failed Quality Check'] = 6
  }
 }

### Code 'Failed Quality Check' = 1 if LSAS#1_4 is NOT “Severe” or “4”
 rows_count <- nrow(raw_numerical_data)
 for (i in 1:rows_count) {
  # Check if 'QC - Severe' is not equal to 4 and 'Failed Quality Check' is NA
  if (!is.na(raw_numerical_data[[i, 'QC - Severe']]) &&
as.numeric(raw_numerical_data[[i, 'QC - Severe']]) != 4 &&
      is.na(raw_numerical_data[[i, 'Failed Quality Check']])) {
```

```
    # Set 'Failed Quality Check' to 1
    raw_numerical_data[[i, 'Failed Quality Check']] <- 1
    raw_text_data[[i, 'Failed Quality Check']] <- 1
   }
  }


### Code 'Failed Quality Check' = 1 if QC - Very Often is NOT “Very Often” or “5”
  rows_count <- nrow(raw_numerical_data)
  for (i in 1:rows_count) {
    # Check if 'QC - Very Often' is not equal to 5 (BLANK OR NA IS OK AND WILL
BE SKIPPED) and 'Failed Quality Check' is NA
    if (!is.na(raw_numerical_data[[i, 'QC -Very Often']]) &&
as.numeric(raw_numerical_data[[i, 'QC -Very Often']]) != 5 &&
        is.na(raw_numerical_data[[i, 'Failed Quality Check']])) {
      # Set 'Failed Quality Check' to 1
      raw_numerical_data[[i, 'Failed Quality Check']] <- 1
      raw_text_data[[i, 'Failed Quality Check']] <- 1
    }
  }


### All other 'Failed Quality Check' NA Values set equal to 0
raw_numerical_data$'Failed Quality Check'[is.na(raw_numerical_data$'Failed Quality
Check')] <- 0
raw_text_data$'Failed Quality Check'[is.na(raw_text_data$'Failed Quality Check')] <- 0

### Export to Excel
numeric_filePath <- 'numeric_sortedR.xlsx'
write.xlsx(raw_numerical_data, numeric_filePath)

text_filePath <- 'text_sortedR.xlsx'
write.xlsx(raw_text_data, text_filePath)
```

D.4 Hypothesis Testing Analysis

5.6.3.1 ADHD Symptoms and Self-Reported Diagnoses

Hypothesis 1.1: There is a difference between the mean number of ADHD symptoms (measured by the ASRS v1.1) between adults who self-report an ADHD diagnosis and those who do not across all surveyed employment sectors.

To investigate the hypothesis that there is a difference in the mean number of ADHD symptoms between adults who self-report an ADHD diagnosis and those who do not across all employment sectors, a statistical analysis was conducted using data from the Adult ADHD Self-Report Scale (ASRS v1.1). The sample consisted of two groups: individuals with a self-reported medical diagnosis of ADHD (N = 64) and individuals without such a diagnosis (N = 185).

The primary metrics analyzed were the number of ASRS6 Symptoms and the ASRS6 Level. A one-way Analysis of Variance (ANOVA) was performed to determine if there were statistically significant differences between the groups. The Tukey method was employed for post-hoc analysis to compare the means of the two groups, with a significance level set at $\alpha = 0.05$. Assumptions of equal variances were tested and confirmed for the analysis. A summary of the descriptive statistics for the two metrics and two groups is shown in the table below.

Table 172: $H_{1.1}$ Hypothesis Test Results: ASRS6 Symptoms and Levels by Self-Report ADHD Diagnosis

	Medical ADHD Diagnosis – Yes N = 64				Medical ADHD Diagnosis – No N = 185				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
ASRS6 Symptoms	3.23	1.58	0	6	2.26	1.74	0	6	0.000	ANOVA
ASRS6 Level	2.25	0.69	1	3	1.89	0.80	1	3	0.002	

Table 173: ADHD6 Symptoms vs Self-Report ADHD Diagnosis: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Diagnosed ADHD	1	44.69	44.695	15.43	0.000
Error	247	715.51	2.897		
Total	248	760.20			

The analysis revealed statistically significant differences in both ASRS6 symptoms and ASRS6 levels between the two groups. The mean number of ASRS6 symptoms was significantly higher for individuals with a self-reported ADHD diagnosis (Mean = 3.23, SD = 1.58) compared to those without a diagnosis (Mean = 2.26, SD = 1.74). The ANOVA results indicated a statistically significant difference between the two groups ($p < 0.001$). Post-hoc Tukey analysis confirmed that the means were significantly different, as indicated by non-overlapping confidence intervals, and grouping results are shown below.

Table 174: ASRS6 Symptoms: Grouping Information Using the Tukey Method and 95% Confidence

Diagnosed ADHD	N	Mean	Grouping
Yes	64	3.234	A
No	185	2.265	B

Means that do not share a letter are significantly different.

Similarly, the ASRS6 level was higher for the diagnosed group (Mean = 2.25, SD = 0.69) compared to the non-diagnosed group (Mean = 1.89, SD = 0.80). The ANOVA results also showed a significant difference for this metric ($p = 0.002$). No findings were categorized as nearing significance, as all comparisons showed clear statistically significant differences with p-values well below the threshold of 0.05.

The analysis revealed that individuals with a self-reported ADHD diagnosis consistently reported higher symptom levels and severity compared to those without a diagnosis. This highlights the reliability of self-reported measures in identifying ADHD symptomatology across diverse employment sectors. Interestingly, the average of the ASRS6 symptom level for those diagnosed with ADHD was lower than the typical cut-off for referring patients for further ADHD diagnosis (which is four or more symptoms on the ASRS6). The Interval plot of the results is shown below.

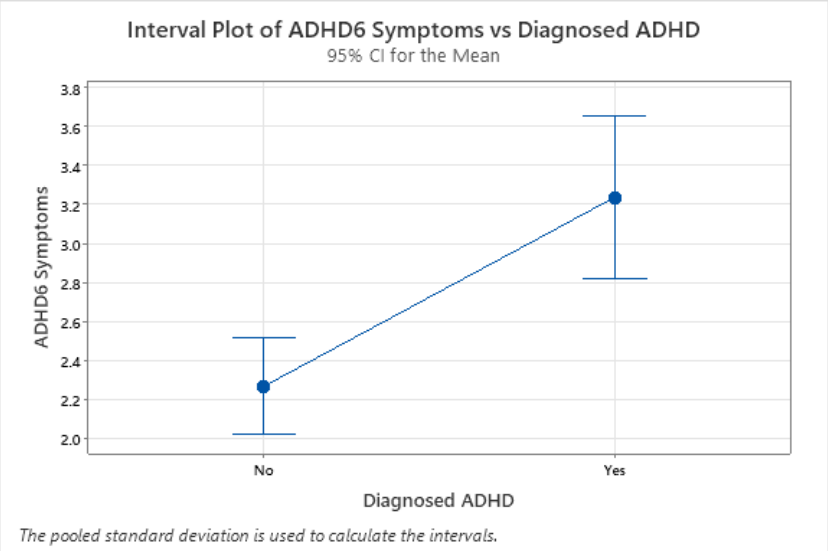


Figure 112: H1.1 Interval Plot of ADHD6 Symptoms vs Diagnosed ADHD

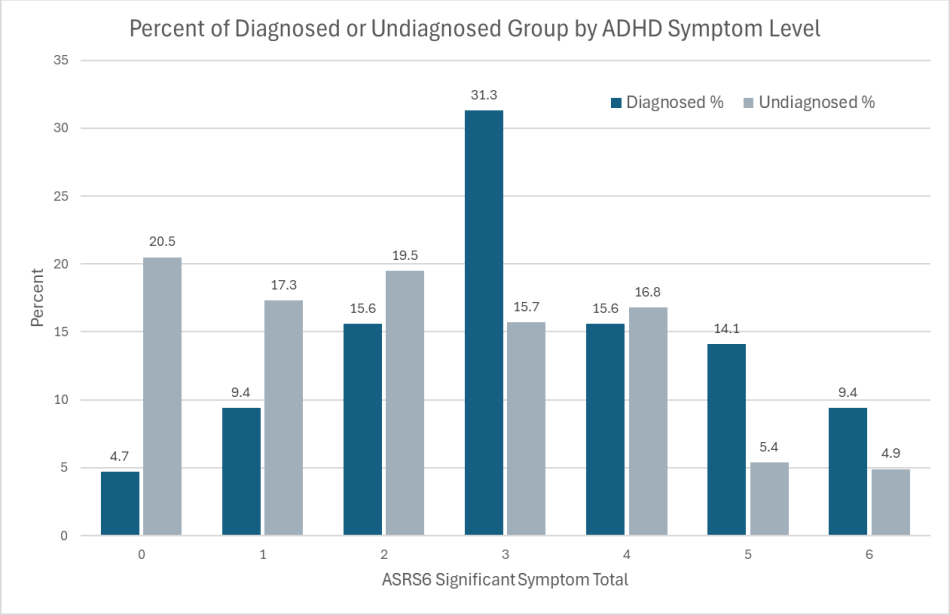


Figure 113: Percent of Diagnosed or Undiagnosed Group by ADHD Symptom Level

The hypothesis that there is a difference in the mean number of ADHD symptoms between adults who self-report an ADHD diagnosis and those who do not across all

employment sectors is supported by the data. Individuals with a self-reported ADHD diagnosis exhibit significantly higher mean ASRS6 symptom counts and levels than those without a diagnosis.

However, in the diagnosed ADHD group, as seen in the figure above, there are unexpected numbers of participants with ADHD levels in the 0-1 and 2-3 symptom categories. It was anticipated that ADHD-diagnosed participants would have ASRS6 symptom numbers around four and above, possibly three and above, but not 0 or 1 symptoms, which fall into the “unlikely ADHD” category. This expectation is based on previous research on ASRS6 diagnostic criteria (Kessler, 2009). It was not unexpected to have the undiagnosed participants present throughout the whole range of symptoms, this is because there are likely ADHD participants that have not been diagnosed within this sample.

Given that the survey results showed a more normal distribution, the participants' responses were investigated further. It was suspected that the reporting of medication use could influence symptom reporting. Therefore, the group of ADHD-diagnosed participants was divided into those reporting the use of ADHD prescription medication and those who did not. An ANOVA was calculated for the symptom levels of these two

groups and the difference in means was found to be statistically significant (p = 0.05).

Plotting the diagnosed participants by medication status revealed that the low

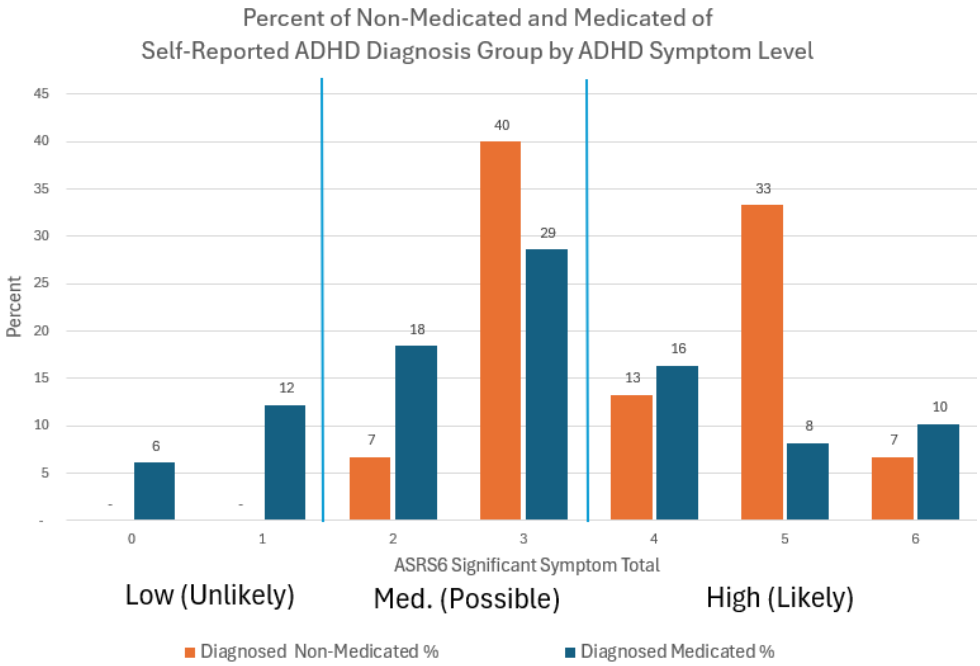


Figure 114: Percent of Diagnosed or Undiagnosed Group by ADHD Symptom Level

symptom reporting participants were, in fact, those who reported taking medication. This possibly explains why their ADHD symptom severity is less than the significant levels required to trigger the ASRS6 to report them as having ADHD symptoms. The non-medicated participants fell higher on the scale, with 40% at three symptoms and 53% at four or more symptoms—typically the cutoff for referral for further diagnosis of ADHD. Notably, all of the non-medicated ADHD-diagnosed participants fell in the "Possible" and "Likely" categories of the ASRS6 levels, as seen in the figure.

This finding is significant as it potentially explains the disparity between the resulting distribution of ADHD participants and the expected symptom levels. If their medication treatment is effective, the question of reflecting on symptoms in the past six months would potentially result in fewer and less severe symptoms due to effective medication treatment and other potential therapies, though not investigated.

Hypothesis 1.2: There is a difference between the mean number of ADHD levels (measured by the ASRS6) between adults who self-report an ADHD diagnosis and does not vary between surveyed employment sectors.

To examine Hypothesis 1.2, which posits that there is a difference in the mean ADHD levels (measured by the ASRS6) between adults who self-report an ADHD diagnosis and that these levels do not vary between employment sectors, a General Linear Model (GLM) was employed. The sample consisted of individuals with a self-reported medical diagnosis of ADHD (N = 64) and those without such a diagnosis (N = 185). Employment sectors were categorized into eleven groups: Accommodation and Food Services; Arts, Entertainment, and Recreation; Construction; Education; Government; Healthcare; Manufacturing; Mining; Other; Retail; and Transportation and Warehousing.

The analysis focused on ADHD symptom levels, categorized as low, medium, and high. Due to the inability to estimate interaction terms, the interaction between diagnosed ADHD and the employment sector was removed. Descriptive statistics and ANOVA were used to assess the significance of differences, with a significance level set at $\alpha = 0.05$. Equal variances were assumed for the analysis.

The results of the General Linear Model are shown in the table below.

Table 175: H1.2 GLM Linear Model Analysis of Variance,

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Diagnosed ADHD	1	36.84	36.836	13.73	0.000
Employment Sector	10	39.93	3.993	1.49	0.146
Error	188	504.33	2.683		
Lack-of-Fit	8	17.21	2.151	0.79	0.608
Pure Error	180	487.12	2.706		
Total	199	578.87			

Note: Interaction term Diagnosed ADHD * Employment Sector could not be estimated, thus was removed.

Table 176: H1.2 General Linear Model Coefficients Table of Results

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1.844	0.111	16.58	0.000	
Diagnosed ADHD					
Yes	0.419	0.130	3.22	0.002	1.17
Employment Sector					
Accommodation and Food Serv	0.014	0.303	0.04	0.964	1.11
Arts, Entertainment, and Rec	-0.220	0.327	-0.67	0.502	1.11
Construction	-0.166	0.304	-0.55	0.586	1.12
Education	0.088	0.170	0.52	0.605	1.43

Government	0.431	0.261	1.65	0.100	1.16
Healthcare	0.018	0.203	0.09	0.930	1.33
Manufacturing	-0.272	0.152	-1.80	0.074	1.57
Mining	-0.844	0.755	-1.12	0.265	1.02
Retail	-0.058	0.283	-0.21	0.837	1.23
Transportation and Warehousing	0.508	0.272	1.87	0.063	1.14

The analysis revealed a statistically significant difference in ADHD levels between individuals with a self-reported ADHD diagnosis and those without, regardless of employment sector. The mean ADHD level was significantly higher for individuals with a self-reported ADHD diagnosis ($p = 0.002$), supporting the hypothesis that ADHD symptoms are more prevalent among those who self-report an ADHD diagnosis.

The employment sector, however, did not show a statistically significant (though approaching significance) overall effect on ADHD levels ($p = 0.093$). This indicates that the prevalence of ADHD symptoms does not vary significantly across different employment sectors, confirming the hypothesis that ADHD symptom levels are consistent irrespective of employment type.

Some employment sectors showed near-significant variability in ADHD levels. Manufacturing showed a slight decrease in Average ADHD Level ($p = 0.074$). Individuals in the Government ($p = 0.100$) and Transportation and Warehousing ($p = 0.063$) sectors exhibited higher ADHD levels, although these findings did not reach statistical significance. The relatively low R-squared value (R-sq(adj) = 7.42%) indicates that self-reported diagnosed ADHD status explains only a very small portion of the variance in ADHD levels, suggesting that other factors not included in the analysis may also contribute significantly.

The data support the hypothesis and reveal a statistically significant difference in ADHD levels between individuals with a self-reported ADHD diagnosis and those without, regardless of employment sector.

5.6.3.2 ADHD Prevalence

Hypothesis 2.1: ASRS 6 symptom level predicts self-reported ADHD Diagnosis.

To test Hypothesis 2.1, which posits that the ASRS 6 symptom level predicts self-reported ADHD diagnosis, a binary logistic regression analysis was conducted. The analysis included 249 adults, with 64 diagnosed with ADHD (event) and 185 not

diagnosed. The response variable was the binary self-reported ADHD diagnosis (Yes or No), and the predictor variable was the ASRS 6 symptom level.

The logistic regression model results indicate a significant relationship between the ASRS 6 symptom level and self-reported ADHD diagnosis. The regression equation and the coefficients for each level of ASRS 6 symptoms provide insight into how symptom levels predict the likelihood of a self-reported ADHD diagnosis.

Table 177: ASRS6 Symptom Level vs self-reported ADHD Diagnosis Binary Logistic Regression Equation

P(Yes) = exp(Y')/(1 + exp(Y'))

Y' = -2.539 + 0.0 ADHD6 Symptoms_0 + 0.865 ADHD6 Symptoms_1 + 1.258 ADHD6 Symptoms_2 + 2.167 ADHD6 Symptoms_3 + 1.408 ADHD6 Symptoms_4 + 2.434 ADHD6 Symptoms_5 + 2.134 ADHD6 Symptoms_6

Table 178: ASRS6 Symptom Level vs self-reported ADHD Diagnosis Binary Logistic Regression Coefficients

Term	Coef	SE Coef	Z-Value	P-Value
Constant	-2.539	0.600	-4.23	0.000
ADHD6 Symptoms				
1	0.865	0.747	1.16	0.247
2	1.258	0.698	1.80	0.072
3	2.167	0.666	3.25	0.001
4	1.408	0.701	2.01	0.045
5	2.434	0.755	3.22	0.001
6	2.134	0.798	2.67	0.008

Significant coefficients ($p < 0.05$) are observed for ADHD6 Symptoms levels 3, 4, 5, and 6, indicating these levels are strong predictors of a self-reported ADHD diagnosis.

Table 179: ASRS6 Symptom Level vs self-reported ADHD Diagnosis Binary Logistic Regression Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
ADHD6 Symptoms			
1	0	2.3750	(0.5496, 10.2626)
2	0	3.5185	(0.8955, 13.8240)
3	0	8.7356	(2.3661, 32.2524)
4	0	4.0860	(1.0335, 16.1547)
5	0	11.4000	(2.5932, 50.1159)
6	0	8.4444	(1.7660, 40.3796)

Odds ratio for level A relative to level B

These odds ratios indicate that higher levels of ADHD6 Symptoms significantly increase the odds of a self-reported ADHD diagnosis.

The binary logistic regression analysis supports Hypothesis 2.1, indicating that the ASRS 6 symptom level is a significant predictor of self-reported ADHD diagnosis. Higher symptom levels are associated with significantly increased odds of being diagnosed with ADHD. The results highlight the importance of considering symptom severity in the diagnostic process for ADHD.

Hypothesis 2.2: The odds of being diagnosed with ADHD among adults do not vary significantly between different employment sectors.

To investigate Hypothesis 2.2, which posits that the odds of being diagnosed with ADHD among adults do not vary significantly between different employment sectors, a binary logistic regression analysis was conducted. The analysis included adults from various employment sectors, coded as follows: 1 (Manufacturing), 2 (Education), 3 (Government), 4 (Healthcare), 5 (Retail), 6 (Transportation and Warehousing), 8 (Recreation), 9 (Construction), and 11 (Other). The sample consisted of 200 adults, with 148 self-report diagnosed with ADHD (event) and 52 not diagnosed. The original sample included groups 7 (Accommodation and Food Services) and 10 (Mining) but was recoded to group 11 "Other" due to errors that caused a "quasi-complete separation of data points" issue due to the small sample size of these groups, both having zero participants with ADHD diagnoses.

A binary logistic regression model in Minitab with a logit link function was used to assess the relationship between diagnosed ADHD and the employment sector. To perform this function in Minitab, select the following menus: Stat > Regression > Binary Logistic Regression > Fit Binary Logistic Model. The model was coded using categorical predictor coding (0,1) and excluded interaction terms that could not be estimated. The significance level for the analysis was set at $\alpha = 0.05$.

The logistic regression analysis revealed that the odds of being diagnosed with ADHD vary significantly among different employment sectors. The regression equation showed that three employment sectors had positive coefficients, indicating higher odds of self-reported ADHD diagnosis compared to the reference sector (Education). The Binary

Logistic Regression Coefficients are shown below:

Table 180: $H_{2.2}$ Binary Logistic Regression Coefficients

Term	Coef	SE Coef	95% CI	Z-Value	P-Value
Constant	-2.303	0.605	(-3.489, -1.116)	-3.80	0.000
Employment Sector					
Manufacturing	1.331	0.682	(-0.006, 2.667)	1.95	0.051
Government	1.455	0.918	(-0.344, 3.255)	1.59	0.113
Healthcare	2.102	0.754	(0.624, 3.580)	2.79	0.005
Retail	3.56	1.00	(1.59, 5.52)	3.54	0.000
Transportation and Warehousing	1.05	1.00	(-0.92, 3.02)	1.04	0.296
Other	0.953	0.676	(-0.372, 2.277)	1.41	0.159

The model's coefficients indicated that individuals in the Manufacturing (Coef = 1.331, p = 0.051), Healthcare (Coef = 2.102, p = 0.005), and Retail (Coef = 3.56, p<0.0001) sectors had significantly increased odds of being diagnosed with ADHD compared to the Education sector. All other sectors showed positive associations, though they were not statistically significant.

The model explains between 6.64% and 9.25% of the variance in self-reported ADHD diagnosis, indicating modest explanatory power. Goodness-of-fit tests show an acceptable fit:

- Hosmer-Lemeshow Test: A perfect fit with a p-value of 1.000.
- Pearson and Deviance Tests: Both suggest acceptable fit with p-values of 0.350 and 0.218, respectively.
- The Wald test results also support the model's significance in predicting self-reported ADHD diagnosis based on the employment sector (p = 0.009).

Odds ratios provide clearer insights into the strength of associations:

- Retail workers are 35 times more likely to be diagnosed with ADHD compared to those in Education, and 9.25 times more than Manufacturing.
- Healthcare employees have odds 8.18 times greater than Education workers.
- Other notable comparisons include Retail relative to Government, with an odds ratio of 8.17, indicating significantly higher risk.
- Manufacturing workers are 3.78 times more likely to be diagnosed with ADHD compared to those in Education, approaching significance with a confidence interval of (0.9943, 14.3996).

The full table of Odds Ratios from the Binary Logistic Regression are shown below.

Table 181: $H_{2.2}$ Binary Logistic Regression Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
Employment Sector			
Manufacturing	Education	3.7838	(0.9943, 14.3996)
Government	Education	4.2857	(0.7090, 25.9071)
Healthcare	Education	8.1818	(1.8665, 35.8647)
Retail	Education	35.0000	(4.8852, 250.7549)
Transportation and Warehousing	Education	2.8571	(0.3988, 20.4698)
Other	Education	2.5926	(0.6897, 9.7459)
Government	Manufacturing	1.1327	(0.2564, 5.0044)
Healthcare	Manufacturing	2.1623	(0.7385, 6.3316)
Retail	Manufacturing	9.2500	(1.7110, 50.0060)
Transportation and Warehousing	Manufacturing	0.7551	(0.1397, 4.0821)
Other	Manufacturing	0.6852	(0.2926, 1.6043)
Healthcare	Government	1.9091	(0.3800, 9.5901)
Retail	Government	8.1667	(1.0271, 64.9364)
Transportation and Warehousing	Government	0.6667	(0.0838, 5.3009)
Other	Government	0.6049	(0.1384, 2.6435)
Retail	Healthcare	4.2778	(0.7060, 25.9190)
Transportation and Warehousing	Healthcare	0.3492	(0.0576, 2.1158)
Other	Healthcare	0.3169	(0.1099, 0.9137)
Transportation and Warehousing	Retail	0.0816	(0.0088, 0.7534)
Other	Retail	0.0741	(0.0138, 0.3966)
Other	Transportation and Warehousing	0.9074	(0.1695, 4.8581)

Odds ratio for level A relative to level B

The analysis indicates that the employment sector is possibly an important factor in the likelihood of an ADHD diagnosis, with sectors like Retail and Healthcare showing a significantly higher likelihood of self-reported ADHD diagnosis. It is unknown why certain sectors might have a higher prevalence of self-reported ADHD diagnosis. Due to the small sample sizes for some sectors, it is advised to note confidence intervals when interpreting these results. This information could guide the development of tailored workplace policies or health interventions aimed at sectors with elevated ADHD diagnosis rates. The hypothesis that the odds of being diagnosed with ADHD among adults do not vary significantly between different employment sectors is not supported by the data.

Hypothesis 2.3: The odds of being undiagnosed with ADHD and having significant ADHD symptomology among adults varies significantly between different employment sectors.

To investigate Hypothesis 2.3, which posits that the odds of being undiagnosed with ADHD among adults vary significantly between different employment sectors, a binary logistic regression analysis was conducted. The analysis included adults from various employment sectors, coded as follows: 1 (Manufacturing), 2 (Education), 3 (Government), 4 (Healthcare), 5 (Retail), 6 (Transportation and Warehousing), and 11 (Other). The sample consisted of 200 adults, with 34 participants reporting ASRS6 Level three symptoms (high level) but not indicating ADHD diagnosis (event) and 166 with ASRS6 Levels one or two (low or medium symptom level). The original sample included groups 7 (Accommodation and Food Services), 8 (Construction), 9 (Arts, Entertainment, and Recreation), and 10 (Mining) but were recoded to group 11 "Other" due to errors that caused a "quasi-complete separation of data points" issue due to the small sample size of suspected undiagnosed participants these groups, both having zero participants with ADHD diagnoses. The "undiagnosed" metric was calculated by coding participants with four or more ASRS6 symptoms who did not report an ADHD medical diagnosis.

A binary logistic regression model with a logit link function was used to assess the relationship between undiagnosed ADHD and the employment sector. The model was coded using categorical predictor coding (1, 0) and excluded interaction terms that could not be estimated. The significance level for the analysis was set at $\alpha = 0.05$.

The logistic regression analysis revealed that the odds of being undiagnosed with ADHD vary significantly between different employment sectors. The regression equation showed that several employment sectors had negative coefficients, indicating lower odds of undiagnosed ADHD compared to the reference sector (Manufacturing). Also, several employment factors had positive coefficients, indicating higher odds of undiagnosed ADHD compared to the reference sector. The table of coefficients is shown below.

Table 182: H2.3 Binary Logistic Regression: Coefficients

Term	Coef	SE Coef	95% CI	Z-Value	P-Value
Constant	-2.015	0.435	(-2.867, -1.163)	-4.64	0.000
Employment Sector					

Education	1.034	0.585	(-0.112, 2.180)	1.77	0.077
Government	1.609	0.778	(0.084, 3.135)	2.07	0.039
Healthcare	-0.182	0.863	(-1.873, 1.509)	-0.21	0.833
Retail	-0.06	1.15	(-2.31, 2.18)	-0.06	0.955
Transportation and Warehousing	1.792	0.799	(0.225, 3.358)	2.24	0.025
Other	-0.000	0.575	(-1.127, 1.127)	-0.00	1.000

The coefficients indicate the change in log odds of having undiagnosed ADHD relative to the baseline employment sector (Manufacturing). Significant predictors include Government (Coef = 1.609, p = 0.039) and Transportation and Warehousing (Coef = 1.792, p = 0.025), suggesting these sectors are associated with higher odds of undiagnosed ADHD compared to Manufacturing. Approaching significance was the Education sector (Coef = 1.034, p = 0.077), also indicating a positive coefficient. The odds ratios for the categorical predictors are shown below.

Table 183: H2.3 Binary Logistic Regression: Odds Ratios for Categorical Predictors

Level A	Level B	Odds Ratio	95% CI
Employment Sector			
Education	Manufacturing	2.8125	(0.8944, 8.8437)
Government	Manufacturing	5.0000	(1.0879, 22.9801)
Healthcare	Manufacturing	0.8333	(0.1536, 4.5206)
Retail	Manufacturing	0.9375	(0.0992, 8.8642)
Transportation and Warehousing	Manufacturing	6.0000	(1.2525, 28.7421)
Other	Manufacturing	1.0000	(0.3241, 3.0859)
Government	Education	1.7778	(0.4051, 7.8020)
Healthcare	Education	0.2963	(0.0569, 1.5420)
Retail	Education	0.3333	(0.0364, 3.0552)
Transportation and Warehousing	Education	2.1333	(0.4658, 9.7706)
Other	Education	0.3556	(0.1228, 1.0299)
Healthcare	Government	0.1667	(0.0241, 1.1511)
Retail	Government	0.1875	(0.0164, 2.1373)
Transportation and Warehousing	Government	1.2000	(0.1935, 7.4406)
Other	Government	0.2000	(0.0462, 0.8651)
Retail	Healthcare	1.1250	(0.0887, 14.2748)
Transportation and Warehousing	Healthcare	7.2000	(1.0088, 51.3874)
Other	Healthcare	1.2000	(0.2336, 6.1643)
Transportation and Warehousing	Retail	6.4000	(0.5470, 74.8878)
Other	Retail	1.0667	(0.1175, 9.6828)
Other	Transportation and Warehousing	0.1667	(0.0369, 0.7526)

Odds ratio for level A relative to level B

The model's fit was assessed using the deviance R-squared (6.78%), adjusted R-squared (3.49%), and various goodness-of-fit tests:

- Hosmer-Lemeshow Test: A perfect fit with a p-value of 1.000.
- Deviance and Pearson Tests: Indicated a good model fit with p-values of 0.882 and 0.350, respectively.
- The Wald test for the overall regression model showed significance ($p = 0.048$), confirming the importance of employment sector in predicting undiagnosed ADHD.

Odds ratios at the significant level demonstrated varied risks across sectors:

- Individuals in Transportation and Warehousing are six times more likely to have undiagnosed ADHD than those in Manufacturing.
- The odds for Government sector workers are five times that of Manufacturing workers.
- Transportation and Warehousing showed a 7.2-fold increase over Healthcare sector.
- Government and Transportation and Warehousing both showed a decrease in odds of undiagnosed ADHD compared to all Others, with OR 0.2 and 0.17, respectively.

The analysis suggests that employment sector significantly impacts the likelihood of having undiagnosed ADHD symptoms, with sectors like Government and Transportation and Warehousing showing higher odds. These findings could inform targeted interventions or further investigations into workplace environments conducive to undiagnosed symptoms of ADHD. While the model provides a basic understanding, the modest explanatory power indicates the need for incorporating more factors or larger datasets to better study potential trends.

The results of this analysis support the hypothesis that there are differences between employment sectors in the odds of being undiagnosed with ADHD. The analysis provides substantial evidence that the odds of being undiagnosed with ADHD among adults vary significantly between different employment sectors.

5.6.3.3 Impact on Self-Efficacy and Social Anxiety

The pie charts above display the differences in reported General Perceived Self-Efficacy Scale (GPSES) scores and ADHD diagnoses for all participants in the High-Quality dataset. Notably, the non-ADHD group lacks participants with "Low Self-Efficacy." In contrast, the "Mild" and "Moderate" self-efficacy groups are larger, reducing the highest self-efficacy group among those diagnosed with ADHD. This section examines these differences using statistical hypothesis testing.

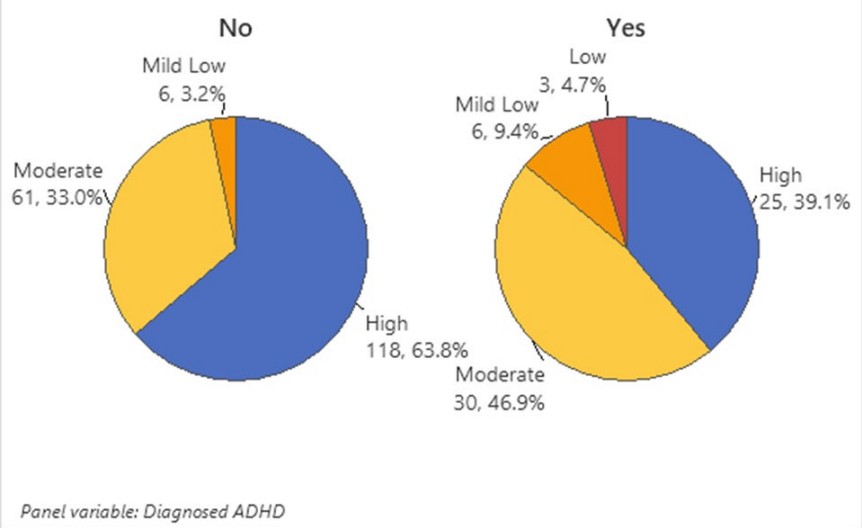


Figure 115: Pie Chart of GPSES (Self-Efficacy) Classification by Self-Reported ADHD Diagnosis

This section explores the relationship between ADHD and social anxiety, measured by the Liebowitz Social Anxiety Scale (LSAS). The pie charts below compare LSAS scores with ADHD diagnoses. For participants with ADHD, there is an increased percentage in the "Very Severe Social Anxiety" category and an absence of the "No Social Anxiety" category.

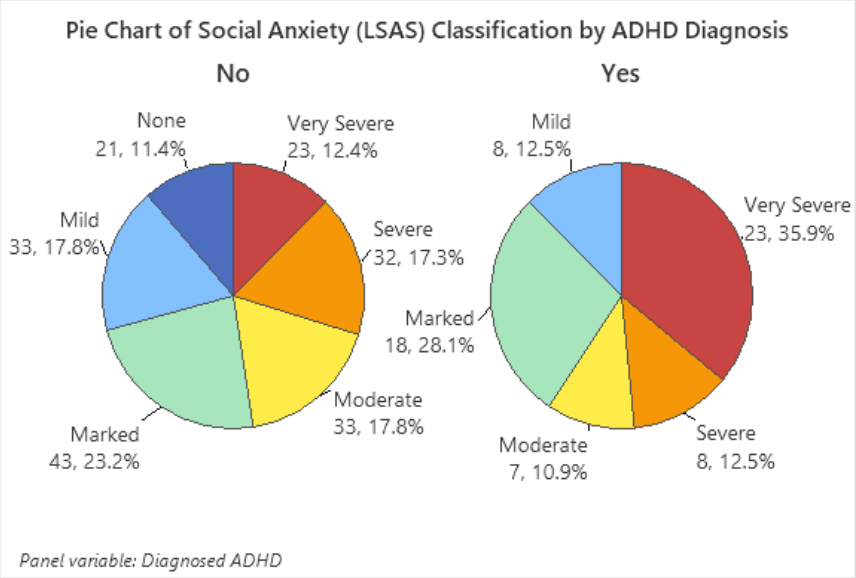


Figure 116: Pie Chart of LSAS (Social Anxiety) Classification by Self-Reported ADHD Diagnosis

The section also investigates the connections between reported ADHD symptoms and levels of self-efficacy and social anxiety. The pie charts show the scales compared to

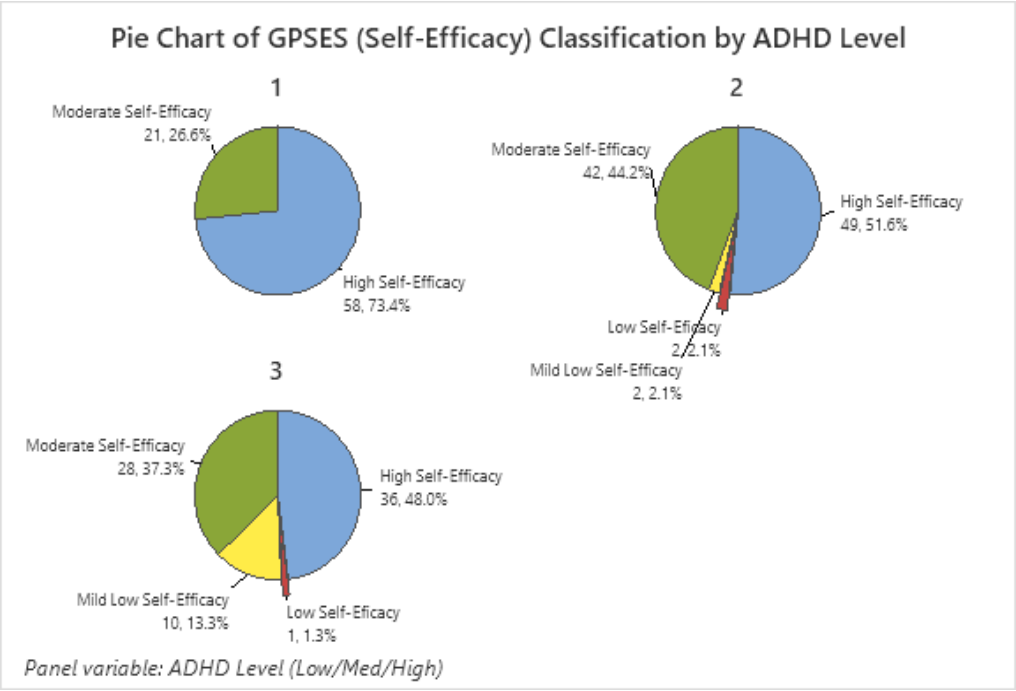


Figure 117: Pie Chart of GPSES (Self-Efficacy) Classification by ADHD Level

three levels of ADHD symptoms: Low (0-1 significant symptoms, unlikely ADHD), Medium (2-3 significant symptoms, possibly ADHD), and High (4-6 significant symptoms, probably ADHD).

Noteworthy in the GPSES pie charts, the most severe two levels of Self-Efficacy do not have participants for the ADHD Low group. ADHD High group has the largest proportion of the most severe self-efficacy deficiencies. The Mild Low Self-Efficacy sector increases over six-fold between levels 2 (Medium) and 3 (High).

The LSAS pie charts by ADHD level reveal interesting trends. The "Very Severe Social Anxiety" category is present at a small percentage (3.8%) in the lowest ADHD symptom level. Still, it increases almost fivefold between ADHD Levels 1 and 2 and nearly twofold between Levels 2 and 3. The "No Social Anxiety" category disappears completely at ADHD Level 3. These trends are illustrated in the pie charts below. Statistical significance is tested in the hypothesis testing section that follows this summary.

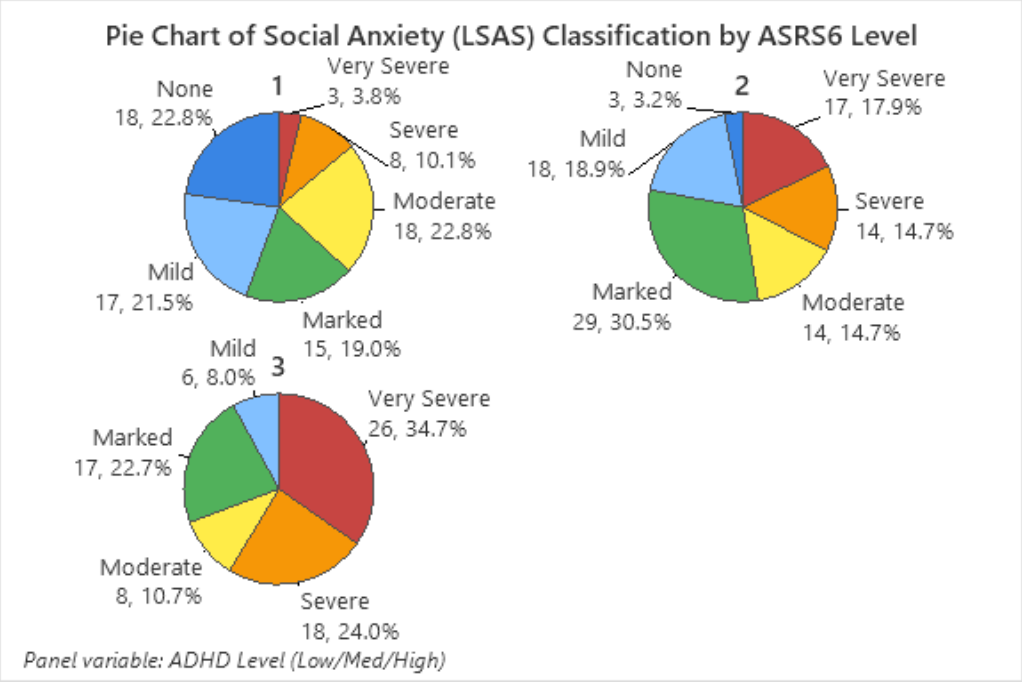


Figure 118: Pie Chart of LSAS (Social Anxiety) Classification by ADHD Level

Table 184: H3.1 Descriptive Statistics for GPSES and LSAS vs. self-reported ADHD

Diagnosis

	No ADHD Diagnosis N = 185				ADHD Diagnosis N = 64				p-value
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	
GPSES Point Total	16.32	2.71	7	20	14.53	3.92	5	20	0.000
LSAS Point Total	22.06	9.22	4	49	27.61	9.13	11	48	0.000

Table 185: GPSES vs Self-Reported ADHD Diagnosis: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Diagnosed ADHD	1	1921	12.16%	1921	1920.86	236.35	0.000
Error	1708	13881	87.84%	13881	8.13		
Total	1709	15802	100.00%				

Table 186: LSAS vs Self-Reported ADHD Diagnosis: Analysis of Variance

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Diagnosed ADHD	1	6598	8.39%	6598	6597.55	156.42	0.000
Error	1708	72041	91.61%	72041	42.18		
Total	1709	78639	100.00%				

Hypothesis 3.2: There is a significant difference in the means of self-efficacy and social anxiety levels depending on the ADHD symptoms level.

To investigate this hypothesis, each of the scales was tested against the ASRS6 Symptom Level factor in one-way ANOVAs. The descriptive statistics and results are shown in the table below. Both factors were found to be statistically different between the ASRS6 Symptom levels.

Table 187: H3.2 Descriptive Statistics for GPSES and LSAS vs. ASRS6 Symptom Level

		GPSES (p<0.001)				LSAS (p<0.001)			
ASRS6 Symptoms	N	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
0	41	17.44	1.99	13	20	16.15	7.40	4	32
1	38	16.74	1.97	12	20	19.45	8.47	4	44
2	46	15.41	3.22	5	20	24.09	9.55	8	45
3	49	15.82	2.71	7	20	24.45	7.74	10	41

		GPSES (p<0.001)				LSAS (p<0.001)			
ASRS6 Symptoms	N	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max
4	41	15.05	3.78	5	20	27.29	7.08	13	42
5	19	15.47	3.32	7	20	26.00	8.55	11	44
6	15	13.60	4.93	7	20	35.27	10.40	17	49

The ANOVA results and Tukey analysis results for both metrics are shown below.

Table 188: LSAS Point Total vs ASRS6 Symptoms Analysis of Variance Results and Grouping Information Using the Tukey Method and 95% Confidence

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ASRS6 Symptoms	6	5687	947.75	13.76	0.000
Error	242	16668	68.87		
Total	248	22354			

ASRS6 Symptoms	N	Mean	Grouping		
6	15	35.27	A		
4	41	27.29		B	
5	19	26.00		B	C
3	49	24.45		B	C
2	46	24.09		B	C
1	38	19.45			C D
0	41	16.15			D

Means that do not share a letter are significantly different.

Table 189: GPSES Point Total vs ASRS6 Symptoms Analysis of Variance Results and Grouping Information Using the Tukey Method and 95% Confidence

Source	DF	Adj SS	Adj MS	F-Value	P-Value
ASRS6 Symptoms	6	247.2	41.192	4.47	0.000
Error	242	2230.2	9.216		
Total	248	2477.4			

ASRS6 Symptoms	N	Mean	Grouping		
0	41	17.439	A		
1	38	16.737	A	B	
3	49	15.816	A	B	C
5	19	15.474	A	B	C
2	46	15.413		B	C
4	41	15.049		B	C
6	15	13.60			C

Means that do not share a letter are significantly different.

The analysis demonstrated significant differences (p<0.001) in both self-efficacy

and social anxiety levels between adults with various levels of ADHD Symptoms, thus supporting the hypothesis that there is a significant difference in the means of self-efficacy and social anxiety levels depending on the ADHD symptoms level. Specifically, individuals with a higher number of ADHD symptoms reported higher levels of social anxiety and lower self-efficacy compared to those with fewer ADHD symptoms.

Hypothesis 3.3: Self-efficacy and social anxiety scales predict the probability of an ADHD diagnosis.

Hypothesis 3.3a: Self-efficacy (GPSES) scale predicts the probability of an ADHD diagnosis.

Failed to Reject - Hypothesis 3.3b: Social anxiety (LSAS) scale predicts the probability of an ADHD diagnosis

To test the hypothesis that self-efficacy (measured by GPSES) and social anxiety (measured by LSAS) predict the probability of a self-reported ADHD diagnosis, a binary logistic regression was performed. In Minitab, use the following menus (Stat>Regression>Binary Logistic Regression>Fit Binary Logistic Model). The response variable was whether the participant was diagnosed with ADHD (Yes or No), and the predictor variables were the LSAS point total and the GPSES point total.

The regression equation used to predict the probability of a self-reported ADHD diagnosis was:

Equation 2: $H_{3.3}$ Binary Logistic Regression Equation

$$P(\text{Yes}) = \exp(Y')/(1 + \exp(Y'))$$
$$Y' = -0.61 + 0.0431 \text{ LSAS Point Total} - 0.0979 \text{ GPSES Point Total}$$

Table 190: Coefficients for the LSAS and GPSES point totals

Term	Coef	SE Coef	Z-Value	P-Value	VIF
Constant	-0.61	1.24	-0.49	0.623	
LSAS Point Total	0.0431	0.0199	2.17	0.030	1.48
GPSES Point Total	-0.0979	0.0564	-1.73	0.083	1.48

Table 191: Odds Ratios for Continuous Predictors of LSAS and GPSES for ADHD Diagnosis

	Odds Ratio	95% CI
LSAS Point Total	1.0441	(1.0042, 1.0856)
GPSES Point Total	0.9068	(0.8118, 1.0128)

The results suggest that while the overall model is significant, indicating that the predictors as a group are related to the probability of a self-reported ADHD diagnosis, only the LSAS point total is a significant individual predictor. The positive coefficient for LSAS point total indicates that higher social anxiety scores increase the likelihood of a self-reported ADHD diagnosis. The odds ratio of 1.0441 means that for each one-point increase in LSAS point total, the odds of being diagnosed with ADHD increase by approximately 4.41%.

Conversely, the GPSES point total has a negative coefficient, suggesting that higher self-efficacy scores are associated with a lower likelihood of a self-reported ADHD diagnosis. However, this relationship is not statistically significant at the 0.05 level, with a p-value of 0.083.

The binary logistic regression analysis provides partial support for the hypothesis that self-efficacy and social anxiety scales predict the probability of a self-reported ADHD diagnosis. Social anxiety, as measured by LSAS, is a significant predictor, indicating that higher levels of social anxiety increase the likelihood of a self-reported ADHD diagnosis. Self-efficacy, as measured by GPSES, shows a trend towards significance, suggesting possibly that lower self-efficacy may be associated with higher self-reported ADHD diagnosis probability. Still, this relationship is not statistically significant in this analysis. Thus, the hypothesis that self-efficacy and social anxiety scales predict the probability of a self-reported ADHD diagnosis is rejected, as *only* the social anxiety scale showed a significant prediction probability.

Hypothesis 3.4: There is no interaction effect between ADHD symptoms and the employment sector on the means of self-efficacy and social anxiety levels.

To test this hypothesis, two General Linear Model (GLM) analyses were conducted: one for the LSAS (social anxiety) point total and one for the GPSES (self-efficacy) point total, considering the employment sector and ADHD symptoms as factors and their interactions.

LSAS Point Total Analysis

A General Linear Model (GLM) was applied to the LSAS point total, with the employment sector and ASRS6 symptoms as fixed factors. The interaction term between the employment sector and ASRS6 symptoms could not be estimated and was removed from the model.

Table 192: H3.4 LSAS General Linear Model Results: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Employment Sector	10	1801	180.13	2.89	0.002
ADHD6 Symptoms	6	4204	700.59	11.25	0.000
Error	183	11400	62.30		
Lack-of-Fit	41	2644	64.50	1.05	0.411
Pure Error	142	8756	61.66		
Total	199	18265			

Table 193: H3.4 LSAS General Linear Model Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	13.82	1.74	7.95	0.000	
Employment Sector					
Accommodation and Food Services	1.99	3.23	0.62	0.539	1.13
Arts, Entertainment, and Recreation	-2.69	3.43	-0.78	0.434	1.10
Construction	-1.08	3.21	-0.34	0.736	1.12
Education	3.76	1.81	2.08	0.039	1.44
Government	1.43	2.82	0.51	0.612	1.21
Healthcare	7.53	2.14	3.51	0.001	1.33
Manufacturing	0.42	1.66	0.25	0.802	1.67
Mining	-0.82	8.08	-0.10	0.919	1.04
Retail	10.03	2.91	3.45	0.001	1.17
Transportation and Warehousing	0.78	2.94	0.26	0.792	1.19
ADHD6 Symptoms					
1	3.38	1.95	1.73	0.085	1.64
2	6.33	1.91	3.31	0.001	1.80
3	9.02	1.88	4.79	0.000	1.85
4	12.45	2.06	6.04	0.000	1.74
5	9.20	2.55	3.60	0.000	1.36
6	18.75	2.99	6.27	0.000	1.23

The analysis included 199 observations and excluded 50 rows of participants who did not have current jobs; thus, there was no sector to report. The analysis of variance (ANOVA) revealed significant effects for both employment sectors ($p = 0.002$) and ASRS6 symptoms ($p < 0.001$). The model summary showed an R-squared value of 37.58%, indicating that the model explains 37.58% of the variance in the LSAS point total.

The coefficients revealed that several employment sectors showed significant effects, notably Healthcare (Coef = 7.53, p = 0.001) and Retail (Coef = 10.03, p = 0.001). ASRS6 symptoms also showed significant effects, particularly at higher levels of symptoms (e.g., ASRS6 Symptoms_6: Coef = 18.75, p < 0.001). Positive higher coefficients indicated increased social anxiety for these significant outcome sectors and symptom levels.

GPSES Point Total Analysis

A General Linear Model (GLM) was applied to the GPSES point total, with the employment sector and ASRS6 symptoms as fixed factors. Similar to the LSAS analysis, the interaction term between the employment sector and ASRS6 symptoms could not be estimated and was removed from the model.

Table 194: H3.4 GPSES General Linear Model Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Employment Sector	10	244.8	24.483	2.79	0.003
ADHD6 Symptoms	6	164.1	27.357	3.12	0.006
Error	183	1604.6	8.768		
Lack-of-Fit	41	371.4	9.058	1.04	0.415
Pure Error	142	1233.3	8.685		
Total	199	2051.7			

Table 195: GPSES General Linear Model Analysis of Variance Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	17.720	0.652	27.16	0.000	
Employment Sector					
Accommodation and Food Services	1.31	1.21	1.08	0.283	1.13
Arts, Entertainment, and Recreation	-0.01	1.29	-0.01	0.991	1.10
Construction	1.16	1.21	0.96	0.338	1.12
Education	-0.646	0.678	-0.95	0.342	1.44
Government	0.88	1.06	0.83	0.409	1.21
Healthcare	-2.719	0.804	-3.38	0.001	1.33
Manufacturing	-0.061	0.621	-0.10	0.922	1.67
Mining	2.28	3.03	0.75	0.453	1.04
Retail	-3.04	1.09	-2.78	0.006	1.17
Transportation and Warehousing	0.05	1.10	0.05	0.962	1.19
ADHD6 Symptoms					
1	-0.518	0.732	-0.71	0.480	1.64
2	-1.384	0.716	-1.93	0.055	1.80
3	-1.850	0.706	-2.62	0.010	1.85

4	-2.634	0.774	-3.41	0.001	1.74
5	-1.500	0.958	-1.57	0.119	1.36
6	-3.29	1.12	-2.93	0.004	1.23

The analysis of variance (ANOVA) revealed significant effects for both the employment sector ($p = 0.003$) and ASRS6 symptoms ($p = 0.006$). The model summary showed an R-squared value of 21.79%, indicating that the model explains 21.79% of the variance in the GPSES point total.

The coefficients showed that significant effects were observed for certain employment sectors, such as Healthcare (Coef = -2.719, $p = 0.001$) and Retail (Coef = -3.04, $p = 0.006$). ASRS6 symptom levels three and above showed significant negative effects, indicating lower self-efficacy with higher ADHD symptom levels (e.g., ASRS6 Symptoms_6: Coef = -3.29, $p = 0.004$).

The analyses indicated that both employment sector and ADHD6 symptoms are significant predictors of self-efficacy (GPSES) and social anxiety (LSAS) levels. However, the interaction term between the employment sector and ADHD6 symptoms was not estimable and thus removed from the models, suggesting that no significant interaction effect could be assessed. This indicates that while both factors independently influence self-efficacy and social anxiety, their combined interaction does not have a measurable additional impact. Therefore, these results partially support Hypothesis 3.3 by showing that there is no significant interaction effect between ADHD symptoms and the employment sector on the means of self-efficacy and social anxiety levels. Both factors independently contribute to variations in these psychological outcomes, but their interaction does not significantly alter the effects.

Hypothesis 3.5: The relationship between self-efficacy, social anxiety, and ADHD symptom reporting differs significantly between the manufacturing sector and other employment sectors.

To test this hypothesis, two General Linear Model (GLM) analyses were conducted, one for the GPSES (self-efficacy) point total and one for the LSAS (social anxiety) point total. The variable “Recoded Employment Sector” was used to distinguish between “Manufacturing” and “Other” sectors – the employment sector was recoded to

separate manufacturing from all other sectors.

LSAS Point Total Analysis

A General Linear Model (GLM) was applied to the LSAS point total, with recoded employment sector and ASRS6 symptoms as fixed factors. The interaction term between the recoded employment sector and ASRS6 symptoms was included. The analysis included 199 observations and excluded 50 rows because not all subjects were employed. The analysis of variance (ANOVA) revealed significant effects for both the recoded employment sector ($p = 0.035$) and ASRS6 symptoms ($p < 0.001$), but the interaction term was not significant ($p = 0.431$). The model summary showed an R-squared value of 30.84%, indicating that the model explains 30.84% of the variance in LSAS point total.

Table 196: LSAS General Linear Model: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Recoded Employment Sector	1	307.1	307.05	4.52	0.035
ASRS6 Symptoms	6	2216.3	369.38	5.44	0.000
Recoded Employment Sector*ASRS6 Symptoms	6	404.8	67.46	0.99	0.431
Error	186	12632.3	67.92		
Total	199	18265.0			

Table 197: LSAS General Linear Model: Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	11.93	2.13	5.61	0.000	
Recoded Employment Sector					
Other	5.92	2.79	2.13	0.035	4.34
ADHD6 Symptoms					
1	6.45	3.12	2.07	0.040	3.86
2	7.07	4.26	1.66	0.098	8.21
3	15.73	3.98	3.95	0.000	7.61
4	17.82	4.64	3.84	0.000	8.08
5	10.87	4.26	2.55	0.011	3.47
6	20.07	5.21	3.85	0.000	3.44
Recoded Employment Sector*ADHD6 Symptoms					
Other 1	-5.26	4.07	-1.29	0.198	4.19
Other 2	-1.83	4.84	-0.38	0.705	9.50
Other 3	-9.48	4.58	-2.07	0.040	8.94
Other 4	-7.48	5.23	-1.43	0.154	9.11
Other 5	-1.28	5.38	-0.24	0.812	3.66
Other 6	-1.26	6.46	-0.19	0.846	3.58

The coefficients showed that the “Other” employment sector had a significant positive effect on the LSAS point total (Coef = 5.92, $p = 0.035$). Among the ASRS6

symptoms, levels 1, 3, 4, 5, and 6 showed significant positive effects, with the highest level (ASRS6 Symptoms_6) having the largest effect (Coef = 20.07, $p < 0.001$). The interaction terms were generally non-significant, with only one term (Other 3) showing a significant negative effect (Coef = -9.48, $p = 0.040$).

GPSES Point Total Analysis

The same analysis was applied to the GPSES point total. The analysis of variance (ANOVA) revealed that neither the recoded employment sector ($p = 0.463$) nor the interaction between the recoded employment sector and ASRS6 symptoms ($p = 0.548$) was significant. However, the ASRS6 symptoms was approaching significance ($p = 0.056$). The model summary showed an R-squared value of 12.53%, indicating that the model explains 12.53% of the variance in the GPSES point total.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Recoded Employment Sector	1	5.21	5.207	0.54	0.463
ADHD6 Symptoms	6	121.41	20.235	2.10	0.056
Recoded Employment Sector*ADHD6 Symptoms	6	48.03	8.005	0.83	0.548
Error	186	1794.68	9.649		
Total	199	2051.68			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	17.867	0.802	22.28	0.000	
Recoded Employment Sector					
Other	-0.77	1.05	-0.73	0.463	4.34
ADHD6 Symptoms					
1	-0.33	1.18	-0.28	0.781	3.86
2	-1.87	1.60	-1.16	0.246	8.21
3	-1.53	1.50	-1.02	0.308	7.61
4	-5.62	1.75	-3.21	0.002	8.08
5	-2.07	1.60	-1.29	0.199	3.47
6	-2.53	1.96	-1.29	0.199	3.44
Recoded Employment Sector*ADHD6 Symptoms					
Other 1	-0.19	1.53	-0.12	0.903	4.19
Other 2	0.44	1.82	0.24	0.810	9.50
Other 3	-0.10	1.73	-0.06	0.952	8.94
Other 4	3.64	1.97	1.84	0.067	9.11
Other 5	0.53	2.03	0.26	0.795	3.66
Other 6	-1.40	2.43	-0.57	0.567	3.58

The coefficients revealed that none of the employment sectors had significant effects on the GPSES point total. Among the ASRS6 symptoms, only level 4 showed a significant negative effect (Coef = -5.62, $p = 0.002$). The interaction terms were all non-significant.

The analyses indicated that the relationship between self-efficacy and anxiety with self-reported ADHD symptom (ASRS6) does not differ significantly between the manufacturing sector and other employment sectors. The recoded employment sector did not show significant interaction effects with ASRS6 symptoms on either GPSES or LSAS point totals. However, there were significant independent effects of the employment sector and ASRS6 symptoms on LSAS point totals, suggesting that while the sectors themselves and the symptom levels influence social anxiety, their interaction does not.

These results support Hypothesis 3.5 by demonstrating that there is no significant interaction effect between ADHD symptoms and the employment sector on the means of self-efficacy and social anxiety levels. Both factors independently contribute to variations in these psychological outcomes, but their combined interaction does not significantly alter the effects.

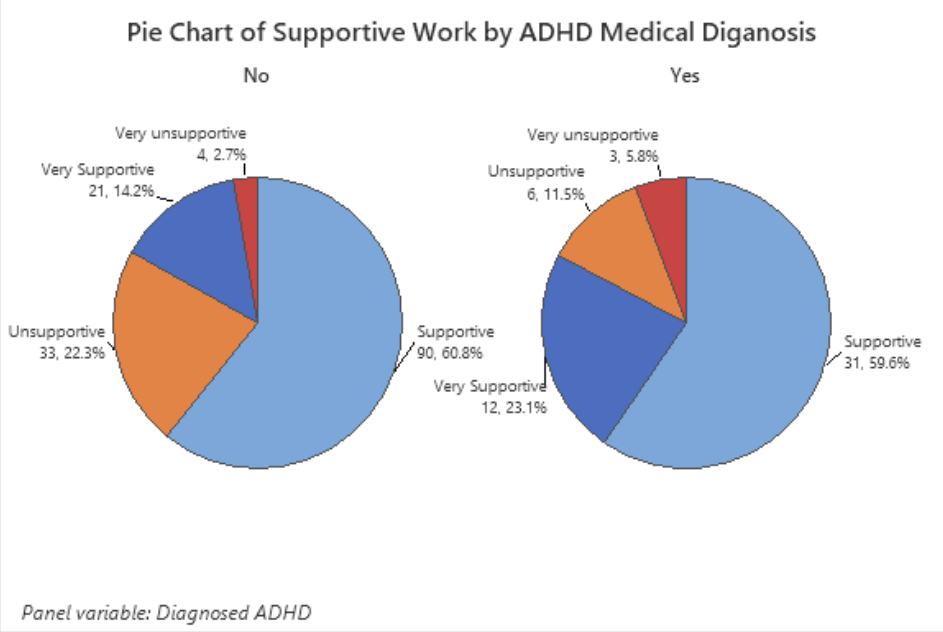
5.6.3.4 Satisfaction with Workplace Support Systems

Questions in the survey that evaluate subject satisfaction with the workplace support systems were presented in two ways. Question 14 asked: "How would you rate the overall work environment in terms of supporting employees with ADHD or anxiety issues?" giving a four-part Likert scale answer option: Very Supportive, Supportive, Unsupportive, and Very Unsupportive. Additionally, question 16 asked: "Do you feel that your workplace provides effective support for managing stress and anxiety?" giving a five-part Likert scale answer option: not effective at all, slightly effective, moderately effective, very effective, and extremely effective. Question 14 is referred to as "Supportive Work" as a variable in the following section, and Question 16 responses are referred to as "Effective Support."

Hypothesis 4.1: Adults with an ADHD diagnosis self-report lower satisfaction with workplace support systems compared to those without a self-reported ADHD diagnosis.

Adults taking the survey were asked two questions assessing their feelings on the supportiveness and effectiveness of workplace support systems. Each of these questions

is evaluated to determine the significance of this hypothesis. Percentages of the responses for each question divided by self-reported ADHD Diagnosis are given in the figures below.



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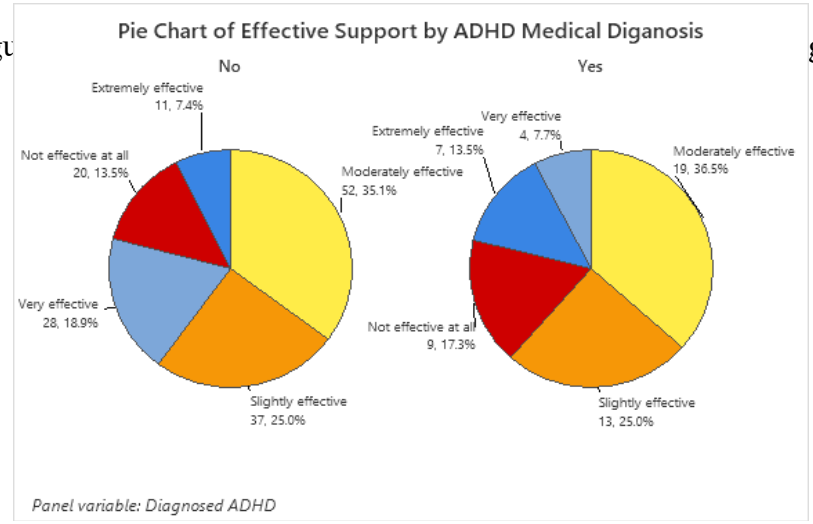

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Figure 119: Pie Chart of Effective Support by Self-Reported ADHD Medical Diagnosis

Table 198: $H_{4.3}$ Hypothesis Test Results- Self-Reported ADHD Diagnosis

	Medical ADHD Diagnosis – Yes N = 64				Medical ADHD Diagnosis – No N = 185				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Q14: Workplace Support Satisfaction	2.0	0.77	1	4	2.14	0.68	1	4	0.132	2 sample t-test

	Medical ADHD Diagnosis – Yes N = 64				Medical ADHD Diagnosis – No N = 185				Statistical Test two-tailed α = 0.05	
Metric	Mean	St. Dev	Min	Max	Mean	St. Dev	Min	Max	p-value	Type of Test
Q16: Effective Support of Systems	2.74	1.23	1	5	2.82	1.12	1	5	0.729	2 sample t-test

For the question on workplace support satisfaction (Q14), the two-sample t-test resulted in a p-value of 0.132, indicating that the difference in satisfaction between the two groups is not statistically significant at the 0.05 level. For the question on the effectiveness of support systems (Q16), the two-sample t-test resulted in a p-value of 0.729, indicating that the difference in perceived effectiveness between the two groups is not statistically significant.

The analysis indicates that there is no statistically significant difference in workplace support satisfaction or the perceived effectiveness of workplace support systems between adults with an self-reported ADHD diagnosis and those without; thus, the hypothesis is rejected. Both groups reported similar levels of satisfaction and effectiveness, leading to the conclusion that an self-reported ADHD diagnosis does not significantly impact these perceptions in the workplace.

Hypothesis 4.2: The impact of ADHD symptoms on satisfaction with workplace support systems (Q14) is more pronounced in the manufacturing sector compared to other sectors.

To test this hypothesis, a General Linear Model (GLM) analysis was conducted, examining one aspect of workplace support: its supportiveness. The data was divided into two categories: the manufacturing sector and all other sectors. ADHD symptoms were included as a continuous variable, with interaction terms between ADHD symptoms and the employment sector to assess their combined effect.

Supportive Workplace (Q14) Results

The analysis for the supportive workplace (where higher values indicate less supportiveness) showed that neither the recoded employment sector nor ADHD symptoms had significant effects. The interaction term between ADHD symptoms and the manufacturing sector was also not significant.

Table 199: General Linear Model: Supportive Workplace vs. Manufacturing Sector/Other and ASRS6 Symptoms Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Manufacturing/Other Sector	1	0.0960	0.09603	0.20	0.659
ASRS6 Symptoms	6	3.4529	0.57548	1.17	0.323
Manufacturing/Other Sector*ASRS6 Symptoms	6	2.1810	0.36349	0.74	0.618
Error	186	91.2807	0.49076		
Total	199	98.0000			

None of the coefficients for the interaction terms were significant, suggesting that the impact of ADHD symptoms on perceived workplace supportiveness does not differ significantly between the manufacturing sector and other sectors.

The analysis rejects Hypothesis 4.2, demonstrating that the general impact of ADHD symptoms on satisfaction with workplace support systems does not differ significantly across sectors. No significant, nor nearing significant, differences were found.

Hypothesis 4.3: The impact of ADHD symptoms on satisfaction with workplace support systems effectiveness perceptions (Q16) are more pronounced in the manufacturing sector compared to other sectors.

To test this hypothesis, a General Linear Model (GLM) analysis was conducted, examining one aspect of workplace support: its effectiveness (measured by Q16). The data were divided into two categories: the manufacturing sector and all other sectors. ADHD symptoms were included as a continuous variable, with interaction terms between ADHD symptoms and the employment sector to assess their combined effect.

Effective Support (Q16) Results

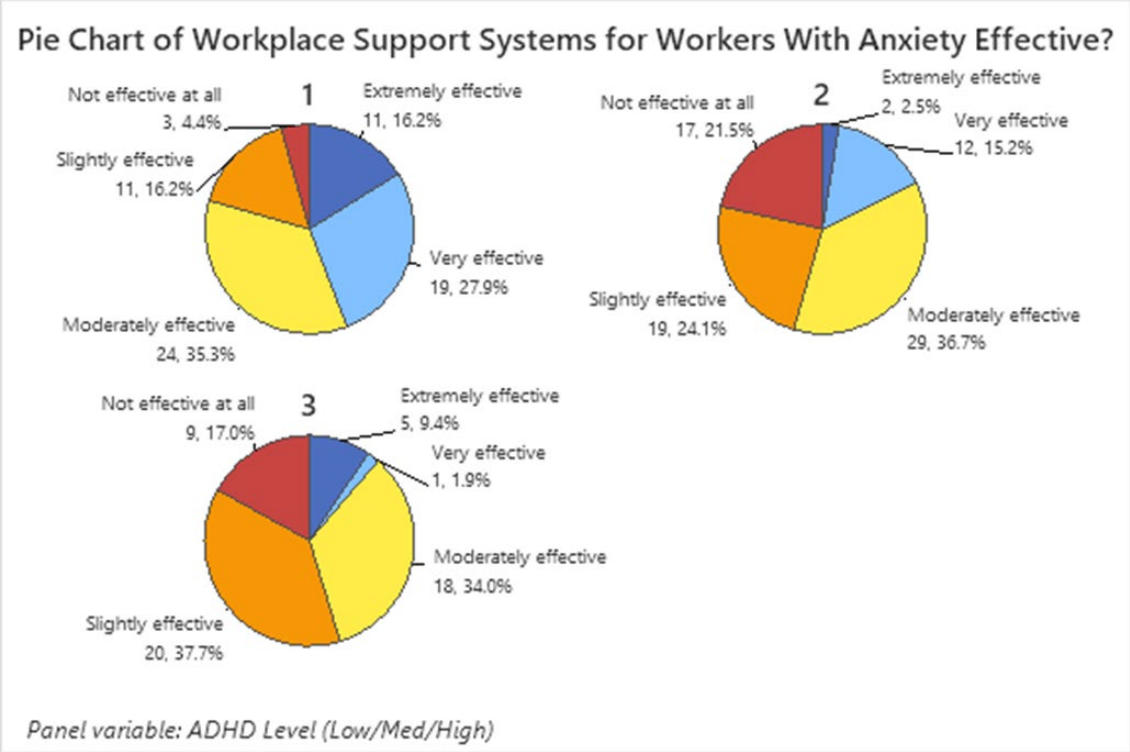

Figure 121: Pie Chart of Workplace Support Systems for Workers with Anxiety Effective? by ASRS6 Level

The analysis for effective support (where higher values indicate more effectiveness) revealed significant effects for both the recoded employment sector and ADHD symptoms. The interaction term between ADHD symptoms and the manufacturing sector approached significance.

Table 200: General Linear Model: Effective Support vs. Manufacturing Sector/Other and

ASRS6 Symptoms Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Manufacturing/Other Sector	1	9.257	9.257	8.05	0.005
ASRS6 Symptoms	6	16.808	2.801	2.43	0.027
Manufacturing/Other Sector*ASRS6 Symptoms	6	13.107	2.184	1.90	0.083
Error	186	214.008	1.151		
Total	199	262.000			

The Manufacturing/Other Sector variable had a significant positive coefficient (Coef = 1.029, p = 0.005), indicating higher satisfaction with support systems in the manufacturing sector. Several interaction terms between ADHD symptoms and the manufacturing sector were also significant. For example, the interaction term for ADHD symptom level 1 with the manufacturing sector was significantly negative (Coef = -1.271, p = 0.017), indicating that for individuals with low ADHD symptom levels, those in the manufacturing sector reported lower satisfaction compared to those in other sectors. Similarly, the interaction term for ADHD symptom level 6 was also significantly negative (Coef = -2.029, p = 0.017), suggesting that individuals with high ADHD symptom levels in the manufacturing sector reported significantly lower satisfaction.

Table 201: General Linear Model: Effective Support vs. Manufacturing Sector/Other and ASRS6 Symptoms Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	2.905	0.234	12.41	0.000	
Recoded Employment Sector					
Manufacturing	1.029	0.363	2.84	0.005	4.34
ADHD6 Symptoms					
1	0.569	0.340	1.68	0.096	2.69
2	-0.481	0.299	-1.60	0.110	2.40
3	-0.390	0.296	-1.32	0.189	2.48
4	-0.366	0.315	-1.16	0.246	2.20
5	-0.349	0.427	-0.82	0.415	2.07
6	-0.238	0.497	-0.48	0.632	1.84
Recoded Employment Sector*ADHD6 Symptoms					
Manufacturing 1	-1.271	0.530	-2.40	0.017	2.96
Manufacturing 2	-1.053	0.630	-1.67	0.096	1.68
Manufacturing 3	-0.210	0.597	-0.35	0.726	1.80
Manufacturing 4	-1.067	0.681	-1.57	0.119	1.58
Manufacturing 5	-1.184	0.700	-1.69	0.092	2.07
Manufacturing 6	-2.029	0.841	-2.41	0.017	1.82

Notably, all coefficients in the analysis (both ADHD Symptoms and Manufacturing Sector/ADHD Symptom interactions are all negative, many are statistically significant, and some approaching significance – with one exception, subjects

with only one ADHD symptom had a positive response to the effectiveness of systems in their workplace to manage stress and anxiety compared to those with zero symptoms.

The analysis supports Hypothesis 4.3, demonstrating that the effectiveness of workplace support systems is perceived differently in the manufacturing sector compared to other sectors. Specifically, the presence of ADHD symptoms significantly influences satisfaction levels in the manufacturing sector, with both low and high symptom levels negatively affecting perceived support effectiveness.

D.5 Qualitative Response Analysis

D.5.1 Everyday Stress and Anxiety Reduction Strategies

Since both the Failed Quality Check and High-Quality datasets were considered to be human responders, this Qualitative Response Analysis includes both data sets (N=442). Participants in the survey were asked which of the everyday stress and anxiety reduction activities they regularly use with "What strategies do you use to manage **everyday** stress or anxiety?". The list included: planning and organizational tools, taking regular breaks, seeking support from family and friends, professional counseling, physical activities, and other (please specify). The response to this question is summarized in the table below, showing the frequency of each provided response. The participants chose 2.31 different techniques from the list, on average.

Table 202: Frequency of Responses to Everyday Stress and Anxiety Reduction Activities

Theme	Frequency of Selection
Planning and Organizational tools	211
Taking regular breaks	237
Seek support from family and friends	259
Professional counseling	154
Physical activities	256
Other	31
None	2

The participants who chose “other” were asked to provide an example. The examples are summarized in the table below.

Table 203: Thematic Summary of Free Responses to Everyday Stress and Anxiety Reduction Activities

Theme	Frequency of Mention	Examples
Hobbies	5	“Participating in hobbies and activities for myself” “sewing and crocheting” “Fun activities such as puzzles of reading books”
Entertainment Media	4	“entertainment media like games podcast tv shows music etc” “Watching TV Journaling Reading” “Embrace recreational passions like videos games” “Playing music for relaxation”
Religious/Spiritual Practices	10	“Talking to God” “Prayer” “Religion Faith Spirituality” “Reading the Bible praying worship” “Bible study and prayer” “Faith” “Prayer or deep breaths”
Meditation	5	No specifics, just “meditation” or “meditation app”
Social Activities	2	“attending social events” “beer JK”
Mental Strategies	3	“Focus on what I can fix Disregard factors out of my control” “Positive self talk and mindfulness” “Working with a to do list”
Medication	5	“Anxiety medicine” “Medications” “prescription medication” “Medication for OCD”
Sleep/Relaxation	2	“Sleep or relax”
Pets/Animals	1	“Hug the dogs”

A word cloud of the responses is illustrated below to highlight the most prominent responses and themes visually.

Figure 122: Word cloud of most prevalent responses to everyday activities to reduce stress and anxiety. Created by Matplotlib Chart 6/10/2024

D.5.2 Workplace Stress and Anxiety Reduction Techniques

Participants in the survey were asked which of the workplace stress and anxiety reduction activities they regularly use with “What strategies do you use to manage **work-related** stress or anxiety?”. The list included: planning and organizational tools, taking regular breaks, seeking support from colleagues, professional counseling, physical activities, and other.

The response to this question is summarized in the table below, showing the

frequency of each provided response. The participants chose 2.32 different techniques from the list, on average.

Table 204: Frequency of Responses to Workplace Stress and Anxiety Reduction Activities

Theme	Frequency of Selection
Planning and Organizational tools	207
Taking regular breaks	189
Seek support from colleagues	197
Professional counseling	148
Physical activities	200
Other	18
None	2

The participants who chose "other" were asked to provide an example. The examples are summarized in the table below.

Table 205: Thematic Summary of Free Responses to Workplace Stress and Anxiety Reduction Activities

Theme	Frequency of Mention	Examples
Religious/Spiritual Practices	6	"talking to GOD" "Religion Faith Spirituality" "Reading the Bible praying worship" "Prayer" "Prayer or slow breathing"
Medication	3	"Medications" "Anxiety medication" "Medication for OCD"
Social Support	3	"Seek family support" "Seeking support from outside friends" "Talking with family"
Mental Strategies	4	"work through it" "Reminding myself that my work is not related to life or death scenarios " "mindfullness exercises" "Managing time according to when my brain is most efficient"
Self-Care/Relaxation	2	"self care such as pedicure or nice meal"
Work Strategies	1	"adjusting work position sit to stand desk"
Pets/Animals	1	"Hug the dogs"
Entertainment Media	2	"Listening to the tv while I work" "Playing video games"
Substance Use	2	"Drink JK" "Alcohol"

A word cloud of the responses is illustrated below to highlight the most prominent responses and themes visually.

Figure 123: Word cloud of most prevalent responses to workplace activities to reduce stress and anxiety. Created by Matplotlib Chart 6/10/2024

D.5.3 Additional Comments

At the end of the survey, participants were asked: "Please provide any additional comments or information you feel is relevant to this study: (optional)". Of the medium-quality data set, 120 participants provided comments. The themes of the comments and frequencies are summarized below.

Table 206: Thematic Summary of Free Responses to the Additional Comments Question.

Theme	Frequency of Mention	Examples
No Additional Comments	69	"None" "N/A" "No comments" "No additional comments"
Challenges with ADHD/ADD and Focus	11	"I have a difficult time focusing on meetings and find myself easily sidetracked by my telephone." "I find myself doodling a lot during class and letting my thoughts take over in situations where I am supposed to be paying attention/listening." "My major problem is concentrating on task and procrastinating more often." "Although I'm constantly trying to find ways to better organize my day and focus on the most important and relevant tasks, I often find myself pulled into putting out fires that can be addressed quickly."
Positive Feedback on the Survey	9	"I really give a high credit for bringing up this survey." "This survey is so educative, I recommend it for future studies."

Theme	Frequency of Mention	Examples
		"The study is interesting." "The survey was perfect."
Personal Experiences with ADHD/ADD or Autism	8	"I'm very aware of my ADD tendencies and have learned skills to manage them." "As a woman recently diagnosed with ADHD, I have always thought that ADHD is associated with being fidgety and restless, which in my case isn't true." "I have diagnosed ASD with possibly comorbidities of ADHD and OCD."
Workplace Environment and Accommodations	8	"Working environment must be conducive in all ramifications to save employees the stress of having to be distracted." "I work in a fast-paced call center environment where there is little to no consideration for those that struggle with ADHD." "Create a work environment that facilitates concentration for employees with ADHD and anxiety, such as providing quiet work spaces and reducing distractions and noise." "ADHD - permit (even purchase) high-quality, noise-blocking (not noise-cancelling, due to security issues) headphones for employees who work in secure spaces, if they need support with blocking out conversations, etc. - require agendas (sent at least one day ahead) and minutes/action items (sent within one day after) for all meetings. - allow additional walls/curtains/etc., if desired, for blocking visual of other folks... particularly in open work areas."
Recommendations for Survey Improvement	2	"I found the 'quality check' questions strange. It took me a second to understand what the survey needed. I got it by the second question, maybe rephrase those if you see a lot of wrong answers?" "This question reads optional but is required to end the survey. Please fix this. Thank you."
Mental Health Awareness and Support	4	"People with ADHD should not be looked down on. Rather, they should be encouraged and loved." "Offering sensitization programs for people with ADHD." "Encouragement employees to take breaks and practice self-care."
Specific Suggestions for Future Research	9	"Investigate how to relieve stress." "To explore the associations of different seasons or climate change on their mood and work performance." "Study the impact of different leadership styles on these employees."

In addition to the themes, several valuable, interesting, unique personal insights were shared. I appreciate everyone who took the time to share their experiences and insight into this vital topic.

- "I'm very aware of my ADD tendencies and have learned skills to manage them - since being prescribed medication, I find that I am much more productive and focused at work."
- "As a woman recently diagnosed with ADHD, I have always thought that ADHD is associated with being fidgety and restless, which in my case isn't true. I struggled a lot with doing boring tasks or finding new hobbies and thought that I was not smart enough or didn't have a purpose in life."
- "Mistakes are part of human nature and for the most part unrelated to ADHD. To imply correlation to these is slightly biased."
- "I feel the 8-hour work day is antiquated at this point and should be abandoned. Mid-day meetings break up concentration required for "deep work" and should be

avoided. Deadlines should be emphasized over specific shift hours (I.e. meet deadlines however is most effective for the individual)."

- "Understanding the prevalence and relationship between psychosocial stress and anxiety related to health factors among workers is crucial for workplace well-being initiatives. Consider including measures to assess stress levels, such as the Perceived Stress Scale, and anxiety levels using standardized tools like the Generalized Anxiety Disorder scale."
- "Create a work environment that facilitates concentration for employees with ADHD and anxiety, such as providing quiet work spaces and reducing distractions and noise. Help them use task management tools and planners to organize work, set priorities, and provide necessary time management training."
- "Our goal is to continuously monitor and improve the work environment, to understand the needs of our employees by collecting their feedback on a regular basis, and to adapt our strategy based on this feedback."
- "At my age, I find it important to minimize distractions when driving. I turn off music and the radio when I need to focus on the road and traffic. People in the backseat know I need quiet when driving in high-pedestrian areas."
- "Related to what do I do to relieve stress and anxiety: Begin by eating as nutritionally healthy diet in smaller portions as often as can fit into a day. Drink water often to flush toxins. Stay busy with physically demanding chores and tasks in lieu of routine exercise."
- "Sometimes it is difficult to express how behaviorally challenging some tasks are, especially in work environments."

Finally, it is helpful, especially for those who are visually oriented, to highlight the main thoughts and themes of the comments section by illustrating the results with a

Figure 124: Word cloud of Free Response to Additional Comments Question

word cloud.

D.6 Failed Quality Check Dataset Analysis

In an effort to be thorough, this brief analysis has been added to give insight into the differences between the two groups suspected of being primarily human respondents, the High-Quality Dataset (that is used for the primary analysis in this study) and the Failed Quality Check Dataset that was removed due to participants failing one or more of the three the quality check questions in the survey. The comparison begins by comparing basic descriptive statistics of the two groups.

D.6.1 Descriptive Statistics

The pie charts shown in the figure below demonstrate the differences in self-reported medical ADHD diagnosis reported by the participants in the two data sets. The Quality Check failed group has twice the frequency of ADHD-diagnosed participants than the High-Quality data set. The High-Quality data set has a prevalence of self-reported ADHD diagnosis of 25.7%, which is higher than most literature measures of ADHD prevalence in the United States (typically ranging between 5-10% of the population).

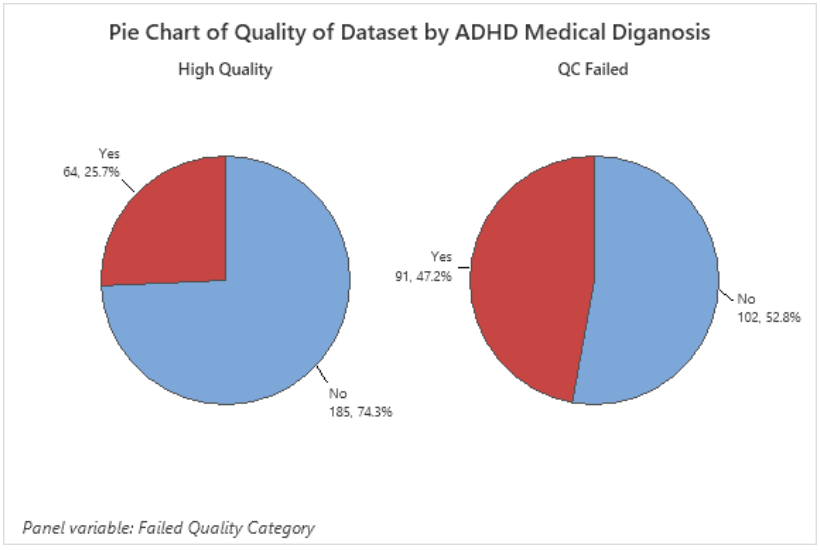

Figure 125: Pie Charts of Quality of Dataset by ADHD Medical Diagnosis, High Quality Data (left) Failed Quality Check Questions Dataset (right)

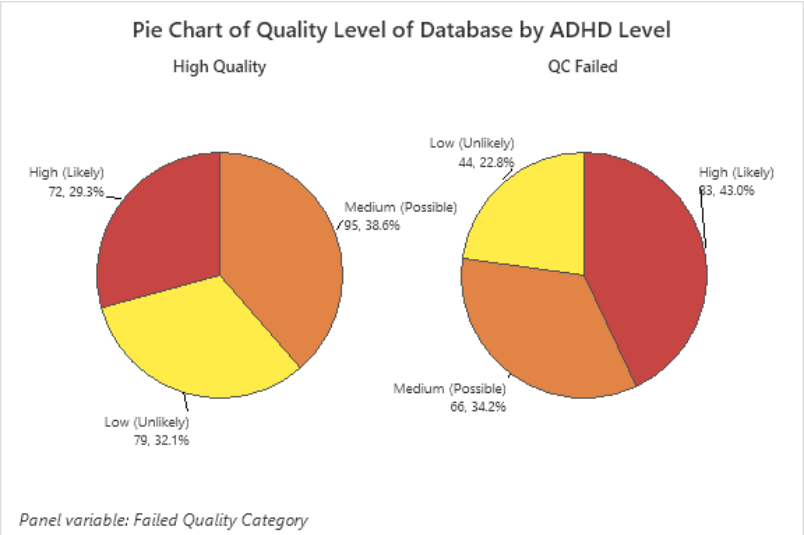

Figure 126: Pie Chart of ASRS6 ADHD Level, High Quality Dataset (left), Failed Quality Check Questions Dataset (right)

An additional metric to compare the two data sets is the ASRS6 Level based on the number of reported severe ADHD symptoms. The three groups of this metric are shown below for each data set. Note the similar medium-level percentages, but the differences in low and high are between the groups. The Quality Check Failed dataset has a higher percentage (43.0%) of the ASRS6 High group compared to the High-Quality data set (29.3%).

D.6.2 Dataset Hypothesis Testing

Hypothesis 5.1: There is a significant difference in the mean of ADHD Symptoms reported between the High Quality, Quality Check Failed, and Bot Datasets.

To evaluate this hypothesis, a one-way ANOVA was conducted to compare the ASRS6 Symptom Level across three categories: High Quality, Quality Check Failed (QC Failed), and Suspected Bot (Sus Bot)—the analysis aimed to determine if there are significant differences in the means of this category.

Table 207: ASRS6 Symptom Level by Dataset: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Failed Quality Category	2	167.2	83.600	38.66	0.000

Error	1685	3643.5	2.162
Total	1687	3810.7	

Table 208: ASRS6 Symptom Level by Dataset: Grouping Information Using the Tukey Method and 95% Confidence

Failed Quality Category	N	Mean	Grouping		
Sus Bot	1246	3.4013	A		
QC Failed	193	3.104		B	
High Quality	249	2.514			C

Means that do not share a letter are significantly different.

As evidenced by the significant results, $p<0.001$, there is, in fact, a difference between the three data sets in terms of the frequency of reported significant ADHD Symptoms. The High-Quality data set has the fewest symptoms (mean = 2.51), the QC Failed data set is middle (mean = 3.10), and the Suspected Bot data set is the highest (mean = 3.40). This evidence leads to the conclusion that the hypothesis will not be rejected.

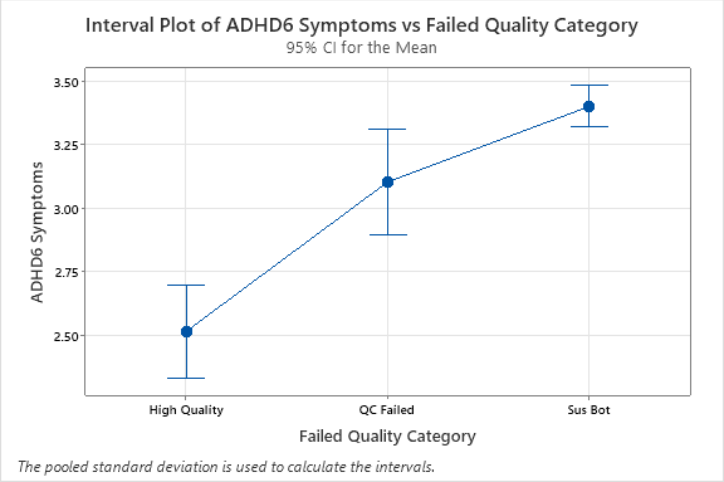

Figure 127: Interval Plot of ADHD6 Symptoms Vs Dataset

Hypothesis 5.2: There is a significant difference in the means of self-efficacy and social anxiety levels between the High Quality, Quality Check Failed, and Bot

Datasets.

To evaluate this hypothesis, two one-way ANOVA were conducted to compare the LSAS (social anxiety) point totals and the QSES (self-efficacy) across three categories: High Quality, Quality Check Failed (QC Failed), and Suspected Bot (Sus Bot). The analysis aimed to determine if there are significant differences in the means of these categories.

LSAS Total Points Analysis Results

The ANOVA results indicated a significant effect of the quality category on LSAS point totals, with a p-value < 0.001, well below the significance threshold. This suggests that there are indeed significant differences between the means of the three categories.

Table 209: Social Anxiety vs Datasets Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Failed Quality Category	2	8009	4004.60	97.93	0.000
Error	1685	68906	40.89		
Total	1687	76915			

Fisher Pairwise Comparisons

Grouping Information Using the Fisher LSD Method and 95% Confidence

Failed Quality Category	N	Mean	Grouping
Sus Bot	1246	29.339	A
QC Failed	193	26.057	B
High Quality	249	23.490	C

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
QC Failed - High Quality	2.567	0.613	(1.364, 3.770)	4.19	0.000
Sus Bot - High Quality	5.849	0.444	(4.978, 6.719)	13.18	0.000
Sus Bot - QC Failed	3.282	0.495	(2.311, 4.252)	6.63	0.000

Simultaneous confidence level = 87.81%

Figure 128: LSAS vs Datasets Fisher Pairwise Comparison Results

The Fisher Pairwise Comparisons show the means of each group and illustrate the lack of overlap between the 95% CIs. The analysis showed significant differences in LSAS point totals among the three datasets. The Suspected Bot dataset had the highest

mean social anxiety levels, followed by the Quality Check Failed dataset, and finally, the High-Quality dataset with the lowest mean. These differences were statistically significant across all comparisons, as evidenced by the Tukey pairwise comparison results.

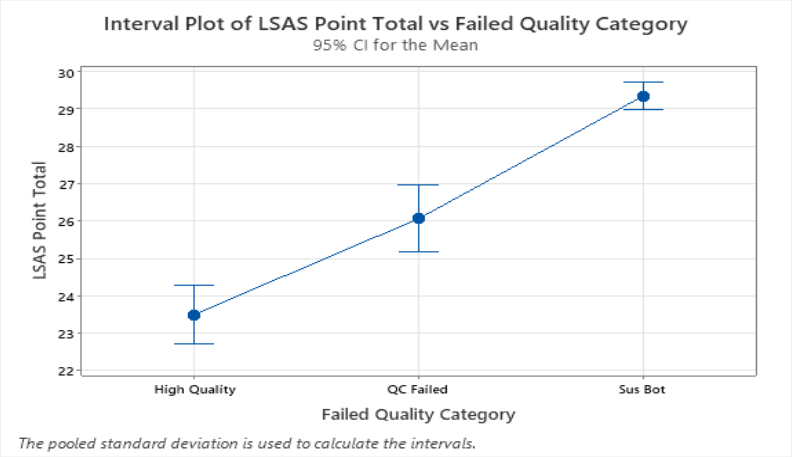

Figure 129: LSAS Interval Plot by Dataset

GPSES (Self-Efficacy) Analysis Results

To evaluate this hypothesis, a one-way ANOVA was conducted to compare the GPSES (self-efficacy) point totals across three categories: High Quality, Quality Check Failed (QC Failed), and Suspected Bot (Sus Bot). The analysis aimed to determine if there are significant differences in the means of these categories.

Table 210: GPSES Total Points vs Data Set Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Failed Quality Category	2	1820	909.977	112.15	0.000
Error	1685	13672	8.114		
Total	1687	15492			

The ANOVA results indicated a significant effect of the quality category on GPSES point totals, with a p-value of 0.000, well below the significance threshold. This suggests that there are indeed significant differences between the means of the three categories. Fisher Pairwise Comparisons also had a significant effect between the groups; the means and grouping are shown in the results below.

The analysis showed significant differences in GPSES point totals among the three datasets. The High-Quality dataset (mean = 15.9) had the highest mean self-efficacy

Fisher Pairwise Comparisons

Grouping Information Using the Fisher LSD Method and 95% Confidence

Failed Quality Category	N	Mean	Grouping
High Quality	249	15.863	A
QC Failed	193	14.746	B
Sus Bot	1246	13.1035	C

Means that do not share a letter are significantly different.

Fisher Individual Tests for Differences of Means

Difference of Levels	Difference of Means	SE of Difference	95% CI	T-Value	Adjusted P-Value
QC Failed - High Quality	-1.117	0.273	(-1.653, -0.582)	-4.09	0.000
Sus Bot - High Quality	-2.760	0.198	(-3.148, -2.372)	-13.96	0.000
Sus Bot - QC Failed	-1.643	0.220	(-2.075, -1.210)	-7.45	0.000

Simultaneous confidence level = 87.81%

Figure 130: GPSES vs Data Set Fisher Pairwise Comparison Results

levels, the Quality Check Failed dataset (mean = 14.7), and the Suspected Bot dataset (mean = 13.1) had the lowest mean. These differences were statistically significant across all comparisons, as evidenced by the Tukey pairwise comparison results.

The analysis supports the hypothesis that there is a significant difference in the means of self-efficacy and social anxiety levels between the High Quality, Quality Check Failed, and Bot Datasets.

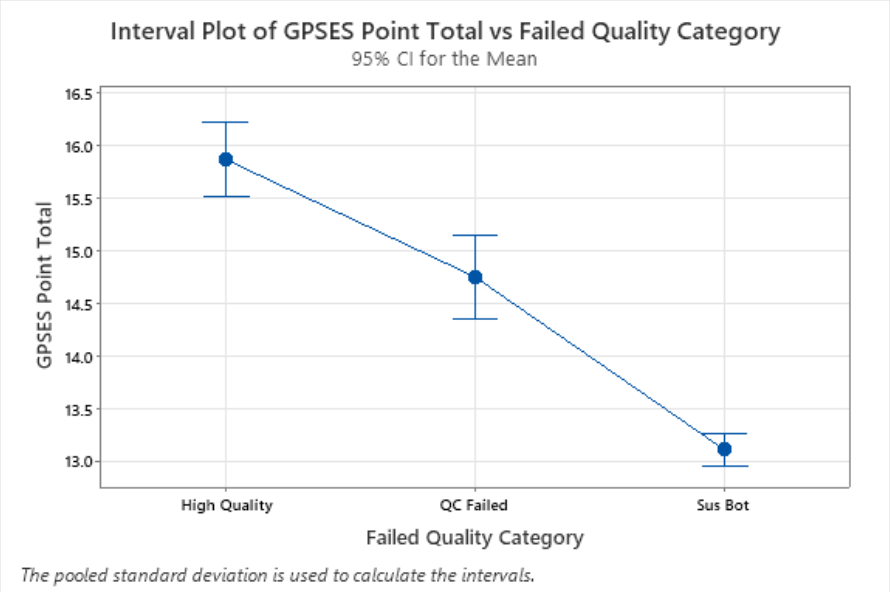

Figure 131: GPSES vs Dataset Interval Plot

D.6.3 Dataset Analysis Conclusions

The significant differences in self-efficacy and social anxiety levels across the High Quality, QC Failed, and Sus Bot datasets underscore the importance of data quality in survey analysis. Since these datasets exhibit substantial differences, excluding the QC Failed and Sus Bot datasets from the primary analysis of survey data is beneficial. Including these datasets would greatly affect the results and potentially lead to inaccurate conclusions.

For instance, the QC Failed group has twice the frequency of ADHD-diagnosed participants compared to the High-Quality group, which already has a higher prevalence of self-reported ADHD diagnosis than typically reported in the literature. Similarly, the Sus Bot dataset shows the highest levels of social anxiety and the lowest levels of self-efficacy, likely due to their non-human nature or incorrect data entries.

Removing the suspected bot respondents' answers and the suspected humans who

failed the quality check helps to maintain the integrity and reliability of the primary analysis. Future studies could further investigate these excluded datasets, but such analyses are outside the scope of the current study. The primary focus remains on the High-Quality dataset to secure accurate and meaningful insights into survey participants' self-efficacy and social anxiety levels.

Failed to Reject - Hypothesis 5.1: There is a significant difference in the mean of ADHD Symptoms reported between the High Quality, Quality Check Failed, and Bot Datasets.

- As evidenced by the significant results, $p<0.001$, there is a difference between the three data sets regarding the frequency of reported significant ADHD Symptoms.
- The High-Quality data set has the fewest symptoms (mean = 2.51), the QC Failed data set is middle (mean = 3.10), and the Suspected Bot data set is the highest (mean = 3.40).

Failed to Reject - Hypothesis 5.2: There is a significant difference in the means of self-efficacy and social anxiety levels between the High Quality, Quality Check Failed, and Bot Datasets.

- The analysis showed significant differences in GPSES point totals among the three datasets.
- For the GPSES averages, the High-Quality dataset had the highest mean self-efficacy levels, followed by the Quality Check Failed dataset, and finally, the Suspected Bot dataset with the lowest mean.
- For the LSAS averages among the three datasets. The Suspected Bot dataset had the highest mean social anxiety levels, followed by the Quality Check Failed dataset, and finally, the High-Quality dataset with the lowest mean.
- These differences were statistically significant across all comparisons, as evidenced by the Tukey pairwise comparison results.

D.7 Covariate Analysis

GPSES Point Total

The analysis of variance (ANOVA) for the GPSES point total revealed that employment level and diagnosed ADHD status were significant predictors. Employment level had a statistically significant effect ($p = 0.041$), indicating that differences in

employment level are associated with variations in GPSES scores. Specifically, lower employment levels were negatively associated with GPSES scores, as indicated by a coefficient of -0.319, based on the direction of the analysis coding. Diagnosed ADHD status also showed a significant impact ($p = 0.001$), with a coefficient of 1.656, suggesting that individuals undiagnosed with ADHD tend to have higher GPSES scores.

Table 211: Analysis of Variance for GPSES Point Total, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	18.94	7.56	7.557	0.80	0.372
Age	1	25.63	14.92	14.924	1.58	0.210
Education	1	3.33	0.10	0.101	0.01	0.918
Marital	1	44.21	34.40	34.399	3.65	0.058
Employment Sector	1	5.33	1.95	1.947	0.21	0.650
Employ Level	1	52.40	39.96	39.963	4.24	0.041
Diagnosed ADHD	1	100.52	100.52	100.516	10.66	0.001
Error	191	1800.39	1800.39	9.426		
Total	198	2050.75				

The model summary indicated that the predictors explained 12.21% of the variance in GPSES point totals, with an adjusted R-squared of 8.99%. Several observations were flagged as having large, standardized residuals, which may suggest potential outliers within the dataset.

LSAS Point Total

For the LSAS point total, both employment level and diagnosed ADHD status were significant covariates. Employment level had a significant effect ($p < 0.001$), with a coefficient of 1.769, indicating that lower employment levels are associated with higher LSAS scores, based on the coding of the analysis. Diagnosed ADHD status also significantly affected LSAS scores ($p < 0.001$), with a negative coefficient of -5.84, suggesting that individuals undiagnosed with ADHD reported lower LSAS scores.

Table 212: Analysis of Variance for LSAS Point Total, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	316.8	84.5	84.53	1.13	0.289
Age	1	717.2	225.8	225.83	3.01	0.084
Education	1	8.6	186.4	186.44	2.49	0.116
Marital	1	136.2	94.5	94.47	1.26	0.263
Employment Sector	1	44.6	4.8	4.84	0.06	0.800

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Employ Level	1	1470.8	1229.6	1229.56	16.41	0.000
Diagnosed ADHD	1	1250.2	1250.2	1250.24	16.69	0.000
Error	191	14309.9	14309.9	74.92		
Total	198	18254.4				

The model explained 21.61% of the variance in LSAS point totals, with an adjusted R-squared of 18.74%. Several observations were noted as having large, standardized residuals, indicating potential outliers.

ADHD6 Symptoms

The ANOVA for ADHD6 Symptoms highlighted employment level and diagnosed ADHD status as significant factors. Employment level significantly influenced ADHD6 symptoms ($p = 0.036$), with a coefficient of 0.176, suggesting that higher employment levels are associated with fewer ADHD symptoms, based on the direction of coding for the analysis. Self-reported diagnosed ADHD status also had a significant effect ($p = 0.002$), with a negative coefficient of -0.857, indicating fewer ADHD symptoms among un-diagnosed individuals, also based on the direction of coding for the analysis.

Table 213: Analysis of Variance for ADHD6 Symptoms, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	0.119	0.426	0.4258	0.16	0.693
Age	1	11.561	5.489	5.4894	2.01	0.157
Education	1	0.034	1.993	1.9934	0.73	0.393
Marital	1	3.135	1.359	1.3585	0.50	0.481
Employment Sector	1	0.558	1.516	1.5155	0.56	0.457
Employ Level	1	15.755	12.206	12.2058	4.48	0.036
Diagnosed ADHD	1	26.901	26.901	26.9010	9.87	0.002
Error	191	520.420	520.420	2.7247		
Total	198	578.482				

The model summary showed that the predictors accounted for 10.04% of the variance in ADHD6 symptoms, with an adjusted R-squared of 6.74%. Several observations displayed large, standardized residuals, pointing to potential outliers.

Workplace Effective Support: Do you feel that your workplace provides effective support for managing stress and anxiety?

In terms of the supportive work environment, none of the covariates demonstrated a statistically significant effect. The model explained only 3.55% of the variance in perceptions of a supportive work environment, with an adjusted R-squared of 0.02%. A few observations were flagged for having large, standardized residuals; this indicates the potential for large residuals.

Table 214: Analysis of Variance for Workplace Effective Support, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	0.3342	0.2367	0.23666	0.50	0.482
Age	1	1.0977	0.4110	0.41101	0.86	0.354
Education	1	1.1633	1.1987	1.19866	2.52	0.114
Marital	1	0.0002	0.0053	0.00534	0.01	0.916
Employment Sector	1	0.1620	0.1931	0.19309	0.41	0.525
Employ Level	1	0.2514	0.3040	0.30398	0.64	0.425
Diagnosed ADHD	1	0.3423	0.3423	0.34228	0.72	0.398
Error	191	91.0207	91.0207	0.47655		
Total	198	94.3719				

Workplace Supportiveness: How would you rate the overall work environment in terms of supporting employees with ADHD or anxiety issues?

The analysis of variance for workplace supportiveness for employees with ADHD or anxiety issues indicated that employment level was a significant covariate ($p = 0.042$), with a negative coefficient of -0.118. This suggests that higher employment levels are associated with lower perceptions of workplace supportiveness. Self-reported ADHD diagnosis status, however, did not show a significant effect.

Table 215: Analysis of Variance for workplace supportiveness for workers with ADHD or anxiety, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	1.645	0.941	0.94109	0.72	0.396
Age	1	0.135	1.887	1.88701	1.45	0.230
Education	1	0.766	0.060	0.06023	0.05	0.830
Marital	1	0.980	1.045	1.04492	0.80	0.371
Employment Sector	1	1.205	1.784	1.78360	1.37	0.243
Employ Level	1	5.669	5.455	5.45461	4.20	0.042

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Diagnosed ADHD	1	0.166	0.166	0.16607	0.13	0.721
Error	191	248.177	248.177	1.29936		
Total	198	258.744				

MANOVA Tests

The multivariate analysis of variance (MANOVA) tests showed that sex at birth, age, education, marital status, and employment sector did not have significant multivariate effects. In contrast, employment level ($p = 0.003$) and self-reported ADHD diagnosis status ($p < 0.001$) were significant, indicating that these factors influence the combined set of dependent variables.

D.7.1 Covariate Analysis Statistical Report

HIGH QUALITY DATA SET NUMERICAL RESPONSES

COVARIATE ANALYSIS General Linear Model: GPSES Point Total, LSAS Point Total, ADHD6 Symptoms, supportive work, workplace supportive? Versus Sex at Birth, Age, Education, Marital Status, Employment Sector, Employment Level, and Self-Diagnosed ADHD Status

Analysis of Variance for GPSES Point Total, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	18.94	7.56	7.557	0.80	0.372
Age	1	25.63	14.92	14.924	1.58	0.210
Education	1	3.33	0.10	0.101	0.01	0.918
Marital	1	44.21	34.40	34.399	3.65	0.058
Employment Sector	1	5.33	1.95	1.947	0.21	0.650
Employ Level	1	52.40	39.96	39.963	4.24	0.041
Diagnosed ADHD	1	100.52	100.52	100.516	10.66	0.001
Error	191	1800.39	1800.39	9.426		
Total	198	2050.75				

Model Summary

S	R-sq	R-sq(adj)
3.07020	12.21%	8.99%

Coefficients

Term	Coef	SE Coef	T	P
Constant	15.12	1.84	8.24	0.000
Sex at Birth	-0.394	0.440	-0.90	0.372
Age	0.0313	0.0249	1.26	0.210
Education	-0.020	0.193	-0.10	0.918

Marital	-0.696	0.364	-1.91	0.058
Employment	0.0262	0.0577	0.45	0.650
Sector				
Employ Level	-0.319	0.155	-2.06	0.041
Diagnosed ADHD	1.656	0.507	3.27	0.001

Analysis of Variance for LSAS Point Total, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	316.8	84.5	84.53	1.13	0.289
Age	1	717.2	225.8	225.83	3.01	0.084
Education	1	8.6	186.4	186.44	2.49	0.116
Marital	1	136.2	94.5	94.47	1.26	0.263
Employment	1	44.6	4.8	4.84	0.06	0.800
Sector						
Employ Level	1	1470.8	1229.6	1229.56	16.41	0.000
Diagnosed ADHD	1	1250.2	1250.2	1250.24	16.69	0.000
Error	191	14309.9	14309.9	74.92		
Total	198	18254.4				

Model Summary

S	R-sq	R-sq(adj)
8.65570	21.61%	18.74%

Coefficients

Term	Coef	SE Coef	T	P
Constant	21.68	5.18	4.19	0.000
Sex at Birth	1.32	1.24	1.06	0.289
Age	-0.1219	0.0702	-1.74	0.084
Education	0.857	0.543	1.58	0.116
Marital	1.15	1.03	1.12	0.263
Employment	-0.041	0.163	-0.25	0.800
Sector				
Employ Level	1.769	0.437	4.05	0.000
Diagnosed ADHD	-5.84	1.43	-4.09	0.000

Analysis of Variance for ADHD6 Symptoms, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	0.119	0.426	0.4258	0.16	0.693
Age	1	11.561	5.489	5.4894	2.01	0.157
Education	1	0.034	1.993	1.9934	0.73	0.393
Marital	1	3.135	1.359	1.3585	0.50	0.481
Employment	1	0.558	1.516	1.5155	0.56	0.457
Sector						
Employ Level	1	15.755	12.206	12.2058	4.48	0.036
Diagnosed ADHD	1	26.901	26.901	26.9010	9.87	0.002
Error	191	520.420	520.420	2.7247		
Total	198	578.482				

Model Summary

S	R-sq	R-sq(adj)
1.65067	10.04%	6.74%

Coefficients

Term	Coef	SE Coef	T	P
Constant	3.140	0.987	3.18	0.002
Sex at Birth	-0.093	0.236	-0.40	0.693
Age	-0.0190	0.0134	-1.42	0.157
Education	0.089	0.104	0.86	0.393
Marital	0.138	0.196	0.71	0.481
Employment Sector	0.0232	0.0310	0.75	0.457
Employ Level	0.1762	0.0833	2.12	0.036
Diagnosed ADHD	-0.857	0.273	-3.14	0.002

Analysis of Variance for supportive work, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	0.3342	0.2367	0.23666	0.50	0.482
Age	1	1.0977	0.4110	0.41101	0.86	0.354
Education	1	1.1633	1.1987	1.19866	2.52	0.114
Marital	1	0.0002	0.0053	0.00534	0.01	0.916
Employment Sector	1	0.1620	0.1931	0.19309	0.41	0.525
Employ Level	1	0.2514	0.3040	0.30398	0.64	0.425
Diagnosed ADHD	1	0.3423	0.3423	0.34228	0.72	0.398
Error	191	91.0207	91.0207	0.47655		
Total	198	94.3719				

Model Summary

S	R-sq	R-sq(adj)
0.690325	3.55%	0.02%

Coefficients

Term	Coef	SE Coef	T	P
Constant	1.111	0.413	2.69	0.008
Sex at Birth	0.0697	0.0989	0.70	0.482
Age	0.00520	0.00560	0.93	0.354
Education	0.0687	0.0433	1.59	0.114
Marital	0.0087	0.0819	0.11	0.916
Employment Sector	0.0083	0.0130	0.64	0.525
Employ Level	0.0278	0.0348	0.80	0.425
Diagnosed ADHD	0.097	0.114	0.85	0.398

Analysis of Variance for workplace supportive?, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Sex at Birth	1	1.645	0.941	0.94109	0.72	0.396
Age	1	0.135	1.887	1.88701	1.45	0.230
Education	1	0.766	0.060	0.06023	0.05	0.830
Marital	1	0.980	1.045	1.04492	0.80	0.371
Employment Sector	1	1.205	1.784	1.78360	1.37	0.243
Employ Level	1	5.669	5.455	5.45461	4.20	0.042
Diagnosed ADHD	1	0.166	0.166	0.16607	0.13	0.721
Error	191	248.177	248.177	1.29936		
Total	198	258.744				

Model Summary

S	R-sq	R-sq(adj)
1.13989	4.08%	0.57%

Coefficients

Term	Coef	SE Coef	T	P
Constant	3.624	0.682	5.32	0.000
Sex at Birth	-0.139	0.163	-0.85	0.396
Age	-0.01114	0.00924	-1.21	0.230
Education	0.0154	0.0715	0.22	0.830
Marital	0.121	0.135	0.90	0.371
Employment Sector	-0.0251	0.0214	-1.17	0.243
Employ Level	-0.1178	0.0575	-2.05	0.042
Diagnosed ADHD	0.067	0.188	0.36	0.721

Appendix E: IRB Documents

E.1 Pilot Study: Non-Human Subjects Research Email

RE: Quality Assessment/Improvement Project Request

Sally Headley <sbh0043@auburn.edu>

Fri 6/17/2022 8:37 AM

To:Victoria Ballard <vzb0024@auburn.edu>
Cc:Richard Sesek <rfs0006@auburn.edu>;Tom Devall <tld0017@auburn.edu>

Good Friday morning Victoria and all,

Based on information shared during yesterday's telephone conversation and confirmed in your email (below), the described activities meet the criteria for a determination of Not Human Subjects Research (NHSR). No further action is required by the AU IRB.
Should your activities evolve into future human subject research, submit an application for IRB Review.
Save a copy of this email for documentation purposes.

Best to you in your pursuits!
Sally

Sally Blake Headley
Manager, Human Research Protection Program
Office of Research Compliance
Research and Innovation Center 540 Devall Avenue
Auburn University, AL 36832
(334) 844-5966 | sbh0043@auburn.edu

From: Victoria Ballard <vzb0024@auburn.edu>
Sent: Thursday, June 16, 2022 9:53 PM
To: Sally Headley <sbh0043@auburn.edu>
Cc: Richard Sesek <rfs0006@auburn.edu>; Tom Devall <tld0017@auburn.edu>
Subject: Quality Assessment/Improvement Project Request

Dear Ms. Headly,

I am following up on the telephone conversation that Dr. Sesek and I had with you yesterday regarding plans in the Industrial and Systems Engineering Tiger Motors Lab (Affectionately called the Lego™ Lab).

As we discussed, we believe that the activities that are planned in the lab this summer and early fall semester qualify as a Quality Assessment and Quality Improvement project.

We wish to evaluate the implementation strategies of the Light Guide Augmented Reality System (a projection and camera system) to determine the best method to incorporate this technology into our curriculum for the campus and online courses. This system is used to train people on how to build the Lego™ cars at that station by projecting lights onto the work area to indicate the location and order of the parts to be assembled. This and similar devices are in common use in industry and we want to familiarize students with this technology in laboratory exercises. This does not fundamentally change the physical nature of the tasks students perform in these labs (i.e., building lego cars).

Thank you for your input and assistance in this matter.

Best Regards,
Victoria Ballard

Victoria Ballard, MSE
Doctoral Student, Lean Manufacturing TA
HFES/ASSP Auburn University Student Chapter President
Industrial and Systems Engineering
3322 Shelby Center for Engineering Technology
https://auburn.zoom.us/my/victoriaballard
TheVictoria@Auburn.edu

Life is Short. † Pray Hard.

E.2 Manufacturing Technology Support Investigation and Manufacturing Support Systems Investigation Auburn University IRB Documents

Studying Manufacturing with LEGO(R) Research

Participate in research in Auburn's Tiger Motors Lab!

The Effects of Lean Tools and Industry 4.0 Technology on Manufacturing Assembly Performance

Want to help the future of manufacturing research?
Want to use the latest vision inspection equipment and play with LEGO?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technology on industrial assembly tasks. The effect of a model check piece, camera inspection technology, and a combination of the two will be compared with paper-based materials. Participants will assemble one station of LEGO vehicles in four scenarios. The time for completion is approximately 1.5 hours. No compensation for the study, but you will get to build LEGO cars in the world-famous Auburn Tiger Motors Lean Education Center (AKA LEGO Lab!).

This study is open to anyone 18 and older.

TIGER MOTORS
LEAN EDUCATION CENTER

AUBURN UNIVERSITY

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the QR code to generate an email.

Scan to Email!

The Auburn University Institutional Review Board has approved this Document for use from 02/21/2023 to ----------
Protocol # 22-538 EP 2301

O'Leary Protocol Review – AU IRB Protocol #22-538

The Effects of Augmented Instruction on Manufacturing Assembly Training

Version History

Version	Description	Sub Date	Resp Date	Result	Outcome
1.0	Original submission	12/7/22	12/27/22	Rejected	Add elements related to COVID protocol and risks
1.1	COVID changes	1/6/23	1/30/23	Approved	Initial protocol approved
2.0	Expanded protocol, 2 investigations	2/2/23	n/a	None	Skipped due to v1.1a, which backport changes; not sub'ed as modification
1.1a	Backport v2 changes for first invest.	2/6/23	2/6/23	Rejected	Not submitted as a modification, adjust format
1.1a1	Resub 1.1a as modification	2/7/23	2/13/23	Approved	v1.1a1 is approved, added team members and part. intake sheet form

Thank you for the recent approval of my IRB modification v1.1a1, dated 2/7/23.

Enclosed please find an amended and expanded protocol, which incorporates a second interrelated investigation per previous discussions with Sally Headley and Richard Sesek.

Best Regards,

Dan O'Leary

Summary of Changes:

- Expanded Protocol, 2/20/2023
  - Protocol Review Form (PRF):
    - Dates and versions updated
    - 6A. Added photos as data collection element
    - 8A and B. Incorporated overview and summary of methodology for the second investigation.
    - 9A. Updated purpose and aims of first investigation to include use of survey data. Added details for second investigation.
    - 10. Added Kralyn Thomas, Yen-Ting Guo, and Lucie Wang to the key personnel.
    - 12A, B, C. Updated intended participation sizes and qualifications for both investigations. Slightly revised the recruiting plan.
    - 13B. Updated the first investigation's research design to account for adjustments to the order of survey data collection. Added research design for second investigation.
    - 13C. Updated to explicitly re-state video and photography data collection steps.
    - 16B. Added benefits of second investigation.
    - 17D. Updated location of identifying data.
  - Informed Consent (IC):
    - No changes required for the first investigation.
    - Added separate IC for second investigation.
  - Appendices:
    - A – Reference List
      - Added separate reference list for second investigation.
    - B – Recruiting Materials
      - Updated language to reflect 2 investigations

        - Added flyer for the second investigation and PPT slided formatted versions for both investigations
    - C – Data Collection Instruments
        - Subject Recruitment Data Sheet – reformatted for two investigations
        - Code Sheet – reformatted for two investigations
        - Data Collection Sheet #1 and 2 – reformatted for two investigations
        - Other pages – added detail to headers
        - Separated General Feedback onto it's on page, added discomfort question
    - D – Emergency Plan
        - No changes
    - E – CITI Training Documentation
        - Updated names and order of team members
- Additional Changes
    - None.

Attached:

1. Modification form
2. CITI certificates for added key personnel
3. Updated protocol form, new Informed Consent for the 2nd investigation, and updated appendix, all with changes highlighted
4. Clean versions of all updated forms that require new IRB stamps.
5. All current IRB stamped docs

AUBURN UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM (HRPP)

REQUEST for MODIFICATION

For Information or help completing this form, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu**

- **Federal regulations require IRB approval before implementing proposed changes.**
- **Change means any change, in content or form, to the protocol, consent form, or any supportive materials (such as the investigator's Brochure, questionnaires, surveys, advertisements, etc.). See Item 4 for more examples.**

1. Today's Date	**2/20/2023**

2. Principal Investigator (PI) Name: Dan O'Leary			
PI's Title:	Instructor / PhD Candidate	**Faculty PI (if PI is a student):**	Dr. Richard Sesek
Department:	Industrial & Systems Eng	**Department:**	Industrial & Systems Eng
Phone:	407-399-3189	**Phone:**	334-728-1438
AU-E-Mail:	djo0008@auburn.edu	**AU E-Mail:**	rfs0006@auburn.edu
Contact person who should receive copies of IRB correspondence (Optional):	Click or tap here to enter text.	**Department Head Name:**	Dr. Gregory Harris
Phone:	Click or tap here to enter text.	**Phone:**	334-844-1407
AU E-Mail:	Click or tap here to enter text.	**AU E-Mail:**	gah0015@auburn.edu

3. AU IRB Protocol Identification

3.a. Protocol Number: 22-538

3.b. Protocol Title: The Effects of Augmented Instruction on Manufacturing Assembly Training

3. c. Current Status of Protocol – For active studies, check ONE box at left; provide numbers and dates where applicable

☐	**Study has not yet begun; no data has been entered or collected**	
☒	**In progress If YES, number of data/participants entered:** 2 trials run, others scheduled	**Current Approval Dates From:** 1/30/2023
☐	**Is this modification request being made in conjunction with/as a result of protocol renewal? ☐ YES ☐ NO**	
☐	**Adverse events since last review If YES, describe:** Click or tap here to enter text.	**To:** Click or tap to enter a date.
☐	**Data analysis only**	
☐	**Funding Agency and Grant Number:** Click or tap here to enter text.	**AU Funding Information:** Click or tap here to enter text.
☐	**List any other institutions and/ or AU approved studies associated with this project:** Click or tap here to enter text.	

The Auburn University Institutional Review Board has approved this Document for use from
02/21/2023 to ----------
Protocol # 22-538 EP 2301

4. Types of Change
Mark all that apply, and describe the changes in item 5

☒ **Change in Key Personnel**
List the name(s) of personnel being added to or removed from the study and attach a copy of the CITI documentation for personnel being added to the study.
Adding: Kralyn Thomas, Yen-Ting Guo, and Lucie Wang

☐ **Additional Sites or Change in Sites, including AU classrooms, etc.**
Attach permission forms for new sites.

☒ **Change in methods for data storage/ protection or location of data/ consent documents**
Added location for storage of consent forms for 2nd investigation.

☒ **Change in project purpose or project questions**
Added 2nd investigation using similar methods to explore other augmentations.

☒ **Change in population or recruitment**
Attach new or revised recruitment materials as needed; both highlighted version & clean copy for IRB approval stamp
Expanded target number of participants in the same population. See revised protocol for details.

☒ **Change in study procedure(s)**
Attach new or revised consent documents as needed; both highlighted revised copy & clean copy for IRB approval stamp
Updated procedures and added separate consent for 2nd investigation. Consent for 1st investigation unchanged.

☒ **Change in data collection instruments/forms (surveys, data collection forms)**
Attach new forms as needed; both highlighted version & clean copy for IRB approval stamp
Reformatted to support both investigations. No material changes to data collected. Attached.

☐ **Other**
(BUAs, DUAs, etc.) Indicate the type of change in the space below, and provide details in the Item 5.c. or 5.d. as applicable. Include a copy of all affected documents, with revisions highlighted as applicable.
Click or tap here to enter text.

5. Description and Rationale

5.a. For each item marked in Question #4 describe the requested change(s) to your research protocol, and the rationale for each.

Expanded scope of the experiment to include a second, directly related investigation. Needed added team members to help run the protocol.

5.b. Briefly list (numbered or bulleted) **the activities that have occurred up to this point, particularly those that involved participants.**

Recruiting ongoing, two trial runs, additional scheduled. All those will continue to utilize the methods and forms previously approved. This modification creates no material change in the first investigation. Once the modification is approved we will revise our recruiting methods as described and begin running trials for the 2nd.

5.c. Does the requested change affect participants, such as procedures, risks, costs, benefits, etc.

Not for the first investigation. The 2nd will affect the participants recruited for it as described in the corresponding Informed Consent document.

5.d. Attach a copy of all "IRB stamped" documents currently used. (Information letters, consent forms, flyers, etc.)

Attached.

5.e. List all revised documents and attach two copies of the revised documents – one copy which highlights the revisions and one clean copy of the revised documents for the IRB approval stamp.

Attached.

6. Signatures

Principal Investigator: _____

Faculty Advisor PI, if applicable: _____

Version Date: 2/20/2023

CITI PROGRAM

Completion Date 13-Feb-2023
Expiration Date 13-Feb-2026
Record ID 54396396

This is to certify that:

Kralyn Thomas

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Responsible Conduct of Research
(Curriculum Group)
AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
(Course Learner Group)
1 - RCR
(Stage)

Under requirements set by:

Auburn University

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?wb69d798f-5552-4035-be13-88ab7b7d1a93-54396396

CITI PROGRAM

Completion Date 11-Sep-2022
Expiration Date 10-Sep-2025
Record ID 51085631

This is to certify that:

Yen-Ting Guo

Not valid for renewal of certification through CME.

Has completed the following CITI Program course:

Responsible Conduct of Research
(Curriculum Group)
AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
(Course Learner Group)
1 - RCR
(Stage)

Under requirements set by:

Auburn University

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?w30b4110d-dd8b-443d-84ae-d45ee40e3179-51085631

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Yuqing Wang (ID: 9720808)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** yzw0155@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** (334) 844-4340

- **Curriculum Group:** Responsible Conduct of Research
- **Course Learner Group:** AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
- **Stage:** Stage 1 - RCR
- **Description:** This course is for investigators, staff and students with an interest or focus in **Biomedical Research**. This course contains text, embedded case studies AND quizzes.

- **Record ID:** 50317945
- **Completion Date:** 30-Nov-2022
- **Expiration Date:** 30-Nov-2025
- **Minimum Passing:** 90
- **Reported Score*:** 100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Authorship (RCR-Basic) (ID: 16597)	30-Nov-2022	5/5 (100%)
Collaborative Research (RCR-Basic) (ID: 16598)	30-Nov-2022	5/5 (100%)
Conflicts of Interest (RCR-Basic) (ID: 16599)	30-Nov-2022	5/5 (100%)
Data Management (RCR-Basic) (ID: 16600)	30-Nov-2022	5/5 (100%)
Mentoring (RCR-Basic) (ID: 16602)	30-Nov-2022	5/5 (100%)
Peer Review (RCR-Basic) (ID: 16603)	30-Nov-2022	5/5 (100%)
Research Misconduct (RCR-Basic) (ID: 16604)	30-Nov-2022	5/5 (100%)
Plagiarism (RCR-Basic) (ID: 15156)	30-Nov-2022	5/5 (100%)
Using Animal Subjects in Research (RCR-Basic) (ID: 13301)	30-Nov-2022	5/5 (100%)
Research Involving Human Subjects (RCR-Basic) (ID: 13566)	30-Nov-2022	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?k365e856e-2cdf-41df-97ba-a5a5bbdacf73-50317945

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Yuqing Wang (ID: 9720808)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** yzw0155@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** (334) 844-4340

- **Curriculum Group:** Responsible Conduct of Research
- **Course Learner Group:** AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
- **Stage:** Stage 1 - RCR
- **Description:** This course is for investigators, staff and students with an interest or focus in **Biomedical Research**. This course contains text, embedded case studies AND quizzes.

- **Record ID:** 50317945
- **Report Date:** 14-Feb-2023
- **Current Score**:** 100

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Using Animal Subjects in Research (RCR-Basic) (ID: 13301)	30-Nov-2022	5/5 (100%)
Research Involving Human Subjects (RCR-Basic) (ID: 13566)	30-Nov-2022	5/5 (100%)
Plagiarism (RCR-Basic) (ID: 15156)	30-Nov-2022	5/5 (100%)
Authorship (RCR-Basic) (ID: 16597)	30-Nov-2022	5/5 (100%)
Collaborative Research (RCR-Basic) (ID: 16598)	30-Nov-2022	5/5 (100%)
Conflicts of Interest (RCR-Basic) (ID: 16599)	30-Nov-2022	5/5 (100%)
Data Management (RCR-Basic) (ID: 16600)	30-Nov-2022	5/5 (100%)
Mentoring (RCR-Basic) (ID: 16602)	30-Nov-2022	5/5 (100%)
Peer Review (RCR-Basic) (ID: 16603)	30-Nov-2022	5/5 (100%)
Research Misconduct (RCR-Basic) (ID: 16604)	30-Nov-2022	5/5 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?k365e856e-2cdf-41df-97ba-a5a5bbdacf73-50317945

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

Modified Forms

AUBURN UNIVERSITY INSTITUTIONAL REVIEW BOARD for RESEARCH INVOLVING HUMAN SUBJECTS

PROTOCOL REVIEW FORM
FULL BOARD or EXPEDITED REVIEW

For assistance, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**
Submit completed form and supporting materials as one PDF through the IRB Submission Page
Handwritten forms are not accepted. Where links are found hold down the control button (Ctrl) then click the link.

1. Proposed Start Date of Study:1/11/2023 Today's Date: February 20, 2023
Submission Status (Check One): ☐ New ☒ Revisions (to address IRB Review Comments)
Proposed Review Category (Check One): ☐ Full Board (greater than minimal risk) ☒ Expedited
If Expedited, Indicate Category(ies) ((Link to Expedited Category Review Sheet) 6

2. Project Title: The Effects of Augmented Instruction on Manufacturing Assembly Training

3. Principal Investigator (PI): Dan O'Leary Degree(s): BS Mech Eng, MS Eng Mgmt
Rank/Title: Graduate Student Department/School: Industrial & Systems Engineering
Role/responsibilities in this project: Organize and conduct research, perform data collection and analysis
Preferred Phone Number: 407-399-3189 AU Email: djo0008@auburn.edu

Faculty Advisor Principal Investigator (if applicable): Richard Sesek
Rank/Title: Associate Professor Department/School: Industrial & Systems Engineering
Role/responsibilities in this project: Supervise and advise the design and execution of the experiment
Preferred Phone Number: 334-728-1438 AU Email: rfs0006@auburn.edu

Department Head: Gregory Harris Department/School: Industrial & Systems Engineering
Preferred Phone Number: 334-844-1407 AU Email: gah0015@auburn.edu
Role/responsibilities in this project: Dissertation co-chair and primary project advisor

4. Funding Support: ☒ N/A ☐ Internal External Agency: n/a Pending ☐ Received ☐
For federal funding, list funding agency and grant number (if available): n/a

5. a) List any contractors, sub-contractors, and other entities associated with this project: n/a

b) List any other AU IRB approved protocols associated with this study and describe the association: n/a

c) List any other institutions associated with this study and submit a copy of their IRB approval(s): n/a

Protocol Packet Checklist

Check all applicable boxes. A completed checklist is required.

☒ **Protocol Review Form** (All required signatures included and all sections completed)
(Examples of appended documents are found on the website: https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

☒ **CITI Training Certificates** for key personnel

☒ **Consent Form or Information Letter** and any releases (audio, video or photo) that participants will review and/or sign

☒ **Appendix A** "Reference List"

☒ **Appendix B** if e-mails, flyers, advertisements, social media posts, generalized announcements or scripts, etc., will be used to recruit participants.

☒ **Appendix C** if data collection sheets, surveys, tests, other recording instruments, interview scripts, etc. will be used for data collection. Attach documents in the order they are listed in item 13c.

Continued on Page 2

☒ **Appendix D** if they study will use a debriefing form or will include emergency plans/ procedures and medical referral lists. (A referral list may be attached to the consent document.)

☐ **Appendix E** if research is being conducted at sites other than Auburn University or in cooperation with other entities. A **permission letter** from the site/ program director must be included indicating their cooperation or involvement in the project. NOTE: If the proposed research is a multi-site project, involving investigators or participants at other academic institutions, hospitals or private research organizations, a letter of **IRB approval** from each entity is required prior to initiating the project.

☐ **Appendix F** Written evidence of approval by the host country, local IRB or institutions if research is conducted outside the United States

6. General Research Project Characteristics

6A. Research Methodology

Check all descriptions that best apply to the research methodology.

Data Source(s): ☒ New Data ☐ Existing Data

Will recorded data directly or indirectly identify participants?
☒ Yes ☐ No

Data collection will involve the use of:

- ☒ Educational Tests (cognitive diagnostic, aptitude, etc.)
- ☒ Interview
- ☒ Observation
- ☐ Locations or Tracking Measures
- ☐ Physical / Physiological Measures or Specimens
- ☒ Surveys / Questionnaires
- ☐ Other: Click or tap here to enter text.
- ☒ Internet / Electronic
- ☒ Audio
- ☒ Video
- ☒ Photos
- ☐ Digital Images
- ☐ Private records or files

6B. Participant Information

Check all descriptors that apply to the TARGET population.
(link to definition of target population)
☐ Males ☐ Females ☐ AU students

Vulnerable Populations
☐ Pregnant Women/Fetuses ☐ Prisoners ☐ Institutionalized
☐ Children and / or Adolescents (under age 18 in AL; if minor participants, at least 2 adults must be present during all research procedures that include the minors)

Persons with:
☐ Economic Disadvantages ☐ Physical Disabilities
☐ Educational Disadvantages ☐ Intellectual Disabilities

Will participants be compensated? ☐ Yes ☒ No

6C. Risks to Participants

Identify all risks participants might encounter in this research.

- ☒ Breach of Confidentiality*
- ☐ Deception
- ☐ Psychological
- ☐ None
- ☒ Other (COVID-19, other medical):
- ☐ Coercion
- ☐ Physical
- ☐ Social

COVID-19 Exposure; Discomfort, including possibility of mild nausea, see section 14

*Note that if the investigator is using or accessing confidential or identifiable data, reach of confidentiality is always a risk.

6D. Corresponding Approval/ Oversight

- **Does the study include participant exposure to radiation?** ☐ **Yes** ☒ **No**
  If yes indicate: ☐ **DEXA** ☐ **PQCT** ☐ **Other**

- **Is IBC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, BUA # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Is IACUC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, PRN # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Does this study involve the Auburn University MRI Center?**
  ☐ **Yes** ☒ **No**

Which MRI(s) will be used for this project? (Check all that apply)
☐ **3T** ☐ **7T**

Continued on Page 3

Does any portion of this project require review by the MRI Safety Advisory Council?
☐ **Yes** ☒ **No**

Signature of one MRI Center Representative:_____
Required for all projects involving the AU MRI Center
Appropriate MRI Center Representatives:
Dr. Thomas S. Denney, Director AU MRI Center
Dr. Ron Beyers, MR Safety Officer

7. Project Assurances

7A. Principal Investigator's Assurances

1. I certify that all information provided in this application is complete and correct.
2. I understand that, as Principal Investigator, I have ultimate responsibility for the conduct of this study, the ethical performance this project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the Auburn University IRB.
3. I certify that all individuals involved with the conduct of this project are qualified to carry out their specified roles and responsibilities and are in compliance with Auburn University policies regarding the collection and analysis of the research data.
4. I agree to comply with all Auburn policies and procedures, as well as with all applicable federal, state, and local laws regarding the protection of human subjects, including, but not limited to the following:
    a. Conducting the project by qualified personnel according to the approved protocol
    b. Implementing no changes in the approved protocol or consent form without prior approval from the Office of Research Compliance
    c. Obtaining the legally effective informed consent from each participant or their legally responsible representative prior to their participation in this project using only the currently approved, stamped consent form
    d. Promptly reporting significant adverse events and / or effects to the Office of Research Compliance in writing within 5 working days of the occurrence.
5. If I will be unavailable to direct this research personally, I will arrange for a co-investigator to assume direct responsibility in my absence. This person has not been named as co-investigator in this application, or I will advise ORC, by letter, in advance of such arrangements.
6. I agree to conduct this study only during the period approved by the Auburn University IRB.
7. I will prepare and submit a renewal request and supply all supporting documents to the Office of Research Compliance before the approval period has expired if it is necessary to continue the research project beyond the time period approved by the Auburn University IRB.
8. I will prepare and submit a final report upon completion of this research project.

My signature indicates I have read, understand and agree to conduct this research project in accordance with the assurances listed above.

____Dan O'Leary_____	_____	_2/20/2023_
Principal Investigator Name	**Principal Investigator Signature**	**Date**

7B. Faculty Advisor / Sponsor's Assurances

1. I have read the protocol submitted for this project for content, clarity, and methodology.
2. By my signature as faculty advisor / sponsor on this research application, I certify that the student or guest investigator is knowledgeable about the regulations and policies governing research with human subjects and has sufficient training and experience to conduct this particular study in accord with the approved protocol.
3. I agree to meet with the investigator on a regular basis to monitor study progress. Should problems arise during the course of the study, I agree to be available, personally, to supervise the investigator in solving them.
4. I assure that the investigator will promptly report significant incidents and / or adverse events and / or effects to the ORC in writing within 5 working days of the occurrence.
5. If I will be unavailable, I will arrange for an alternate faculty sponsor to assume responsibility during my absence, and I will advise the ORC by letter of such arrangements. If the investigator is unable to fulfill requirements for submission of renewals, modifications or the final report, I will assume that responsibility.

Revised 07/12/2022

____Richard Sesek_____	_____	_____
Faculty Advisor / Sponsor Name	**Faculty Advisor Signature**	**Date**

Continued on Page 4

7C. Department Head's Assurance

By my signature as department head, I certify that I will cooperate with the administration in the application and enforcement of all Auburn University policies and procedures, as well as all applicable federal, state, and local laws regarding the protection and ethical treatment of human participants by researchers in my department

____Gregory Harris_____	_____	_____
Department Head Name	**Department Head Signature**	**Date**

8. Project Overview:

8A. A summary of relevant research findings leading to this research proposal:
*(Cite source; include a "Reference List" as **Appendix A**.)*

This experiment incorporates two separate but related investigations that employ similar methods. Each is described separately in sections of the proposal, as required. Where no distinction is made, the protocol is identical.

First Investigation

Augmented Reality (AR) systems "combine real and virtual, are interactive in real time, and are registered in 3-D" [1]. By realistically integrating informative and/or interactive virtual objects in our view of the world, AR aims to enhance the users' interaction with and perception of it. Its essential affordance is the direct and natural manipulation of virtual objects in everyday surroundings. Relative to metaphorical digital interfaces, this is thought to improve the uptake of knowledge by reducing the overall cognitive load and better distributing it across multiple sensory pathways [2]. AR-assisted learners demonstrate improved perception, performance, and understanding of spatial concepts, with outcomes correlated to the amount of physical engagement involved [3]. As a result, AR is thought to be well-suited for task-related learning. Using untethered, hands-free devices with optical see-through head-mounted displays, AR can continuously enhance the user's actions in the real world [4]. These benefits have broad industrial applications.

In manufacturing, operator support has been a common application of AR research and development since the early 1990s [5]. It is also seen as a source of innovative operator training methods required to meet rapidly increasing demand for skilled labor due to high retirement rates, global expansion, and increasing specialization [6]. Manufacturing support, training, and related applications have been identified in the areas of assembly, maintenance, operations, quality control, safety, design, visualization, logistics, and marketing [7].

Despite great potential, the adoption of AR is slowed by technical, market, and other important social and legal obstacles [8]. To successfully transition from research projects and proof of concepts and gain widespread adoption in manufacturing, AR must demonstrate a worthwhile return on investment [9; 10]. But AR remains a highly fragmented market, including a diverse selection of screen-based, projected, and head-mounted technologies [6]. Studies show that the efficacy of these systems varies with the task type, technology used, application design, and other factors [11]. Thus, the success rate of AR adoption in industry would be improved by frameworks for strategic decision making based on quantified benefits in various scenarios [12–14]. Research in this area is young but accelerating. Most of it focuses on efficiency (task time) and accuracy (error count). These are relevant but incomplete measures for assessing training outcomes, where the learning rate and transfer effectiveness must also be considered [15]. This investigation extends prior work [16] to explore the relationship between a variety of AR technologies and their underlying affordances [17] and learning outcomes for manufacturing assembly operations. By controlling for the task type and application design we hope to better understand the relative value of these systems, filling in important gaps that can lead to a cohesive framework for successful adoption.

Second Investigation

Cognitive load is challenging to measure but is essential in designing systems for worker safety, reliability, quality, and health [1]. Typically, cognitive load assessment is estimated by directly querying subjects using survey instruments such as the NASA Task Load Index (TLX) [1]. The NASA-TLX is perhaps the most widely used such instrument, having been adapted for use in many fields during its almost 40 years in application [2], [3].

In the National Occupational Research Agenda for Healthy Work Design and Well-Being (January 2020), the first objective is: "Identify and examine the impact of worker demographics on employer or organizational practices and worker safety, health, and well-being." [4] This is because worker characteristics can adversely affect these areas. I propose to include information on the participant's status of disability, particularly ADHD, to gather data on how the presence of this disability affects the worker's performance in a manufacturing setting. The goal is to gather data to develop best practices for workers with particular needs to increase worker safety, health, and overall well-being. ADHD is an optimal place to start with this type of investigation because of its high prevalence in society, an estimated 11% adults have some level of ADHD [5]. A study of days lost and safety incidents have also shown that adults with ADHD are twice as likely to have a safety mishap in the workplace [6]. This statistic highlights the importance of gathering more information on the mental load of persons with ADHD in the manufacturing environment and investigating ways to design the workplace to accommodate their specific needs. Reliable assessment of the presence of ADHD symptoms is effectively obtained through use of the World Health Organization Adult ADHD Self-Report Scale, which we have incorporated into our exit survey in both investigations [7].

Since the early 1990s, Lean Production (LP) has been widely used in manufacturing because of its effectiveness and efficiency in waste reduction, lead time shortening, and productivity improvement [8]. LP primarily focuses on standardizing work, reducing the non-value-added activities, shifting the production systems from capacity to demand-oriented, and installing a distributed production improvement system with closed loops between workstations [8]–[10]. Meanwhile, Industry 4.0 (I-4.0) technologies have also been diffused in manufacturing in the last decade, enabling cyber-physical systems, the Internet of Things (IoT), Augmented Reality (AR), Sensor technology, and others [{Citation}].

As both Lean and I-4.0 paradigms are being used in the manufacturing world simultaneously, a question raised by manufacturers: Is there any complementary effect of I-4.0 on the performance improvement of LP systems? We conducted a literature review to find the answer to the abovementioned question. In several studies, authors revealed a significant co-relationship between Lean & I-4 [5-8]. In a study, the authors mentioned that LP could be integrated with I-4.0 technologies to meet customers' changing demand [11].

In most cases, the complementary effects of Lean and I-4.0 are conceptual. For instance, the authors suggested integrating I-4.0 technology in the LP system to overcome some limitations of Lean [12], while they did not specify strategies [13]. It is stated that LP can be considered a pre-requisite for the I-4.0 application [14], but it is not demonstrated how Lean and I-4.0 co-exist together. Several authors also acknowledge that direction on how Lean and I-4.0 work together are immature [8], [15], [16].

The literature review revealed a gap in the current body of knowledge. The gap is a lack of empirical studies of the interaction between Lean and I-4.0. To answer this need, we plan to conduct an experimental investigation of the interaction between Lean and I-4.0.

8B. A brief summary/abstract of the study methodology, including design, population, and variables of interest. **(**350 word maximum, in language understandable to someone who is not familiar with your area of study. Note this summary/abstract can be used to prepare the concise summary in the consent document.):

Figure 1- LEGO Speedster Assembly

This experiment will be conducted in the Tiger Motors Lean Education Center, which simulates automotive manufacturing best practices using LEGO® cars. Participants will act as operators assembling the SUV (Model T) car at stations 8 and 10. This process has been used thousands of times in INSY 5/6800 without significant incident.

Figure 2 - Work Station 8

Figure 3- Work Station 10

First Investigation

A population of 40-60 adults will be recruited from Auburn University. Candidates with experience using head-mounted or projected AR or building cars in the Lean Lab will be excluded. Participants in this between-groups design will experience a single level of the Instructional Media Type (IMT) treatment, with increasingly augmented work instructions:

1. Paper Work Instructions (PWI): traditional printed instructions (control)
2. Projector Augmented Reality (PAR): interactive instructions projected on the work surface via the LightGuide system with a stationary model
3. Head-Mounted Display AR (HMDAR): interactive instructions presented in the user's field of view using the HoloLens2 (HL2) HMD with a stationary model
4. HMD Mixed Reality (HMDMR): extends the third treatment by leveraging advanced capabilities of the HL2, allowing for more natural interactions and movement of the model

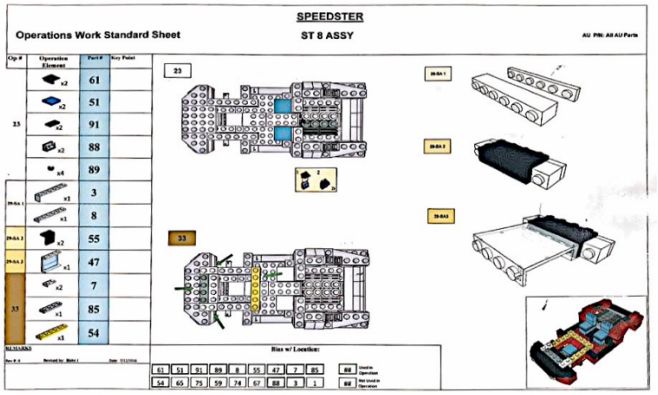

Figure 4 – Paper Work Instructions for Station 8

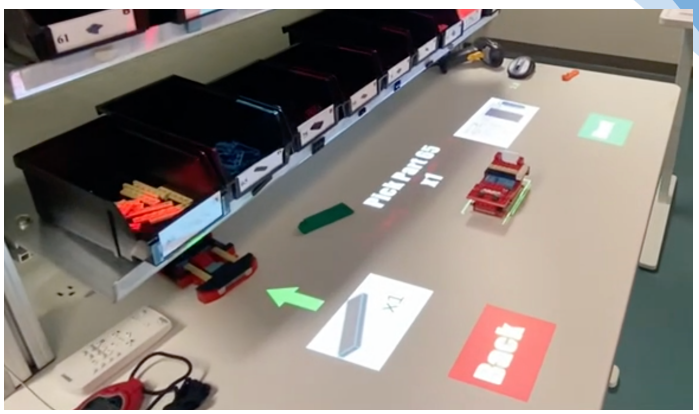

Figure 5- LightGuide Work Instructions

Participant groups will be set randomly. We hypothesize that HDMR will outperform other treatments in accuracy-based performance measures, as well as learning rate and transfer. In contrast, we expect participants assigned the PWI treatment to have the best times.

Figure 6 – HoloLens2 Wireless, See-Through Design

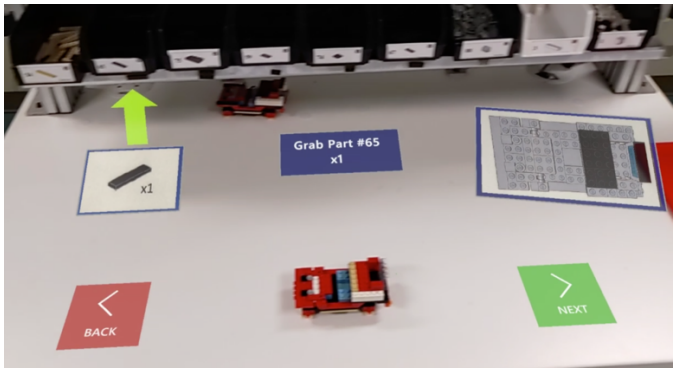

Figure 7- HoloLens2 Work Instructions, 1st Person View

First, participants will be shown how to interpret paper work instructions and use them to construct a sample LEGO assembly. Next, those assigned to an AR treatment level are given a brief introduction to its operation. Questions are allowed throughout this process.

The hypotheses are then tested in two phases. The first compares the effects of instructional media on the speed (task completion time) and accuracy (number and type of corrected and uncorrected errors) with which participants perform each repetition of the task. These measures are tracked for each assembly completed in the 10-minute session, allowing us to assess learning rates.

During the second phase, participants repeat the task four times in the control condition while the same measures are observed. Their results in each phase will be analyzed to compare transfer effectiveness between treatments.

Second Investigation

A population of 30-40 adults will be recruited from Auburn University. Participant treatment order will be set randomly. Participants in this within-subjects design will experience one of four scenarios in a random order:

1. Control: Paper Work Instructions (PWI): traditional printed instructions.
2. Lean Tool: Pre-made finished car provided for quality checks.
3. I-4.0 Tool: Inspection camera for quality check.
4. Lean + I-4.0 Tools: Pre-made finished car and inspection camera.

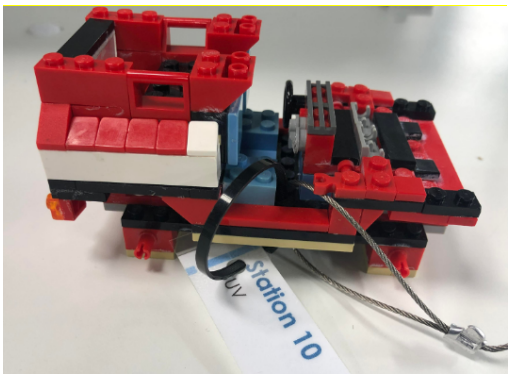

Figure 8- Pre-Made Finished Car Provided for Quality Checks

Before beginning any of the treatments, participants will be shown how to interpret the paper work instructions and use them to construct a sample LEGO assembly. Participants will practice the assembly five times. Questions are allowed throughout this process.

We hypothesize that treatment four will outperform other treatments in accuracy-based performance measures. In contrast, we expect treatment two to have the best times.

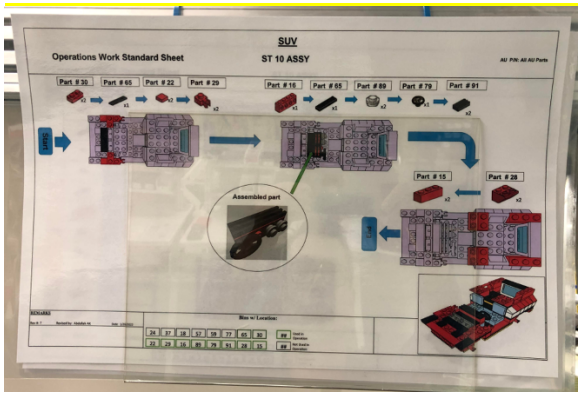

Figure 9 – Paper Work Instructions for Station 10

Figure 10 – Working Station 10

9. Purpose

9A. State the purpose of the study and all research questions or aims. (Include a sentence that begins, "The purpose of this study is…")

First Investigation

The purpose of this study is to measure the effect of instructional media type (IMT) on learning rates and skills transfer for industrial assembly tasks. The first phase will help us understand how each IMT affects the operator's learning rate (time or cycles to learn the process) and ultimate measures of performance (speed and accuracy). The second will help assess how learning transfer varies with each treatment. Finally, the exit surveys will help us understand the relationship between those results and perceived workload, system usability, and the participant's self-reported behavioral control.

Second Investigation

The purpose of this study is to measure the effect of Lean and I-4.0 Tools on process performance and quality.

Research questions:

- Does the interaction between Lean & I-4.0 tools significantly impact the operator Performance?

- Are there significant differences in the performance, cognitive load, and usability scales for participants with few self-reported behavioral control symptoms or many?

9B. Describe how results of this study will be used? (e.g., presentation? publication? thesis? dissertation?)
The data collected during this project will be used for thesis and dissertations, scholarly publications and presentations, and grant proposals.

10. Key Personnel. Describe responsibilities as specifically as possible. Include information on research training or certifications related to this project. **To determine key personnel see decision tree at https://cws.auburn.edu/OVPR/pm/compliance/irb/training. Submit a copy of CITI training documentation for all key personnel.** (For additional personnel, add lines as needed).

To determine Auburn University HIPAA – covered entities click link to HIPAA Policy.

If any key personnel have a formal association with institutions/entities involved in the study (for example is an employee or supervisor at the site research will occur), describe that affiliation. For all non-AU affiliated key personnel, submit a copy of their IRB approval.

Principal Investigator: Dan O'Leary **Rank/Title:** Graduate Student
Email Address: djo0008@auburn.edu **Degree(s):** BS ME, MS Eng Mgmt
Dept / Affiliation: Industrial & Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Overall responsibility for the project, including design and administration of experiments, coordinating recruitment, obtaining consent, and data collection and analysis.
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: n/a
- Plan for IRB approval for non-AU affiliated personnel? n/a
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: n/a
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 8/26/2025

Individual: Richard Sesek **Rank/Title:** Associate Professor
Email Address: rfs0006@auburn.edu **Degree(s):** BS, MS, MPH, PhD
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Advise, oversee, and assist with experiment design, IRB review process, obtaining consent, conducting trials, data collection and analysis.
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: n/a
- Plan for IRB approval for non-AU affiliated personnel? n/a
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: n/a
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 4/25/2023

Choose a course Expiration Date

Individual: Gregory Harris **Rank/Title:** Associate Professor
Email Address: gah0015@auburn.edu **Degree(s):** PhD
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Dissertation co-chair and primary advisor
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**

Revised 07/12/2022

- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 5/12/2024
  Choose a course Expiration Date

Individual: Gregory Purdy **Rank/Title:** Assistant Professor
Email Address: greg.purdy@auburn.edu **Degree(s):** PhD
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: primary advisor for second investigation

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 2/1/2026
  Choose a course Expiration Date

Individual: Victoria Ballard **Rank/Title:** Graduate Student
Email Address: vzb0024@auburn.edu **Degree(s):** BS CHE, MS CivE
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab manager, design and conduct research

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 2/9/2025
  Choose a course Expiration Date

Individual: Md Monir Hossain **Rank/Title:** Graduate Student
Email Address: mzh0116@auburn.edu **Degree(s):**BS BE, MS TM, MS ISE
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab assistant, design and conduct research

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 8/29/2025

Choose a course Expiration Date

Individual: Diego Roberto Caputo Rodriguez **Rank/Title:** Graduate Student
Email Address: drc0040@auburn.edu **Degree(s):**BS IE, MEM
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab assistant, assists conducting research
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 10/6/2025

Choose a course Expiration Date

Individual: Yuqing "Lucie" Wang **Rank/Title:** Graduate Student
Email Address: yzw0155@auburn.edu **Degree(s):**BS Geo, MS IE
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab assistant, assists conducting research
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 11/30/2025

Individual: Yen-Ting Guo **Rank/Title:** Graduate Student
Email Address: yzg0069@auburn.edu **Degree(s):**BS IE, MS IE
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab assistant, assists conducting research
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 9/10/2025

Individual: Alex Barras **Rank/Title:** Other (Undergraduate RA)
Email Address: jab0217@auburn.edu **Degree(s):** BS CS/SWE, Spr23
Dept. / Affiliation: Computer Science & Software Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Assist with administration of protocol
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No

Revised 07/12/2022

- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 1/13/2026
  Choose a course Expiration Date

Individual: David "Brown" Teague **Rank/Title:** Other (Undergraduate RA)
Email Address: dbt0013@auburn.edu **Degree(s):** BS CS/SWE, Spr23
Dept. / Affiliation: Computer Science & Software Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Assist with administration of protocol

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 1/16/2026
  Choose a course Expiration Date

Individual: Carson Tillery **Rank/Title:** Other (Undergraduate RA)
Email Address: cwt0013@auburn.edu **Degree(s):** BS CS/SWE, Spr23
Dept. / Affiliation: Computer Science & Software Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Assist with administration of protocol

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 1/15/2026
  Choose a course Expiration Date

Individual: Kralyn Thomas **Rank/Title:** Other (Undergraduate RA)
Email Address: kzt0044@auburn.edu **Degree(s):**n/a
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Assist with administration of protocol

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: AU Basic RCR Training 2/13/2026

11. Location of research.

Revised 07/12/2022

11A. List all locations where data collection will occur. If applicable, attach permission letters as Appendix E. (School systems, organizations, businesses, buildings and room numbers, servers for web surveys, etc.) **Be as specific as possible.** (See sample letters at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

Data collection will take place at the Lean Lab in the basement of the Shelby Center for Engineering Technology, room 0317, located at 345 W Magnolia Ave, Auburn, AL 36849

11B. Will study data be stored within a HIPAA covered facility? Yes ☐ No ☒

If yes, which facility(ies) (To determine AU HIPPA covered entities, go to VII of the HIPPA Hybrid Entity Policy)**:**

n/a

12. Participants (If minor participants, at least 2 adults must be present during all research procedures that include the minors.)

12A. Describe the targeted/ intended participant population for the study. Include the anticipated number of participants and inclusion and exclusion criteria and the procedures to ensure more than 1 adult is present during all research procedures which include the minor.

☐ **Check here if existing data will be used and describe the population from whom data was collected including the number of data files.**

☐ **Check here if permission to access existing data is required and submit a copy of the agreement to access.**

For both investigations a total of between 70 and 100 subjects will be recruited from the Auburn University community. Between 40 and 60 of those will participate in the first investigation, and 30 to 40 in the second. Potential participants in the first investigation will be screened for exclusion based on the following: 1. Under 18 years of age 2. Prone to motion sickness 3. Prior experience with head-mounted or projected AR systems 4. Prior experience building cars in the Lean Lab as part of INSY 5800/6800 or otherwise. Note that third item does not exclude those having experience with Virtual Reality headsets like the Occulus Rift, which are much more commonly available than AR devices. For the second investigation, any volunteer 18 or older will qualify. A shared screening form will be used for both investigations, and candidates will be assigned to one or both investigation(s) accordingly. Active recruiting efforts will focus on freshman and sophomore engineering students in Industrial & Systems Engineering (ISE), as they are accessible and are likely to meet all requirements.

12B. Describe, step-by-step in lay language all procedures to recruit participants. Include in **Appendix B** a copy of all e-mails, flyers, advertisements, recruiting scripts, invitations, etc., that will be used to invite people to participate. (See sample documents at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

Students and Faculty will be recruited using flyers distributed around the Auburn University campus. Additionally, ISE students will be recruited via in-class announcements and the distribution of emails. Copies of each are included in Appendix B. Interested participants will be instructed to contact the PI for more information. In the call that follows, the PI will: 1. Briefly explain the investigation, recapping and elaborating on the recruiting materials 2. Explain the exclusion criteria and identify relevant issues for the candidate 3. Set expectations for participant involvement, including time commitment and tasks 4. Answer any questions the candidate has regarding participation in the investigation If the candidate is ready and willing to proceed, their information will be collected using the Subject Recruitment Data Sheet provided in Appendix C. They will be assigned a unique participant ID, the investigation(s) most appropriate for their exclusions, and a date and time for data collection. If interest in either investigation exceeds capacity, additional participants will be thanked for their interest and informed that enrollment is limited. They will be given the option to remain "waitlisted" if additional participants or follow-up studies are required.

12C. Minimum number of participants required to validate the study? 30-40 for each investigation (total 70)

Number of participants expected to enroll? 35-50 for each investigation (total 100, without duplication)

Provide the rationale for the number of participants. Appropriate for the desired power given the number of treatments and expected differences in outcomes.

Is there a limit to the number of participants that will be included in the study?

☐ **No** ☒ **Yes, the number is** 100 in total, due to time constraints

12D. Describe the process to compensate, amount and method of compensation and/or incentives for participants. AU Procurement and Business Services (PBS) policies
(benefits to participants are NOT compensation)

If participants will not be compensated, check here: ☒
Indicate the amount of compensation per procedure and in total: Click or tap here to enter text.
Indicate the type of compensation: ☐ Monetary ☐ Incentives
☐ Raffle or Drawing incentive (Include the chances of winning.)
☐ Extra Credit (State the value)
☐ Other

Describe how compensation will be distributed (USPS, email, etc.): Click or tap here to enter text.

13. Project Design & Methods

13A. Describe, step-by-step, all procedures and methods that will be used to consent participants. If a waiver is being requested, indicate the waiver, and describe how the study meets the criteria for the waiver. If minors will be enrolled describe the process to obtain parental/ legally authorized guardian permission.

☐ Waiver of Consent (including using existing data)
☐ Waiver of Documentation of Consent (use of Information Letter)
☐ Waiver of Parental Permission (for college students 18 years or younger)

As each participant arrives, they will be welcomed and given brief introductions to members of the team administering the study. We will then ask them to review the consent document, encouraging them to ask any questions they have. After a verbal confirmation that the participant has read and is satisfied with the terms of this document, we will ask that they sign and date it.

13B. In lay language, understandable by someone not familiar with the area of study, describe the complete research design and methods that will be used to address the purpose. Include a clear description of who, when, where and how data will be collected. Include specific information about participants' time and effort.

First Investigation

Following the recruitment, eligibility screening, and consent processes described above, participants are asked to provide basic demographic information, read the NASA TLX instruction sheet, and complete a Behavior Control Survey based on the Adult ADHD Self-Report Scale (ASRSv1.1). Finally, emergency procedures are described, and the participant is given the opportunity to use the restroom. Once the intake process is complete, the participant is ushered to work station 8 where a short orientation process acclimates them to the work area. A research associate will point out the key features of a work cell (work surface, part bins, etc.), describe how to interpret the paperwork instructions, demonstrate typical assembly steps, and answer any relevant questions. (5-10 mins)

Next, participants assigned to any AR IMT (PAR, HMDAR, or HMDMR) will receive a brief demonstration of its basic operation. In all cases, the participant will be shown how to use the appropriate forward and back triggers, and how the system signals instructions and feedback related to part bin and placement. PAR and HMDAR users will be instructed that the model must remain in the fixture. HMDMR users will understand that the model can be freely manipulated during assembly. (5-10 mins)

Once orientation and training are complete, the experiment is conducted in two phases. Regardless of IMT assigned, all participants will wear the HL2 during both phases to control for its effects and allow us to record each session from their POV.

In the first phase, participants will be asked to complete the assembly process for as many cars as they can, while learning the steps and limiting the number of errors produced. This phase will be conducted with the support of the assigned IMT and will last 10 minutes. Observations will be recorded on Data Collection Sheet #1. During that time, we

expect that each participant will produce between 3 and 6 cars, based on prior performance data and the 60-second takt time for which the instructions were designed. (10 mins)

During a short break to reset the workstation, the participant will complete the NASA TLX and System Usability surveys for the assigned treatment. In the second phase each participant will build 4 more cars using only paper work instructions. Their stated goal will be to deliver error-free results quickly, while referencing the instructions only when necessary. Observations will be recorded on Data Collection Sheet #2. (5-10 mins)

Participant performance in both phases will be recorded on two cameras, one first-person view from onboard the HL2, and one third-person view from a camera mounted nearby. Experimental data will be derived from subsequent analysis of these videos. Participants will not be allowed to ask questions during either data collection phase of the experiment.

Once the experiment is concluded, each participant will complete an exit survey that incorporates the NASA TLX and System Usability Scale instruments for PWI. When the surveys are completed a research associate will solicit any additional general feedback, ask if the participant experienced any injury or discomfort, and invite them to attend a follow-up session for more in-depth exploration of the HoloLens2. Their responses will be recorded on the exit survey. (5-10 mins)

We conservatively estimate a total time commitment of 45-60 minutes for each participant.

Second Investigation

Following the recruitment, eligibility screening, and consent processes described above, participants are asked to provide basic demographic information, read the NASA TLX instruction sheet, and complete a Behavior Control Survey based on the Adult ADHD Self-Report Scale (ASRSv1.1). Finally, emergency procedures are described, and the participant is given the opportunity to use the restroom. Once the intake process is complete, the participant is ushered to work station 10 where a short orientation process acclimates them to the work area and emergency procedures are described. A research associate will point out the key features of a work cell (work surface, part bins, etc.), describe how to interpret the paperwork instructions, demonstrate typical assembly steps, and answer any relevant questions. Participants practice the station with four vehicles while researchers record results on Data Collection Sheet #2. (10-15 mins)

Next, participants will learn how to use the camera inspection I-4.0 tool. In all cases, the participant will be shown how to use the technology to find errors in the construction on the top of the vehicle and identify which part is incorrect.

In the first phase, participants will be asked to complete the assembly process for as many cars as they can and limit the number of errors produced. The participants will complete the four treatments in the order randomly selected for them, each treatment will last 10 minutes. During that time, we expect that each participant will produce between 3 and 6 cars, based on prior performance data and the 60-second cycle time for which the instructions were designed. Observations will be recorded on Data Collection Sheet #1. (10 mins) We expected approximately 5 minutes between treatments to have participants complete the NASA TLX and System Usability Scale. (Total of 55 minutes of treatment completion time).

Participant performance in all treatments will be recorded on two cameras, a third-person view from a camera mounted nearby, and a head-mounted device. Experimental data will be derived from subsequent analysis of these videos. Participants will not be allowed to ask questions during any data collection phase of the experiment. Once the experiment is concluded, each participant will complete an exit survey that incorporates the NASA TLX and System Usability Scale instruments. When the surveys are completed a research associate will solicit any additional general feedback and ask if the participant experienced any injury or discomfort, and invite them to attend a follow-up session for more in-depth exploration of Augmented Reality. Their responses will be recorded on the exit survey. (5-10 mins) We conservatively estimate a total time commitment of 70-90 minutes for each participant.

13C. List all data collection instruments used in this project, in the order they appear in Appendix C.
(e.g., surveys and questionnaires in the format that will be presented to participants, educational tests, data collection sheets, interview questions, audio/video taping methods etc.)

1. Subject Recruitment Data Sheet: filled out during the screening call; includes the exclusion checklist, participant number, basic demographics (age and gender), and date / time of scheduled trial
2. Code Sheet: collects the personally identifiable data for eligible participants, including name, contact info (phone, email) and subject number
3. Participant Intake Sheet: collects basic demographics and relevant prior experience

4. Data Collection Sheet: consists of general notes from the experiment and data derived from subsequent analysis of video recordings
5. NASA Task Load Index (TLX) instrument.
6. System Usability Scale (SUS) instrument.
7. Behavioral Control Survey based on the Adult ADHD Self-Report Scale (ASRSv1.1)
8. General feedback form to collect open-ended comments and to note any participant injury or discomfort as well as their interest in the follow-up session.

Additionally, video of each session will be recorded as described above, and pictures of the assembled LEGO vehicles will be taken after each task is completed. These items are not included in the Appendix.

13D. Data analysis: Describe how data will be analyzed. If a data collection form (DCF) will be used, submit a copy of the DCF.

In both investigations, the independent variable is treatment type, and the dependent variables are task completion time and number of errors. The dependent variables will be recorded for each car completed in both sessions.

Data will be analyzed with a combination of visual (e.g., box plots) and statistical methods. Methods based on analysis of variance (ANOVA) will be used to test the stated hypotheses. Additional analysis will be done to explore the relationship between other variables of interest, including demographics, mental workload, behavioral control, and system usability with the measured outcomes.

13E. List any drugs, medications, supplements, or imaging agents that participants will ingest/ receive during participation in the study or indicate not applicable (N/A).

n/a

14. Risks & Discomforts: List and describe all the risks participants may encounter in this research including risks from item 6d of this form, in this research. If deception will be part of the study, provide the rationale for the deception, describe the debriefing process, and attach a copy of the debriefing form that will be used as Appendix D. (Examples of possible risks are in section #6C)

1. Physical Discomfort: All participants will be required to wear the HoloLens2 device, regardless of treatment group to control for its effects on user fatigue, etc., and to allow us to record a first-person view of their session. As a result, they may experience mild physical discomfort including neck strain after prolonged use. The limited duration of this study should mitigate this effect.
2. Vestibular and Visual Discomfort: Participants assigned to the HMDAR and HMDMR treatments will experience display technology that may cause mild dizziness, eye strain, and related effects. Owing to the see-through design of the HoloLens2 device these effects are less common and less pronounced than seen in fully immersive Virtual Reality (VR) headsets.
3. Trip and Impact Risk: Any head-mounted display can reduce the wearer's peripheral vision and otherwise impact their natural field of view. Consequently, they may become more susceptible to tripping over or running into things around them. This risk is minimized by the HoloLens2's design, which offers a very wide, minimally obscured field of view. Furthermore, the HL2 is a standalone device, so there is no risk of tripping over a cord. Additionally, the participant is generally stationary in an environment free of obstruction. Finally, the Lean Lab is a clean, organized, safe, and well-lit environment with no history of related hazards.
4. Breach of Confidentiality Risk: All resulting data will be anonymized, and video of each session will be recorded from the first person and top-down angles to prevent participant exposure. That said, subjects could be seen entering, leaving, or during the experiment. All of these create a small possibility that subjects could be identified, inadvertently breaching their confidentiality. Additionally, there is the possibility that the subject code list, which connects each participant's identity with their experimental data, could be obtained. Mitigation methods for this risk are described in section 17 Protection of Data.
5. Psychological Discomfort: Due to the nature of the experiment, some participants may experience mild psychological discomfort induced by its time and performance-based measures. Participants will be told that their objective is to learn to perform the task quickly and error free. Otherwise, no overt pressure is put on the subjects to perform. Given that the outcome of their performance has no impact on their life outside the experiment, any related psychological discomfort should be minimal and short-lived.

6. COVID-19 Exposure: This study will be a Category C study with no High-Risk Procedures or Participants. Precautions will be implemented using the COVID-19 2022 Precautions Matrix to determine appropriate precautions at the time of data collection(s) for a Category C study. All work surfaces and the HMD will be wiped down before and after each participant. Necessary supplies will be made available, including as masks, hand sanitizer (60%+ alcohol), tissues, paper towels, trash baskets, and cleaners / disinfectants. All research participants will follow the University's guidance on self-screening. At the time of this writing, the CDC's COVID-19 community level for Lee County, Alabama is LOW, so participant screening is not required. The Shelby Center for Engineering Technology, where this protocol will be administered, is assigned the highest level of building readiness due to increased air turn-over and filtration. Further details and resources can be found in Appendix D.

15. Precautions / Minimization of Risks

15A. Identify and describe all precautions that will be taken to eliminate or reduce risks listed in items 6.c. and 14. If participants can be classified as a "vulnerable" population, describe additional safeguards that will be used to assure the ethical treatment of vulnerable individuals. **If applicable, submit a copy of any emergency plans/procedures and medical referral lists in Appendix D. (Sample documents can be found online at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs precautions)**

This study does not involve any vulnerable populations. Please see section 14, where the primary mitigations are described for each identified risk. Additionally, all participant activities will be supervised and monitored for relevant symptoms. If any participant experiences dizziness or related vestibular issues, or any other significant but unexpected side-effect, we will suspend the experiment, remove the HMD, have them sit and offer drinking water while assessing the situation. If escalation is required, the emergency plan and contact list is included in Appendix D. During the debriefing all participants will be asked if they were injured or experienced any discomfort during their trials. The debriefing also serves to keep each participant under our supervision long enough to ensure no lingering or delayed effects.

15B. If the internet, mobile apps, or other electronic means will be used to collect data, describe confidentiality and/or security precautions that will be used to protect (or not collect) identifiable data? Include protections used during collection of data, transfer of data, and storage of data. If participant data may be obtained and/or stored by apps during the study, describe.

n/a

15C. Does this research include purchase(s) that involve technology hardware, software or online services?

☐ **YES** ☒ **NO**

If YES:

A. **Provide the name of the product** Click or tap here to enter text.
and the manufacturer of the product Click or tap here to enter text.
B. **Briefly describe use of the product in the proposed human subject's research.**
Click or tap here to enter text.

C. **To ensure compliance with AU's Electronic and Information Technology Accessibility Policy, contact AU IT Vendor Vetting team at vetting@auburn.edu to learn the vendor registration process (prior to completing the purchase).**
D. **Include a copy of the documentation of the approval from AU Vetting with the revised submission.**

15D. Additional Safeguards

Will DEXA, pQCT, or other devices which emit radiation be used? ☐ Yes ☒ No
If yes, the IRB will notify the Auburn Department of Risk Management and Safety, who will contact the Alabama Department of Public Health (ADPH) and secure approval. Research which includes device(s) which emit radiation may NOT be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of ADPH approval.

Will a Certificate of Confidentiality (CoC) issued by NIH be obtained ☐ Yes ☒ No If yes, include CoC language in consent documents and include the documentation of CoC approval. Research which includes a CoC may not be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of CoC approval. AU Required CoC Language

Is the study a clinical trial? ☐ Yes ☒ No
If yes, provide the National Clinical Trial (NCT) # Click or tap here to enter text. **and include required clinical trial information in all consent documents. AU Clinical Trial Information**

16. Benefits

16A. List all realistic direct benefits participants can expect by participating in this study. (Compensation is not a benefit) If participants will not directly benefit check here. ☒

There are no direct benefits for participants in this study. It will offer all of them an opportunity to interact with projection and/or head-mounted AR hardware and training methods for the first time. This may lead them to a greater appreciation for the benefits and opportunities these technologies offer.

16B. List realistic benefits for the general population that may be generated from this study.

First Investigation
Turnover in the workforce and the lack of skilled labor necessitates scalable, efficient training methods. Furthermore, the shift from mass production to mass customization forces operators to contend with wide variance in the assembly steps required at each workstation. Together, these trends demand innovative methods for operator training and support.

Augmented and mixed reality are expected to help fill that need, but it is a fragmented market with a variety of solutions. Few studies explore the relationship between those methods (and the affordances that differentiate them) and corresponding learning rates and transfer. We believe this investigation will make meaningful contributions to that effort, helping to build a cohesive understanding of the utility of these systems and best practices for their application.

Second Investigation
The ultimate goal of this investigation is to develop a smart production system through the integration of Lean and Industry 4.0 (I-4.0) technology. However, still, in the literature, there is a research gap to see how the Lean and I-4.0 technologies are aligned. Through this investigation, this research gap would be mitigated. Additionally, the proposed production model will be transferred to Small and Medium Enterprises (SMEs), and thus millions of people will be benefited.

Additionally, by investigating the different impacts of technology and workplace changes on participants with few or many self-reported behavioral control symptoms, recommendations for future implementation can be made to best suit workers with conditions, such as ADD and ADHD. Designing manufacturing workplaces with an end goal of universal design that will be better suited for a variety of workers will benefit many in the workplace.

17. Protection of Data

17A. Data are collected:

☐ Anonymously with no direct or indirect coding, link, or awareness by key personnel of who participated in the study (skip to item E)

☐ Confidentially, but without a link to participant's data to any identifying information (collected as "confidential" but recorded and analyzed "anonymous") (Skip to item E).

☒ Confidentially with collection and protection of linkages to identifiable information.

17B. If data are collected with identifiers and coded or as coded or linked to identifying information, describe the identifiers and how identifiers are linked to participants' data.

In addition to the consent form, a code list will be maintained that includes identifying data of each participant (name, contact information, and ID number). This will be linked to all other data collection forms by the participant number. The consent forms and code list will be maintained on paper only, to facilitate secure storage and disposal (shredding). The consent form will not include reference to the participant's ID number. Only the code list will directly connect participants to their data.

The video recordings may also allow for participants to be identified, though the first-person recording will not allow a view of their face and the third-person view will focus on the work area. If the recorders do not provide a video-only option, audio from those sessions, which may also provide identifying data, will be stripped from the recordings before storage.

17C. Provide the rationale for need to code participants' data or link the data with identifying information.

Only for the purpose of contacting participants while the protocol is open. Once completed, the code list will be destroyed, making the data anonymous.

17D. Describe how and where identifying data and/or code lists will be stored. (Building, room number, AU BOX?) **Describe how the location where data is stored will be secured. For electronic data, describe security measures. If applicable, describe where IRB-approved and participant signed consent documents will be kept on campus for 3 years after the study ends.**

Signed consent forms and the code list will be kept in a secure, locked file in offices 3301J (first investigation) or 0317 (second investigation) of Shelby Center.

17E. Describe how and where data will be stored (e.g., hard copy, audio/ visual files, electronic data, etc.), and how the location where data is stored is separated from identifying data and will be secured. For electronic data, describe security. Note use of a flash drive or portable hard drive is not appropriate if identifiable data will be stored; rather, identifying participant data must be stored on secured servers.

All electronic data pertaining to the study will be stored on a secured server. Non-identifiable data will be available to other members of the research team.

17F. List the names of all who will have access to participants' data? (If a student PI, the faculty advisor must have full access and be able to produce study data in the case of a federal or institutional audit.)

- Consent forms and code list: Dan O'Leary, Victoria Ballard, Md Monir Hossain, Dr. Richard Sesek, Dr. Gregory Purdy
- Non-identifiable data: full research team, by request

17G. When is the latest date that identifying information or links will be retained and how will that information or links be destroyed? (Check here if only anonymous data will be retained ☒)

December 2023

AUBURN UNIVERSITY

INDUSTRIAL & SYSTEMS ENGINEERING

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
for a Research Study entitled

Studying Manufacturing with LEGO® Research

Concise Summary

You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the consent form. The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technologies on productivity, learning rates, and skills transfer for industrial assembly tasks. Following an initial phone screening, the experiment will be scheduled at your convenience. After a brief orientation, you will be asked to learn a simulated manufacturing assembly task – building model "cars" with LEGO® bricks. For this phase you will be randomly assigned an order to complete the following treatments: paper work instructions (PWI), assembly with a pre-completed model for quality checks, an inspection camera for quality checks, and both the pre-completed model and inspection camera. You will be asked to complete four car assemblies for training using the paper work instructions prior to using the prescribed tasks. After the training, each treatment will last 10 minutes for a total of four treatments. Paper work instructions will remain available for reference as needed. Between each task you will be asked to complete two brief surveys about your experience. Finally, you will be asked to complete a survey with questions about the experience and related personal traits. The entire process will take 70-90 minutes.

This study has some risk of physical and psychological discomfort, including fatigue and performance anxiety. Finally, all of your personally identifiable data is carefully secured to protect against the risk of a breach of confidentiality. Your safety and privacy is our utmost priority, and steps have been taken to mitigate all known risks.

Beyond the opportunity to experience training in the Tiger Motors Lab, there are no direct benefits to you for participating in this study. The researchers will benefit from a greater understanding of this emerging field that could potentially benefit the community. The alternative is to not participate in this study.

You are invited to participate in a research study to measure the effect of Lean Tools and Industry 4.0 Technologies on productivity. The study is being conducted by Victoria Ballard and Md Monir Hossain, Ph. D. students, under the direction of Dr. Richard Sesek, Tim Cook Associate Professor in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you meet all the following qualifications:

1. Are age 18 or older.

What will be involved if you participate?
If you decide to participate in this research study, you will be asked to follow work instructions to build LEGO car models in a realistic manufacturing setting. Your total time commitment will -be approximately 70-90 minutes. Video of your session will be recorded for later analysis. Camera placement is designed to prevent / limit the capture of personally identifiable imagery.

Are there any risks or discomforts?
The risks associated with participating in this study are identified below.

1. Psychological discomfort may be experienced by those prone to anxiety when encountering time and performance-based measures.
2. Participant confidentiality may be breached if identifying data is compromised or participants are observed entering, leaving, or taking part in the experiment.

Confidentiality of the study data is of utmost importance. All research personnel are trained in research ethics and are aware of procedures to protect the confidentiality of participants and associated data. Paper files with personally identifiable information will be secured in an office that only the PI and Faculty Advisor have access to. Electronic data, including video recordings, will be maintained on a password-protected computer accessible only to the research team.

Are there any benefits to yourself or others?
There are no direct benefits from participating in this study. However, it is a unique opportunity for eligible participants to participate in research in the Tiger Motors Lab. This may lead them to a greater appreciation for the benefits and opportunities these technologies offer.

Will you receive compensation for participating?
No compensation is offered for your participation.

Are there any costs?
There is no cost for you to participate in this study. Auburn University has not provided for any payment if you are harmed as a result of participating in this study.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering or any member of the research team.

Your privacy will be protected. Any information obtained in connection with this study will remain confidential. Information obtained through your participation may be used in a variety of capacities, including fulfillment of educational requirements, publication in professional journals, and/or presentation at professional meetings. In any case, your identity will not be revealed, and your information will remain private.

If you have questions about this study, please ask now or contact Victoria Ballard at victoria.ballard@auburn.edu,360-632-1359, or Dr. Richard Sesek at rfs0006@auburn.edu, 334-728-1438. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

_____	_____
Participant's signature Date	Investigator obtaining consent Date
_____	_____
Printed Name	Printed Name

Appendix A - Reference List

First Investigation

[1] R. T. Azuma, "A Survey of Augmented Reality," *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355-385, 1997

[2] B. E. Shelton and N. R. Hedley, "Exploring a Cognitive Basis for Learning Spatial Relationships with Augmented Reality," *Technology, Instruction, Cognition and Learning*, vol. 1, no. 4, 2003

[3] C. Chen *et al.*, "Using Microsoft HoloLens to improve memory recall in anatomy and physiology: A pilot study to examine the efficacy of using augmented reality in education," *Journal of Educational Technology Development and Exchange*, vol. 12, no. 1, 2019

[4] S. N. Leonard and R. N. Fitzgerald, "Holographic learning: A mixed reality trial of Microsoft HoloLens in an Australian secondary school," *Research in Learning Technology*, vol. 26, no. 0, 2018

[5] R. T. Azuma and G. Bishop, "Improving Static and Dynamic Registration in an Optical See-through HMD Proceedings of the 21st Annual Conference on Computer Graphics and Interactive Techniques," *SIGGRAPH '94*, pp. 197-204, 1994

[6] B. C. Kress, "Optical Architectures for Augmented-, Virtual-, and Mixed-Reality Headsets," SPIE, 2020.

[7] E. Oztemel and S. Gursev, "Literature Review of Industry 4.0 and Related Technologies," *Journal of Intelligent Manufacturing*, vol. 31, pp. 127-182, 2020

[8] R. T. Azuma, "The road to ubiquitous consumer augmented reality systems," *Human Behavior and Emerging Technologies*, vol. 1, pp. 26-32, 2019

[9] T. Masood and J. Egger, "Augmented reality in support of Industry 4.0—Implementation challenges and success factors," *Robotics and Computer-Integrated Manufacturing*, vol. 58, pp. 181-195, 2019

[10] T. Masood and J. Egger, "Adopting augmented reality in the age of industrial digitalisation," *Computers in Industry*, vol. 115, pp. 103112, 2020

[11] A. D. Kaplan *et al.*, "The Effects of Virtual Reality, Augmented Reality, and Mixed Reality as Training Enhancement Methods: A Meta-Analysis," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 63, no. 4, pp. 706-726, 2021

[12] S. Borsci *et al.*, "Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance," *Computers in Industry*, vol. 67, pp. 17-26, 2015

[13] J. Jetter *et al.*, "Augmented reality tools for industrial applications: What are potential key performance indicators and who benefits," *Computers in Human Behavior*, vol. 87, pp. 18-33, 2018

[14] O. Danielsson *et al.*, "Augmented reality smart glasses in industrial assembly: Current status and future challenges," *Journal of Industrial Information Integration*, vol. 20, pp. 100175, 2020

[15] S. Büttner *et al.*, "Augmented Reality Training for Industrial Assembly Work - Are Projection-based AR Assistive Systems an Appropriate Tool for Assembly Training," *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 2020

[16] V. Havard *et al.*, "A use case study comparing augmented reality (AR) and electronic document-based maintenance instructions considering tasks complexity and operator competency level," *Virtual Reality*, vol. 25, no. 4, pp. 999-1014, 2021

[17] D. Parsons and K. MacCallum, "Current Perspectives on Augmented Reality in Medical Education: Applications, Affordances and Limitations," *Advances in Medical Education and Practice*, vol. Volume 12, pp. 77-91, 2021

Second Investigation

[1] A. Giorgi *et al.*, "Wearable Technologies for Mental Workload, Stress, and Emotional State Assessment during Working-Like Tasks: A Comparison with Laboratory Technologies," *Sensors*, vol. 21, no. 7, Art. no. 7, Jan. 2021, doi: 10.3390/s21072332.

[2] H. Devos *et al.*, "Psychometric Properties of NASA-TLX and Index of Cognitive Activity as Measures of Cognitive Workload in Older Adults," *Brain Sci.*, vol. 10, no. 12, Art. no. 12, Dec. 2020, doi: 10.3390/brainsci10120994.

[3] S. G. Hart, "Nasa-Task Load Index (NASA-TLX); 20 Years Later," Nov. 2016, doi: 10.1177/154193120605000909.

[4] "CDC - NORA - Healthy Work Design and Well-Being Sector Agenda," Jan. 30, 2020. https://www.cdc.gov/nora/councils/hwd/research-agenda.html (accessed Apr. 18, 2022).

[5] "Attention-Deficit/Hyperactivity Disorder (ADHD)," *National Institute of Mental Health (NIMH)*. https://www.nimh.nih.gov/health/statistics/attention-deficit-hyperactivity-disorder-adhd (accessed Apr. 19, 2022).

[6] R. C. Kessler, M. Lane, P. E. Stang, and D. L. V. Brunt, "The prevalence and workplace costs of adult attention deficit hyperactivity disorder in a large manufacturing firm," *Psychol. Med.*, vol. 39, no. 1, pp. 137–147, Jan. 2009, doi: 10.1017/S0033291708003309.

[7] R. C. Kessler, L. A. Adler, M. J. Gruber, C. A. Sarawate, T. Spencer, and D. L. Van Brunt, "Validity of the World Health Organization Adult ADHD Self-Report Scale (ASRS) Screener in a representative sample of health plan members," *Int. J. Methods Psychiatr. Res.*, vol. 16, no. 2, pp. 52–65, 2007, doi: 10.1002/mpr.208.

[8] M. P. Ciano, P. Dallasega, G. Orzes, and T. Rossi, "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study," *Int. J. Prod. Res.*, vol. 59, no. 5, pp. 1386–1410, Mar. 2021, doi: 10.1080/00207543.2020.1821119.

[9] J. P. Womack and D. T. Jones, "From lean production to lean enterprise.," *Harv. Bus. Rev.*, vol. 72, no. 2, 1994, Accessed: Jun. 26, 2022. [Online]. Available: https://elibrary.ru/item.asp?id=1991549

[10] V. L. Bittencourt, A. C. Alves, and C. P. Leão, "Lean Thinking contributions for Industry 4.0: a Systematic Literature Review," *IFAC-Pap.*, vol. 52, no. 13, pp. 904–909, Jan. 2019, doi: 10.1016/j.ifacol.2019.11.310.

[11] D. Kolberg, J. Knobloch, and D. Zühlke, "Towards a lean automation interface for workstations," *Int. J. Prod. Res.*, vol. 55, no. 10, pp. 2845–2856, May 2017, doi: 10.1080/00207543.2016.1223384.

[12] M. P. Ciano, P. Dallasega, G. Orzes, and T. Rossi, "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study," *Int. J. Prod. Res.*, vol. 59, no. 5, pp. 1386–1410, 2021.

[13] L. S. Dalenogare, G. B. Benitez, N. F. Ayala, and A. G. Frank, "The expected contribution of Industry 4.0 technologies for industrial performance," *Int. J. Prod. Econ.*, vol. 204, pp. 383–394, Oct. 2018, doi: 10.1016/j.ijpe.2018.08.019.

[14] G. Tortorella, R. Sawhney, D. Jurburg, I. C. de Paula, D. Tlapa, and M. Thurer, "Towards the proposition of a Lean Automation framework: Integrating Industry 4.0 into Lean Production," *J. Manuf. Technol. Manag.*, vol. 32, no. 3, pp. 593–620, Jan. 2020, doi: 10.1108/JMTM-01-2019-0032.

[15] B. Wang, J. Zhao, Z. Wan, J. Ma, H. Li, and J. Ma, "Lean Intelligent Production System and Value Stream Practice," 2016, doi: 10.12783/DTEM/ICEM2016/4106.

[16] M. Rossini, F. Costa, G. L. Tortorella, and A. Portioli-Staudacher, "The interrelation between Industry 4.0 and lean production: an empirical study on European manufacturers," *Int. J. Adv. Manuf. Technol.*, vol. 102, no. 9, pp. 3963–3976, Jun. 2019, doi: 10.1007/s00170-019-03441-7.

Appendix B - Recruiting Materials

In-Class Recruiting Script

Hello, Class.

Industrial Engineering graduate students pursuing their PhDs are recruiting participants for a research study. They are investigating the effectiveness of Mixed Reality, Lean, and Industry 4.0 methods for operator training and support in manufacturing. These investigations hope to better understand the relationships between those methods, learning effectiveness, and operator performance. A flyer with details of the study will be emailed to each of you. If you are interested, please follow up as described therein.

Email Script

Dear Student,

Please review the attached flyer, which provides details of the study recently described in __class name__. You are invited to participate in a research study on the effectiveness of Mixed Reality, Lean, and Industry 4.0 methods for operator training and support in manufacturing. The research team is conducting this study as Ph.D. Candidates under the supervision of Dr. Richard Sesek, Tim Cook Associate Professor in the Department of Industrial and Systems Engineering at Auburn University.

If you would like to participate, simply respond to this email or via text / phone to 407-399-3189. Questions or concerns can be directed to me through the same channels, or you may contact my advisor Dr. Sesek (sesek@auburn.edu).

Thank you for your consideration,

Confirmation Email

Dear <student name>,

Thank you for your interest in our study, and for taking the time to discuss it with me. I'm happy to confirm that your trial is scheduled as follows:

Date and Time:<date and time>

Location: Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab), in the basement of the Shelby Center for Engineering Technology, room 0317, located at 345 W Magnolia Ave, Auburn, AL 36849

Please arrive on time. We anticipate that it will take 45-90 minutes to complete the session.

If you need to reschedule or have further questions, feel free to respond to this email or call / text me at 407-399-3189.

Thank you for your participation,

Flyer

On the following pages are flyers for both investigations, formatted as posters and slides.

Augmented Reality Research Study

Training methods for tomorrow's workforce, today!

The Effects of Augmented Instruction on Manufacturing Assembly Training

Interested in Augmented and Mixed Reality?
Want to experience the latest in Projected and Head-Mounted AR?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of augmented instruction on learning rates and skills transfer for industrial assembly tasks. The effect of projected (LightGuide) and head-mounted (HoloLens2) augmented reality methods will be compared with paper-based materials for instruction and support.

This study is open to anyone 18 and older, that isn't prone to motion sickness, has no prior experience with head-mounted or projected AR systems and hasn't worked in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise.

Microsoft HoloLens

LightGuide

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the QR code to generate an email.

Scan to Email!

Studying Manufacturing with LEGO(R) Research

Participate in research in Auburn's Tiger Motors Lab!

The Effects of Lean Tools and Industry 4.0 Technology on Manufacturing Assembly Performance

Want to help the future of manufacturing research?
Want to use the latest vision inspection equipment and play with LEGO?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technology on industrial assembly tasks. The effect of a model check piece, camera inspection technology, and a combination of the two will be compared with paper-based materials. Participants will assemble one station of LEGO vehicles in four scenarios. The time for completion is approximately 1.5 hours. No compensation for the study, but you will get to build LEGO cars in the world-famous Auburn Tiger Motors Lean Education Center (AKA LEGO Lab!).

This study is open to anyone 18 and older.

TIGER MOTORS
LEAN EDUCATION CENTER

AUBURN
UNIVERSITY

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the QR code to generate an email.

Scan to Email!

Augmented Reality Research Study

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If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the included QR code to generate an email.

Scan to Email!

Microsoft HoloLens

LightGuide

Studying Manufacturing with LEGO®

The Effects of Lean Tools & Industry 4.0 Technology on Manufacturing Assembly Performance

Want to help the future of manufacturing research?
Want to use the latest vision inspection equipment and play with LEGO?
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Participants will assemble one station of LEGO vehicles in four scenarios. The time for completion is approximately 1.5 hours. No compensation for the study, but you will get to build LEGO cars in the world-famous Auburn Tiger Motors Lean Education Center (AKA LEGO Lab)!

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If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the included QR code to generate an email.

Scan to Email!

TIGER MOTORS
LEAN EDUCATION CENTER

Appendix C - Data Collection Instruments

See attached, on the pages that follow:

1. Subject Recruitment Data Sheet
2. Code Sheet
3. Participant Intake Sheet
4. Data Collection Sheet #1
5. Data Collection Sheet #2
6. Task Loading Index (NASA TLX)
7. System Usability Scale
8. Behavioral Control Survey
9. General Feedback

Subject Recruitment Data Sheet

Eligibility Checklist:

- ☐ 18 or older
- ☐ Not prone to motion sickness
- ☐ No prior experience with projected or head-mounted augmented reality systems
- ☐ No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and subject number in code sheet.

Participant Number: _____

Gender: _____

Age: _____

Eligible: ____ I1 ____ I2 ____ Both

Scheduled Trial(s): _____

Notes:

Eligibility Checklist:

- ☐ 18 or older
- ☐ Not prone to motion sickness
- ☐ No prior experience with projected or head-mounted augmented reality systems
- ☐ No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and participant number in code sheet.

Participant Number: _____

Gender: _____

Age: _____

Eligible: ____ I1 ____ I2 ____ Both

Scheduled Trial(s): _____

Notes:

Participant Intake Sheet, p1 / 2

Participant #: _____ **Date: _____**

1. Gender:
   - ☐ Female
   - ☐ Male
   - ☐ Other
2. Age: _____
3. Race (select those with which you identify):
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African-American
   - ☐ Native Hawaiian or Other Pacific Islander
   - ☐ White
   - ☐ More than one race
   - ☐ Unknown or not reported
4. Ethnicity (select ONLY one with which you most closely identify):
   - ☐ Hispanic or Latino
   - ☐ Not Hispanic or Latino
   - ☐ Unknown or not reported
5. Country of Origin: _____
6. What language do you mainly speak at home?
   - ☐ English
   - ☐ Other
7. What is the highest level of school you have completed or the highest degree you have received?
   - ☐ Less than high school degree
   - ☐ High school degree or equivalent (e.g., GED)
   - ☐ Some college but no degree
   - ☐ Associate degree
   - ☐ Bachelor degree
   - ☐ Graduate degree: ____ Master or ____ PhD

Participant #: _____ **Date: _____**

8. If you are currently pursuing a degree, please complete the following:

   College (e.g. Education or Business): _____

   Program (e.g. MS Adult Ed or BS Accounting) : _____

9. Which of the following statements best describes your experience building LEGO models?

   - ☐ I have little to no experience building LEGO models.
   - ☐ I have some experience building LEGO models.
   - ☐ I have lots of experience building LEGO models.
   - ☐ I consider myself an expert in building LEGO models.

10. Please indicate your level of manufacturing experience

    - ☐ I have no experience in manufacturing.
    - ☐ I have taken one or more classes in manufacturing.
    - ☐ I have held a part-time or temporary position in manufacturing.
    - ☐ I have 1 or more years of experience working in manufacturing.

Code Sheet

Part. #	Date	Name	Email	Phone	Assigned	Notes
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	

Data Collection Sheet #1

Participant #: _____ **Date:** _____

First Investigation
Circle Training Treatment:
PWI / PAR / HMDAR / HMDMR

Second Investigation	
Treatment Number	**Treatment**
1 / 2 / 3 / 4	Control / Lean / I-4.0 / Lean+I-4.0

Car #	**TCT**	**Errors Made**		**Uncorrected Error Types**			**PWI Ref Count**	**Trial Notes**
		Corrected	**Uncorrected**	**Sel**	**Pos**	**Rot**		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Observer Initials: _____

Data Collection Sheet #2

Participant #: _____ **Date:** _____

First Investigation
Circle Training Treatment:
PWI / PAR / HMDAR / HMDMR

Second Investigation
Training with
Paper Work Instructions

Car #	**TCT**	**Errors Made**		**Uncorrected Error Types**			**PWI Ref Count**	**Trial Notes**
		Corrected	**Uncorrected**	**Sel**	**Pos**	**Rot**		
1								
2								
3								
4								

General Notes:

Observer Initials: _____

Task Loading Index, p1 / 2

Participant #: _____ **Invest / Treat:** _____ **Date:** _____

Sources of Workload

Consider the following definitions:

Title	Range	Description
Mental Demand	Low / High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low / High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experiment (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

For each of the following pairs, circle the word that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

Effort or **Performance**	**Temporal Demand** or **Frustration**	**Physical Demand** or **Performance**	**Temporal Demand** or **Mental Demand**	**Mental Demand** or **Physical Demand**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**	**Frustration** or **Effort**	**Performance** or **Mental Demand**	**Effort** or **Physical Demand**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**	**Performance** or **Temporal Demand**	**Mental Demand** or **Effort**	**Frustration** or **Mental Demand**

Task Loading Index, p2 / 2

Participant #: _____ Invest / Treat: _____ Date: _____

Workload Rating Sheet

For each of the following 6 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

1. How mentally demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

2. How physically demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

3. How hurried or rushed was the pace of the task?

1	2	3	4	5	6	7
Very Low						Very High

4. How successful were you in accomplishing what you were asked to do?

1	2	3	4	5	6	7
Perfect						Failure

5. How hard did you have to work to accomplish your level of performance?

1	2	3	4	5	6	7
Very Low						Very High

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1	2	3	4	5	6	7
Very Low						Very High

System Usability Scale

Participant #: _____ Invest / Treat: _____ Date: _____

For each of the following 10 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

		Strongly Agree				Strongly Disagree
1	I think that I would like to use this system frequently.	1	2	3	4	5
2	I found the system unnecessarily complex.	1	2	3	4	5
3	I thought the system was easy to use.	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5	I found the various functions in this system were well integrated.	1	2	3	4	5
6	I thought there was too much inconsistency in this system.	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8	I found the system very cumbersome to use.	1	2	3	4	5
9	I felt very confident using the system.	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Behavioral Control Survey

Participant #: _____ Date: _____

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					

General Feedback

Participant #: _____ Date: _____

Please share with us any other feedback you have regarding this experiment.

For Research Associate Only

Follow-up? _____ Injury? _____ Discomfort? _____ Initial: _____

Appendix D - Emergency Plan, Contact List, and COVID Resources

Emergency Action Plan

In Case of Emergency ***DIAL 911***

For non-emergency assistance:

Service	On-Campus	Off-Campus
Ambulance (EMS)	9-749-8504	334-749-8504
City of Auburn Police	9-501-3100	334-501-3100
Auburn Medical Pavilion	9-364-3000	334-364-3000
East Alabama Medical Center, Opelika	9-749-3411	334-749-3411

Research Team Contact List:

Contact	Phone	Email
Dan O'Leary, Principal Investigator	407-399-3189 (cell)	djo0008@auburn.edu
Dr. Richard Sesek, Faculty Advisor	334-728-1438 (cell)	rfs0006@auburn.edu
Victoria Ballard, Graduate Student	360-632-1359 (cell)	vzb0024@auburn.edu
Dr. Gregory Harris, Faculty Advisor	334-844-1407 (office)	gah0015@auburn.edu
Dr. John Evans, Faculty Advisor	334-844-1418 (office)	evansjl@auburn.edu
Tom Devall, Tiger Motors Director	334-740-3905 (office)	tld0017@auburn.edu
Industrial & Systems Engineering Department	334-844-4340 (main office)	insy@eng.auburn.edu

Lab Location and Access:

Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab), Basement, Shelby Center, Auburn University, room 0317. Street address: 345 W Magnolia Ave, Auburn, AL 36849.

Elevator access: exit the lab and turn left

Stairwell access: exit the lab, turn left, proceed around the elevator in either direction. Stairwell entrance is on the inside wall behind the elevator.

Emergency exit: exit the lab and turn right. Continue to exit at ground level.

Emergency Equipment:

First aid kit, eye wash and shower station are present, as are fire extinguisher and alarm pull.

COVID-19 Resources

CDC COVID-19 Data Tracker for Lee County, Alabama

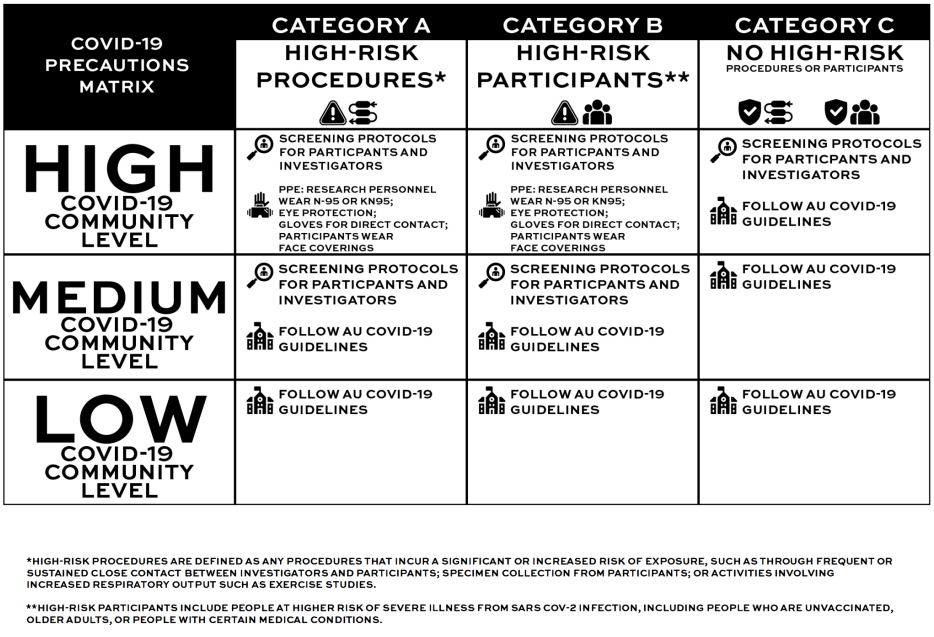
University Policies for Research Exposure and Related Resources:

- Human Research COVID-19 Precautions
- COVID-19 Guidance on Self Screening
- AU Facilities COVID Building Readiness Status Page

Auburn University Screening Protocol (source):

> All research participants should be screened remotely (by phone or Zoom) for fever, cough, and flu-like symptoms the day before, with a repeat screening at the time of an in-person visit. Appropriate screening questions might include the following, which could be modified to fit your participant population and the location of in-person interactions:
>
> 1. Do you have a fever or Respiratory Symptoms? Symptoms include fever, acute respiratory infection, persistent cough, sore throat, fatigue and shortness of breath, or sudden loss of taste or smell with or without a fever.
> 2. Are you waiting on COVID-19 test results?
> 3. Have you been asked to self-isolate by your doctor?
> 4. In the past three weeks, have you visited another state, country, or facility with a substantial or high community COVID-19 level (see CDC COVID-19 Community Levels)?
> 5. Health/Vaccination Status - Do you have underlying medical conditions, or are you unvaccinated?

Precautions Matrix:



*HIGH-RISK PROCEDURES ARE DEFINED AS ANY PROCEDURES THAT INCUR A SIGNIFICANT OR INCREASED RISK OF EXPOSURE, SUCH AS THROUGH FREQUENT OR SUSTAINED CLOSE CONTACT BETWEEN INVESTIGATORS AND PARTICIPANTS; SPECIMEN COLLECTION FROM PARTICIPANTS; OR ACTIVITIES INVOLVING INCREASED RESPIRATORY OUTPUT SUCH AS EXERCISE STUDIES.

**HIGH-RISK PARTICIPANTS INCLUDE PEOPLE AT HIGHER RISK OF SEVERE ILLNESS FROM SARS COV-2 INFECTION, INCLUDING PEOPLE WHO ARE UNVACCINATED, OLDER ADULTS, OR PEOPLE WITH CERTAIN MEDICAL CONDITIONS.

Appendix E - CITI Training Documentation

See attached, on the pages that follow:

1. Dan O'Leary (3)
2. Victoria Ballard (9)
3. Gregory Harris (1)
4. Richard Sesek (3)
5. Gregory Purdy (3)
6. Md Monir Hossain (6)
7. Diego Roberto Caputo Rodriguez (1)
8. Alex Barras (1)
9. Brown Teague (1)
10. Carson Tillery (1)
11. Kralyn Thomas (1)
12. Yen-Ting Guo (1)
13. Yuqing "Lucie" Wang (1)

Clean Modified Forms for Restamp

AUBURN
UNIVERSITY

INDUSTRIAL & SYSTEMS
ENGINEERING

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
for a Research Study entitled

Studying Manufacturing with LEGO® Research

Concise Summary

You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the consent form. The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technologies on productivity, learning rates, and skills transfer for industrial assembly tasks. Following an initial phone screening, the experiment will be scheduled at your convenience. After a brief orientation, you will be asked to learn a simulated manufacturing assembly task – building model "cars" with LEGO® bricks. For this phase you will be randomly assigned an order to complete the following treatments: paper work instructions (PWI), assembly with a pre-completed model for quality checks, an inspection camera for quality checks, and both the pre-completed model and inspection camera. You will be asked to complete four car assemblies for training using the paper work instructions prior to using the prescribed tasks. After the training, each treatment will last 10 minutes for a total of four treatments. Paper work instructions will remain available for reference as needed. Between each task you will be asked to complete two brief surveys about your experience. Finally, you will be asked to complete a survey with questions about the experience and related personal traits. The entire process will take 70-90 minutes.

This study has some risk of physical and psychological discomfort, including fatigue and performance anxiety. Finally, all of your personally identifiable data is carefully secured to protect against the risk of a breach of confidentiality. Your safety and privacy is our utmost priority, and steps have been taken to mitigate all known risks.

Beyond the opportunity to experience training in the Tiger Motors Lab, there are no direct benefits to you for participating in this study. The researchers will benefit from a greater understanding of this emerging field that could potentially benefit the community. The alternative is to not participate in this study.

You are invited to participate in a research study to measure the effect of Lean Tools and Industry 4.0 Technologies on productivity. The study is being conducted by Victoria Ballard and Md Monir Hossain, Ph. D. students, under the direction of Dr. Richard Sesek, Tim Cook Associate Professor in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you meet all the following qualifications:

1. Are age 18 or older.

What will be involved if you participate?
If you decide to participate in this research study, you will be asked to follow work instructions to build LEGO car models in a realistic manufacturing setting. Your total time commitment will -be approximately 70-90 minutes. Video of your session will be recorded for later analysis. Camera placement is designed to prevent / limit the capture of personally identifiable imagery.

Are there any risks or discomforts?
The risks associated with participating in this study are identified below.

1. Psychological discomfort may be experienced by those prone to anxiety when encountering time and performance-based measures.
2. Participant confidentiality may be breached if identifying data is compromised or participants are observed entering, leaving, or taking part in the experiment.

Confidentiality of the study data is of utmost importance. All research personnel are trained in research ethics and are aware of procedures to protect the confidentiality of participants and associated data. Paper files with personally identifiable information will be secured in an office that only the PI and Faculty Advisor have access to. Electronic data, including video recordings, will be maintained on a password-protected computer accessible only to the research team.

Are there any benefits to yourself or others?
There are no direct benefits from participating in this study. However, it is a unique opportunity for eligible participants to participate in research in the Tiger Motors Lab. This may lead them to a greater appreciation for the benefits and opportunities these technologies offer.

Will you receive compensation for participating?
No compensation is offered for your participation.

Are there any costs?
There is no cost for you to participate in this study. Auburn University has not provided for any payment if you are harmed as a result of participating in this study.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering or any member of the research team.

Your privacy will be protected. Any information obtained in connection with this study will remain confidential. Information obtained through your participation may be used in a variety of capacities, including fulfillment of educational requirements, publication in professional journals, and/or presentation at professional meetings. In any case, your identity will not be revealed, and your information will remain private.

If you have questions about this study, please ask now or contact Victoria Ballard at victoria.ballard@auburn.edu,360-632-1359, or Dr. Richard Sesek at rfs0006@auburn.edu, 334-728-1438. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

_____	_____
Participant's signature Date	Investigator obtaining consent Date
_____	_____
Printed Name	Printed Name

The Auburn University Institutional Review Board has approved this Document for use from
02/21/2023 to ----------
Protocol # 22-538 EP 2301

Appendix B - Recruiting Materials

In-Class Recruiting Script

Hello, Class.

Industrial Engineering graduate students pursuing their PhDs are recruiting participants for a research study. They are investigating the effectiveness of Mixed Reality, Lean, and Industry 4.0 methods for operator training and support in manufacturing. These investigations hope to better understand the relationships between those methods, learning effectiveness, and operator performance. A flyer with details of the study will be emailed to each of you. If you are interested, please follow up as described therein.

Email Script

Dear Student,

Please review the attached flyer, which provides details of the study recently described in __class name__. You are invited to participate in a research study on the effectiveness of Mixed Reality, Lean, and Industry 4.0 methods for operator training and support in manufacturing. The research team is conducting this study as Ph.D. Candidates under the supervision of Dr. Richard Sesek, Tim Cook Associate Professor in the Department of Industrial and Systems Engineering at Auburn University.

If you would like to participate, simply respond to this email or via text / phone to 407-399-3189. Questions or concerns can be directed to me through the same channels, or you may contact my advisor Dr. Sesek (sesek@auburn.edu).

Thank you for your consideration,

Confirmation Email

Dear <student name>,

Thank you for your interest in our study, and for taking the time to discuss it with me. I'm happy to confirm that your trial is scheduled as follows:

Date and Time:<date and time>

Location: Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab), in the basement of the Shelby Center for Engineering Technology, room 0317, located at 345 W Magnolia Ave, Auburn, AL 36849

Please arrive on time. We anticipate that it will take 45-90 minutes to complete the session.

If you need to reschedule or have further questions, feel free to respond to this email or call / text me at 407-399-3189.

Thank you for your participation,

Flyer

On the following pages are flyers for both investigations, formatted as posters and slides.

Studying Manufacturing with LEGO(R) Research

Participate in research in Auburn's Tiger Motors Lab!

The Effects of Lean Tools and Industry 4.0 Technology on Manufacturing Assembly Performance

Want to help the future of manufacturing research?
Want to use the latest vision inspection equipment and play with LEGO?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technology on industrial assembly tasks. The effect of a model check piece, camera inspection technology, and a combination of the two will be compared with paper-based materials. Participants will assemble one station of LEGO vehicles in four scenarios. The time for completion is approximately 1.5 hours. No compensation for the study, but you will get to build LEGO cars in the world-famous Auburn Tiger Motors Lean Education Center (AKA LEGO Lab!).

This study is open to anyone 18 and older.

TIGER MOTORS
LEAN EDUCATION CENTER

AUBURN UNIVERSITY

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the QR code to generate an email.

Scan to Email!

The Auburn University Institutional Review Board has approved this Document for use from 02/21/2023 to ----------
Protocol # 22-538 EP 2301

Augmented Reality Research Study

The Effects of Augmented Instruction on Manufacturing Assembly Training

Interested in Augmented and Mixed Reality?
Want to experience the latest in Projected and Head-Mounted AR?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of augmented instruction on learning rates and skills transfer for industrial assembly tasks. The effect of projected (LightGuide) and head-mounted (HoloLens2) augmented reality methods will be compared with paper-based materials for instruction and support.

This study is open to anyone 18 and older, that isn't prone to motion sickness, has no prior experience with head-mounted or projected AR systems, and hasn't worked in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab)as part of INSY 5/6800 or otherwise.

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the included QR code to generate an email.

Scan to Email!

Microsoft HoloLens

LightGuide

The Auburn University Institutional Review Board has approved this Document for use from 02/21/2023 to ----------
Protocol # 22-538 EP 2301

Studying Manufacturing with LEGO®

The Effects of Lean Tools & Industry 4.0 Technology on Manufacturing Assembly Performance

Want to help the future of manufacturing research?
Want to use the latest vision inspection equipment and play with LEGO?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of Lean Tools and Industry 4.0 Technology on industrial assembly tasks. The effect of a model check piece, camera inspection technology, and a combination of the two will be compared with paper-based materials.

Participants will assemble one station of LEGO vehicles in four scenarios. The time for completion is approximately 1.5 hours. No compensation for the study, but you will get to build LEGO cars in the world-famous Auburn Tiger Motors Lean Education Center (AKA LEGO Lab)!

This study is open to anyone 18 and older.

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the included QR code to generate an email.

Scan to Email!

TIGER MOTORS
LEAN EDUCATION CENTER

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Protocol # 22-538 EP 2301

Subject Recruitment Data Sheet

Eligibility Checklist:

- ☐ 18 or older
- ☐ Not prone to motion sickness
- ☐ No prior experience with projected or head-mounted augmented reality systems
- ☐ No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and subject number in code sheet.

Participant Number: _____

Gender: _____

Age: _____

Eligible: ____ I1 ____ I2 ____ Both

Scheduled Trial(s): _____

Notes:

Eligibility Checklist:

- ☐ 18 or older
- ☐ Not prone to motion sickness
- ☐ No prior experience with projected or head-mounted augmented reality systems
- ☐ No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and participant number in code sheet.

Participant Number: _____

Gender: _____

Age: _____

Eligible: ____ I1 ____ I2 ____ Both

Scheduled Trial(s): _____

Notes:

Code Sheet

Part. #	Date	Name	Email	Phone	Assigned	Notes
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	
					1 2	

CONFIDENTIAL **PAGE ___ of ___**

Data Collection Sheet #1

Participant #: _____ **Date:** _____

First Investigation
Circle Training Treatment:
PWI / PAR / HMDAR / HMDMR

Second Investigation	
Treatment Number	**Treatment**
1 / 2 / 3 / 4	Control / Lean / I-4.0 / Lean+I-4.0

Car #	TCT	Errors Made		Uncorrected Error Types			PWI Ref Count	Trial Notes
		Corrected	Uncorrected	Sel	Pos	Rot		
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								

Observer Initials: _____

Data Collection Sheet #2

Participant #: _____ **Date:** _____

First Investigation
Circle Training Treatment:
PWI / PAR / HMDAR / HMDMR

Second Investigation
Training with
Paper Work Instructions

Car #	TCT	Errors Made		Uncorrected Error Types			PWI Ref Count	Trial Notes
		Corrected	Uncorrected	Sel	Pos	Rot		
1								
2								
3								
4								

General Notes:

Observer Initials: _____

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Protocol # 22-538 EP 2301

Task Loading Index, p1 / 2

Participant #: _____ **Invest / Treat:** _____ **Date:** _____

Sources of Workload

Consider the following definitions:

Title	Range	Description
Mental Demand	Low / High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low / High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experiment (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

For each of the following pairs, circle the word that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

Effort or **Performance**	**Temporal Demand** or **Frustration**	**Physical Demand** or **Performance**	**Temporal Demand** or **Mental Demand**	**Mental Demand** or **Physical Demand**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**	**Frustration** or **Effort**	**Performance** or **Mental Demand**	**Effort** or **Physical Demand**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**	**Performance** or **Temporal Demand**	**Mental Demand** or **Effort**	**Frustration** or **Mental Demand**

Task Loading Index, p2 / 2

Participant #: _____ Invest / Treat: _____ Date: _____

Workload Rating Sheet

For each of the following 6 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

1. How mentally demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

2. How physically demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

3. How hurried or rushed was the pace of the task?

1	2	3	4	5	6	7
Very Low						Very High

4. How successful were you in accomplishing what you were asked to do?

1	2	3	4	5	6	7
Perfect						Failure

5. How hard did you have to work to accomplish your level of performance?

1	2	3	4	5	6	7
Very Low						Very High

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1	2	3	4	5	6	7
Very Low						Very High

System Usability Scale

Participant #: _____ Invest / Treat: _____ Date: _____

For each of the following 10 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

		Strongly Agree				Strongly Disagree
1	I think that I would like to use this system frequently.	1	2	3	4	5
2	I found the system unnecessarily complex.	1	2	3	4	5
3	I thought the system was easy to use.	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5	I found the various functions in this system were well integrated.	1	2	3	4	5
6	I thought there was too much inconsistency in this system.	1	2	3	4	5
7	I would imagine that most people would learn to use this system very quickly.	1	2	3	4	5
8	I found the system very cumbersome to use.	1	2	3	4	5
9	I felt very confident using the system.	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this system.	1	2	3	4	5

Behavioral Control Survey

Participant #: _____ **Date:** _____

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					

General Feedback

Participant #: _____ **Date: _____**

Please share with us any other feedback you have regarding this experiment.

For Research Associate Only

Follow-up? _____ Injury? _____ Discomfort? _____ Initial: _____

All Current IRB Stamped Documents

AUBURN UNIVERSITY INSTITUTIONAL REVIEW BOARD for RESEARCH INVOLVING HUMAN SUBJECTS

PROTOCOL REVIEW FORM
FULL BOARD or EXPEDITED REVIEW

For assistance, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**
Submit completed form and supporting materials as one PDF through the IRB Submission Page
Handwritten forms are not accepted. Where links are found hold down the control button (Ctrl) then click the link.

1. Proposed Start Date of Study:1/11/2023 Today's Date: January 4, 2023
Submission Status (Check One): ☐ New ☒ Revisions (to address IRB Review Comments)
Proposed Review Category (Check One): ☐ Full Board (greater than minimal risk) ☒ Expedited
If Expedited, Indicate Category(ies) ((Link to Expedited Category Review Sheet) 6

2. Project Title: The Effects of Augmented Instruction on Manufacturing Assembly Training

3. Principal Investigator (PI): Dan O'Leary Degree(s): BS Mech Eng, MS Eng Mgmt
Rank/Title: Graduate Student Department/School: Industrial & Systems Engineering
Role/responsibilities in this project: Organize and conduct research, perform data collection and analysis
Preferred Phone Number: 407-399-3189 AU Email: djo0008@auburn.edu

Faculty Advisor Principal Investigator (if applicable): Richard Sesek
Rank/Title: Associate Professor Department/School: Industrial & Systems Engineering
Role/responsibilities in this project: Supervise and advise the design and execution of the experiment
Preferred Phone Number: 334-728-1438 AU Email: rfs0006@auburn.edu

Department Head: Gregory Harris Department/School: Industrial & Systems Engineering
Preferred Phone Number: 334-844-1407 AU Email: gah0015@auburn.edu
Role/responsibilities in this project: Dissertation co-chair and primary project advisor

4. Funding Support: ☒ N/A ☐ Internal External Agency: n/a Pending ☐ Received ☐
For federal funding, list funding agency and grant number (if available): n/a

5. a) List any contractors, sub-contractors, and other entities associated with this project: n/a

b) List any other AU IRB approved protocols associated with this study and describe the association: n/a

c) List any other institutions associated with this study and submit a copy of their IRB approval(s): n/a

Protocol Packet Checklist

Check all applicable boxes. A completed checklist is required.

☒ **Protocol Review Form** (All required signatures included and all sections completed)
(Examples of appended documents are found on the website: https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

☒ **CITI Training Certificates** for key personnel

☒ **Consent Form or Information Letter** and any releases (audio, video or photo) that participants will review and/or sign

☒ **Appendix A** "Reference List"

☒ **Appendix B** if e-mails, flyers, advertisements, social media posts, generalized announcements or scripts, etc., will be used to recruit participants.

☒ **Appendix C** if data collection sheets, surveys, tests, other recording instruments, interview scripts, etc. will be used for data collection. Attach documents in the order they are listed in item 13c.
Continued on Page 2

☒ **Appendix D** if they study will use a debriefing form or will include emergency plans/ procedures and medical referral lists. (A referral list may be attached to the consent document.)

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Protocol # 22-538 EP 2301

☐ **Appendix E** if research is being conducted at sites other than Auburn University or in cooperation with other entities. A **permission letter** from the site/ program director must be included indicating their cooperation or involvement in the project. NOTE: If the proposed research is a multi-site project, involving investigators or participants at other academic institutions, hospitals or private research organizations, a letter of **IRB approval** from each entity is required prior to initiating the project.

☐ **Appendix F** Written evidence of approval by the host country, local IRB or institutions if research is conducted outside the United States

6. General Research Project Characteristics

6A. Research Methodology

Check all descriptions that best apply to the research methodology.

Data Source(s): ☒ New Data ☐ Existing Data

Will recorded data directly or indirectly identify participants?
☒ Yes ☐ No

Data collection will involve the use of:

- ☒ Educational Tests (cognitive diagnostic, aptitude, etc.)
- ☒ Interview
- ☒ Observation
- ☐ Locations or Tracking Measures
- ☐ Physical / Physiological Measures or Specimens
- ☒ Surveys / Questionnaires
- ☐ Other: Click or tap here to enter text.
- ☒ Internet / Electronic
- ☒ Audio
- ☒ Video
- ☐ Photos
- ☐ Digital Images
- ☐ Private records or files

6B. Participant Information

Check all descriptors that apply to the TARGET population.
(link to definition of target population)
☐ Males ☐ Females ☐ AU students

Vulnerable Populations
☐ Pregnant Women/Fetuses ☐ Prisoners ☐ Institutionalized
☐ Children and / or Adolescents (under age 18 in AL; if minor participants, at least 2 adults must be present during all research procedures that include the minors)

Persons with:
☐ Economic Disadvantages ☐ Physical Disabilities
☐ Educational Disadvantages ☐ Intellectual Disabilities

Will participants be compensated? ☐ Yes ☒ No

6C. Risks to Participants

Identify all risks participants might encounter in this research.

- ☒ Breach of Confidentiality*
- ☐ Deception
- ☐ Psychological
- ☐ None
- ☒ Other (COVID-19, other medical):
- ☐ Coercion
- ☐ Physical
- ☐ Social

COVID-19 Exposure; Discomfort, including possibility of mild nausea, see section 14

*Note that if the investigator is using or accessing confidential or identifiable data, reach of confidentiality is always a risk.

6D. Corresponding Approval/ Oversight

- **Does the study include participant exposure to radiation?** ☐ **Yes** ☒ **No**
  If yes indicate: ☐ **DEXA** ☐ **PQCT** ☐ **Other**

- **Is IBC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, BUA # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Is IACUC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, PRN # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Does this study involve the Auburn University MRI Center?**
  ☐ **Yes** ☒ **No**

  Which MRI(s) will be used for this project? (Check all that apply)
  ☐ **3T** ☐ **7T**

Continued on Page 3

Does any portion of this project require review by the MRI Safety Advisory Council?

☐ **Yes** ☒ **No**

Signature of one MRI Center Representative:_____

Required for all projects involving the AU MRI Center

Appropriate MRI Center Representatives:

Dr. Thomas S. Denney, Director AU MRI Center

Dr. Ron Beyers, MR Safety Officer

7. Project Assurances

7A. Principal Investigator's Assurances

1. I certify that all information provided in this application is complete and correct.
2. I understand that, as Principal Investigator, I have ultimate responsibility for the conduct of this study, the ethical performance this project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the Auburn University IRB.
3. I certify that all individuals involved with the conduct of this project are qualified to carry out their specified roles and responsibilities and are in compliance with Auburn University policies regarding the collection and analysis of the research data.
4. I agree to comply with all Auburn policies and procedures, as well as with all applicable federal, state, and local laws regarding the protection of human subjects, including, but not limited to the following:
    a. Conducting the project by qualified personnel according to the approved protocol
    b. Implementing no changes in the approved protocol or consent form without prior approval from the Office of Research Compliance
    c. Obtaining the legally effective informed consent from each participant or their legally responsible representative prior to their participation in this project using only the currently approved, stamped consent form
    d. Promptly reporting significant adverse events and / or effects to the Office of Research Compliance in writing within 5 working days of the occurrence.
5. If I will be unavailable to direct this research personally, I will arrange for a co-investigator to assume direct responsibility in my absence. This person has not been named as co-investigator in this application, or I will advise ORC, by letter, in advance of such arrangements.
6. I agree to conduct this study only during the period approved by the Auburn University IRB.
7. I will prepare and submit a renewal request and supply all supporting documents to the Office of Research Compliance before the approval period has expired if it is necessary to continue the research project beyond the time period approved by the Auburn University IRB.
8. I will prepare and submit a final report upon completion of this research project.

My signature indicates I have read, understand and agree to conduct this research project in accordance with the assurances listed above.

____Dan O'Leary_____	_____	1/4/2023
Principal Investigator Name	**Principal Investigator Signature**	**Date**

7B. Faculty Advisor / Sponsor's Assurances

1. I have read the protocol submitted for this project for content, clarity, and methodology.
2. By my signature as faculty advisor / sponsor on this research application, I certify that the student or guest investigator is knowledgeable about the regulations and policies governing research with human subjects and has sufficient training and experience to conduct this particular study in accord with the approved protocol.
3. I agree to meet with the investigator on a regular basis to monitor study progress. Should problems arise during the course of the study, I agree to be available, personally, to supervise the investigator in solving them.
4. I assure that the investigator will promptly report significant incidents and / or adverse events and / or effects to the ORC in writing within 5 working days of the occurrence.
5. If I will be unavailable, I will arrange for an alternate faculty sponsor to assume responsibility during my absence, and I will advise the ORC by letter of such arrangements. If the investigator is unable to fulfill requirements for submission of renewals, modifications or the final report, I will assume that responsibility.

____Richard Sesek_____	_____	1/4/2023
Faculty Advisor / Sponsor Name	**Faculty Advisor Signature**	**Date**

Continued on Page 4

Revised 07/12/2022

7C. Department Head's Assurance

By my signature as department head, I certify that I will cooperate with the administration in the application and enforcement of all Auburn University policies and procedures, as well as all applicable federal, state, and local laws regarding the protection and ethical treatment of human participants by researchers in my department

Gregory Harris		1/4/23
Department Head Name	**Department Head Signature**	**Date**

8. Project Overview:

8A. A summary of relevant research findings leading to this research proposal:
*(Cite source; include a "Reference List" as **Appendix A**.)*

Augmented Reality (AR) systems "combine real and virtual, are interactive in real time, and are registered in 3-D" [1]. By realistically integrating informative and/or interactive virtual objects in our view of the world, AR aims to enhance the users' interaction with and perception of it. Its essential affordance is the direct and natural manipulation of virtual objects in everyday surroundings. Relative to metaphorical digital interfaces, this is thought to improve the uptake of knowledge by reducing the overall cognitive load and better distributing it across multiple sensory pathways [2]. AR-assisted learners demonstrate improved perception, performance, and understanding of spatial concepts, with outcomes correlated to the amount of physical engagement involved [3]. As a result, AR is thought to be well-suited for task-related learning. Using untethered, hands-free devices with optical see-through head-mounted displays, AR can continuously enhance the user's actions in the real world [4]. These benefits have broad industrial applications.

In manufacturing, operator support has been a common application of AR research and development since the early 1990s [5]. It is also seen as a source of innovative operator training methods required to meet rapidly increasing demand for skilled labor due to high retirement rates, global expansion, and increasing specialization [6]. Manufacturing support, training, and related applications have been identified in the areas of assembly, maintenance, operations, quality control, safety, design, visualization, logistics, and marketing [7].

Despite great potential, the adoption of AR is slowed by technical, market, and other important social and legal obstacles [8]. To successfully transition from research projects and proof of concepts and gain widespread adoption in manufacturing, AR must demonstrate a worthwhile return on investment [9; 10]. But AR remains a highly fragmented market, including a diverse selection of screen-based, projected, and head-mounted technologies [6]. Studies show that the efficacy of these systems varies with the task type, technology used, application design, and other factors [11]. Thus, the success rate of AR adoption in industry would be improved by frameworks for strategic decision making based on quantified benefits in various scenarios [12–14]. Research in this area is young but accelerating. Most of it focuses on efficiency (task time) and accuracy (error count). These are relevant but incomplete measures for assessing training outcomes, where the learning rate and transfer effectiveness must also be considered [15]. This study extends prior work [16] to explore the relationship between a variety of AR technologies and their underlying affordances [17] and learning outcomes for manufacturing assembly operations. By controlling for the task type and application design we hope to better understand the relative value of these systems, filling in important gaps that can lead to a cohesive framework for successful adoption.

8B. A brief summary/abstract of the study methodology, including design, population, and variables of interest.
(350 word maximum, in language understandable to someone who is not familiar with your area of study. Note this summary/abstract can be used to prepare the concise summary in the consent document.):

This experiment will be conducted in the Tiger Motors Lean Education Center, which simulates automotive manufacturing best practices using LEGO® cars. Participants will act as operators assembling the SUV car at station 8. This process has been used thousands of times in INSY 5/6800 without significant incident.

Figure 1 - Work Station 8

Figure 2- LEGO Speedster Assembly

A population of 40-60 adults will be recruited from Auburn University. Candidates with experience using head-mounted or projected AR or building cars in the Lean Lab will be excluded. Participants in this between-groups design will experience a single level of the Instructional Media Type (IMT) treatment, with increasingly augmented work instructions:

1. Paper Work Instructions (PWI): traditional printed instructions (control)
2. Projector Augmented Reality (PAR): interactive instructions projected on the work surface via the LightGuide system with a stationary model
3. Head-Mounted Display AR (HMDAR): interactive instructions presented in the user's field of view using the HoloLens2 (HL2) HMD with a stationary model
4. HMD Mixed Reality (HMDMR): extends the third treatment by leveraging advanced capabilities of the HL2, allowing for more natural interactions and movement of the model

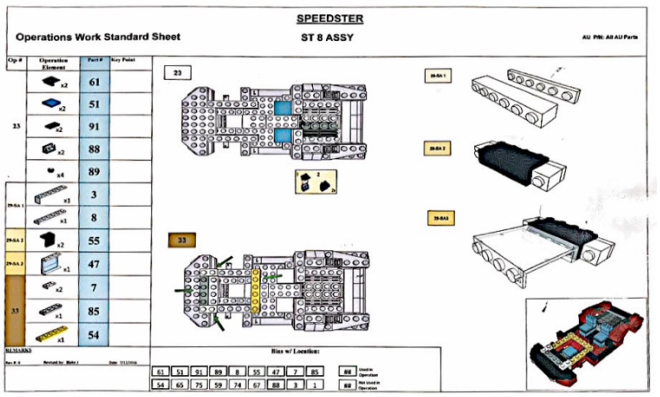

Figure 3 – Paper Work Instructions for Station 8

Figure 4- LightGuide Work Instructions

Participant groups will be set randomly. We hypothesize that HDMR will outperform other treatments in accuracy-based performance measures, as well as learning rate and transfer. In contrast, we expect participants assigned the PWI treatment to have the best times.

Figure 5 – HoloLens2 Wireless, See-Through Design

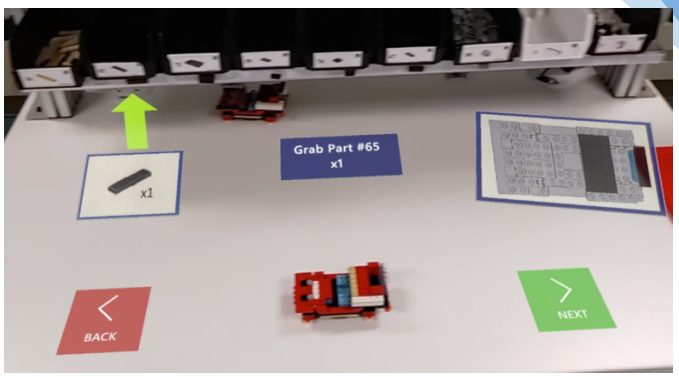

Figure 6- HoloLens2 Work Instructions, 1st Person View

First, participants will be shown how to interpret paper work instructions and use them to construct a sample LEGO assembly. Next, those assigned to an AR treatment level are given a brief introduction to its operation. Questions are allowed throughout this process.

The hypotheses are then tested in two phases. The first compares the effects of instructional media on the speed (task completion time) and accuracy (number and type of corrected and uncorrected errors) with which participants perform each repetition of the task. These measures are tracked for each assembly completed in the 10-minute session, allowing us to assess learning rates.

During the second phase, participants repeat the task four times in the control condition while the same measures are observed. Their results in each phase will be analyzed to compare transfer effectiveness between treatments.

9. Purpose

9A. State the purpose of the study and all research questions or aims. (Include a sentence that begins, "The purpose of this study is…")

The purpose of this study is to measure the effect of instructional media type (IMT) on learning rates and skills transfer for industrial assembly tasks. The first phase will help us understand how each IMT affects the operator's learning rate (time or cycles to learn the process) and ultimate measures of performance (speed and accuracy). The second will help assess how learning transfer varies with each treatment.

9B. Describe how results of this study will be used? (e.g., presentation? publication? thesis? dissertation?)
The data collected during this project will be used for thesis and dissertations, scholarly publications and presentations, and grant proposals.

10. Key Personnel. Describe responsibilities as specifically as possible. Include information on research training or certifications related to this project. **To determine key personnel see decision tree at https://cws.auburn.edu/OVPR/pm/compliance/irb/training. Submit a copy of CITI training documentation for all key personnel.** (For additional personnel, add lines as needed).

To determine Auburn University HIPAA – covered entities click link to HIPAA Policy.

If any key personnel have a formal association with institutions/entities involved in the study (for example is an employee or supervisor at the site research will occur), describe that affiliation. For all non-AU affiliated key personnel, submit a copy of their IRB approval.

Principal Investigator: Dan O'Leary **Rank/Title:** Graduate Student
Email Address: djo0008@auburn.edu **Degree(s):** BS ME, MS Eng Mgmt
Dept / Affiliation: Industrial & Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Overall responsibility for the project, including design and administration of experiments, coordinating recruitment, obtaining consent, and data collection and analysis.
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: n/a
- Plan for IRB approval for non-AU affiliated personnel? n/a
- Do you have any known competing financial interests, personal relationships, or other interests that could have

influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: n/a
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 8/26/2025

Individual: Richard Sesek **Rank/Title:** Associate Professor
Email Address: rfs0006@auburn.edu **Degree(s):** BS, MS, MPH, PhD
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Advise, oversee, and assist with experiment design, IRB review process, obtaining consent, conducting trials, data collection and analysis.
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: n/a
- Plan for IRB approval for non-AU affiliated personnel? n/a
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: n/a
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 4/25/2023

Choose a course Expiration Date

Individual: Gregory Harris **Rank/Title:** Associate Professor
Email Address: gah0015@auburn.edu **Degree(s):** PhD
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Dissertation co-chair and primary advisor
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 5/12/2024

Choose a course Expiration Date

Individual: Victoria Ballard **Rank/Title:** Graduate Student
Email Address: vzb0024@auburn.edu **Degree(s):** BS CHE, MS CivE
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Lab manager, design and conduct research
- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 2/9/2025

Choose a course Expiration Date

Revised 07/12/2022

Individual: Md Monir Hossain **Rank/Title:** Graduate Student

Email Address: mzh0116@auburn.edu **Degree(s):**BS BE, MS TM, MS ISE

Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**

Roles / Responsibilities: Lab assistant, design and conduct research

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: **n/a**
- Plan for IRB approval for non-AU affiliated personnel? **n/a**
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: **n/a**
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed: Human Sciences Basic Course 8/29/2025

Choose a course Expiration Date

11. Location of research.

11A. List all locations where data collection will occur. If applicable, attach permission letters as Appendix E. (School systems, organizations, businesses, buildings and room numbers, servers for web surveys, etc.) **Be as specific as possible.** (See sample letters at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

Data collection will take place at the Lean Lab in the basement of the Shelby Center for Engineering Technology, room 0317, located at 345 W Magnolia Ave, Auburn, AL 36849

11B. Will study data be stored within a HIPAA covered facility? Yes ☐ No ☒

If yes, which facility(ies) (To determine AU HIPPA covered entities, go to VII of the HIPPA Hybrid Entity Policy)**:**

n/a

12. Participants (If minor participants, at least 2 adults must be present during all research procedures that include the minors.)

12A. Describe the targeted/ intended participant population for the study. Include the anticipated number of participants and inclusion and exclusion criteria and the procedures to ensure more than 1 adult is present during all research procedures which include the minor.

☐ Check here if existing data will be used and describe the population from whom data was collected including the number of data files.

☐ Check here if permission to access existing data is required and submit a copy of the agreement to access.

Between 40 and 60 subjects will be recruited from the Auburn University community. Potential participants will be screened for exclusion based on the following: 1. Under 18 years of age 2. Prone to motion sickness 3. Prior experience with head-mounted or projected AR systems 4. Prior experience building cars in the Lean Lab as part of INSY 5800/6800 or otherwise Active recruiting efforts will focus on freshman and sophomore engineering students in Industrial & Systems Engineering (ISE), as they are accessible and are likely to meet all requirements.

12B. Describe, step-by-step in lay language all procedures to recruit participants. Include in **Appendix B** a copy of all e-mails, flyers, advertisements, recruiting scripts, invitations, etc., that will be used to invite people to participate. (See sample documents at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

Students and Faculty will be recruited using flyers distributed around the Auburn University campus. Additionally, ISE students will be recruited via in-class announcements and the distribution of emails. Copies of each are included in Appendix B. Interested participants will be instructed to contact the PI for more information. In the call that follows, the PI will: 1. Briefly explain the study, recapping and elaborating on the recruiting materials 2. Explain the exclusion criteria and identify relevant issues for the candidate 3. Set expectations for participant involvement, including time commitment and tasks 4. Answer any questions the candidate has regarding participation in the study If the candidate is ready and willing to proceed, their information will be collected using the Subject Recruitment Data Sheet provided in Appendix C. They will be assigned a unique participant ID and a date and time for data collection. If interest in the study exceeds capacity,

additional participants will be thanked for their interest and informed that enrollment is limited. They will be given the option to remain "waitlisted" if additional participants or follow-up studies are required.

12C. Minimum number of participants required to validate the study? 40

Number of participants expected to enroll? About 50

Provide the rationale for the number of participants. Appropriate for the desired power given the number of treatments.

Is there a limit to the number of participants that will be included in the study?
☐ **No** ☒ **Yes, the number is** 60, due to time constraints

12D. Describe the process to compensate, amount and method of compensation and/or incentives for participants. **AU Procurement and Business Services (PBS) policies**
(benefits to participants are NOT compensation)

If participants will not be compensated, check here: ☒
Indicate the amount of compensation per procedure and in total: Click or tap here to enter text.
Indicate the type of compensation: ☐ Monetary ☐ Incentives
☐ Raffle or Drawing incentive (Include the chances of winning.)
☐ Extra Credit (State the value)
☐ Other

Describe how compensation will be distributed (USPS, email, etc.): Click or tap here to enter text.

13. Project Design & Methods

13A. Describe, step-by-step, all procedures and methods that will be used to consent participants. If a waiver is being requested, indicate the waiver, and describe how the study meets the criteria for the waiver. If minors will be enrolled describe the process to obtain parental/ legally authorized guardian permission.

☐ **Waiver of Consent (including using existing data)**
☐ **Waiver of Documentation of Consent (use of Information Letter)**
☐ **Waiver of Parental Permission (for college students 18 years or younger)**

As each participant arrives, they will be welcomed and given brief introductions to members of the team administering the study. We will then ask them to review the consent document, encouraging them to ask any questions they have. After a verbal confirmation that the participant has read and is satisfied with the terms of this document, we will ask that they sign and date it.

13B. In lay language, understandable by someone not familiar with the area of study, describe the complete research design and methods that will be used to address the purpose. Include a clear description of who, when, where and how data will be collected. Include specific information about participants' time and effort.

Following the recruitment, eligibility screening, and consent processes described above, a short orientation process acclimates the participant to the work area and emergency procedures are described. A research associate will point out the key features of a work cell (work surface, part bins, etc.), describe how to interpret the paperwork instructions, demonstrate typical assembly steps, and answer any relevant questions. (5-10 mins)

Next, participants assigned to any AR IMT (PAR, HMDAR, or HMDMR) will receive a brief demonstration of its basic operation. In all cases, the participant will be shown how to use the appropriate forward and back triggers, and how the system signals instructions and feedback related to part bin and placement. PAR and HMDAR users will be instructed that the model must remain in the fixture. HMDMR users will understand that the model can be freely manipulated during assembly. (5-10 mins)

Once orientation and training are complete, the experiment is conducted in two phases. Regardless of IMT assigned, all participants will wear the HL2 during both phases to control for its effects and allow us to record each session from their POV.

In the first phase, participants will be asked to complete the assembly process for as many cars as they can, while learning the steps and limiting the number of errors produced. This phase will be conducted with the support of the assigned IMT and will last 10 minutes. During that time, we expect that each participant will produce between 3 and 6 cars, based on prior performance data and the 60-second takt time for which the instructions were designed. (10 mins)

Following a short break to reset the workstation, the second phase will begin. In this phase each participant will build 4 more cars using only paper work instructions. Their stated goal will be to deliver error-free results quickly, while referencing the instructions only when necessary. (5-10 mins)

Participant performance in both phases will be recorded on two cameras, one first-person view from onboard the HL2, and one third-person view from a camera mounted nearby. Experimental data will be derived from subsequent analysis of these videos. Participants will not be allowed to ask questions during either data collection phase of the experiment.

Once the experiment is concluded, each participant will complete an exit survey that incorporates the NASA TLX and System Usability Scale instruments, along with the Adult ADHD Self-Report Scale (ASRSv1.1). It also includes a section for open-ended feedback. When the survey is collected a research associate will ask if the participant experienced any injury and if they are interested in attending a follow-up session for more in-depth exploration of the HoloLens2. Their responses will be recorded on the exit survey. (5-10 mins)

We conservatively estimate a total time commitment of 45-60 minutes for each participant.

13C. List all data collection instruments used in this project, in the order they appear in Appendix C.
(e.g., surveys and questionnaires in the format that will be presented to participants, educational tests, data collection sheets, interview questions, audio/video taping methods etc.)

1. Subject Recruitment Data Sheet: filled out during the screening call; includes the exclusion checklist, participant number, basic demographics (age and gender), and date / time of scheduled trial
2. Code Sheet: collects the personally identifiable data for eligible participants, including name, contact info (phone, email) and subject number
3. Data Collection Sheet: consists of general notes from the experiment and data derived from subsequent analysis of video recordings
4. Exit Survey: incorporates the NASA TLX and System Usability Scale instruments, open-ended feedback, and area for research associate to indicate answers about participant injury and interest in follow-up session

13D. Data analysis: Describe how data will be analyzed. If a data collection form (DCF) will be used, submit a copy of the DCF.

In both phases of this study, the independent variable is treatment type, and the dependent variables are task completion time and number of errors. The dependent variables will be recorded for each car completed in both sessions.

Data will be analyzed with a combination of visual (e.g., box plots) and statistical methods. Methods based on analysis of variance (ANOVA) will be used to test the stated hypotheses. Additional analysis will be done to explore the relationship between other variables of interest, including demographics, mental workload, behavioral control, and system usability with the measured outcomes.

13E. List any drugs, medications, supplements, or imaging agents that participants will ingest/ receive during participation in the study or indicate not applicable (N/A).

n/a

14. Risks & Discomforts: List and describe all the risks participants may encounter in this research including risks from item 6d of this form, in this research. If deception will be part of the study, provide the rationale for the deception, describe the debriefing process, and attach a copy of the debriefing form that will be used as Appendix D. (Examples of possible risks are in section #6C)

1. Physical Discomfort: All participants will be required to wear the HoloLens2 device, regardless of treatment group to control for its effects on user fatigue, etc., and to allow us to record a first-person view of their

session. As a result, they may experience mild physical discomfort including neck strain after prolonged use. The limited duration of this study should mitigate this effect.

2. Vestibular and Visual Discomfort: Participants assigned to the HMDAR and HMDMR treatments will experience display technology that may cause mild dizziness, eye strain, and related effects. Owing to the see-through design of the HoloLens2 device these effects are less common and less pronounced than seen in fully immersive Virtual Reality (VR) headsets.
3. Trip and Impact Risk: Any head-mounted display can reduce the wearer's peripheral vision and otherwise impact their natural field of view. Consequently, they may become more susceptible to tripping over or running into things around them. This risk is minimized by the HoloLens2's design, which offers a very wide, minimally obscured field of view. Furthermore, the HL2 is a standalone device, so there is no risk of tripping over a cord. Additionally, the participant is generally stationary in an environment free of obstruction. Finally, the Lean Lab is a clean, organized, safe, and well-lit environment with no history of related hazards.
4. Breach of Confidentiality Risk: All resulting data will be anonymized, and video of each session will be recorded from the first person and top-down angles to prevent participant exposure. That said, subjects could be seen entering, leaving, or during the experiment. All of these create a small possibility that subjects could be identified, inadvertently breaching their confidentiality. Additionally, there is the possibility that the subject code list, which connects each participant's identity with their experimental data, could be obtained. Mitigation methods for this risk are described in section 17 Protection of Data.
5. Psychological Discomfort: Due to the nature of the experiment, some participants may experience mild psychological discomfort induced by its time and performance-based measures. Participants will be told that their objective is to learn to perform the task quickly and error free. Otherwise, no overt pressure is put on the subjects to perform. Given that the outcome of their performance has no impact on their life outside the experiment, any related psychological discomfort should be minimal and short-lived.
6. COVID-19 Exposure: This study will be a Category C study with no High-Risk Procedures or Participants. Precautions will be implemented using the COVID-19 2022 Precautions Matrix to determine appropriate precautions at the time of data collection(s) for a Category C study. All work surfaces and the HMD will be wiped down before and after each participant. Necessary supplies will be made available, including as masks, hand sanitizer (60%+ alcohol), tissues, paper towels, trash baskets, and cleaners / disinfectants. All research participants will follow the University's guidance on self-screening. At the time of this writing, the CDC's COVID-19 community level for Lee County, Alabama is LOW, so participant screening is not required. The Shelby Center for Engineering Technology, where this protocol will be administered, is assigned the highest level of building readiness due to increased air turn-over and filtration. Further details and resources can be found in Appendix D.

15. Precautions / Minimization of Risks

15A. Identify and describe all precautions that will be taken to eliminate or reduce risks listed in items 6.c. and 14. If participants can be classified as a "vulnerable" population, describe additional safeguards that will be used to assure the ethical treatment of vulnerable individuals. **If applicable, submit a copy of any emergency plans/procedures and medical referral lists in Appendix D. (Sample documents can be found online at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs precautions)**

This study does not involve any vulnerable populations. Please see section 14, where the primary mitigations are described for each identified risk. Additionally, all participant activities will be supervised and monitored for relevant symptoms. If any participant experiences dizziness or related vestibular issues, or any other significant but unexpected side-effect, we will suspend the experiment, remove the HMD, have them sit and offer drinking water while assessing the situation. If escalation is required, the emergency plan and contact list is included in Appendix D. During the debriefing all participants will be asked if they were injured or experienced any discomfort during their trials. The debriefing also serves to keep each participant under our supervision long enough to ensure no lingering or delayed effects.

15B. If the internet, mobile apps, or other electronic means will be used to collect data, describe confidentiality and/or security precautions that will be used to protect (or not collect) identifiable data? Include protections used during collection of data, transfer of data, and storage of data. If participant data may be obtained and/or stored by apps during the study, describe.

n/a

15C. Does this research include purchase(s) that involve technology hardware, software or online services?

☐ **YES** ☒ **NO**

If YES:

A. **Provide the name of the product** Click or tap here to enter text.
and the manufacturer of the product Click or tap here to enter text.

B. **Briefly describe use of the product in the proposed human subject's research.**
Click or tap here to enter text.

C. **To ensure compliance with AU's Electronic and Information Technology Accessibility Policy, contact AU IT Vendor Vetting team at vetting@auburn.edu to learn the vendor registration process (prior to completing the purchase).**

D. **Include a copy of the documentation of the approval from AU Vetting with the revised submission.**

15D. Additional Safeguards

Will DEXA, pQCT, or other devices which emit radiation be used? ☐ Yes ☒ No
If yes, the IRB will notify the Auburn Department of Risk Management and Safety, who will contact the Alabama Department of Public Health (ADPH) and secure approval. Research which includes device(s) which emit radiation may NOT be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of ADPH approval.

Will a Certificate of Confidentiality (CoC) issued by NIH be obtained ☐ Yes ☒ No If yes, include CoC language in consent documents and include the documentation of CoC approval. Research which includes a CoC may not be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of CoC approval. AU Required CoC Language

Is the study a clinical trial? ☐ Yes ☒ No
If yes, provide the National Clinical Trial (NCT) # Click or tap here to enter text. **and include required clinical trial information in all consent documents. AU Clinical Trial Information**

16. Benefits

16A. List all realistic direct benefits participants can expect by participating in this study. (Compensation is not a benefit) If participants will not directly benefit check here. ☒

There are no direct benefits for participants in this study. It will offer all of them an opportunity to interact with projection and/or head-mounted AR hardware and training methods for the first time. This may lead them to a greater appreciation for the benefits and opportunities these technologies offer.

16B. List realistic benefits for the general population that may be generated from this study.

Turnover in the workforce and the lack of skilled labor necessitates scalable, efficient training methods. Furthermore, the shift from mass production to mass customization forces operators to contend with wide variance in the assembly steps required at each workstation. Together, these trends demand innovative methods for operator training and support.

Augmented and mixed reality are expected to help fill that need, but it is a fragmented market with a variety of solutions. Few studies explore the relationship between those methods (and the affordances that differentiate them) and corresponding learning rates and transfer. We believe this study will make meaningful contributions to that effort, helping to build a cohesive understanding of the utility of these systems and best practices for their application.

17. Protection of Data

17A. Data are collected:

☐ **Anonymously with no direct or indirect coding, link, or awareness by key personnel of who participated in the study (skip to item E)**

☐ **Confidentially, but without a link to participant's data to any identifying information (collected as "confidential" but recorded and analyzed "anonymous") (Skip to item E).**

☒ **Confidentially with collection and protection of linkages to identifiable information.**

17B. If data are collected with identifiers and coded or as coded or linked to identifying information, describe the identifiers and how identifiers are linked to participants' data.

In addition to the consent form, a code list will be maintained that includes identifying data of each participant (name, contact information, and ID number). This will be linked to all data collection forms by the participant number. The consent forms and code list will be maintained on paper only, to facilitate secure storage and disposal (shredding). The consent form will not include reference to the participant's ID number. Only the code list will directly connect participants to their data.

The video recordings may also allow for participants to be identified, though the first-person recording will not allow a view of their face and the third-person view will focus on the work area. If the recorders do not provide a video-only option, audio from those sessions, which may also provide identifying data, will be stripped from the recordings before storage.

17C. Provide the rationale for need to code participants' data or link the data with identifying information.

Only for the purpose of contacting participants while the protocol is open. Once completed, the code list will be destroyed, making the data anonymous.

17D. Describe how and where identifying data and/or code lists will be stored. (Building, room number, AU BOX?) **Describe how the location where data is stored will be secured. For electronic data, describe security measures. If applicable, describe where IRB-approved and participant signed consent documents will be kept on campus for 3 years after the study ends.**

Signed consent forms and the code list will be kept in a secure, locked file in office 3301J of Shelby Center.

17E. Describe how and where data will be stored (e.g., hard copy, audio/ visual files, electronic data, etc.), and how the location where data is stored is separated from identifying data and will be secured. For electronic data, describe security. Note use of a flash drive or portable hard drive is not appropriate if identifiable data will be stored; rather, identifying participant data must be stored on secured servers.

All electronic data pertaining to the study will be stored on a secured server. Non-identifiable data will be available to other members of the research team.

17F. List the names of all who will have access to participants' data? (If a student PI, the faculty advisor must have full access and be able to produce study data in the case of a federal or institutional audit.)

- Consent forms and code list: Dan O'Leary, Gregory Harris
- Non-identifiable data: full research team, by request

17G. When is the latest date that identifying information or links will be retained and how will that information or links be destroyed? (Check here if only anonymous data will be retained ☒)

August 2023

AUBURN UNIVERSITY HUMAN RESEARCH PROTECTION PROGRAM (HRPP)

REQUEST for MODIFICATION

For Information or help completing this form, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu**

- **Federal regulations require IRB approval before implementing proposed changes.**
- **Change means any change, in content or form, to the protocol, consent form, or any supportive materials (such as the investigator's Brochure, questionnaires, surveys, advertisements, etc.). See Item 4 for more examples.**

1. Today's Date	**2/6/2023**

2. Principal Investigator (PI) Name: Dan O'Leary			
PI's Title:	Instructor / PhD Candidate	**Faculty PI (if PI is a student):**	Dr. Richard Sesek
Department:	Industrial & Systems Eng	**Department:**	Industrial & Systems Eng
Phone:	407-399-3189	**Phone:**	334-728-1438
AU-E-Mail:	djo0008@auburn.edu	**AU E-Mail:**	rfs0006@auburn.edu
Contact person who should receive copies of IRB correspondence (Optional):	Click or tap here to enter text.	**Department Head Name:**	Dr. Gregory Harris
Phone:	Click or tap here to enter text.	**Phone:**	334-844-1407
AU E-Mail:	Click or tap here to enter text.	**AU E-Mail:**	gah0015@auburn.edu

3. AU IRB Protocol Identification

3.a. Protocol Number: 22-538

3.b. Protocol Title: The Effects of Augmented Instruction on Manufacturing Assembly Training

3. c. Current Status of Protocol – For active studies, check ONE box at left; provide numbers and dates where applicable

☒	**Study has not yet begun; no data has been entered or collected**	
☐	**In progress If YES, number of data/participants entered:** Click or tap here to enter text.	**Current Approval Dates From:** 1/30/2023
☐	**Is this modification request being made in conjunction with/as a result of protocol renewal? ☐ YES ☐ NO**	
☐	**Adverse events since last review If YES, describe:** Click or tap here to enter text.	**To:** Click or tap to enter a date.
☐	**Data analysis only**	
☐	**Funding Agency and Grant Number:** Click or tap here to enter text.	**AU Funding Information:** Click or tap here to enter text.
☐	**List any other institutions and/ or AU approved studies associated with this project:** Click or tap here to enter text.	

The Auburn University Institutional Review Board has approved this Document for use from
02/09/2023 to ----------
Protocol # 22-538 EP 2301

4. Types of Change
Mark all that apply, and describe the changes in item 5

☒ **Change in Key Personnel**
List the name(s) of personnel being added to or removed from the study and attach a copy of the CITI documentation for personnel being added to the study.
Adding: Dr. Gregory Purdy, Diego Caputo Rodriguez, Alex Barras, David "Brown" Teague, Carson Tillery

☐ **Additional Sites or Change in Sites, including AU classrooms, etc.**
Attach permission forms for new sites.

☐ **Change in methods for data storage/ protection or location of data/ consent documents**

☐ **Change in project purpose or project questions**

☐ **Change in population or recruitment**
Attach new or revised recruitment materials as needed; both highlighted version & clean copy for IRB approval stamp

☒ **Change in study procedure(s)**
Attach new or revised consent documents as needed; both highlighted revised copy & clean copy for IRB approval stamp
No change is required to the consent documents.

☒ **Change in data collection instruments/forms (surveys, data collection forms)**
Attach new forms as needed; both highlighted version & clean copy for IRB approval stamp
Attached.

☐ **Other**
(BUAs, DUAs, etc.) Indicate the type of change in the space below, and provide details in the Item 5.c. or 5.d. as applicable. Include a copy of all affected documents, with revisions highlighted as applicable.
Click or tap here to enter text.

5. Description and Rationale

5.a. For each item marked in Question #4 describe the requested change(s) to your research protocol, and the rationale for each.

Needed added team members to help run the protocol. Minor changes to streamline procedure. Added an expanded demographics form. Asking participants to repeat the NASA TLX and SUS instruments after each phase (twice total, one additional time).

5.b. Briefly list (numbered or bulleted) **the activities that have occurred up to this point, particularly those that involved participants.**

Only initial recruiting. No trials run or scheduled yet.

5.c. Does the requested change affect participants, such as procedures, risks, costs, benefits, etc.

No. Added surveys may add a little time but that was offset by streamlined procedure.

5.d. Attach a copy of all "IRB stamped" documents currently used. (Information letters, consent forms, flyers, etc.)

Attached.

5.e. List all revised documents and attach two copies of the revised documents – one copy which highlights the revisions and one clean copy of the revised documents for the IRB approval stamp.

Attached.

6. Signatures

Principal Investigator: _____

Faculty Advisor PI, if applicable: _____

Version Date: Click or tap to enter a date.

AUBURN UNIVERSITY

INDUSTRIAL & SYSTEMS ENGINEERING

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT
for a Research Study entitled

The Effects of Augmented Instruction on Manufacturing Assembly Training

Concise Summary

You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the consent form. The purpose of this study is to measure the effect of augmented instruction on learning rates and skills transfer for industrial assembly tasks. Following an initial phone screening the experiment will be scheduled at your convenience. After a brief orientation you will be asked to learn a simulated manufacturing assembly task – building model "cars" with LEGO® bricks. For this phase you will be randomly assigned one of the following forms of instructional media: paper work instructions (PWI), projected augmented reality (PAR), head-mounted AR (HMDAR), or head-mounted mixed reality (HMDMR). After a 10-minute training session you will be asked to repeat the assembly task from memory for 4 cars. Paper work instructions will remain available for reference as needed. Finally, you will be asked to complete a survey with questions about the experience and related personal traits. The entire process will take 45-60 minutes.

This study has some risk of physical and psychological discomfort, including fatigue, dizziness, eyestrain, and performance anxiety. Participants assigned the HMD instructional media are most susceptible to physical discomfort due to the nature of its display system, which can also increase the risk of tripping and impact. Finally, all of your personally identifiable data is carefully secured to protect against the risk of a breach of confidentiality. Your safety and privacy is our utmost priority, and steps have been taken to mitigate all known risks.

Beyond the opportunity to experience modern AR training methods, there are no direct benefits to you for participating in this study. The researchers will benefit from a greater understanding of this emerging field that could potentially benefit the community. The alternative is to not participate in this study.

You are invited to participate in a research study to measure the effect of augmented instruction on learning rates and skills transfer for industrial assembly tasks. The study is being conducted by Dan O'Leary, Ph.D. Candidate, under the direction of Dr. Richard Sesek, Tim Cook Associate Professor in the Auburn University Department of Industrial and Systems Engineering. You were selected as a possible participant because you meet all the following qualifications:

1. Are not prone to motion sickness.
2. Have no prior experience with head-mounted or projected Augmented Reality (AR) systems.
3. Have no prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO Lab) as part of INSY 5800/6800 or otherwise.
4. Are age 18 or older.

What will be involved if you participate?
If you decide to participate in this research study, you will be asked to follow a mix of paper and augmented (projected or head-mounted AR) work instructions to build LEGO car models in a realistic manufacturing setting. Your total time commitment will be approximately 45-60 minutes. You will be required to wear a HoloLens2 head-mounted display (HMD) and video of your session will be recorded for later analysis. Another video camera will capture the work area from above. Camera placement is designed to prevent / limit the capture of personally identifiable imagery. Fully redacted versions of these videos, wherein any personally identifiable imagery is removed, will be kept indefinitely. Original recordings will be deleted within 1 year of the protocol's completion.

Are there any risks or discomforts?
The risks associated with participating in this study are identified below.

1. Physical discomfort and/or fatigue related to the weight of the HoloLens2 HMD.
2. Vestibular and/or visual discomfort for participants assigned to the HMD AR instructional methods, which may cause mild dizziness, eye strain, and related effects in some users.
3. Psychological discomfort may be experienced by those prone to anxiety when encountering time and performance-based measures.
4. Trip and impact risk due to slightly altered field of view and reduced peripheral vision while wearing the HoloLens2 HMD.
5. Participant confidentiality may be breached if identifying data is compromised or participants are observed entering, leaving, or taking part in the experiment.
6. Exposure to COVID-19 or other respiratory illnesses, such as the flu.

The discomforts identified are considered mild and unlikely. The HoloLens2 is well-balanced and uses a state-of-the-art optical see-through design that limits display-related discomforts. To minimize the risk of tripping and impact, participants are largely stationary in a well-lit area that is free of hazards. The HoloLens2 features a wireless design, which eliminates cables as a source of tripping hazard. Finally, all activities will be supervised, and participants will be continuously monitored for relevant symptoms.

Confidentiality of the study data is of utmost importance. All research personnel are trained in research ethics and are aware of procedures to protect the confidentiality of participants and associated data. Paper files with personally identifiable information will be secured in an office that only the PI and Faculty Advisor have access to. Electronic data, including video recordings, will be maintained on a password-protected computer accessible only to the research team.

To mitigate the risk of exposure to COVID-19 and other respiratory illnesses, the research team will follow University policies outlined on the Human Research COVID-19 Precautions page. All work surfaces and equipment will be wiped down before and after each participant, and all necessary supplies (e.g. masks, hand sanitizer) will be made available. The research staff will follow the University's guidance on self-screening. Finally, conditions will be monitored, and precautions adjusted as necessary throughout the data collection process.

Are there any benefits to yourself or others?
There are no direct benefits from participating in this study. However, it is a unique opportunity for eligible participants to interact with projection and/or head-mounted AR hardware and training methods. This may lead them to a greater appreciation for the benefits and opportunities these technologies offer.

Will you receive compensation for participating?
No compensation is offered for your participation.

Are there any costs?
There is no cost for you to participate in this study. Auburn University has not provided for any payment if you are harmed as a result of participating in this study.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering or any member of the research team.

Your privacy will be protected. Any information obtained in connection with this study will remain confidential. Information obtained through your participation may be used in a variety of capacities, including fulfillment of educational requirements, publication in professional journals, and/or presentation at professional meetings. In any case, your identity will not be revealed, and your information will remain private.

If you have questions about this study, please ask now or contact Dan O'Leary at djo0008@auburn.edu, 407-399-3189, or Dr. Richard Sesek at rfs0006@auburn.edu, 334-728-1438. A copy of this document will be given to you to keep.

If you have questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or e-mail at IRBadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

_____	_____
Participant's signature Date	Investigator obtaining consent Date
_____	_____
Printed Name	Printed Name

The Auburn University Institutional Review Board has approved this Document for use from 01/28/2023 to ----------
Protocol # 22-538 EP 2301

Appendix B - Recruiting Materials

In-Class Recruiting Script

Hello, Class.

An Industrial Engineering graduate student pursuing his PhD is recruiting participants for a research study. He is investigating the effectiveness of mixed reality methods for operator training and support in manufacturing. The study hopes to better understand the relationship between augmented/mixed reality methods, learning effectiveness, and operator performance. A flyer with details of the study will be emailed to each of you. If you are interested, please follow up as described therein.

Email Script

Dear Student,

Please review the attached flyer, which provides details of the study recently described in __class name__. You are invited to participate in a research study on the effectiveness of mixed reality for operator training and support in manufacturing. I am conducting this study as a Ph.D. Candidate under the supervision of Dr. Richard Sesek, Tim Cook Associate Professor in the Department of Industrial and Systems Engineering at Auburn University.

If you would like to participate, simply respond to this email or via text / phone to 407-399-3189. Questions or concerns can be directed to me through the same channels, or you may contact my advisor Dr. Sesek (sesek@auburn.edu).

Thank you for your consideration,

Confirmation Email

Dear <student name>,

Thank you for your interest in our study, and for taking the time to discuss it with me. I'm happy to confirm that your trial is scheduled as follows:

Date and Time:<date and time>

Location: Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab), in the basement of the Shelby Center for Engineering Technology, room 0317, located at 345 W Magnolia Ave, Auburn, AL 36849

Please arrive on time. We anticipate that it will take 45-60 minutes to complete the session.

If you need to reschedule or have further questions, feel free to respond to this email or call / text me at 407-399-3189.

Thank you for your participation,

Flyer

Attached on the following page.

Augmented Reality Research Study

Training methods for tomorrow's workforce, today!

The Effects of Augmented Instruction on Manufacturing Assembly Training

Interested in Augmented and Mixed Reality?
Want to experience the latest in Projected and Head-Mounted AR?
You may be eligible to participate in an important study!

The purpose of this study is to measure the effect of augmented instruction on learning rates and skills transfer for industrial assembly tasks. The effect of projected (LightGuide) and head-mounted (HoloLens2) augmented reality methods will be compared with paper-based materials for instruction and support.

This study is open to anyone 18 and older, that isn't prone to motion sickness, has no prior experience with head-mounted or projected AR systems, and hasn't worked in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab)as part of INSY 5/6800 or otherwise.

Microsoft HoloLens

LightGuide

Conducted by graduate students in the Department of Industrial & Systems Engineering at Auburn University.

If you are interested in participating or have questions, please contact Dan O'Leary (djo0008@auburn.edu, 407-399-3189), or scan the QR code to generate an email.

Scan to Email!

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Subject Recruitment Data Sheet

The Effects of Augmented Instruction on Manufacturing Assembly Training

Eligibility Checklist:

- 18 or older
- Not prone to motion sickness
- No prior experience with projected or head-mounted augmented reality systems
- No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and subject number in code sheet.

Subject Number: _____

Gender: _____

Age: _____

Scheduled Trial: _____

Eligibility Checklist:

- 18 or older
- Not prone to motion sickness
- No prior experience with projected or head-mounted augmented reality systems
- No prior experience building cars in the Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab) as part of INSY 5/6800 or otherwise

If eligible, record name, contact info (phone, email), and participant number in code sheet.

Subject Number: _____

Gender: _____

Age: _____

Scheduled Trial: _____

Participant #: _____ **Date:** _____

1. Gender:
   - ☐ Female
   - ☐ Male
   - ☐ Other
2. Age: _____
3. Race (select those with which you identify):
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African-American
   - ☐ Native Hawaiian or Other Pacific Islander
   - ☐ White
   - ☐ More than one race
   - ☐ Unknown or not reported
4. Ethnicity (select ONLY one with which you most closely identify):
   - ☐ Hispanic or Latino
   - ☐ Not Hispanic or Latino
   - ☐ Unknown or not reported
5. Country of Origin: _____
6. What language do you mainly speak at home?
   - ☐ English
   - ☐ Other
7. What is the highest level of school you have completed or the highest degree you have received?
   - ☐ Less than high school degree
   - ☐ High school degree or equivalent (e.g., GED)
   - ☐ Some college but no degree
   - ☐ Associate degree
   - ☐ Bachelor degree
   - ☐ Graduate degree: ____ Master or ____ PhD

Participant #: _____ **Date: _____**

8. If you are currently pursuing a degree, please complete the following:

   College (e.g. Education or Business): _____

   Program (e.g. MS Adult Ed or BS Accounting) : _____

9. Which of the following statements best describes your experience building LEGO models?

   - ☐ I have little to no experience building LEGO models.
   - ☐ I have some experience building LEGO models.
   - ☐ I have lots of experience building LEGO models.
   - ☐ I consider myself an expert in building LEGO models.

10. Please indicate your level of manufacturing experience

    - ☐ I have no experience in manufacturing.
    - ☐ I have taken one or more classes in manufacturing.
    - ☐ I have held a part-time or temporary position in manufacturing.
    - ☐ I have 1 or more years of experience working in manufacturing.

Code Sheet

The Effects of Augmented Instruction on Manufacturing Assembly Training

Participant #	Date	Name	Email	Phone	Notes

CONFIDENTIAL

Data Collection Sheet

The Effects of Augmented Instruction on Manufacturing Assembly Training

Participant #: _____ **IMT: PWI / PAR / HMDAR / HMDMR** **Date: _____**

Study 1 – Training with Assigned Treatment

Car #	TCT	Errors Made		Uncorrected Error Types			Trial Notes
		Corrected	Uncorrected	Sel	Pos	Rot	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

Observer Initials: _____

Data Collection Sheet

The Effects of Augmented Instruction on Manufacturing Assembly Training

Participant #: _____ **IMT: PWI / PAR / HMDAR / HMDMR** **Date: _____**

Study 2 – Learning Assessment

Car #	TCT	Errors Made		Uncorrected Error Types			PWI Ref Count	Trial Notes
		Corrected	Uncorrected	Sel	Pos	Rot		
1								
2								
3								
4								

General Notes:

Observer Initials: _____

Exit Survey

The Effects of Augmented Instruction on Manufacturing Assembly Training

Participant #: _____ **IMT: _____** **Date: _____**

Sources of Workload

Consider the following definitions:

Title	Range	Description
Mental Demand	Low / High	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low / High	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low / High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good / Poor	How successful do you think you were in accomplishing the goals of the task set by the experiment (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low / High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration	Low / High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

For each of the following pairs, circle the word that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

Effort or **Performance**	**Temporal Demand** or **Frustration**	**Physical Demand** or **Performance**	**Temporal Demand** or **Mental Demand**	**Mental Demand** or **Physical Demand**
Temporal Demand or **Effort**	**Physical Demand** or **Frustration**	**Frustration** or **Effort**	**Performance** or **Mental Demand**	**Effort** or **Physical Demand**
Performance or **Frustration**	**Physical Demand** or **Temporal Demand**	**Performance** or **Temporal Demand**	**Mental Demand** or **Effort**	**Frustration** or **Mental Demand**

Workload Rating Sheet

For each of the following 6 questions, consider the assembly task you just completed. Record your immediate response to each item by circling the number that you feel best represents your experience.

1. How mentally demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

2. How physically demanding was the task?

1	2	3	4	5	6	7
Very Low						Very High

3. How hurried or rushed was the pace of the task?

1	2	3	4	5	6	7
Very Low						Very High

4. How successful were you in accomplishing what you were asked to do?

1	2	3	4	5	6	7
Perfect						Failure

5. How hard did you have to work to accomplish your level of performance?

1	2	3	4	5	6	7
Very Low						Very High

6. How insecure, discouraged, irritated, stressed, and annoyed were you?

1	2	3	4	5	6	7
Very Low						Very High

Behavioral Control Survey

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, place an X in the box that best describes how you have felt and conducted yourself over the past 6 months.	Never	Rarely	Sometimes	Often	Very Often
1. How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?					
2. How often do you have difficulty getting things in order when you have to do a task that requires organization?					
3. How often do you have problems remembering appointments or obligations?					
4. When you have a task that requires a lot of thought, how often do you avoid or delay getting started?					
5. How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?					
6. How often do you feel overly active and compelled to do things, like you were driven by a motor?					
7. How often do you make careless mistakes when you have to work on a boring or difficult project?					
8. How often do you have difficulty keeping your attention when you are doing boring or repetitive work?					
9. How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?					
10. How often do you misplace or have difficulty finding things at home or at work?					
11. How often are you distracted by activity or noise around you?					
12. How often do you leave your seat in meetings or other situations in which you are expected to remain seated?					
13. How often do you feel restless or fidgety?					
14. How often do you have difficulty unwinding and relaxing when you have time to yourself?					
15. How often do you find yourself talking too much when you are in social situations?					
16. When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
17. How often do you have difficulty waiting your turn in situations when turn taking is required?					
18. How often do you interrupt others when they are busy?					

Appendix D - Emergency Plan, Contact List, and COVID Resources

Emergency Action Plan

In Case of Emergency ***DIAL 911***

For non-emergency assistance:

Service	On-Campus	Off-Campus
Ambulance (EMS)	9-749-8504	334-749-8504
City of Auburn Police	9-501-3100	334-501-3100
Auburn Medical Pavilion	9-364-3000	334-364-3000
East Alabama Medical Center, Opelika	9-749-3411	334-749-3411

Research Team Contact List:

Contact	Phone	Email
Dan O'Leary, Principal Investigator	407-399-3189 (cell)	djo0008@auburn.edu
Dr. Richard Sesek, Faculty Advisor	334-728-1438 (cell)	rfs0006@auburn.edu
Victoria Ballard, Graduate Student	360-632-1359 (cell)	vzb0024@auburn.edu
Dr. Gregory Harris, Faculty Advisor	334-844-1407 (office)	gah0015@auburn.edu
Dr. John Evans, Faculty Advisor	334-844-1418 (office)	evansjl@auburn.edu
Tom Devall, Tiger Motors Director	334-740-3905 (office)	tld0017@auburn.edu
Industrial & Systems Engineering Department	334-844-4340 (main office)	insy@eng.auburn.edu

Lab Location and Access:

Tiger Motors Lean Education Center (Lean Lab, aka LEGO® Lab), Basement, Shelby Center, Auburn University, room 0317. Street address: 345 W Magnolia Ave, Auburn, AL 36849.

Elevator access: exit the lab and turn left

Stairwell access: exit the lab, turn left, proceed around the elevator in either direction. Stairwell entrance is on the inside wall behind the elevator.

Emergency exit: exit the lab and turn right. Continue to exit at ground level.

Emergency Equipment:

First aid kit, eye wash and shower station are present, as are fire extinguisher and alarm pull.

COVID-19 Resources

CDC COVID-19 Data Tracker for Lee County, Alabama

University Policies for Research Exposure and Related Resources:

- Human Research COVID-19 Precautions
- COVID-19 Guidance on Self Screening
- AU Facilities COVID Building Readiness Status Page

Auburn University Screening Protocol (source):

> All research participants should be screened remotely (by phone or Zoom) for fever, cough, and flu-like symptoms the day before, with a repeat screening at the time of an in-person visit. Appropriate screening questions might include the following, which could be modified to fit your participant population and the location of in-person interactions:
>
> 1. Do you have a fever or Respiratory Symptoms? Symptoms include fever, acute respiratory infection, persistent cough, sore throat, fatigue and shortness of breath, or sudden loss of taste or smell with or without a fever.
> 2. Are you waiting on COVID-19 test results?
> 3. Have you been asked to self-isolate by your doctor?
> 4. In the past three weeks, have you visited another state, country, or facility with a substantial or high community COVID-19 level (see CDC COVID-19 Community Levels)?
> 5. Health/Vaccination Status - Do you have underlying medical conditions, or are you unvaccinated?

Precautions Matrix:

COVID-19 PRECAUTIONS MATRIX	CATEGORY A HIGH-RISK PROCEDURES*	CATEGORY B HIGH-RISK PARTICIPANTS**	CATEGORY C NO HIGH-RISK PROCEDURES OR PARTICIPANTS
HIGH COVID-19 COMMUNITY LEVEL	SCREENING PROTOCOLS FOR PARTICPANTS AND INVESTIGATORS PPE: RESEARCH PERSONNEL WEAR N-95 OR KN95; EYE PROTECTION; GLOVES FOR DIRECT CONTACT; PARTICIPANTS WEAR FACE COVERINGS	SCREENING PROTOCOLS FOR PARTICPANTS AND INVESTIGATORS PPE: RESEARCH PERSONNEL WEAR N-95 OR KN95; EYE PROTECTION; GLOVES FOR DIRECT CONTACT; PARTICIPANTS WEAR FACE COVERINGS	SCREENING PROTOCOLS FOR PARTICPANTS AND INVESTIGATORS FOLLOW AU COVID-19 GUIDELINES
MEDIUM COVID-19 COMMUNITY LEVEL	SCREENING PROTOCOLS FOR PARTICPANTS AND INVESTIGATORS FOLLOW AU COVID-19 GUIDELINES	SCREENING PROTOCOLS FOR PARTICPANTS AND INVESTIGATORS FOLLOW AU COVID-19 GUIDELINES	FOLLOW AU COVID-19 GUIDELINES
LOW COVID-19 COMMUNITY LEVEL	FOLLOW AU COVID-19 GUIDELINES	FOLLOW AU COVID-19 GUIDELINES	FOLLOW AU COVID-19 GUIDELINES

*HIGH-RISK PROCEDURES ARE DEFINED AS ANY PROCEDURES THAT INCUR A SIGNIFICANT OR INCREASED RISK OF EXPOSURE, SUCH AS THROUGH FREQUENT OR SUSTAINED CLOSE CONTACT BETWEEN INVESTIGATORS AND PARTICIPANTS; SPECIMEN COLLECTION FROM PARTICIPANTS; OR ACTIVITIES INVOLVING INCREASED RESPIRATORY OUTPUT SUCH AS EXERCISE STUDIES.

**HIGH-RISK PARTICIPANTS INCLUDE PEOPLE AT HIGHER RISK OF SEVERE ILLNESS FROM SARS COV-2 INFECTION, INCLUDING PEOPLE WHO ARE UNVACCINATED, OLDER ADULTS, OR PEOPLE WITH CERTAIN MEDICAL CONDITIONS.

E.3 Workplace Psychosocial Survey IRB Documents

PARTICIPATE IN A WORKPLACE PSYCHOSOCIAL

RESEARCH STUDY

INVESTIGATING WORKPLACE STRESS AND ANXIETY RELATED HEALTH FACTORS

COMPLETE AN ANONYMOUS SURVEY ONLINE IN ABOUT 10 MIN

$50AMAZON GIFT CARD RAFFLE!

MUST BE AGE 18 AND OVER TO PARTICIPATE

No Direct Benefits to Participants, Voluntary Participation.

Please take a few minutes today to help provide necessary data for PhD Research at Auburn University.

To participate go to:

https://aub.ie/research_survey6

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AUBURN UNIVERSITY INSTITUTIONAL REVIEW BOARD for RESEARCH INVOLVING HUMAN SUBJECTS

PROTOCOL REVIEW FORM
FULL BOARD or EXPEDITED REVIEW

For assistance, contact: **The Office of Research Compliance (ORC)**
Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**
Submit completed form and supporting materials as one PDF through the IRB Submission Page
Handwritten forms are not accepted. Where links are found hold down the control button (Ctrl) then click the link.

1. Proposed Start Date of Study:3/1/2024 Today's Date: Click or tap to enter a date.
Submission Status (Check One): ☒ New ☐ Revisions (to address IRB Review Comments)
Proposed Review Category (Check One): ☐ Full Board (greater than minimal risk) ☒ Expedited
If Expedited, Indicate Category(ies) ((Link to Expedited Category Review Sheet) 2

2. Project Title: Determination of prevalence and relationship between psychosocial stress and anxiety related to health factors of workers.

3. Principal Investigator (PI): Victoria Ballard Degree(s): MSCivE, MSISE
Rank/Title: Doctoral Candidate Department/School: Industrial and Systems Engineering
Role/responsibilities in this project: Principal Investigator
Preferred Phone Number: 360-632-1359 AU Email: vzb0024@auburn.edu

Faculty Advisor Principal Investigator (if applicable): Dr. Richard Sesek
Rank/Title: PhD Department/School: Industrial and Systems Engineering
Role/responsibilities in this project: Advisor
Preferred Phone Number: 334-728-1438 AU Email: rfs0006@auburn.edu

Department Head: Dr. Greg Harris Department/School: Industrial and Systems Engineering
Preferred Phone Number: 334-844-1407 AU Email: gah0015@auburn.edu
Role/responsibilities in this project: Click or tap here to enter text.

4. Funding Support: ☒ N/A ☐ Internal External Agency: Click or tap here to enter text. Pending ☐ Received ☐
For federal funding, list funding agency and grant number (if available): Click or tap here to enter text.
Funding participant raffle with personal funds.
5. a) List any contractors, sub-contractors, and other entities associated with this project: N/A

b) List any other AU IRB approved protocols associated with this study and describe the association: N/A

c) List any other institutions associated with this study and submit a copy of their IRB approval(s): N/A

Protocol Packet Checklist

Check all applicable boxes. A completed checklist is required.

☒ **Protocol Review Form** (All required signatures included and all sections completed)
(Examples of appended documents are found on the website: https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

☒ **CITI Training Certificates** for key personnel

☐ **Consent Form or Information Letter** and any releases (audio, video or photo) that participants will review and/or sign

☒ **Appendix A** "Reference List"

☒ **Appendix B** if e-mails, flyers, advertisements, social media posts, generalized announcements or scripts, etc., will be used to recruit participants.

☒ **Appendix C** if data collection sheets, surveys, tests, other recording instruments, interview scripts, etc. will be used for data collection. Attach documents in the order they are listed in item 13c

☐ **Appendix D** if they study will use a debriefing form or will include emergency plans/ procedures and medical referral lists. (A referral list may be attached to the consent document.) .

Continued on Page 2

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Protocol # 24-748 EX 2404

☐ **Appendix E** if research is being conducted at sites other than Auburn University or in cooperation with other entities. A **permission letter** from the site/ program director must be included indicating their cooperation or involvement in the project. NOTE: If the proposed research is a multi-site project, involving investigators or participants at other academic institutions, hospitals or private research organizations, a letter of **IRB approval** from each entity is required prior to initiating the project.

☐ **Appendix F** Written evidence of approval by the host country, local IRB or institutions if research is conducted outside the United States

6. General Research Project Characteristics

6A. Research Methodology

Check all descriptions that best apply to the research methodology.

Data Source(s): ☒ New Data ☐ Existing Data

Will recorded data directly or indirectly identify participants?
☐ Yes ☒ No

Data collection will involve the use of:

- ☐ Educational Tests (cognitive diagnostic, aptitude, etc.)
- ☐ Interview
- ☐ Observation
- ☐ Locations or Tracking Measures
- ☐ Physical / Physiological Measures or Specimens
- ☒ Surveys / Questionnaires
- ☐ Other: X-Sens digital modeling of subject postures without corresponding video (to maintain confidentiality of 3rd parties: patients and other providers).
- ☐ Internet / Electronic
- ☐ Audio
- ☐ Video
- ☐ Photos
- ☐ Digital Images
- ☐ Private records or files

6B. Participant Information

Check all descriptors that apply to the TARGET population. (link to definition of target population)
☒ Males ☒ Females ☐ AU students

Vulnerable Populations
☐ Pregnant Women/Fetuses ☐ Prisoners ☐ Institutionalized
☐ Children and / or Adolescents (under age 18 in AL; if minor participants, at least 2 adults must be present during all research procedures that include the minors)

Persons with:
☐ Economic Disadvantages ☐ Physical Disabilities
☐ Educational Disadvantages ☐ Intellectual Disabilities

Will participants be compensated? ☐ Yes ☒ No

6C. Risks to Participants

Identify all risks participants might encounter in this research.

- ☒ Breach of Confidentiality*
- ☐ Deception
- ☐ Psychological
- ☐ None
- ☐ Other (COVID-19, other medical):

Click or tap here to enter text.

- ☐ Coercion
- ☐ Physical
- ☐ Social

*Note that if the investigator is using or accessing confidential or identifiable data, breach of confidentiality is always a risk.

6D. Corresponding Approval/ Oversight

- **Does the study include participant exposure to radiation?** ☐ **Yes** ☒ **No**
  If yes indicate: ☐ **DEXA** ☐ **PQCT** ☐ **Other**

- **Is IBC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, BUA # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Is IACUC Approval required for this study?**
  ☐ **Yes** ☒ **No**

  If yes, PRN # Click or tap here to enter text. **Expiration Date** Click or tap to enter a date.

- **Does this study involve the Auburn University MRI Center?**
  ☐ **Yes** ☒ **No**

  Which MRI(s) will be used for this project? (Check all that apply)
  ☐ **3T** ☐ **7T**

Continued on Page 3

Does any portion of this project require review by the MRI Safety Advisory Council?
☐ **Yes** ☒ **No**

Signature of one MRI Center Representative:_____
Required for all projects involving the AU MRI Center
Appropriate MRI Center Representatives:
Dr. Thomas S. Denney, Director AU MRI Center
Dr. Ron Beyers, MR Safety Officer

7. Project Assurances

7A. Principal Investigator's Assurances

1. I certify that all information provided in this application is complete and correct.
2. I understand that, as Principal Investigator, I have ultimate responsibility for the conduct of this study, the ethical performance this project, the protection of the rights and welfare of human subjects, and strict adherence to any stipulations imposed by the Auburn University IRB.
3. I certify that all individuals involved with the conduct of this project are qualified to carry out their specified roles and responsibilities and are in compliance with Auburn University policies regarding the collection and analysis of the research data.
4. I agree to comply with all Auburn policies and procedures, as well as with all applicable federal, state, and local laws regarding the protection of human subjects, including, but not limited to the following:
    a. Conducting the project by qualified personnel according to the approved protocol
    b. Implementing no changes in the approved protocol or consent form without prior approval from the Office of Research Compliance
    c. Obtaining the legally effective informed consent from each participant or their legally responsible representative prior to their participation in this project using only the currently approved, stamped consent form
    d. Promptly reporting significant adverse events and / or effects to the Office of Research Compliance in writing within 5 working days of the occurrence.
5. If I will be unavailable to direct this research personally, I will arrange for a co-investigator to assume direct responsibility in my absence. This person has not been named as co-investigator in this application, or I will advise ORC, by letter, in advance of such arrangements.
6. I agree to conduct this study only during the period approved by the Auburn University IRB.
7. I will prepare and submit a renewal request and supply all supporting documents to the Office of Research Compliance before the approval period has expired if it is necessary to continue the research project beyond the time period approved by the Auburn University IRB.
8. I will prepare and submit a final report upon completion of this research project.

My signature indicates I have read, understand and agree to conduct this research project in accordance with the assurances listed above.

__ ____Victoria Ballard_____ Victoria Ballard 3/21/2024
Principal Investigator Name **Principal Investigator Signature** **Date**

7B. Faculty Advisor / Sponsor's Assurances

1. I have read the protocol submitted for this project for content, clarity, and methodology.
2. By my signature as faculty advisor / sponsor on this research application, I certify that the student or guest investigator is knowledgeable about the regulations and policies governing research with human subjects and has sufficient training and experience to conduct this particular study in accord with the approved protocol.
3. I agree to meet with the investigator on a regular basis to monitor study progress. Should problems arise during the course of the study, I agree to be available, personally, to supervise the investigator in solving them.
4. I assure that the investigator will promptly report significant incidents and / or adverse events and / or effects to the ORC in writing within 5 working days of the occurrence.
5. If I will be unavailable, I will arrange for an alternate faculty sponsor to assume responsibility during my absence, and I will advise the ORC by letter of such arrangements. If the investigator is unable to fulfill requirements for submission of renewals, modifications or the final report, I will assume that responsibility.

Richard Sesek Richard Sesek 3/21/2024
Faculty Advisor / Sponsor Name **Faculty Advisor Signature** **Date**

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7C. Department Head's Assurance

By my signature as department head, I certify that I will cooperate with the administration in the application and enforcement of all Auburn University policies and procedures, as well as all applicable federal, state, and local laws regarding the protection and ethical treatment of human participants by researchers in my department

Dr. Greg Harris	Gregory A. Harris	3/21/24
Department Head Name	**Department Head Signature**	**Date**

8. Project Overview:

8A. A summary of relevant research findings leading to this research proposal:

*(Cite source; include a "Reference List" as **Appendix A**.)*

Attention Deficit Hyperactivity Disorder (ADHD) can affect workers in a variety of ways, especially if their workplaces are not supportive of their neurodivergent condition [1]. Having a better understanding of how workers perceive the supportiveness of their workplace and how that affects their sense of self-efficacy, social anxiety, and workplace stress is an important first step toward making changes that can improve the working conditions for those who are neurodivergent, such as those workers with ADHD. A very limited amount of research has been done in this area, especially related to the prevalence of workers with ADHD and related stress and workplace anxiety. The most recent prevalence study working to establish US norms for ADHD failed to analyze the prevalence of undiagnosed ADHD persons experiencing and living with a significant number of ADHD symptoms [2]. Al-Yateem et al. surveyed a population of young United Arab Emirates adults (aged 18-20) and found 141 out of 406 respondents reporting a significant number of ADHD symptoms, at a rate of 34.7%, much higher than other surveys that report from 4-8% medically diagnosed ADHD prevalence [3], [4], [5], [6]. Kessler et al. performed a survey in a single manufacturing facility to assess the prevalence and workplace cost in this facility and determined higher rates of injury and low medication treatment rates for ADHD-diagnosed workers [5]. Adler et al. did find a high burden of symptoms of other conditions, such as insomnia, depression, and anxiety, in those respondents who have been diagnosed with ADHD [2]. Waite et al. performed a similar survey to the instrument we are proposing here, with the target audience US college students, finding a prevalence of undiagnosed ADHD of 10 percent and higher rates of diminished self-efficacy and increased rates of social anxiety for those participants with higher ADHD symptom reporting [7]. This study plans to expand this investigation to workers in the US, particularly workers in manufacturing, to investigate the prevalence of ADHD diagnosed and undiagnosed and possible connections to rates of stress, anxiety, and perception of self-efficacy.

8B. A brief summary/abstract of the study methodology, including design, population, and variables of interest.

(350 word maximum, in language understandable to someone who is not familiar with your area of study. Note this summary/abstract can be used to prepare the concise summary in the consent document.):

Background: In manufacturing environments, individuals exhibiting symptoms of ADHD often remain undiagnosed, leading to increased levels of workplace stress, anxiety, and other potentially negative outcomes. This study aims to address three objectives: first, to evaluate ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS v1.1) and compare these to self-reported diagnoses; second, to determine the prevalence of undiagnosed adults; third, to explore the relationship between self-efficacy and anxiety in individuals scoring 4 or higher on the ASRS v1.1 whether diagnosed or undiagnosed.

Methods: This research will employ an online survey targeting participants from selected manufacturing facilities as well as a broader national sample. Instruments used in the survey include the ASRS v1.1, six items from the Global Self-Efficacy Scale, and two 4-item subscales from the Liebowitz Social Anxiety Index, supplemented by questions capturing basic demographic information and participants' perceptions of workplace support for managing stress and anxiety.

9. Purpose

9A. State the purpose of the study and all research questions or aims. (Include a sentence that begins, "The purpose of this study is…")

The purpose of this study is to assess prevalence of ADHD in workers in the US and particularly in manufacturing and evaluate potential connections with self-efficacy, anxiety, and stress with ADHD symptom presence.

This study aims to address three objectives: first, to evaluate ADHD symptoms among participants using the ADHD Adult Self-Report Scale (ASRS v1.1) and compare these to self-reported diagnoses; second, to determine the prevalence of undiagnosed adults; third, to explore the relationship between self-efficacy and anxiety in individuals scoring 4 or higher on the ASRS v1.1 whether diagnosed or undiagnosed.

9B. Describe how results of this study will be used? (e.g., presentation? publication? thesis? dissertation?)

Results will be used for conference and university-level presentations, publication, and dissertation.

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10. Key Personnel. Describe responsibilities as specifically as possible. Include information on research training or certifications related to this project. **To determine key personnel see decision tree at https://cws.auburn.edu/OVPR/pm/compliance/irb/training. Submit a copy of CITI training documentation for all key personnel.** (For additional personnel, add lines as needed).

To determine Auburn University HIPAA – covered entities click link to HIPAA Policy.

If any key personnel have a formal association with institutions/entities involved in the study (for example is an employee or supervisor at the site research will occur), describe that affiliation. For all non-AU affiliated key personnel, submit a copy of their IRB approval.

Principal Investigator: Victoria Ballard **Rank/Title:** Graduate Research Assistant
Email Address: vzb0024@auburn.edu **Degree(s): MSCivE, MISE, GC OSE**
Dept. / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Data collection, analysis and publishing the results.

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: Click or tap here to enter text.
- Plan for IRB approval for non-AU affiliated personnel? Click or tap here to enter text.
- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: Click or tap here to enter text.
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed:

Conflicts of Interest in Research Involving Human Subjects (ID 110748) 1/25/2025

Records-Based Research (ID 32236) 02/09/2025

Social and Behavioral Research for Biomedical Researchers (ID 32237) 02/09/2025

Vulnerable Subjects - Research with Minors (ID 32239) 02/09/2025

Workers as Research Subjects - A Vulnerable Population (ID 32249) 11/20/2025

AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students (ID 269966) 11/19/2025

Research with Audio-Visual Mobile Data Collection Tools: Ethics and Regulations (ID 250206) 11/20/2025

Human Sciences Basic Course 11/19/2025

Advising Faculty: Dr. Richard Sesek **Rank/Title:** Professor
Email Address: rfs0006@auburn.edu **Degree(s):** PhD
Dept / Affiliation: Industrial and Systems Engineering **HIPAA Covered Entity? Yes ☐ No ☒**
Roles / Responsibilities: Supervision of the project and data collection

- AU affiliated? ☒ Yes ☐ No If no, name of home institution: Click or tap here to enter text.
- Plan for IRB approval for non-AU affiliated personnel?

- Do you have any known competing financial interests, personal relationships, or other interests that could have influence or appear to have influence on the work conducted in this project? ☐ Yes ☒ No
- If yes, briefly describe the potential or real conflict of interest: Click or tap here to enter text.
- Completed required CITI training? ☒ Yes ☐ No If NO, complete the appropriate CITI basic course and update the revised Exempt Application form.
- If YES, choose course(s) the researcher has completed:

IRB Additional Modules - HIPAA and Human Subjects Research (ID 32235) 5/12/2026

Responsible Conduct of Research - AU Basic RCR Training for ALL Faculty, Staff,Postdocs, and Students (ID 269966) 5/12/2026

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IRB Additional Modules - International Research (ID 26456) 5/12/2026

IRB Additional Modules - International Research - SBE (ID 32240) 5/12/2026

IRB Additional Modules - Internet Research - SBE (ID 32248) 5/12/2026

IRB Additional Modules - Populations in Research Requiring Additional Considerations and/or Protections (ID 32238) 5/12/2026

IRB Additional Modules - Populations in Research Requiring Additional Considerationsand/or Protections (ID 32238) 5/12/2026

IRB Additional Modules - Records-Based Research (ID 32236) 5/12/2026

IRB Additional Modules - Research at/with the Veteran's Administration (ID 26455) 5/12/2026

IRB Additional Modules - Research in Public Elementary and Secondary Schools (ID26458) 5/12/2026

IRB Additional Modules - Research in Public Elementary and Secondary Schools - SBE(ID 32241) 5/12/2026

IRB Additional Modules - Research Involving Pregnant Women, Human Fetuses, andNeonates (ID 26459) 5/12/2026

IRB Additional Modules - Research with Children - SBE (ID 32243) 5/12/2026

IRB Additional Modules - Social and Behavioral Research for Biomedical Researchers(ID 32237) 5/12/2026

IRB Additional Modules - Students in Research (ID 32250) 5/12/2026

IRB Additional Modules - Vulnerable Subjects - Research with Minors (ID 32239) 5/12/2026

IRB Additional Modules - Workers as Research Subjects - A Vulnerable Population (ID32249) 5/12/2026

Responsible Conduct of Research - Biomedical Sciences RCR (ID 38146) 4/23/2025

CITI Conflicts of Interest - Conflicts of Interest (ID 62402) 5/12/2027

IRB #1 Health Science Emphasis - AU Personnel - Basic/Refresher - IRB #1 HealthScience Emphasis - AU Personnel (ID 72743) 5/12/2026

11. Location of research. Online Survey

11A. List all locations where data collection will occur. If applicable, attach permission letters as Appendix E. (School systems, organizations, businesses, buildings and room numbers, servers for web surveys, etc.) **Be as specific as possible.**
(See sample letters at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)
Online Survey

11B. Will study data be stored within a HIPAA covered facility? Yes ☐ No ☒
If yes, which facility(ies) (To determine AU HIPPA covered entities, go to VII of the HIPPA Hybrid Entity Policy)**:**
Click or tap here to enter text.

12. Participants (If minor participants, at least 2 adults must be present during all research procedures that include the minors.)

Adults, age 18 and over, persons who respond to the request for survey participation.

12A. Describe the targeted/ intended participant population for the study. Include the anticipated number of participants and inclusion and exclusion criteria and the procedures to ensure more than 1 adult is present during all research procedures which include the minor.

☐ **Check here if existing data will be used and describe the population from whom data was collected including the number of data files.**

☐ **Check here if permission to access existing data is required and submit a copy of the agreement to access.**

Target Population: Anyone who 18 or more years of age, specifically manufacturing workers. **Number of Participants:** No maximum, minimum 100 respondents.
Inclusion Criteria: 18 or more years of age
Exclusion Criteria: less than 18 years of age

12B. Describe, step-by-step in lay language all procedures to recruit participants. Include in **Appendix B** a copy of all e-mails, flyers, advertisements, recruiting scripts, invitations, etc., that will be used to invite people to participate. (See sample documents at https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs)

Participants will be recruited via personal contacts of the principal investigator and other investigator, and the Auburn Alumni network. Emails will be sent to contacts making the request to send the survey link to the employees at their company. A post will be made to LinkedIn that is able to be shared throughout our network requesting participation.

12C. Minimum number of participants required to validate the study? 100

Number of participants expected to enroll? 300

Provide the rationale for the number of participants. Similar studies of this type have had respondent numbers in the range of 200-500 participants.

Is there a limit to the number of participants that will be included in the study?

☒ **No** ☐ **Yes, the number is** Click or tap here to enter text.

12D. Describe the process to compensate, amount and method of compensation and/or incentives for participants. **AU Procurement and Business Services (PBS) policies**
(benefits to participants are NOT compensation)

If participants will not be compensated, check here: ☐
Indicate the amount of compensation per procedure and in total: $50 gift card raffle
Indicate the type of compensation: ☐ Monetary ☐ Incentives
☒ Raffle or Drawing incentive (Include the chances of winning.)
☐ Extra Credit (State the value)
☐ Other

Describe how compensation will be distributed (USPS, email, etc.): Amazon.com gift cards will be emailed to participants that win the raffle. At the end of the survey participants are asked if they wish to participate in a raffle, if they select "yes" then they get directed to a separate survey to enter their personal email and name. One $50 winner will be selected for each 100 participants, a maximum of $1000 will be awarded to participants. Chances of winning is 1/100 if 100 participants complete the survey and request to participate in the raffle.

13. Project Design & Methods

Participants will be recruited through personal contacts and word of mouth. A survey link and the accompanying flyer for the Qualtrics survey will be provided to participants to complete the anonymous survey. Participants are directed to a second survey at the end of the primary anonymous survey if they indicate they wish to enter the raffle.

13A. Describe, step-by-step, all procedures and methods that will be used to consent participants. If a waiver is being requested, indicate the waiver, and describe how the study meets the criteria for the waiver. If minors will be enrolled describe the process to obtain parental/ legally authorized guardian permission.

☐ **Waiver of Consent (including using existing data)**

☒ **Waiver of Documentation of Consent (use of Information Letter)**

☐ **Waiver of Parental Permission (for college students 18 years or younger)**

Click or tap here to enter text.

Subjects filling out the survey to participate in the study will be presented with the IRB information letter in the first screen of the survey. They will be informed about study procedures as well as their right to discontinue participation at any time. The only exclusion criteria is: less than 18 years of age. If the participant indicates they are under 18 years of age on the first page of the survey, the survey stops. Since there is no personal information collected, we request waiver of consent form and use of an information letter.

13B. In lay language, understandable by someone not familiar with the area of study, describe the complete research design and methods that will be used to address the purpose. Include a clear description of who, when, where and how data will be collected. Include specific information about participants' time and effort.

Who/Where: Participants will be recruited from manufacturing and other facilities to take a approximately ten-minute online survey. Having 25-50 or more survey responses from each facility will aid in the determination of significant differences between each facility. Participants will also be recruited from LinkedIn and email contacts from a variety of workplaces, which will be compared by sector and position type (worker, management, VP, etc.).
When: As soon as IRB Approval is completed, recruiting will start. Data analysis will begin once the minimum number of participants is met, but surveys will stay open for at least one month after the initial recruiting begins.
How: An online survey through Qualtrics will be used to collect the data through an approximately 10-minute survey. At the end of the primary survey, participants will be asked if they want to be entered into a raffle drawing. If they select yes, they will be directed to a secondary survey to enter their name and email address for entry into the random drawing. If they choose "no", the survey will be submitted and they will not be redirected to the raffle survey.

13C. List all data collection instruments used in this project, in the order they appear in Appendix C.
(e.g., surveys and questionnaires in the format that will be presented to participants, educational tests, data collection sheets, interview questions, audio/video taping methods etc.)

Qualtrics Questionnaire survey (anonymous survey), Raffle Drawing Entry (separate from anonymous survey)

13D. Data analysis: Describe how data will be analyzed. If a data collection form (DCF) will be used, submit a copy of the DCF.

Basic statistical tests (F-test, paired t-test, ANOVA) will be used to compare results of the anonymous survey.

13E. List any drugs, medications, supplements, or imaging agents that participants will ingest/ receive during participation in the study or indicate not applicable (N/A).

N/A

14. Risks & Discomforts: List and describe all the risks participants may encounter in this research including risks from item 6d of this form, in this research. <u>If deception will be part of the study, provide the rationale for the deception, describe the debriefing process, and attach a copy of the debriefing form that will be used as Appendix D.</u> (Examples of possible risks are in section #6C)

No risks are identified from taking the survey itself. Breach of confidentiality was checked in section 6C because we considered, though remote, that it could be possible to identify subjects who entered the raffle. This is controlled by having the link to the raffle entry in a completely separate, distinct Qualtrics survey. Participants are not told we are investigating the prevalence of ADHD during the advertising and beginning of the survey, we wish to not have responses skewed by this knowledge. Questions related to ADHD diagnosis are purposefully placed at the end of the survey, without the option to go back and change previous answers.

15. Precautions / Minimization of Risks

15A. Identify and describe all precautions that will be taken to eliminate or reduce risks listed in items 6.c. and 14. If participants can be classified as a "vulnerable" population, describe additional safeguards that will be used to assure the ethical treatment of vulnerable individuals. **If applicable, submit a copy of any emergency plans/procedures and medical referral lists in Appendix D. (Sample documents can be found online at** https://cws.auburn.edu/OVPR/pm/compliance/irb/sampledocs **precautions)**

The only known risk associated with this study is potential breach of confidentiality, there is a very remote chance that time stamps on the Qualtrics survey and the raffle survey could match participants to the information provided anonymously in the survey. No IP Address information or other identifying information is collected in the primary survey instrument.

15B. If the internet, mobile apps, or other electronic means will be used to collect data, describe confidentiality and/or security precautions that will be used to protect (or not collect) identifiable data? Include protections used during collection of data, transfer of data, and storage of data. If participant data may be obtained and/or stored by apps during the study, describe.

All the data will be stored in the password protected personal computer of principal investigator and in the web-based portal of Auburn's Qualtrics account. Raffle entries with participant name and email will be stored in a separate survey from the primary anonymous survey.

15C. Does this research include purchase(s) that involve technology hardware, software or online services?

☐ YES ☒ NO

If YES:

A. Provide the name of the product N/A

B. and the manufacturer of the product Click or tap here to enter text.

C. Briefly describe use of the product in the proposed human subject's research.
Click or tap here to enter text.

D. To ensure compliance with AU's Electronic and Information Technology Accessibility Policy, contact AU IT Vendor Vetting team at vetting@auburn.edu to learn the vendor registration process (prior to completing the purchase).

E. Include a copy of the documentation of the approval from AU Vetting with the revised submission.

15D. Additional Safeguards

Will DEXA, pQCT, or other devices which emit radiation be used? ☐ Yes ☒ No
If yes, the IRB will notify the Auburn Department of Risk Management and Safety, who will contact the Alabama Department of Public Health (ADPH) and secure approval. Research which includes device(s) which emit radiation may NOT be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of ADPH approval.

Will a Certificate of Confidentiality (CoC) issued by NIH be obtained ☐ Yes ☒ No If yes, include CoC language in consent documents and include the documentation of CoC approval. Research which includes a CoC may not be initiated NOR will IRB stamped consent documents be issued until the IRB is notified of CoC approval. AU Required CoC Language

Is the study a clinical trial? ☐ Yes ☒ No
If yes, provide the National Clinical Trial (NCT) # Click or tap here to enter text. **and include required clinical trial information in all consent documents. AU Clinical Trial Information**

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16. Benefits

None to the participants unless they enter and win the raffle. The findings from the study will be used to enhance scientific knowledge about potential work-related concerns for workers with ADHD and prevalence rates of ADHD.

16A. List all realistic direct benefits participants can expect by participating in this study. (Compensation is not a benefit). If participants will not directly benefit check here. ☐

Unless participants enter and win the raffle prize, there are no direct benefits to participants other than the self-knowledge that they learn from this study. These individuals may benefit from self-reflection on the stress and anxiety they experience during work and personal activities. This knowledge may empower the participants to make improvements regarding their or their workplace's efforts for handling stress which may benefit their health. This new information will help fill gaps regarding the impact and prevalence of psychosocial factors for workers with and without symptoms of ADHD.

16B. List realistic benefits for the general population that may be generated from this study.

The information from the study will help fill gaps in research related impact and prevalence of psychosocial factors for workers with and without symptoms of ADHD, particularly those related to evidence-based recommendations for improving employee health and wellbeing.

17. Protection of Data

17A. Data are collected:

☒ Anonymously with no direct or indirect coding, link, or awareness by key personnel of who participated in the study (skip to item E)

☐ Confidentially, but without a link to participant's data to any identifying information (collected as "confidential" but recorded and analyzed "anonymous") (Skip to item E).

☐ Confidentially with collection and protection of linkages to identifiable information.

17B. If data are collected with identifiers and coded or as coded or linked to identifying information, describe the identifiers and how identifiers are linked to participants' data.

17C. Provide the rationale for need to code participants' data or link the data with identifying information.

17D. Describe how and where identifying data and/or code lists will be stored. (Building, room number, AU BOX?) **Describe how the location where data is stored will be secured. For electronic data, describe security measures. If applicable, describe where IRB-approved and participant signed consent documents will be kept on campus for 3 years after the study ends.**

17E. Describe how and where data will be stored (e.g., hard copy, audio/ visual files, electronic data, etc.), and how the location where data is stored is separated from identifying data and will be secured. For electronic data, describe security. Note use of a flash drive or portable hard drive is not appropriate if identifiable data will be stored; rather, identifying participant data must be stored on secured servers.

The data for computational analysis will NOT contain identifying information. It will be stored in the Qualtrics site through the Auburn University account and on PI's password protected computer.

17F. List the names of all who will have access to participants' data? (If a student PI, the faculty advisor must have full access and be able to produce study data in the case of a federal or institutional audit.)

Victoria Ballard and Dr. Richard Sesek. This data will be free of personal identifiers.

17G. When is the latest date that identifying information or links will be retained and how will that information or links be destroyed? (Check here if only anonymous data will be retained ☒)

Click or tap here to enter text.

Appendix A

Reference List

[1] E. M. Hallowell M.D and J. J. Ratey M.D, *ADHD 2.0: New Science and Essential Strategies for Thriving with Distraction--from Childhood through Adulthood*. New York: Ballantine Books, 2021.

[2] L. A. Adler, S. V. Faraone, P. Sarocco, N. Atkins, and A. Khachatryan, "Establishing US norms for the Adult ADHD Self-Report Scale (ASRS-v1.1) and characterising symptom burden among adults with self-reported ADHD," *Int. J. Clin. Pract.*, vol. 73, no. 1, p. e13260, 2019, doi: 10.1111/ijcp.13260.

[3] N. Al-Yateem *et al.*, "Prevalence of Undiagnosed Attention Deficit Hyperactivity Disorder (ADHD) Symptoms in the Young Adult Population of the United Arab Emirates: A National Cross-Sectional Study," *J. Epidemiol. Glob. Health*, Dec. 2023, doi: 10.1007/s44197-023-00167-4.

[4] D. Adamis, C. Flynn, M. Wrigley, B. Gavin, and F. McNicholas, "ADHD in Adults: A Systematic Review and Meta-Analysis of Prevalence Studies in Outpatient Psychiatric Clinics," *J. Atten. Disord.*, vol. 26, no. 12, pp. 1523–1534, Oct. 2022, doi: 10.1177/10870547221085503.

[5] R. C. Kessler, M. Lane, P. E. Stang, and D. L. V. Brunt, "The prevalence and workplace costs of adult attention deficit hyperactivity disorder in a large manufacturing firm," *Psychol. Med.*, vol. 39, no. 01, pp. 137–0, Jan. 2009, doi: 10.1017/S0033291708003309.

[6] M. Faheem, W. Akram, H. Akram, M. A. Khan, F. A. Siddiqui, and I. Majeed, "Gender-based differences in prevalence and effects of ADHD in adults: A systematic review," *Asian J. Psychiatry*, vol. 75, Sep. 2022, doi: 10.1016/j.ajp.2022.103205.

[7] R. Waite, T. Buchanan, and M. Leahy, "Assessing ADHD Symptoms among Young Adults in the University with the ASRS v1.1: Examining Associations with Social Anxiety and Self-Efficacy," *Int. J. Disabil. Dev. Educ.*, vol. 69, no. 5, pp. 1631–1644, Sep. 2022, doi: 10.1080/1034912X.2020.1825643.

Appendix B
To put on first page of the survey:

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER
for a Research Study entitled
Determination of prevalence and relationship between psychosocial stress and anxiety related to health factors of workers.

General Information	You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the consent form.
Purpose	Workplace psychosocial stress and anxiety related to health factors.
Duration and Visits	10 Minutes, one survey
Overview of Procedures	The purpose of the study is psychosocial factors, stress, and anxiety in workplaces, particularly manufacturing environments. You will be asked to complete a questionnaire of work-related stress and anxiety factors, with a few questions related to health-related factors. We anticipate that the study will include approximately 200 participants.
Risks	The only risk is related to the potential loss of confidentiality.
Benefits	There are no direct benefits to you for participating in this study unless you choose to enter the Raffle Drawing for a $50 Amazon.com gift card; a total of up to $1000 will be awarded, and the chances of winning are at least 1:100.
Alternatives	The alternative is to not participate in this study.

You are invited to participate in a study of work-related stress and anxiety. The study is being conducted by Victoria Ballard, MSE, AHFP, and Dr. Richard Sesek (Professor) in the Auburn University Department of Industrial and Systems Engineering. You were invited to participate because you are 18 years old or older. You will be excluded from the study if you are less than 18 years of age.

There are no direct benefits besides the self-knowledge you will learn from this study. You may benefit from self-reflection on the stress and anxiety you experience during work and personal activities. This knowledge may empower you to make improvements regarding your or your workplace's efforts to handle stress, which may benefit your health.

What will be involved if you participate? If you decide to participate in this study, you will be asked to complete an online survey, taking approximately 10 minutes.

Are there any risks or discomforts? The risks associated with participating in this study are minimal and related to breach of confidentiality.

Are there any benefits to yourself or others? If you participate in this study, you may gain knowledge on how your daily work-related stresses and anxiety, which might ultimately improve your health.

Will you receive compensation for participating? Possibly, if you choose to enter the raffle through a separate survey (separate from the anonymous primary survey), you could win a $50 Amazon.com gift card.

Are there any costs? If you decide to participate, you will not have to pay anything.

Any data obtained in connection with this study will remain anonymous. We will protect your privacy and the data you provide by not collecting any personal data. Information collected through your participation may be used to fulfill a PhD requirement, published in aggregate at in a professional journal, and/or presented at a professional meeting.

Date: 3/21/24

YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. Your decision about whether to participate or stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering.

To Contact the Researchers, email Victoria Ballard at VBallard@auburn.edu or Dr. Richard Sesek at Sesek@auburn.edu
To contact: **The Office of Research Compliance (ORC) Auburn University** Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**

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Protocol # 24-748 EX 2404

Do you consent to participate in this study, and are you 18 years of age or older? (If no, you cannot participate, and the survey will automatically terminate.)

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Protocol # 24-748 EX 2404

Email Flyer/Linked In Image

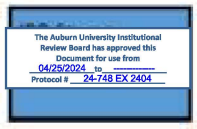
PARTICIPATE IN A WORKPLACE PSYCHOSOCIAL RESEARCH STUDY

INVESTIGATING WORKPLACE STRESS AND ANXIETY RELATED HEALTH FACTORS

No Direct Benefits to Participants, Voluntary Participation.

Please take a few minutes today to help provide necessary data for PhD Research at Auburn University.

To participate go to: aub.ie/ResearchSurvey24



Appendix C: Qualtrics Survey

Psychosocial Questionnaire

https://auburn.qualtrics.com/jfe/form/SV_db8KVmzgS1HGj9s

Survey included in the next pages.

In general, after the general biographical information questions, depending on how participants answer the questions, some questions will be skipped. Near the end of the survey there is an option to complete an additional 13 multiple choice questions, which take less than 5 minutes to complete. Without the additional questions, the average completion time is 5-8 minutes. There is a progress bar on each page to indicate the progression through the survey.

Manufacturing Employee Survey

ExpertReview score Fair

Demographics

Instruction

Thanks for volunteering to complete our survey. It is an essential part of PhD research. We appreciate your willingness to answer these questions, and it should take you approximately 10 minutes to complete the survey.

Optional drawing for at least two $50 Amazon.com gift cards awarded randomly plus an additional $50 for every 100 complete, valid surveys, up to $1000 given in prizes!

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Q25

Skip to

End of Survey if No, I do not consent to par... Is Selected

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Protocol # 24-748 EX 2404

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER

a Research Study entitled

Determination of prevalence and relationship between psychosocial stress and anxiety related to health factors of workers.

General Information	You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the consent form.
Purpose	Workplace psychosocial stress and anxiety related to health factors

Purpose	Workplace psychosocial stress and anxiety related to health factors.
Duration and Visits	10 Minutes, one survey
Overview of Procedures	The purpose of the study is psychosocial factors, stress, and anxiety in workplaces, particularly manufacturing environments. You will be asked to complete a questionnaire of work-related stress and anxiety factors, with a few questions related to health-related factors. We anticipate that the study will include approximately 200 participants.
Risks	The only risk is related to the potential loss of confidentiality.
Benefits	There are no direct benefits to you for participating in this study unless you choose to enter the Raffle Drawing for a $50 Amazon.com gift card; a total of up to $1000 will be awarded, and the chances of winning are at least 1:100.
Alternatives	The alternative is to not participate in this study.

You are invited to participate in a study of work-related stress and anxiety. The study is being conducted by Victoria Ballard, MSE, AHFP, and Dr. Richard Sesek (Professor) in the Auburn University Department of Industrial and Systems Engineering. You were invited to participate because you are 18 years old or older so you will be excluded from the study if you are less than 18 years of age.

There are no direct benefits besides the self-knowledge you will learn from this study. You may benefit from self-reflection on the stress and anxiety you experience during work and personal activities. This knowledge may empower you to make improvements regarding your or your workplace's efforts to handle stress, which may benefit your health.

What will be involved if you participate? If you decide to participate in this study, you will be asked to complete an online survey, taking approximately 15 minutes.

Are there any risks or discomforts? The risks associated with participating in this study are minimal and related to breach of confidentiality.

Are there any benefits to yourself or others? If you participate in this study, you may gain knowledge on how your daily work-related stresses and anxiety, which might ultimately improve your health.

Will you receive compensation for participating? Possibly, if you choose to enter the raffle through a separate survey (separate from the anonymous primary survey), you could win a $50

through a separate survey (separate from the anonymous primary survey), you could win a $50 Amazon.com gift card.

Are there any costs? If you decide to participate, you will not have to pay anything.

Any data obtained in connection with this study will remain anonymous. We will protect your privacy and the data you provide by not collecting any personal data. Information collected through your participation may be used to fulfill a PhD requirement, published in aggregate at a professional journal, and/or presented at a professional meeting.

If you change your mind about participating, you can withdraw at any time during the study. **Your participation is completely voluntary.** Your decision about whether to participate or stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering.

To Contact the Researchers, email Victoria Ballard at VBallard@auburn.edu or Dr. Richard Sesek at Sesek@auburn.edu

Date: March 21, 2024

YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

To contact: **The Office of Research Compliance (ORC) Auburn University** Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**

<<< IRB Stamp will be here once approved>>

Do you consent to participate in this study, and are you 18 years of age or older? (If no, you cannot participate, and the survey will automatically terminate.)

- ○ Yes, I consent to participate in the study and I am 18 years old or older.
- ○ No, I do not consent to participate in the study and/or I am under 18 years old.

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Page Break

Sex at birth *

What was your sex assigned at birth?

- ○ Male
- ○ Female
- ○ Prefer not to answer

Page Break

Age *

What is your age?

Page Break

Page Break

Ethnicity/Race *

How would you describe yourself? Please select all that apply.

- ☐ Asian
- ☐ American Indian or Alaska Native
- ☐ Black or African American
- ☐ Hispanic, Latino, or Spanish origin
- ☐ Native Hawaiian or Pacific Islander
- ☐ White
- ☐ Other
- ☐ Prefer not to answer

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Page Break

Education *

What is the highest degree or level of school you have completed?

- ○ Less than a high school diploma
- ○ High school degree or equivalent (e.g. GED)
- ○ Some college, no degree
- ○ Associate degree (e.g. AA, AS)
- ○ Bachelor's degree (e.g. BA, BS)
- ○ Master's degree (e.g. MA, MS, MEd)
- ○ Doctorate or professional degree (e.g. MD, DDS, PhD)

Page Break

Marital Status

What is your marital status?

- ○ Single (never married)
- ○ Married, or in a domestic partnership
- ○ Widowed
- ○ Divorced
- ○ Separated

Page Break

Employment

What is your current employment status (Choose all that apply)?

- ☐ Employed full time at one or more jobs
- ☐ Employed part time at one or more jobs
- ☐ Student
- ☐ Unemployed
- ☐ Looking for a job or a new job
- ☐ Self-employed
- ☐ Retired
- ☐ Homemaker
- ☐ Unable to work

Employment Sector

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

In which sector are you currently employed for your main source of income?

- ○ Manufacturing
- ○ Education
- ○ Government
- ○ Healthcare
- ○ Retail
- ○ Transportation and Warehousing
- ○ Accommodation and Food Services
- ○ Arts, Entertainment, and Recreation
- ○ Construction
- ○ Mining
- ○ Other (please provide):

Q27

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

Please select the option that best describes your current role within your primary organization of employment:

- Executive Leadership (e.g., CEO, VP, C-level positions)
- Senior Management (e.g., Director, Senior Manager)
- Middle Management (e.g., Manager, Team Leader)
- Professional/Technical (e.g., Engineer, Analyst, Specialist)
- Administrative Support (e.g., Administrative Assistant, Coordinator)
- Operational Staff (e.g., Line Worker, Customer Service Representative)
- Other (please specify)

Import from library | Add new question

Add Block

ASRS

Behavioral Control

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, select the level that best describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very Often
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?	○	○	○	○	○
How often do you have difficulty getting things in order when you have to do a task that requires organization?	○	○	○	○	○
How often do you have problems remembering appointments or obligations?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
When you have a task that requires a lot of thought, how often do you avoid or delay getting started?	○	○	○	○	○
How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?	○	○	○	○	○
How often do you feel overly active and compelled to do things, like you were driven by a motor?	○	○	○	○	○

Import from library | Add new question

Add Block

Block 3

LSAS

For each situation answer the level of anxiousness and avoidance it causes.

	How anxious or fearful do you feel in the situation?				How often do you avoid the situation?			
	None	Mild	Moderate	Severe	Never (0%)	Occasionally (1-33%)	Often (34-66%)	Usually (67-100%)
Participating in small groups	○	○	○	○	○	○	○	○
Acting, performing, or giving a talk in front of an audience	○	○	○	○	○	○	○	○
Working while being observed	○	○	○	○	○	○	○	○
Quality check, please choose Severe and Never	○	○	○	○	○	○	○	○
Speaking up in a meeting	○	○	○	○	○	○	○	○
	None	Mild	Moderate	Severe	Never (0%)	Occasionally (1-33%)	Often (34-66%)	Usually (67-100%)
Talking to people in authority	○	○	○	○	○	○	○	○
Calling someone you don't know very well	○	○	○	○	○	○	○	○
Expressing a disagreement or disapproval to people you don't know well	○	○	○	○	○	○	○	○
Being the center of attention	○	○	○	○	○	○	○	○

Import from library | Add new question

Add Block

GSE

Q13

Indicate the extent to which each item applies to you.

	Not at all true	Hardly true	Moderately true	Exactly true
When I am confronted with a problem, I can usually find several solutions.	○	○	○	○
I am confident that I could deal efficiently with unexpected events.	○	○	○	○
Thanks to my resourcefulness, I know how to handle unforeseen situations.	○	○	○	○
	Not at all true	Hardly true	Moderately true	Exactly true
I can remain calm when facing difficulties because I can rely on my coping abilities.	○	○	○	○
I can usually handle whatever comes my way.	○	○	○	○

Import from library | Add new question

Add Block

Work Environment

Q14

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected

Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected

Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

How would you rate the overall work environment in terms of supporting employees with ADHD or anxiety issues?

Very Supportive	Supportive	Unsupportive	Very unsupportive
○	○	○	○

Q15

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

What strategies do you use to manage **work-related** stress or anxiety? (Select all that apply)

- [ ] Planning and organization tools
- [ ] Taking regular breaks
- [ ] Seeking support from colleagues or supervisors
- [ ] Professional counseling or therapy
- [ ] Physical activities or exercise
- [ ] Other (please specify):
- [ ] None

Q24

What strategies do you use to manage **everyday** stress or anxiety? (Select all that apply)

- [ ] Planning and organization tools
- [ ] Taking regular breaks
- [ ] Seeking support from friends and/or family
- [ ] Professional counseling or therapy
- [ ] Physical activities or exercise
- [ ] Other (please specify):
- [ ] None

Q16

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

Do you feel that your workplace provides effective support for managing stress and anxiety?

- ○ Not effective at all
- ○ Slightly effective
- ○ Moderately effective
- ○ Very effective
- ○ Extremely effective

Import from library | Add new question

Add Block

ADHD Diagnosis

Q17 *

Display this question

If What is your current employment status (Choose all that apply)? Employed full time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Employed part time at one or more jobs Is Selected
Or What is your current employment status (Choose all that apply)? Self-employed Is Selected

Do you have any suggestions for how your workplace could better support employees with Attention Deficit Hyperactivity Disorder (ADHD) and/or anxiety-related challenges? If yes, please share your ideas below. (optional)

Diagnosed *

Have you been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) by a healthcare professional?

- Yes
- No

Friends/Family Diag

Display this question

If Have you been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) by a healthcare prof... No Is Selected

Do your friends or family members comment that they think you might have ADHD based on your behavior or tendencies?

- Yes
- No

Self Diagnose

Display this question

If Have you been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) by a healthcare prof... No Is Selected

Do you think you might have ADHD?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Medication

Display this question

If Have you been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) by a healthcare prof... Yes Is Selected
Or Do you think you might have ADHD? Might or might not Is Selected
Or Do you think you might have ADHD? Probably yes Is Selected
Or Do you think you might have ADHD? Definitely yes Is Selected
Or Do you think you might have ADHD? Probably not Is Selected

Are you currently taking prescription medication for ADHD?

- No
- No, but I self medicate with caffeine or other stimulants
- Yes, prescribed to be taken daily
- Yes, prescribed to be taken as needed

Import from library | Add new question

Add Block

Thank you

Q26

If you have a few more minutes, we would appreciate if you would answer 13 more multiple choice questions related to this research. These are optional, would you like to answer these additional questions?

- Sure! Bring 'em on. I will answer a few more questions.
- No, thank you. I don't care to answer more questions today. Please submit my survey.

Behavioral Control 2

Display this question

If If you have a few more minutes, we would appreciate if you would answer 13 more multiple choice q... Sure! Bring 'em on. I will answer a few more questions. Is Selected

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, select the level that best describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very Often
How often do you make careless mistakes when you have to work on a boring or difficult project?	○	○	○	○	○
How often do you have difficulty keeping your attention when you are doing boring or repetitive work?	○	○	○	○	○
How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?	○	○	○	○	○
For a quality check, please choose Very Often for this response?	○	○	○	○	○
How often do you misplace or have difficulty finding things at home or at work?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
How often are you distracted by activity or noise around you?	○	○	○	○	○
How often do you leave your seat in meetings or other situations in which you are expected to remain seated?	○	○	○	○	○
How often do you feel restless or fidgety?	○	○	○	○	○
How often do you have difficulty unwinding and relaxing when you have time to yourself?	○	○	○	○	○
How often do you find yourself talking too much when you are in social situations?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
When you're in a conversation, how often do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?	○	○	○	○	○
How often do you have difficulty waiting your turn in	○	○	○	○	○

situations when turn taking is required?	○	○	○	○	○
How often do you interrupt others when they are busy?	○	○	○	○	○

Page Break

Comments *

Please provide any additional comments or information you feel is relevant to this study: (optional)

Import from library | Add new question

Add Block

Block 7

Drawing Entry

We are offering each person who completes this survey a chance for a $50 Amazon.com gift card. Are you interested in being redirected to another survey (separate from this survey so your responses on this survey are not connected to your personal information) to enter your name and email address for entry into the drawing?

- ○ YES! I would like to enter the drawing for the gift card!
- ○ NO thank you, I am not interested in entering the drawing.

Import from library | Add new question

Add Block

End of Survey

We thank you for your time spent taking this survey.

Your response has been recorded.

Tools Saved Feb 6, 2024 at 2:08 PM Published Preview Publish

Raffle Entry Manufacturing Survey

ExpertReview score Great

Default Question Block

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Q2

Thank you for completing the survey to support my dissertation research. This raffle entry form is a separate survey from the information entered previously, your personal information is not connected to your survey answers.

Please enter your information below to be entered into the raffle for a $50 Amazon.com gift card. You will be contacted by email if you are selected as a winner.

Q1 *

First Name

Q3 *

Last Name

Q4 *

Email Address

Q5

Thank you, very much, for your participation. Submit your response to enter the drawing.

Import from library Add new question

Add Block

End of Survey

We thank you for your time spent taking this survey.

Your response has been recorded.

English

CITI PROGRAM | My Courses | My Records | My CE/CMEs | Support | Victoria Ballard ID 10879868

Records

All Institutions

Show Records for: All Institutions

Auburn University Records (ID 964)

IRB Additional Modules - Conflicts of Interest in Research Involving Human Subjects (ID 110748)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	46951870	80%	80%	26-Jan-2022	26-Jan-2022	25-Jan-2025	View	View-Print-Share

IRB Additional Modules - Records-Based Research (ID 32236)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	46951862	80%	100%	10-Feb-2022	10-Feb-2022	09-Feb-2025	View	View-Print-Share

IRB Additional Modules - Social and Behavioral Research for Biomedical Researchers (ID 32237)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	46955249	80%	100%	10-Feb-2022	10-Feb-2022	09-Feb-2025	View	View-Print-Share

IRB Additional Modules - Vulnerable Subjects - Research with Minors (ID 32239)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	46955250	80%	100%	10-Feb-2022	10-Feb-2022	09-Feb-2025	View	View-Print-Share

IRB Additional Modules - Workers as Research Subjects - A Vulnerable Population (ID 32249)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	51806244	80%	100%	20-Nov-2022	20-Nov-2022	20-Nov-2025	View	View-Print-Share

Responsible Conduct of Research - AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students (ID 269966)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
RCR	51806249	90%	98%	28-Sep-2022	19-Nov-2022	19-Nov-2025	View	View-Print-Share

IRB #1 Health Science Emphasis - AU Personnel - Basic/Refresher - IRB #1 Health Science Emphasis - AU Personnel (ID 72743)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	47358283	80%	94%	26-Jan-2022	10-Feb-2022	09-Feb-2025	View	View-Print-Share

IRB #1 Health Science Emphasis - Non-AU Personnel - Basic/Refresher - IRB #1 Health Science Emphasis - Non-AU Personnel (ID 72744)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	46955251	80%	91%	26-Jan-2022	10-Feb-2022	09-Feb-2025	View	View-Print-Share

IRB # 2 Social and Behavioral Emphasis - AU Personnel - Basic/Refresher - IRB # 2 Social and Behavioral Emphasis - AU Personnel (ID 72746)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	51806245	80%	92%	26-Jan-2022	-	-	View	-

Essentials of Research Administration (ID 116818)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	51806246	-	-	Due Now	-	-	View	-

Informed Consent and Research with Wearable Tech (ID 230870)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic	51806247	-	-	Due Now	-	-	View	-

Research with Audio-Visual Mobile Data Collection Tools: Ethics and Regulations (ID 250206)

Stage	Record ID	Passing Score	Your Score	Start Date	Completion Date	Expiration Date	Gradebook	Completion Record
Basic Course	51806248	80%	80%	20-Nov-2022	20-Nov-2022	20-Nov-2025	View	View-Print-Share

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Richard Sesek (ID: 1256937)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** sesek@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 334 728-1438

- **Curriculum Group:** Responsible Conduct of Research
- **Course Learner Group:** AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
- **Stage:** Stage 1 - RCR
- **Description:** This course is for investigators, staff and students with an interest or focus in Biomedical Research. This course contains text, embedded case studies AND quizzes.

- **Record ID:** 50315464
- **Completion Date:** 12-May-2023
- **Expiration Date:** 12-May-2026
- **Minimum Passing:** 90
- **Reported Score*:** 94

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Authorship (RCR-Basic) (ID: 16597)	12-May-2023	5/5 (100%)
Collaborative Research (RCR-Basic) (ID: 16598)	12-May-2023	5/5 (100%)
Conflicts of Interest and Commitment (RCR-Basic) (ID: 16599)	12-May-2023	4/5 (80%)
Data Management (RCR-Basic) (ID: 16600)	12-May-2023	5/5 (100%)
Mentoring (RCR-Basic) (ID: 16602)	12-May-2023	5/5 (100%)
Peer Review (RCR-Basic) (ID: 16603)	12-May-2023	5/5 (100%)
Research Misconduct (RCR-Basic) (ID: 16604)	12-May-2023	5/5 (100%)
Plagiarism (RCR-Basic) (ID: 15156)	12-May-2023	4/5 (80%)
Using Animal Subjects in Research (RCR-Basic) (ID: 13301)	12-May-2023	5/5 (100%)
Research Involving Human Subjects (RCR-Basic) (ID: 13566)	12-May-2023	4/5 (80%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

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COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 2 OF 2
COURSEWORK TRANSCRIPT**

** NOTE: Scores on this Transcript Report reflect the most current quiz completions, including quizzes on optional (supplemental) elements of the course. See list below for details. See separate Requirements Report for the reported scores at the time all requirements for the course were met.

- **Name:** Richard Sesek (ID: 1256937)
- **Institution Affiliation:** Auburn University (ID: 964)
- **Institution Email:** sesek@auburn.edu
- **Institution Unit:** Industrial and Systems Engineering
- **Phone:** 334 728-1438

- **Curriculum Group:** Responsible Conduct of Research
- **Course Learner Group:** AU Basic RCR Training for ALL Faculty, Staff, Postdocs, and Students
- **Stage:** Stage 1 - RCR
- **Description:** This course is for investigators, staff and students with an interest or focus in **Biomedical Research**. This course contains text, embedded case studies AND quizzes.

- **Record ID:** 50315464
- **Report Date:** 28-Aug-2023
- **Current Score**:** 94

REQUIRED, ELECTIVE, AND SUPPLEMENTAL MODULES	MOST RECENT	SCORE
Using Animal Subjects in Research (RCR-Basic) (ID: 13301)	12-May-2023	5/5 (100%)
Research Involving Human Subjects (RCR-Basic) (ID: 13566)	12-May-2023	4/5 (80%)
Plagiarism (RCR-Basic) (ID: 15156)	12-May-2023	4/5 (80%)
Authorship (RCR-Basic) (ID: 16597)	12-May-2023	5/5 (100%)
Collaborative Research (RCR-Basic) (ID: 16598)	12-May-2023	5/5 (100%)
Conflicts of Interest and Commitment (RCR-Basic) (ID: 16599)	12-May-2023	4/5 (80%)
Peer Review (RCR-Basic) (ID: 16603)	12-May-2023	5/5 (100%)
Research Misconduct (RCR-Basic) (ID: 16604)	12-May-2023	5/5 (100%)
Data Management (RCR-Basic) (ID: 16600)	12-May-2023	5/5 (100%)
Mentoring (RCR-Basic) (ID: 16602)	12-May-2023	5/5 (100%)

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E.4 Workplace Psychosocial Survey: Copy of Survey from Qualtrics

Demographics

Thanks for volunteering to complete our survey. It is an essential part of PhD research. We appreciate your willingness to answer these questions, and it should take you approximately 10 minutes to complete the survey.

Optional drawing for at least two $50 Amazon.com gift cards awarded randomly plus an additional $50 for every 100 complete, valid surveys, up to $1000 given in prizes!

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMATION LETTER

Research Study entitled

Determination of prevalence and relationship between psychosocial stress and anxiety related to health factors of workers.

General Information	You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risks, and benefits are fully described further in the information letter.
Purpose	Workplace psychosocial stress and anxiety related to health factors.
Duration and Visits	10 Minutes, one survey

Overview of Procedures	The purpose of the study is psychosocial factors, stress, and anxiety in workplaces, particularly manufacturing environments. You will be asked to complete a questionnaire of work-related stress and anxiety factors, with a few questions related to health-related factors. We anticipate that the study will include approximately 200 participants.
Risks	The only risk is related to the potential loss of confidentiality.
Benefits	There are no direct benefits to you for participating in this study unless you choose to enter the Raffle Drawing for a $50 Amazon.com gift card; a total of up to $1000 will be awarded, and the chances of winning are at least 1:100.
Alternatives	The alternative is to not participate in this study.

You are invited to participate in a study of work-related stress and anxiety. The study is being conducted by Victoria Ballard, MSE, AHFP, and Dr. Richard Sesek (Professor) in the Auburn University Department of Industrial and Systems Engineering. You were invited to participate because you are 18 years old or older so you will be excluded from the study if you are less than 18 years of age.

There are no direct benefits besides the self-knowledge you will learn from this study. You may benefit from self-reflection on the stress and anxiety you experience during work and personal activities. This knowledge may empower you to make improvements regarding your or your workplace's efforts to handle stress, which may benefit your health.

What will be involved if you participate? If you decide to participate in this study, you will be asked to complete an online survey, taking approximately 15 minutes.

Are there any risks or discomforts? The risks associated with participating in this study are minimal and related to breach of confidentiality.

Are there any benefits to yourself or others? If you participate in this study, you may gain knowledge on how your daily work-related stresses and anxiety, which might ultimately improve your health.

Will you receive compensation for participating? Possibly, if you choose to enter the raffle through a separate survey (separate from the anonymous primary survey), you could win a $50 Amazon.com gift card.

Are there any costs? If you decide to participate, you will not have to pay anything.

Any data obtained in connection with this study will remain anonymous. We will protect your privacy and the data you provide by not collecting any personal data. Information collected through your participation may be used to fulfill a PhD requirement, published in aggregate at a professional journal, and/or presented at a professional meeting.

If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. Your decision about whether to participate or stop participating will not jeopardize your future relations with Auburn University, the Department of Industrial and Systems Engineering.

To Contact the Researchers, email Victoria Ballard at VBallard@auburn.edu or Dr. Richard Sesek at Sesek@auburn.edu

Date: March 21, 2024

YOU MAY PRINT A COPY OF THIS LETTER TO KEEP.

To contact: **The Office of Research Compliance (ORC) Auburn University** Phone: **334-844-5966** E-Mail: **IRBAdmin@auburn.edu** Web Address: **http://www.auburn.edu/research/vpr/ohs**

Do you consent to participate in this study, and are you 18 years of age or older? (If no, you cannot participate, and the survey will automatically terminate.)

- ○ Yes, I consent to participate in the study and I am 18 years old or older.
- ○ No, I do not consent to participate in the study and/or I am under 18 years old.

What was your sex assigned at birth?

- ○ Male
- ○ Female
- ○ Prefer not to answer

What is your age?

How would you describe yourself? Please select all that apply.

- [ ] Asian
- [ ] American Indian or Alaska Native
- [ ] Black or African American
- [ ] Hispanic, Latino, or Spanish origin
- [ ] Native Hawaiian or Pacific Islander
- [ ] White
- [ ] Other
- [ ] Prefer not to answer

What is the highest degree or level of school you have completed?

- ○ Less than a high school diploma
- ○ High school degree or equivalent (e.g. GED)
- ○ Some college, no degree
- ○ Associate degree (e.g. AA, AS)
- ○ Bachelor's degree (e.g. BA, BS)
- ○ Master's degree (e.g. MA, MS, MEd)
- ○ Doctorate or professional degree (e.g. MD, DDS, PhD)

What is your marital status?

- ○ Single (never married)
- ○ Married, or in a domestic partnership
- ○ Widowed
- ○ Divorced
- ○ Separated

What is your current employment status (Choose all that apply)?

- [ ] Employed full time at one or more jobs
- [ ] Employed part time at one or more jobs
- [ ] Student
- [ ] Unemployed

- [ ] Looking for a job or a new job
- [ ] Self-employed
- [ ] Retired
- [ ] Homemaker
- [ ] Unable to work

In which sector are you currently employed for your main source of income?

- ○ Manufacturing
- ○ Education
- ○ Government
- ○ Healthcare
- ○ Retail
- ○ Transportation and Warehousing
- ○ Accommodation and Food Services
- ○ Arts, Entertainment, and Recreation
- ○ Construction
- ○ Mining
- ○ Other (please provide):

Please select the option that best describes your current role within your primary organization of employment:

- ○ Executive Leadership (e.g., CEO, VP, C-level positions)
- ○ Senior Management (e.g., Director, Senior Manager)
- ○ Middle Management (e.g., Manager, Team Leader)
- ○ Professional/Technical (e.g., Engineer, Analyst, Specialist)
- ○ Administrative Support (e.g., Administrative Assistant, Coordinator)
- ○ Operational Staff (e.g., Line Worker, Customer Service Representative)
- ○ Other (please specify)

ASRS

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, select the level that best describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very Often
How often do you have trouble wrapping up the final details of a project, once the challenging parts have been done?	○	○	○	○	○
How often do you have difficulty getting things in order when you have to do a task that requires organization?	○	○	○	○	○
How often do you have problems remembering appointments or obligations?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
When you have a task that requires a lot of thought, how often do you avoid or delay getting started?	○	○	○	○	○
How often do you fidget or squirm with your hands or feet when you have to sit down for a long time?	○	○	○	○	○
How often do you feel overly active and compelled to do things, like you were driven by a motor?	○	○	○	○	○

Block 3

For each situation answer the level of anxiousness and avoidance it causes.

	How anxious or fearful do you feel in the situation?				How often do you avoid the situation?			
	None	Mild	Moderate	Severe	Never (0%)	Occasionally (1-33%)	Often (34-66%)	Usually (67-100%)
Participating in small groups	○	○	○	○	○	○	○	○
Acting, performing, or giving a talk in front of an audience	○	○	○	○	○	○	○	○
Working while being observed	○	○	○	○	○	○	○	○
Quality check, please choose Severe and Never	○	○	○	○	○	○	○	○
Speaking up in a meeting	○	○	○	○	○	○	○	○
	None	Mild	Moderate	Severe	Never (0%)	Occasionally (1-33%)	Often (34-66%)	Usually (67-100%)
Talking to people in authority	○	○	○	○	○	○	○	○
Calling someone you don't know very well	○	○	○	○	○	○	○	○
Expressing a disagreement or disapproval to people you don't know well	○	○	○	○	○	○	○	○
Being the center of attention	○	○	○	○	○	○	○	○

GSE

Indicate the extent to which each item applies to you.

	Not at all true	Hardly true	Moderately true	Exactly true
When I am confronted with a problem, I can usually find several solutions.	○	○	○	○
I am confident that I could deal efficiently with unexpected events.	○	○	○	○
Thanks to my resourcefulness, I know how to handle unforeseen situations.	○	○	○	○
	Not at all true	Hardly true	Moderately true	Exactly true
I can remain calm when facing difficulties because I can rely on my coping abilities.	○	○	○	○
I can usually handle whatever comes my way.	○	○	○	○

Work Environment

How would you rate the overall work environment in terms of supporting employees with ADHD or anxiety issues?

Very Supportive ○ Supportive ○ Unsupportive ○ Very unsupportive ○

What strategies do you use to manage **work-related** stress or anxiety? (Select all that apply)

- ☐ Planning and organization tools
- ☐ Taking regular breaks
- ☐ Seeking support from colleagues or supervisors
- ☐ Professional counseling or therapy
- ☐ Physical activities or exercise
- ☐ Other (please specify): _____
- ☐ None

What strategies do you use to manage **everyday** stress or anxiety? (Select all that apply)

- [ ] Planning and organization tools
- [ ] Taking regular breaks
- [ ] Seeking support from friends and/or family
- [ ] Professional counseling or therapy
- [ ] Physical activities or exercise
- [ ] Other (please specify):
- [ ] None

Do you feel that your workplace provides effective support for managing stress and anxiety?

- ○ Not effective at all
- ○ Slightly effective
- ○ Moderately effective
- ○ Very effective
- ○ Extremely effective

ADHD Diagnosis

Do you have any suggestions for how your workplace could better support employees with Attention Deficit Hyperactivity Disorder (ADHD) and/or anxiety-related challenges? If yes, please share your ideas below. (optional)

Have you been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD) by a healthcare professional?

- ○ Yes

- No

Do your friends or family members comment that they think you might have ADHD based on your behavior or tendencies?

- Yes
- No

Do you think you might have ADHD?

- Definitely not
- Probably not
- Might or might not
- Probably yes
- Definitely yes

Are you currently taking prescription medication for ADHD?

- No
- No, but I self medicate with caffeine or other stimulants
- Yes, prescribed to be taken daily
- Yes, prescribed to be taken as needed

Thank you

If you have a few more minutes, we would appreciate if you would answer 13 more multiple choice questions related to this research. These are optional, would you like to answer these additional questions?

- Sure! Bring 'em on. I will answer a few more questions.
- No, thank you. I don't care to answer more questions today. Please submit my survey.

Please answer the questions below, rating yourself on each of the criteria shown using the scale on the right side of the page. As you answer each question, select the level that best

describes how you have felt and conducted yourself over the past 6 months.

	Never	Rarely	Sometimes	Often	Very Often
How often do you make careless mistakes when you have to work on a boring or difficult project?	○	○	○	○	○
How often do you have difficulty keeping your attention when you are doing boring or repetitive work?	○	○	○	○	○
How often do you have difficulty concentrating on what people say to you, even when they are speaking to you directly?	○	○	○	○	○
For a quality check, please choose Very Often for this response?	○	○	○	○	○
How often do you misplace or have difficulty finding things at home or at work?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
How often are you distracted by activity or noise around you?	○	○	○	○	○
How often do you leave your seat in meetings or other situations in which you are expected to remain seated?	○	○	○	○	○
How often do you feel restless or fidgety?	○	○	○	○	○
How often do you have difficulty unwinding and relaxing when you have time to yourself?	○	○	○	○	○
How often do you find yourself talking too much when you are in social situations?	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
When you’re in a conversation, how often	○	○	○	○	○

	Never	Rarely	Sometimes	Often	Very Often
do you find yourself finishing the sentences of the people you are talking to, before they can finish them themselves?					
How often do you have difficulty waiting your turn in situations when turn taking is required?	○	○	○	○	○
How often do you interrupt others when they are busy?	○	○	○	○	○

Please provide any additional comments or information you feel is relevant to this study: (optional)

Block 7

We are offering each person who completes this survey a chance for a $50 Amazon.com gift card. Are you interested in being redirected to another survey (separate from this survey so your responses on this survey are not connected to your personal information) to enter your name and email address for entry into the drawing?

- ○ YES! I would like to enter the drawing for the gift card!
- ○ NO thank you, I am not interested in entering the drawing.

Appendix F: Contributions

F.1 Pilot Study Contribution Matrix: Augmented Reality Effects on Performance and Quality

Contributor	Experimental Design	Tiger Motors Facility Support	IRB Writing	IRB Editing and Advising	Primary Experimental Execution	Support Experimental Execution	Participant Recruiting	Participant Scheduling	Experimental Aide	Experiment Technology Development	Experiment Technology Technical Support	Data Collection	Data Analysis for this Dissertation Contribution	Statistical Analysis for this Dissertation Contribution	Poster Creation and Presentation	Conference Session Creation and Presentation	Publication Based on this Experiment Primary Author	Publication Non-Primary Author
Victoria Ballard	X	X	N/A	N/A	X		X	X		N/A	X	X	X	X	X	X	In Press	
Richard Sesek	X		N/A	N/A						N/A								
Tom Devall		X	N/A	N/A						N/A								
Diego Caputo		X	N/A	N/A					X	N/A								

F.2 Experiment 1 Contribution Matrix: Manufacturing Technology Support Investigation- Assessing the Effects of Augmented Reality Technology on ADHD Workers

Contributor	Experimental Design	Tiger Motors Facility Support	IRB Writing	IRB Editing and Advising	Primary Experimental Execution	Support Experimental Execution	Participant Recruiting	Participant Scheduling	Experimental Aide	Experiment Technology Development	Experiment Technology Technical Support	Data Collection	Data Processing for this Dissertation Contribution	Statistical Analysis for this Dissertation Contribution	Poster Creation and/or Presentation	Conference Session Creation and Presentation	Publication Based on this Experiment Primary Author	Publication Non-Primary Author
Victoria Ballard	X	X		X		X	X				X	X	X	X	X	X		
Richard Sesek	X			X											X			
Danny O'Leary	X		X	X	X			X		X	X	X	X				In Press	
Md Monir Hossain	X			X		X	X					X						
Gregory Purdy	X																	
Tom Devall		X																
Diego Caputo		X							X									

F.3 Experiment 2 Contribution Matrix: Manufacturing Workplace Support Investigation- Assessing Effects of Technology Used in Improving Quality and Performance

Contributor	Experimental Design	Tiger Motors Facility Support	IRB Writing	IRB Editing and Advising	Primary Experimental Execution	Support Experimental Execution	Participant Recruiting	Participant Scheduling	Experimental Aide	Experiment Technology Development	Experiment Technology Technical Support	Data Collection	Data Analysis for this Dissertation Contribution	Statistical Analysis for this Dissertation Contribution	Poster Creation and/or Presentation	Conference Session Creation and Presentation	Publication Based on this Experiment Primary Author	Publication Non-Primary Author
Victoria Ballard	X	X		X	X		X	X			X	X	X	X	X	X		X
Richard Sesek	X			X														X
Danny O'Leary	X		X	X		X						X						X
Md Monir Hossain	X			X	X		X	X		X	X	X					X	
Gregory Purdy	X																	X
Tom Devall		X																
Diego Caputo		X							X									

F.4 Survey Contribution Matrix: Workplace Psychosocial Survey

Contributor	Experimental Design	Tiger Motors Facility Support	IRB Writing	IRB Editing and Advising	Primary Experimental Execution	Support Experimental Execution	Participant Recruiting	Participant Scheduling	Experimental Aide	Experiment Technology Development	Experiment Technology Technical Support	Data Collection	Data Analysis for this Dissertation Contribution	Statistical Analysis for this Dissertation Contribution	Poster Creation and Presentation	Conference Session Creation and Presentation	Publication Based on this Experiment Primary Author	Publication Non-Primary Author
Victoria Ballard	X	X	X		X		X	N/A		X	X	X	X	X	TBD	TBD	TBD	
Richard Sesek	X			X			X	N/A										TBD
Chelsea McMeen											X							

Chelsea McMeen provided R programming expertise to create a standard way to clean the dataset and flag fraudulent entries based on guidance and the criterion developed by researcher Victoria Ballard.

F.5 Dissertation Contribution

This dissertation was developed with my dissertation committee's guidance and editorial support: Richard Sesek (Chair), Mark Schall, Richard Garnett, Gregory Purdy, and University Reader Benjamin Bowers. Additional editing assistance was provided by my father, William Vaughn, friend Savannah Maples, and other friends and colleagues who generously reviewed the work and offered their valuable feedback.

Throughout the creation of this dissertation, I utilized several generative AI tools to support various aspects of the research process. These tools included OpenAI's GPT-3.5, GPT-4 models, the latest version, ChatGPT-4o, Grammarly's Grammarly GO, and Microsoft's Co-Pilot. These AI systems were instrumental in aiding the development of the research.

However, it is essential to note that this dissertation's core content, structure, and conclusions are primarily the result of my own intellectual efforts, supplemented by the contributions mentioned above and cited within this document. I bear full responsibility for the originality and scholarly value of the final work.

NOTE. This statement is inspired by a similar acknowledgment in Dan O'Leary's dissertation (O'Leary, In Press).