Evaluating Responses to One-handed Carrying among Older and Obese Individuals

by

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Abstract

Manual material handling (MMH) is associated with the development of work-related musculoskeletal disorders (MSDs). Older and obese workers are more susceptible to MSDs in comparison to younger, non-obese workers. One-handed carrying is a particularly challenging form of MMH as it increases physical responses (e.g., physiological, biomechanical) compared to other methods of load carrying. While older and obese individuals are rapidly growing segments of the working population, the effects of one-handed carrying on physical responses among these populations have not been adequately studied. This dissertation examines the effects of age and obesity on the physiological, psychophysical, and biomechanical responses during one-handed carrying of various loads. First, a systematic review of the literature was performed that synthesizes the scientific literature regarding one-handed carrying as it may pertain to older and obese individuals to identify research gaps. Then, a series of experiments were conducted to evaluate the effects of one-handed carrying on the physiological, psychophysical, and biomechanical responses of older and obese people. Results of the experiments suggested that the changes in physiological and biomechanical responses were mainly attributed to the load magnitude, not age, nor obesity. Physiological responses as well as moments about the L4/L5 vertebral segments were greater among obese participants than among non-obese participants. However, the differences were mitigated when load was normalized to body weight (BW), and BW and height (BW*Ht), respectively. Additionally, older participants self-selected smaller loads to carry, on average, than those selected by younger participants. The results of this dissertation suggest that carrying small load magnitudes (less than or equal to approximately 10 kg) leads to similar responses among older and obese working-age people when compared to younger, healthy working-age people. Future research opportunities are highlighted and discussed in the context of the findings.

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Table of Contents

List of Tables

List of Illustrations

List of Abbreviations

◦	Degree(s)
%	Percentage
η^2	Effect Size
3D	Three-dimensional
ANOVA	Analysis of Variance
AUBE	Auburn University Biomechanical Engineering Laboratory
BMI	Body Mass Index
BP	Blood Pressure
bpm	Beat(s) per Minute
BW	Body Weight
%BW	Percentage of Body Weight
%BW*Ht	Percentage of Body Weight and Height
cm	Centimeter(s)
DEXA	Dual-energy X-ray Absorptiometry
EE	Energy Expenditure
EMG	Electromyography
EMG_i	EMG for a Sample i of the Data in the Walking Files
EMG_{MVC}	Peak Maximum Voluntary Contraction (MVC) across all 33 MVC Files

EMG_{Noise}	Base EMG Noise
Eq.	Equation
Exp	Experiment
F	F Value
Heavy	10.21 kg
HR	Heart Rate
HR_{max}	Age-predicted Maximum HR
$\%HR_{max}$	Age-predicted Percentage of Maximum HR
%HRR	Percentage of the Reserve HR
HR_{rest}	Resting HR
HR_{work}	Walking/Carrying HR
HSD	Honest Significant Difference
Hz	Hertz
kcal/min/kg	Kilocalories per Minute per Kilogram
kg	Kilogram(s)
kg/m^2	Kilogram(s) per Square meter
L	Liter(s)
L3	L3 Vertebrae
L3/L4	L3/L4 Vertebral Segment
L4	L4 Vertebrae
L4/L5	L4/L5 Vertebral Segment
lb	Pound(s)
Light	5.67 kg

L/kg	Liter(s) per Kilogram
LL	Load Location
LM	Load Magnitude
m	Meter(s)
MALC	Maximum Acceptable Load Carried
ml/min	Milliliter(s) per Minute
mm	Millimeter(s)
MMH	Manual Material Handling
m/s	Meter(s) per Second
MSDs	Musculoskeletal Disorders
MVC	Maximum Voluntary Contraction
%MVC	Percentage of MVC
MVIC	Maximum Voluntary Isometric Contraction
n	Number
N	Number
N/A	Not Applicable
NIOSH	National Institute for Occupational Safety and Health
N.m	Newton Meter
No-load	0 kg
ONO	Older/Non-obese
OO	Older/Obese
p	*p*-value
RPE	Ratings of Perceived Exertion

RPE(A)	RPE of the Arm
RPE(BK)	RPE of the Back
RPE(WB)	RPE of the Whole Body
SD	Standard Deviation
Self-selected	Self-selected Load
t	time
$\dot{V}_E$	Pulmonary Ventilation
$\dot{V}O_2$	Oxygen Consumption Rate
$\dot{V}O_{2max}$	Maximum Oxygen Consumption
$\%\dot{V}O_{2max}$	Percentage of Maximum Oxygen Consumption
VO_{2T}	Total Oxygen Consumption for the Trial
VO_{2T}/BW	VO_{2T} Normalized to BW
WE	Estimated Load for Comfortable Carrying
WV	Actual Carried Load Comfortably
YNO	Young/Non-obese
YO	Young/Obese

Chapter 1

Introduction

1.1 Manual Material Handling and Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) represented 31% of the total number of nonfatal occupational injuries and illnesses involving days away from work in 2015 (BLS, 2016). Manual material handling (MMH) activities (e.g., lifting, pulling, pushing, carrying) have been associated with the development of MSDs (Tanaka & McGlothlin, 1993; Village et al., 2005; Natarajan, Lavender, An, & Andersson, 2008; Garg et al., 2014). In addition, 18% of the 2016 total days away from work cases in manufacturing were attributed to injuries and illnesses among transportation and material handling workers (BLS, 2017).

One-handed carrying is a particularly challenging form of MMH. It results in increased muscle activity (Cook & Neumann, 1987; McGill, Marshall, & Andersen, 2013), physiological responses (Lind & McNicol, 1968; Jackson, Reeves, Sheffield, & Burdeshaw, 1973; Legg, 1985; Ganguli & Datta, 1977), and spinal loading (McGill et al., 2013; Rohlmann et al., 2014), in comparison to other types of carrying of the same load magnitude (e.g., on the back, two hands [bilaterally or anteriorly], or on the shoulder). Carrying a load in one hand has been associated with musculoskeletal pain in the low back, neck/shoulder, and knee (Nahit et al., 2001; Paudyal, Ayres, Semple, & Macfarlane, 2013). While a great deal of research has been devoted to two-handed MMH (e.g., the Liberty Mutual MMH Tables; Snook, 1978; Snook & Ciriello, 1991; Wu, 2000; Ciriello, 2005; Lee & Cheng, 2011; Sevene et al., 2012), no formal guidelines have been established for one-handed MMH tasks.

1.2 Changing Population Compositions

Increasing proportions of the United States' general and working populations are comprised of older and obese people (Jacobsen, Kent, Lee, & Mather, 2011; He, Goodkind, & Kowal, 2016; Ogden, Carroll, Fryar, & Flegal, 2015; Ogden et al., 2006; Wang & Beydoun, 2007). By 2050, the number of people aged 65+ years in the United States is expected to double in comparison to the corresponding number in 2012 (Ortman, Velkoff, & Hogan, 2014). The average age of the working population in the United States is continuously increasing as well. The percentage of workers aged 55+ years is expected to increase by 3.1% by 2024, in comparison to 2014 (Toossi, 2015).

Complementary to the increasing age of the workforce, there has been a consistent increase in the prevalence of obesity among American adults since 1999-2000 (Hales, Carroll, Fryar, & Ogden, 2017). Between 2011-2014, obese adults represented approximately 36.5% of the American population (Ogden et al., 2015). This percentage is expected to jump to 51% by 2030 (Wang et al., 2008; Finkelstein et al., 2012). The prevalence of obesity has been higher among people aged 60+ years than among younger adults (20-39 years old; Hales et al., 2017). This is of critical importance as older obese people may be at more risk of work-related MSDs in comparison to younger healthy individuals.

Work-related MSDs are more prevalent among older and obese people, in comparison to other populations (Kouvonen et al., 2013; BLS, 2015; Schulte et al., 2007). Age and obesity are associated with an increased risk of low back pain and intervertebral disc disorders (Hoy et al., 2012; Wong, Karppinen, & Samartzis, 2017; Sheng et al., 2017; Roffey, Budiansky, Coyle, & Wai, 2013; Peng, Pérez, & Gabriel, 2018). Excessive loading due to body weight (BW) among obese people, and the degradation in muscle mass and strength among older people (Frilander et al., 2015) are potential explanations of the elevated rates of MSDs among these two populations (Villareal et al., 2004; Beaufrere & Morio, 2000). The combination of age and obesity may exacerbate the situation (Villareal et al., 2004). As the compositions of the general and working populations change, a more comprehensive understanding of the performance of older and obese workers, populations particularly susceptible to work-related MSDs, during one-handed carrying is needed.

1.3 Specific Aims

The work described in this dissertation was designed to address three specific aims addressing research gaps identified in the scientific literature regarding one-handed carrying among older and obese people. Specifically, the three specific aims were to:

- ***Aim 1. Compare physiological and psychophysical responses of participants in different age and obesity categories while they perform different one-handed carrying tasks.***

- ***Aim 2. Examine the effect of load magnitude on trunk muscle activity among obese and older people during one-handed carrying.***
- ***Aim 3. Evaluate the change in trunk angles and moments about the approximate location of the L4/L5 vertebral segment among older and obese individuals during one-handed carrying of various magnitudes of load.***

The work contained in this dissertation is innovative as it is the first work, to our knowledge, that addresses differences in performance of participants of different age and obesity categories during one-handed carrying. In particular, physiological, psychophysical, and biomechanical responses to one-handed carrying among individuals with different age and obesity levels were examined. Consideration of these different approaches should provide a better understanding of the effects of one-handed carrying on different populations and applicability for ergonomics exposure assessment. For example, the National Institute for Occupational Safety and Health (NIOSH) Revised Lifting Equation is based on physiological, psychophysical, and biomechanical approaches. Each approach focuses on different aspects of lifting (maximum energy expenditure [EE], maximum acceptable load, and maximum disc compression force, respectively). Recommended load weights that meet one criterion may not meet the two others (Waters, Putz-Anderson, Garg, & Fine, 1993). This is also anticipated to occur while investigating the three approaches regarding one-handed carrying tasks.

1.4 Organization of the Dissertation

The dissertation is organized as follows.

- Chapter 2 presents a systematic literature review conducted to synthesizes the scientific literature regarding one-handed carrying as it may pertain to age and obesity individuals to identify research gaps. Chapter 2 was published in the peer-reviewed scientific journal *Ergonomics*. It should be noted that some acronyms and terms were modified in this chapter for consistency with the remaining text of the dissertation. Please refer to Badawy et al. (2018) for the article for citation purposes. In addition, the terms "elderly" were used to search for relevant articles in the literature more inclusive. Accordingly, it was used in this chapter. However, the term "older" was used instead for the rest of the dissertation to remove the ambiguity associated with the term "elderly".
- Chapter 3 compares physiological and psychophysical responses of participants in different age and obesity categories while carrying various loads in one hand.
- Chapter 4 examines the effect of load magnitude on trunk muscle activity among obese and older people during one-handed carrying.
- Chapter 5 evaluates the change in trunk angles and moments about the approximate location of the L4/L5 vertebral segment among older and obese individuals during one-handed carrying of various magnitudes of load.
- Chapter 6 presents the key findings and limitations of the conducted studies. It also discusses ideas regarding potential future research.

Chapter 2

One-handed Carrying among Elderly and Obese Individuals: A Systematic Review to Identify Research Gaps

2.1 Abstract

A systematic review of the literature regarding one-handed load carrying was conducted to identify research gaps for future load carrying studies. Twenty-six articles that may be relevant to elderly and obese people were included. Only two studies evaluated the effect of age as an independent variable during one-handed carrying. Obesity was not included as an independent variable in any of the articles. In general, the results suggested that one-handed carrying is more physically demanding than other methods of load carrying. In many cases, physiological responses to carrying a load in one hand were similar to carrying twice the load equally distributed between two hands. Some studies recommended a one-handed carrying weight limit of approximately 9-10 kg for men and 6-7 kg for women. However, more research on the effects of age and obesity during one-handed carrying are needed to determine if these results hold for elderly and obese people.

2.2 Introduction

Elderly and obese people represent a rapidly increasing proportion of the United States population and workforce (Jacobsen, Kent, Lee, & Mather, 2011; He, Goodkind, & Kowal, 2016; Ogden, Carroll, Fryar, & Flegal, 2015; Ogden et al., 2006; Wang & Beydoun, 2007). By 2050, 20.9% of people in the United States are expected to be 65 years of age or older; an increase of 7.2% since 2012 (Ortman, Velkoff, & Hogan, 2014). By 2030, obese adults are expected to represent 51% of the American population (Wang et al., 2008; Finkelstein et al., 2012); an increase of 14.5% from the years 2011–2014 (Ogden et al., 2015). The increasing percentage of elderly and obese workers is important as age and obesity have been associated with an increase in the frequency and severity of adverse occupational health outcomes, such as work-related musculoskeletal disorders (MSDs) (Kouvonen et al., 2013; BLS, 2015).

Manual material handling (MMH) activities such as lifting, pulling/pushing, and carrying are commonly associated with work-related MSDs, particularly of the low back (BLS, 2016; Tanaka & McGlothlin, 1993; Village et al., 2005; Natarajan, Lavender, An, & Andersson, 2008; Garg et al., 2014). While a great deal of research has been devoted to two-handed MMH (Lu, Putz-Anderson, Garg, & Davis, 2016; Waters, Putz-Anderson, Garg, & Fine, 1993; Wu, 2000; Ciriello, 2005; Lee & Cheng, 2011; Sevene et al., 2012), one-handed carrying has been less commonly studied. For instance, the widely applied Liberty Mutual MMH Tables developed by Snook (1978) and Snook & Ciriello (1991) provide estimates of the maximum acceptable load to be lifted or carried at different handling frequencies and distances using both hands. To our knowledge, no such tables were developed for one-handed carrying tasks.

The objectives of this review were to synthesize the scientific literature regarding one-handed carrying as it may pertain to elderly and obese individuals to identify research gaps for future load carrying studies among this potentially susceptible segment of the working population.

2.3 Method

Relevant articles from the past 50 years were searched from four scientific databases: Web of Science, Ergonomics Abstracts, PubMed, and Google Scholar (1966 to October 30, 2016). Specifically, different combinations of strings (Table 2.1) were searched using the logical operators ‘AND’ and ‘OR’. The search string “(1 AND 2) OR (1 AND 3)” was most applicable and provided results for all databases. However, given the relatively small number of articles identified using Web of Science and Ergonomics Abstracts (n=2 each), the first search string was searched alone for these databases to increase the likelihood of identifying relevant articles. Furthermore, the personal databases of the authors were also reviewed.

Table 2.1: Search strings used to identify articles

Search String	Search Terms
1	“one-handed lifting” OR “one-handed carrying” OR “one-handed manual material handling” OR “one hand lifting” OR “one hand carrying” OR “one hand manual material handling”
2	“elderly” OR “old” OR “age” OR “aging”
3	“obese” OR “obesity” OR “body weight”
4	“work” OR “worker” OR “employee” OR “employment” OR “job” OR “job analysis” OR “workload” OR “occupation” OR “occupational”

The initial article search identified 754 documents. Titles of these documents were screened according to the following criteria: 1) relevance of title to the topic of interest (one-handed carrying in adults); 2) full text papers published in peer-reviewed journals; and 3) written in English. Two independent reviewers performed the screening. Documents in which one reviewer suggested inclusion whereas the other suggested to discard (n=22) were included for abstract review. Based on the above three criteria, 537 records were excluded. Redundant articles (n=43) from the 217 remaining articles were then removed, resulting in 174 articles for abstract review.

Review of the 174 abstracts excluded 102 based on relevance. The remaining 72 articles were classified into three main categories: articles that addressed one-handed lifting (n=51), one-handed carrying (n=15), and both one-handed lifting and one-handed carrying (n=6). Those articles involving some one-handed carrying (n=21) were included in the final review (Figure 2.1). Additionally, five articles referenced within those 21 were also included for a grand total of 26. Four of the 26 articles that included one-handed carrying will not be described further. Two of the articles were survey studies that did not involve laboratory experimentation (Nahit et al., 2001; Paudyal, Ayres, Semple, & Macfarlane, 2013). The other two articles were reviews of research regarding lifting/carrying (Lu & Aghazadeh, 1994; Mital, 1985), including one-handed carrying studies that are included in the reviewed articles in this work. Articles studying one-handed carrying that may not have investigated aging or obesity as independent variables were included in the review as the results may be relevant to elderly and obese people.

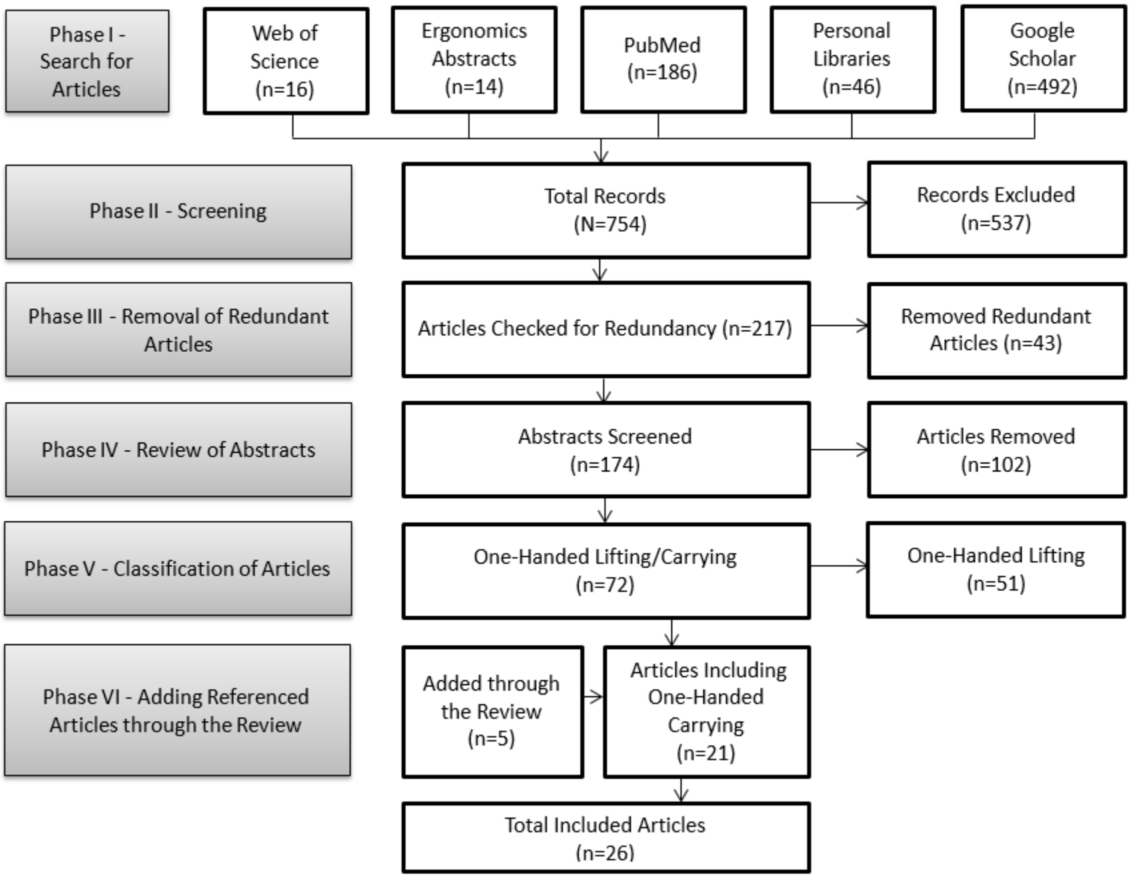


Figure 2.1. Flow chart of article selection process

2.4 Results

Three main experimental approaches were used in the reviewed articles to study one-handed carrying: 1) physiological, 2) psychophysical, and 3) biomechanical. These strategies were used as the basis to summarize the results as they may pertain to obese and elderly individuals in the subsequent sections. The purpose and load holding methods described in each article are provided in Table 2.2. A description of the independent variables as well as the characteristics of the participants is included in Table 2.3. Table 2.4 presents the dependent variables and highlights the main results in each article. The independent and dependent variables were identified by the reviewers when not directly identified by the authors of the papers.

Table 2.2. Purpose and load holding methods in each study

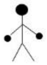
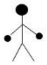
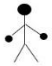
Author(s)	**Study Purpose**	**Experimental Load**			
		Unloaded	**Unilateral**	**Bimanual**	**Posterior**
Lind & McNicol (1968)	Estimate HR and BP responses to holding and carrying weights in hand or by a shoulder harness.	N/A	 Dominant/non-dominant (20 kg)	 20 kg in each hand	 Via shoulder harness (40 kg)
Jackson, Reeves, Sheffield, & Burdeshaw (1973)	Study effects of load and load location on HR and BP.	 0 kg	 18.14 kg	 9.07 kg in each hand	 18.14 kg
Drury (1975)	Examine the force/duration relationships for 1) Statically holding a load and carrying, and 2) One-handed and two-handed carrying.	N/A	 Exp. 1: Static holding/carrying (7.5-41.9 kg) Exp. 2: Carrying (15.9-25 kg)	 Exp. 2: 15.9-25 kg in each hand	N/A
Ganguli & Datta (1977)	Study physiological effects of load location in below knee amputees with prostheses.	 0 kg	 Right/left (7.5 kg)	 Walking/stairs climbing (7.5 kg in each hand)	N/A
Garg, Chaffin, & Herrin (1978)	Estimation of metabolic rates for 48 different MMH jobs including one and two-handed carrying.	N/A			N/A
Mital & Manivasagan (1983)	Estimate physiological and psychophysical effects of carrying distance container shape and volume in one-handed carrying.	N/A	 Self-selected loads	N/A	N/A

Table 2.2 cont. Purpose and load holding methods in each study

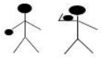
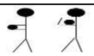
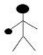
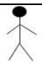
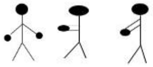
Author(s)	**Study Purpose**	**Experimental Load**			
		Unloaded	**Unilateral**	**Bimanual**	**Posterior**
Legg (1985)	Estimate %$\dot{V}O_{2max}$ and EE of different methods of load carrying.	N/A	 One hand/on one shoulder (30 kg)	 Waist height/clasped to chest (30 kg)	N/A
Neumann & Cook (1985)	Estimate activity of the gluteus medius muscle while carrying various loads using different carrying methods.	 0 kg	 Ipsilateral/contralateral (10% and 20% of BW)	 10% and 20% of BW	 10% and 20% of BW
Cook & Neumann (1987)	Estimate EMG of the paraspinal muscles for different load carrying methods.	N/A	 Ipsilateral /contralateral (10% and 20% of BW)	 10% and 20% of BW	 10% and 20% of BW
Nottrodt & Manley (1989)	Determine the MALC and locomotor patterns of different carrying methods.	 0 kg	 Dominant hand (self-selected loads)	 Bilateral, frontal: elbow angle: 90°, straight arm (self-selected loads)	N/A
Kilbom, Hagg, & Kall (1992)	Estimate local fatigue in hand and forearm during one-handed carrying.	 0 kg	 Variable loads	N/A	N/A

Table 2.2 cont. Purpose and load holding methods in each study

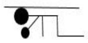
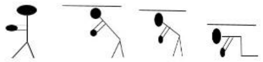
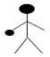
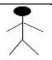
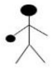
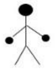
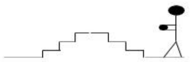
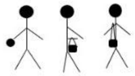
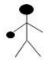
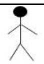
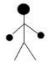
Author(s)	**Study Purpose**	**Experimental Load**			
		Unloaded	**Unilateral**	**Bimanual**	**Posterior**
Smith, Ayoub, & McDaniel (1992)	Assess lifting and carrying capabilities in non-standard postures.	N/A	 Ceiling: 40% of stature [crawling] (self-selected loads)	 Ceiling: unrestricted, 80%, 60%, and 40% of stature [crawling] (self-selected loads)	N/A
Neumann, Cook, Sholty, & Sobush (1992)	Estimate muscle activity of the hip abductor in one and two-handed carrying.	 0 kg	 (10% and 20% of BW)	 (10%, 20%, and 40% of BW total)	N/A
Neumann (1996)	Estimate hip abductor muscle activity for people with hip prosthesis that carry loads in one hand.	N/A	 Ipsilateral /contralateral (5%, 10%, and 15% of BW)	N/A	N/A
Bergmann, Graichen, Rohlmann, & Linke (1997)	Estimate effects of load magnitude and load location on the forces generated in the hip joints.	 0 kg	 Ipsilateral /contralateral (up to 30 kg)	 Up to 30 kg total	N/A
Yoon & Smith (1999)	Determine physiological and psychophysical responses to combined lifting, carrying, and lowering tasks using one and two hands.	N/A	 Combined lift, carry, and lower (self-selected loads)	 Combined lift, carry, and lower (self-selected loads)	N/A

Table 2.2 cont. Purpose and load holding methods in each study

Author(s)	Study Purpose	Experimental Load			
		Unloaded	Unilateral	Bimanual	Posterior
Wright & Mital (1999)	Determine physiological and psychophysical responses to different load carrying methods in older people.	N/A	 One-handed carrying and bag carrying (self-selected loads)	 Three stairs up and down while walking (self-selected loads)	N/A
An, Yoon, Yoo, & Kim (2010)	Comparison of gait parameters of young females carrying a single-strap bag in one hand, on the forearm, and on one shoulder.	 0 kg	 Dominant hand, forearm, shoulder (5% of BW)	N/A	N/A
McGill, Marshall, & Andersen (2013)	Estimate spinal forces due to load carrying one hand and both hands.	N/A	 10, 20, and 30 kg	 5, 10, 15, and 30 kg in each hand	N/A
Rohlmann et al. (2014)	Compare loads on a vertebral body replacement using different load carrying methods.	N/A	 5 and 10 kg	 10 kg in each hand	 4.5 and 9 kg
Bampouras & Dewhurst (2016)	Examine the impact of carrying shopping bags in older females.	 0 kg	 1.5 and 3 kg	 1.5 and 3 kg in each hand	N/A
Webb & Bratsch (2017)	Examine footfall mechanism while carrying a load unilaterally.	 Empty canvas bag	 Canvas bag (21% of BW)	N/A	N/A

BP: blood pressure. BW: body weight. EE: energy expenditure. EMG: electromyography. HR: heart rate. MALC: maximum acceptable load carried. MMH: manual material handling. %$\dot{V}O_{2max}$: percentage of maximum oxygen consumption.

Table 2.3. Independent variables and participants in each study

Author(s)	Participants		Mean Age (SD) or Range		Mean Weight kg (SD) or Range		Mean Height cm (SD) or Range		Independent Variables
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
Lind & McNicol (1968)	10	--	31.3	--	N/A	--	N/A	--	LM, LL, loading time
Jackson et al. (1973)	13	--	32	--	N/A	--	N/A	--	LL
Drury (1975)	Exp. 1: 4 Exp. 2: 6	--	Exp. 1: 18-24 Exp. 2: N/A	--	N/A	--	N/A	--	Exp. 1: LM, holding method (lift/carry). Exp. 2: LM, LL
Ganguli & Datta (1977)	9 healthy; 5 below-knee amputees with a prosthesis system (gender not specified; however, image of male amputee included)		33.3 (5.27); 23.2 (7.05)	--	50.24 (6.921); 50.19 (7.231)	--	160.9 (5.44); 159.6 (4.72)	--	LL, healthy/below-knee amputee
Garg et al. (1978)	3	3	21	19.7	75.5	66.7	177	173.7	LM, BW, grade of walking surface (%), walking speed, time
Mital & Manivasagan (1983)	10	5	22.1	22	80	51.82	178	162	Container shape, container size, carrying distance

Table 2.3 cont. Independent variables and participants in each study

Author(s)	**Participants**		**Mean Age (SD) or Range**		**Mean Weight kg (SD) or Range**		**Mean Height cm (SD) or Range**		**Independent Variables**
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
Legg (1985)	2 (gender not specified; however, image of male soldier included)		22	--	65.1	--	169.1	--	LL
Neumann & Cook (1985)	12	12	26.8	25.1	68.7		173		LL, LM, gender
Cook & Neumann (1987)	12	12	26.8	25.1	69.8	65.7	164	137	LL, LM, gender
Nottrodt & Manley (1989)	10	--	23.1 (3.8)	--	71.8 (5.8)	--	176.3 (6)	--	LL, test session
Kilbom et al. (1992)	5	11	22-30	24-37	58.5 (3.3)	71.4 (9.6)	163.3 (3)	180 (6)	LM, loading time
Smith et al. (1992)	20	20	18-30		Stratified sample plan of range 56.6-102.7	Stratified sample plan of range 42.3-81.9	Stratified sample plan of range 164-193	Stratified sample plan of range 148-178	LL, ceiling height, gender
Neumann et al. (1992)	15	15	21.7 (2)		66.5 (13)		170 (9)		LL, LM, gender

Table 2.3 cont. Independent variables and participants in each study

Author(s)	**Participants**		**Mean Age (SD) or Range**		**Mean Weight kg (SD) or Range**		**Mean Height cm (SD) or Range**		**Independent Variables**
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
Neumann (1996)	16 (with a prosthetic hip at one limb)	9 (with a prosthetic hip at one limb)	63.7 (10.7)		77.42 (16.69)		171 (10)		LM, LL
Bergmann et al. (1997)	6: 5 healthy; 1 with instrumented endo-prostheses in hips	--	37.8; 89	--	75.8; 59	--	N/A	--	Existence of hip implant, LL
Yoon & Smith (1999)	10	--	23	--	75.1 (8.39)	--	173.9 (6.31)	--	LL, frequency
Wright & Mital (1999)	10 young; 10 older	10 young; 10 older	18-35 young; 55-74 older		N/A		N/A		Age, gender, frequency
An et al. (2010)	--	21	--	23 (2.9)	--	52 (3.9)	--	161.5 (4.6)	LL, LM, bag shape
McGill et al. (2013)	9 (Results based upon 6 w/ full data)	--	22.7 (2.1)	--	85.7 (16.7)	--	175 (10)	--	LL, LM

Table 2.3 cont. Independent variables and participants in each study

Author(s)	**Participants**		**Mean Age (SD) or Range**		**Mean Weight kg (SD) or Range**		**Mean Height cm (SD) or Range**		**Independent Variables**
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	
Rohlmann et al. (2014)	4	1	66.2		65.4		171		LL, LM
Bampouras & Dewhurst (2016)	--	9 older; 10 young	--	71.6 (6); 26.7 (5.2)	--	66.3 (10.1); 70.2 (15.1)	--	165 (6); 169 (5)	LM, age
Webb & Bratsch (2017)	9	9	25.1 (11.4)	19.1 (2.52)	76.6 (13.7)	61.2 (8.87)	175.5 (5.4)	165.7 (5.9)	LM, carrying practice, gender

BW: body weight. LL: load location. LM: load magnitude.

Table 2.4. Dependent variables and main results of each study

Author(s)	**Dependent Variables**	**Main Results**
Lind & McNicol (1968)	HR, BP	Carrying a load in one hand results in HR and BP responses comparable to carrying twice the load in both hands (the same load in each hand).
Jackson et al. (1973)	HR, BP	HR and BP due to unilateral carrying are larger than those observed during bilateral or posterior carrying.
Drury (1975)	Endurance time	No statistically significant difference in endurance time was observed between unilateral carrying of a load and bilateral carrying of twice the load (the same load in each hand).
Ganguli & Datta (1977)	EE/load carried (kcal/min/kg)	No statistically significant difference in EE was observed between unilateral carrying of a load and bilateral carrying of twice the load (the same load in each hand).
Garg et al. (1978)	Metabolic rate	A model that predicts metabolic rates during one and two-handed carrying was developed.
Mital & Manivasagan (1983)	HR, WE, WV, RPE(A), RPE(WB)	For self-selected loads, HR responses during one-handed carrying were slightly lower in females than in males. For both genders, one-handed carrying was more strenuous to the arm than to the whole body.
Legg (1985)	%$\dot{V}O_{2max}$, EE	Compared to other methods of load carrying, one-handed carrying resulted in the largest EE and %$\dot{V}O_{2max}$.
Neumann & Cook (1985)	%EMG	The largest hip muscle activity was observed at the contralateral side of the body. Gender was not statistically significant.
Cook & Neumann (1987)	%EMG	The Erector Spinae muscle activity was observed to be statistically affected by the interactions between load size and position as well as gender and position.
Nottrodt & Manley (1989)	MALC, gait parameters	The MALC during one-handed carrying was statistically significantly different from the MALC during two-handed carrying. Walking speed during one-handed carrying was faster than during two-handed carrying, but slower than speed during no-load carrying.

Table 2.4 cont. Dependent variables and main results of each study

Author(s)	Dependent Variables	Main Results
Kilbom et al. (1992)	HR, BP, $\dot{V}_E$, $\dot{V}O_2$, endurance time, carried load, RPE	Physiological responses generally increased with the increase in load magnitude. In general, participants underestimated their endurance.
Smith et al. (1992)	Maximum load to lift and carry	Load location (in one hand versus two hands) was observed to be insignificant in identifying the load magnitude to be lifted and carried in crawling tasks.
Neumann et al. (1992)	Hip Abductor %EMG	Bilateral carrying resulted in lower average of muscle activity of both hips than did the unilateral load carrying.
Neumann (1996)	Hip Abductor %EMG	The largest muscle activity was observed during carrying the load at the contralateral side.
Bergmann et al. (1997)	Hip joint force	Hip joint forces were the largest at the contralateral side of the load.
Yoon & Smith (1999)	HR, tasking time, MALC, RPE(A), RPE(BK), RPE(WB)	During combined lift, carry, and lower tasks of self-selected loads, HR responses were substantially larger in two-handed carrying than in one-handed carrying. Interaction between frequency and load location was observed to be statistically significant in determining RPE(WB), but not for RPE(A) or RPE(BK).
Wright & Mital (1999)	HR, $\dot{V}O_2$, MALC, RPE	No significant effect of age on $\dot{V}O_2$, HR, MALC, or RPE was observed when self-selected loads were carried unilaterally.
An et al. (2010)	Gait parameters	Carrying a bag in one hand resulted in a less stable and asymmetric toe-out gait compared to other unilateral load carrying methods (on the forearm and on the shoulder).
McGill et al. (2013)	Compression and shear forces at L4/L5	Compression forces on the spine were larger when a load was carried in one hand than evenly split between two hands, or even when carrying the same load in both hands (twice the load carried).

Table 2.4 cont. Dependent variables and main results of each study

Author(s)	Dependent Variables	Main Results
Rohlmann et al. (2014)	Forces and moments on a Vertebral Body Replacement	Carrying a load in one hand resulted in forces of the vertebral replacement comparable to those resulted by carrying twice the load in both hands (the same load in each hand).
Bampouras & Dewhurst (2016)	HR, gait parameters	For relatively small loads carried (3 kg maximum load in one or in each hand), HR responses were not statistically different between age groups (older and younger females). Carrying a small load unilaterally may help to stabilize posture in elderly females.
Webb & Bratsch (2017)	Gait parameters	In general, carrying a heavy load in one hand resulted in a decrease of step width.

BP: blood pressure. EE: energy expenditure. EMG: electromyography. HR: heart rate. MALC: maximum acceptable load carried. RPE: ratings of perceived exertion. RPE(A): RPE of the arm. RPE(BK): RPE of the back. RPE(WB): RPE of the whole body. $\dot{V}_E$: pulmonary ventilation $\dot{V}O_2$: oxygen consumption rate. $\%\dot{V}O_2max$: percentage of maximum oxygen consumption. WE: estimated load for comfortable carrying. WV: actual carried load comfortably.

2.4.1. The Physiological Approach

Physiological responses during one-handed carrying were studied in 11 articles. Each study included one or more of three major physiological measurements: 1) heart rate (HR), 2) blood pressure (BP), and 3) oxygen consumption. Other physiological indices included energy expenditure (EE), pulmonary ventilation ($\dot{V}_E$), and endurance time. The effects of obesity were not considered in any of the studies. Two of the studies compared physiological responses in elderly and young people while carrying loads (Bampouras & Dewhurst, 2016; Wright & Mital, 1999). Bampouras & Dewhurst (2016) demonstrated that HR responses were not statistically significantly different between age groups (elderly [68-75 years old] and younger [22-31 years old] females) when carrying relatively small loads (3 kg maximum load in one or in each hand). Wright & Mital (1999) observed similar results regarding the effect of age on oxygen consumption and HR when self-selected loads were carried unilaterally.

In general, the remaining studies involved young and/or middle-aged individuals while focusing on the effects of load location and magnitude on physiological responses during carrying. Results of these studies suggested that HR, BP, EE, and the percentage of maximum oxygen consumption ($\%\dot{V}O_{2max}$) increase, and endurance (defined as the time until participants were no longer willing to hold the load) decreases, more when a load is carried in one hand versus when the load is distributed equally between both hands, carried anteriorly, or carried on the back or the shoulders (Lind & McNicol, 1968; Jackson et al., 1973; Legg, 1985; Ganguli & Datta, 1977; Drury, 1975). Carrying a load in one hand has been shown to be approximately as physiologically demanding as carrying twice the load equally distributed in both hands (Lind & McNicol, 1968; Ganguli & Datta, 1977; Drury, 1975). It is important to note that the amount of self-selected load carried in two hands was occasionally observed to be larger than that carried in one hand, which may result in larger HR responses during two-handed carrying (Yoon & Smith, 1999). However, no clear relationship between HR and carried load was observed (Yoon & Smith, 1999). Load magnitude and carrying time also had an impact on physiological performance where increasing load magnitude generally resulted in an increase in physiological responses (Kilbom et al., 1992; Bampouras & Dewhurst, 2016; Drury, 1975). The maximum load to be carried in one hand has been recommended not to exceed 10 kg in males and 7 kg in females (Lind & McNicol, 1968; Ganguli & Datta, 1977; Kilbom et al., 1992).

2.4.2. The Psychophysical Approach

A psychophysical approach was used in 6 articles. Two main variables were considered: 1) the maximum acceptable load carried (MALC), and 2) ratings of perceived exertion (RPE). Obesity was not included as an independent variable in any of these studies. The effect of age on psychophysical responses during one-handed carrying was discussed in only one study (Wright & Mital, 1999). In this study, participants were provided with random loads and were asked to make adjustments to identify the MALC. Then, the participants were asked to walk for 6 m (3 m back and forth). Results indicated no statistically significant effects of age on MALC or RPE during one-handed carrying. However, the study did not specify the MALC by elderly participants or specify their perceived exertion.

The other studies compared psychophysical responses among young and/or middle-aged individuals. One-handed carrying was perceived to be “somewhat hard” with regard to exertion of the arm (RPE[A]) and “fairly light” with regard to exertion of the whole body (RPE[WB]) for participants carrying self-selected loads (Mital & Manivasagan, 1983). Specifically, RPE(A) was approximately equivalent to one-eighth of the measured HR (Mital & Manivasagan, 1983). An increase in RPE(A) during one-handed carrying relative to two-handed carrying was associated with a decrease in the MALC (Yoon & Smith, 1999). The self-selected carrying capacity of one-handed tasks in young males has been observed to be equivalent to approximately 51-83% of that of a two-handed task (Yoon & Smith, 1999; Nottrodt & Manley, 1989).

Consistent with the recommendations provided by the physiological studies, males and females were observed to select a MALC of approximately 10 and 7 kg, respectively (Mital & Manivasagan, 1983; Mital, 1985). However, it is important to note that in the Wright & Mital (1999) study that involved elderly people, females carried approximately 4.6-5.5 kg. It is unknown how much load was carried by the elderly participants; only that the female group that included elderly people carried less than what was recommended previously.

2.4.3. The Biomechanical Approach

A biomechanical approach was used in 11 articles. The main interest of the majority of the studies was the effect of unilateral carrying on: 1) forces/muscle activity in the hip, 2) forces/muscle activity on low back muscles, and 3) gait parameters (e.g., stride length, step width, etc.). Obesity was not included as an independent variable in any of these studies. Elderly people were included in five studies (Bampouras & Dewhurst, 2016; Webb & Bratsch, 2017; Bergmann et al., 1997; Neumann, 1996; Rohlmann et al., 2014). However, age was included as an independent variable only in Bampouras & Dewhurst (2016) who concluded that elderly females (68-75 years old) were susceptible to a higher risk of falling while walking with no load.

Specifically, results of the study indicated that carrying a load in one hand decreased the medio-lateral displacement of the center of pressure among the elderly females, which increased their stability relative to walking with no load. Webb & Bratsch (2017) demonstrated that, in general, carrying a heavy load in one hand resulted in a decrease of step width in a group of participants ranging in age from 14-55. However, it is unknown how age affected these results.

Carrying a load in one-hand had an effect on gait parameters/postural stability of young people in two other studies (Nottrodt & Manley, 1989; An et al., 2010). Nottrodt & Manley (1989) indicated that walking speed during unilateral carrying of self-selected loads was faster than the walking speeds observed for the two-handed carrying situations (bilateral and front), but slower than walking with no load. Moreover, unilateral load carrying resulted in no statistically significantly different stride length or cadence relative to no-load carrying. An et al. (2010) concluded that carrying a bag on the forearm resulted in the least energy-efficient gait due to a substantive restriction in arm swing. In addition, carrying a bag in one hand resulted in a less stable and asymmetric toe-out gait by modifying the base of support. Accordingly, they suggested that, when unilaterally carrying a bag, carrying on the shoulder has the least effect on gait parameters in comparison to other carrying methods.

When comparing different methods of load carrying (ipsilateral, contralateral, and bilateral), the largest hip muscle activity/joint forces were generally noticed on the body side contralateral to the carried load, and lowest on the ipsilateral side, for both those with and without hip prosthesis (Neumann & Cook, 1985; Neumann et al., 1992; Neumann, 1996; Bergmann et al., 1997). Hip joint forces in the frontal plane were calculated using a mathematical model (Bergmann et al.,

1997) whereas muscle activity was expressed as normalized electromyography (EMG) (Neumann & Cook, 1985; Neumann et al., 1992; Neumann, 1996). Normalization was implemented using different methods; percentage of maximum voluntary isometric contraction (MVIC) (Neumann & Cook, 1985), percentage of EMG while walking with no load (Neumann et al., 1992), and percentage of EMG baseline identified before performing the carrying tasks (Neumann, 1996). Forces and muscle activity increased with the increase in load magnitude. Similar results were observed regarding the effect of unilateral load carrying on the back (Cook & Neumann, 1987; McGill et al., 2013; Rohlmann et al., 2014). Estimates of muscle activity due to contralateral and anterior load carriage were similar to one another and considerably higher than those of no load, posterior, or ipsilateral carrying (Cook & Neumann, 1987). Moreover, the mean muscle activity readings increased with the increase in the load magnitude (Cook & Neumann, 1987). In addition, carrying a load in one hand was observed to incur larger compression and shear forces on the spine (L4/L5 vertebral segment) than when the load was evenly split between two hands, or even when carrying the same load in both hands (twice the load carried) (McGill et al., 2013).

2.5 Discussion

Findings of this systematic review suggest that a relatively limited amount of research has been conducted on one-handed carrying when compared to the body of knowledge on other MMH activities (e.g., two-handed carrying, lifting, etc.), particularly among elderly and obese people. Despite including age and obesity terms in the search strategy, very few studies involved the effects of age or obesity on different physiological, psychophysical, and biomechanical responses during one-handed carrying. Age was not observed to be a significant factor in determining physiological responses in the studies conducted by Wright & Mital (1999) and Bampouras & Dewhurst (2016). Although these results may seem unexpected, small and self-selected loads were considered in these studies that may explain the lack of statistically significant differences. In addition, although a few studies included elderly people while studying biomechanical responses to different load carrying methods including one-handed carrying (Webb & Bratsch, 2017; Bergmann et al., 1997; Neumann, 1996; Rohlmann et al., 2014), the effect of age was not considered as an independent variable. Moreover, to the best of our knowledge, the effect of obesity during one-handed carrying has not been studied in the literature. In many ways, any research on the effects of age and obesity during one-handed carrying may be considered novel and warrants further exploration. Resources should be focused on addressing this critical gap as the proportion of aging and obese people in the general and working populations continues to increase.

Results of this review provide some general conclusions regarding one-handed carrying that are relevant to young adults and middle-aged people:

- The physiological effects of carrying a load in one hand are approximately the same as carrying twice the load equally distributed between two hands. Potential explanations for this phenomenon are one-handed carrying may require greater muscle recruitment and local muscle fatigue than other methods of load carrying (Legg, 1985), the change in center of gravity of the participant's body due to load location (Neumann & Cook, 1985), and the increased lever arm created while carrying off-balance (Bergmann et al., 1997).

- Load location is a significant factor in determining the MALC for different load carrying methods. The average MALC (kg) in one hand was 51-83% of the two-hand MALC.
- Given the same frequency and load magnitude, one-handed carrying had the largest RPE(A), whereas, for two-handed carrying, RPE of the back RPE(BK) was the largest.
- RPE(A) has been observed to be equivalent to approximately one-eighth of the observed HR during one-handed carrying.
- Muscle activity and forces at the hip and low back joints were larger during one-handed carrying (contralateral side) than during two-handed carrying (anteriorly or bilaterally) and posterior carrying.
- To avoid fatigue or injury, loads carried in one hand have been recommended to not exceed 9-10 kg for males and 6-7 kg for females.

Although results of the reviewed articles suggested that the carrying capacity is higher, and potential injury risk is lower, while carrying a load in two hands than when carrying the same load in one-hand, there is no evidence that these suggestions remain true for elderly and obese individuals. Also, although RPE may be used to estimate HR during one-handed carrying of self-selected loads by young adult males and females, it is unknown if RPE represent accurate estimates of physiological responses in elderly and obese individuals during one-handed carrying. In addition, it is unknown if the one-handed loads recommended in the literature are safe for elderly and/or obese people to carry. More research on the effects of age and obesity during one-handed carrying are needed. Studies with larger sample sizes that consider different variables that may affect health and performance (e.g., working temperature, characteristics of the load to be carried, characteristics of walking surface, history of load carrying tasks, etc.) are also warranted. Although different physiological and biomechanical aspects were investigated, even both in one study, no study discussed the effects of muscle fatigue on the change of the biomechanics of carrying. The effect of muscle fatigue on the change of muscle recruitment, and hence load distribution (if existing) remains unknown.

Several limitations of this systematic review should be discussed. One limitation was that articles on one-handed carrying were only included if they were written in English and published in peer-reviewed journals. Accordingly, results published on the topic in other publications (conference proceedings, book chapters, thesis, or dissertations), or in non-English publications, were not reviewed. Another limitation is that, for articles involving more than one study, the review focused only on the study/studies that included one-handed carrying experiment/s. Other topics in some of the reviewed articles were not discussed in the review. Despite these limitations, many research gaps were identified that, once addressed, have the potential to have a positive impact on the health and safety of working people that perform MMH tasks.

Chapter 3

Effects of Age and Obesity on Physiological and Psychophysical Responses during One-handed Carrying

3.1 Abstract

One-handed load carrying is a common form of manual materials handling. Limited research has evaluated the physiological and psychophysical responses of older and obese workers, quickly growing segments of the working population, during one-handed load carrying. This study compared five physiological and three psychophysical responses as well as walking speed across 20 participants divided into four age (young and older) and obesity (obese and non-obese) categories while carrying different loads (*No-load* [0 kg], *Light* [5.67 kg], *Heavy* [10.21 kg], and *Self-selected*) in one hand for a distance of 90 m. Results suggested that loads carried in one-hand are more physiologically demanding for obese people, particularly older obese individuals, despite the load representing a smaller percentage of their total body weight (BW) in comparison with non-obese people. Age did not independently lead to practically meaningful increases in response variables, except that young participants self-selected heavier loads than the older participants.

3.2 Introduction

Increasing proportions of the United States' general and working populations are comprised of older and obese people each year (Jacobsen, Kent, Lee, & Mather, 2011; He, Goodkind, & Kowal, 2016; Ogden, Carroll, Fryar, & Flegal, 2015; Ogden et al., 2006; Wang & Beydoun, 2007). The percentage of American people aged 65 years or older is expected to reach approximately 20.9% by 2050 (Ortman, Velkoff, & Hogan, 2014), and over 50% of American adults are expected to be classified as obese by 2030 (Wang et al., 2008; Finkelstein et al., 2012).

One-handed carrying has been observed to be more physiologically demanding than other types of load carrying (e.g., on the back, two hands [bilaterally or anteriorly], or on the shoulder; Badawy et al., 2018). For example, physiological responses (heart rate [HR], oxygen consumption, blood pressure [BP], and energy expenditure [EE]) due to carrying a load in one hand have been observed to be considerably larger than the corresponding responses when distributing the load between two hands, and in some situations approximately the same as carrying an identical load in each hand (two times the load; Lind & McNicol, 1968; Jackson, Reeves, Sheffield, & Burdeshaw, 1973; Legg, 1985; Ganguli & Datta, 1977). Psychophysical methods have also been applied to obtain estimates of perceived exertion during different carrying scenarios and/or to estimate the load that one could carry comfortably (Mital & Manivasagan, 1983; Nottrodt & Manley, 1989; Smith, Ayoub, & McDaniel, 1992; Yoon & Smith, 1999; Wright & Mital, 1999; Kilbom, Hagg, & Kall, 1992). Some studies have indicated that participants self-selected 51-83% of their self-selected two-handed load capacity for carrying with one hand (Nottrodt & Manley, 1989; Yoon & Smith, 1999). A one-handed carrying weight limit of approximately 9-10 kg for males has been suggested (Ganguli & Datta, 1977; Lind & McNicol, 1968; Kilbom et al., 1992; Badawy et al., 2018).

While these studies provide valuable insight regarding the physiological responses during one-handed carrying for many working age people, to our knowledge, only two studies have discussed the effect of age on physiological and/or psychophysical responses during one-handed carrying (Bampouras & Dewhurst, 2016; Wright & Mital, 1999). Bampouras & Dewhurst (2016) studied the effects of carrying shopping bags in one versus two hands on the age-predicted percentage of maximum heart rate (%HR_{max}) of young (26.7 ± 5.2 years) and older (71.0 ± 6.0 years) females. However, the loads carried were small (up to 1.4 kg in one hand and 2.7 kg evenly distributed between both hands), thereby potentially resulting in small physiological responses that may not be representative of many work scenarios. Wright & Mital (1999) compared young (19-35 years) and older (55-74 years) participants' HR, oxygen consumption, perceptions of the maximum acceptable load carried (MALC), and ratings of perceived exertion (RPE) while a load was carried in one or two hands for a distance of 6 m at different carrying frequencies. While age was reported to have no statistically significant effect in the study, it should be noted that the loads carried by each participant were self-selected (i.e., not equivalent), making it difficult to compare the groups. In addition, no studies directly evaluated the effect of obesity during one-handed carrying (Badawy et al., 2018).

The changing composition of the working population raises the need for a more comprehensive understanding of the effects of one handed carrying on older and obese workers, populations particularly susceptible to work-related musculoskeletal disorders (MSDs; Kouvonen et al., 2013; BLS, 2015). The objective of the present study was to compare physiological and psychophysical responses of participants in different age and obesity categories while they carried various loads in one hand to gather a more comprehensive understanding of the effects of age and obesity on one-handed carrying performance. Specifically, we examined the effects of carrying loads of approximately 10 kg as this mass has been previously suggested to be safe for most working males (Lind & McNicol, 1968; Ganguli & Datta, 1977; Kilbom et al., 1992). The results are anticipated to be useful for developing one-handed carrying guidelines for obese and older workers when designing manual material handling jobs. It was hypothesized that the carrying tasks would be more physiologically demanding for older and/or obese individuals than for young and/or non-obese individuals because of the natural declination of physiological capacity in older people, on average, as well as the increased net metabolic rates during walking in obese people in comparison to non-obese people (Browning, Baker, Herron, & Kram, 2006; Scott-Warren & Maguire, 2017).

3.3 Method

3.3.1. Participants

Twenty (20) right-handed male participants were recruited and divided into four groups with respect to age and obesity (Young/Non-obese [YNO]: 19-35 years of age, body mass index (BMI) < 25 kg/m^2; Young/Obese [YO]: 19-35 years of age, BMI ≥ 30 kg/m^2; Older/Non-obese [ONO]: 55-64 years of age, BMI < 25 kg/m^2; Older/Obese [OO]: 55-64 years of age, BMI ≥ 30 kg/m^2). Descriptive statistics (mean and standard deviation) for age, weight, height, BMI, and percent body fat for each group are presented in Table 3.1. Percent body fat was obtained from a Dual-energy X-ray absorptiometry (DEXA) scan (Appendix 4).

Table 3.1. Mean and standard deviation of personal data of each group of participants

Group	n	Age (years)	Weight (kg)	Height (cm)	BMI (kg/m^2)	Body fat (%)	Self-selected load (kg)
YNO	5	25.4 ± 2.1	70.7 ± 5.3	173.2 ± 5.8	23.7 ± 0.7	15.2 ± 4.2	10.0 ± 2.2
YO	5	29.1 ± 4.5	113.0 ± 19.4	179.3 ± 4.6	35.0 ± 4.7	39.4 ± 7.0	10.9 ± 2.1
ONO	5	59.7 ± 3.5	70.2 ± 6.6	175.3 ± 4.4	22.9 ± 0.9	16.0 ± 5.6	7.3 ± 1.0
OO	5	60.1 ± 0.8	104.2 ± 4.6	180.3 ± 3.6	31.9 ± 1.4	34.0 ± 4.8	8.4 ± 1.0

Five inclusion criteria were adopted for the recruitment of participants (Appendix 7): 1) fit one of the predetermined age and BMI categories; 2) no history of physician-diagnosed cardiovascular disease; 3) no history of physician-diagnosed MSDs in the neck, shoulder, extremities, or low back regions; 4) no chronic pain in the neck, shoulder, extremities, or low back in the six (6) months preceding the study; and 5) not receiving radiation therapy at the time of the study. Informed consent was obtained from all participants. All study procedures were approved by the Auburn University Institutional Review Board.

3.3.2. Experiment

Participants were asked to walk for 90 m (45 m back and forth) four times; once while carrying no load (*No-load*) and three times while carrying three different loads (5.67 kg [*Light*], 10.21 kg [*Heavy*], and a *Self-selected* load [not exceeding 20 kg]) in their dominant hand at their normal self-selected walking speed. The walking/carrying distance was selected according to a similar study conducted by Mital & Manivasagan (1983) and the experiment was performed indoors. An adjustable-weight dumbbell (from 2.27 to 23.81 kg, in 1.13 kg increments) was used for the study. To identify the *Self-selected* load, participants were asked to walk the 90-m distance without a load before beginning the experiment. They were then provided with a random load (2.27-19.28 kg) to hold while standing and decide whether it would be a comfortable load to carry for the specified distance (90 m), or if it needed to be adjusted (increased or decreased, by increments of 1.13 kg). The mean and standard deviation of the *Self-selected* loads carried by each group are presented in Table 3.1. The four experimental conditions were presented in a randomized order to each participant to avoid biasing participants based on possible apprehension of the first condition and/or fatigue on the last (Lind & McNicol, 1968).

Measurements of HR and oxygen consumption rate ($\dot{V}O_2$) were collected from the participants while they completed the trials. A heart rate monitor (Polar Electro Inc., Lake Success, NY, USA) was secured to the chest via a torso strap. The sensor was linked to a data logging watch (Polar M400, Lake Success, NY, USA) worn by the researcher. A portable metabolic measurement system (model K4b2, COSMED, Middlesex, UK) was fitted to the participant to measure $\dot{V}O_2$. A breathing mask was placed on the participant's mouth and the portable data collection unit and a battery [both weighing < 1 kg] were attached to the participant's waist. Data collected from both the HR sensor and metabolic cart were synchronized using a digital video captured during the experiment.

Resting HR (HR_{rest}) and resting $\dot{V}O_2$ (sitting) were captured for 60 seconds after asking the participant to relax on a chair for three minutes before beginning the trials (Theurel, Desbrosses, Roux, & Savescu, 2018). HR (HR_{work}) and $\dot{V}O_2$ measurements were averaged over the entire walking period. To avoid fatigue effects, a rest period of at least 3 minutes separated each trial to allow the physiological values to return to their original HR_{rest} (Chang, Kobetic, & Triolo, 2017; Sugiyama, Kawamura, Tomita, & Katamoto, 2013). The age-predicted percentage of maximum HR ($\%HR_{max} = 208 - 0.7 \times \text{age}$; Tanaka, Monahan, & Seals, 2001) was also calculated.

Nine dependent measures (five physiological, three psychophysical, and walking speed) were evaluated for this analysis. Physiological responses included HR, the percentage of the reserve HR ($\%HRR = 100 \times [HR_{work} - HR_{rest}] / [HR_{max} - HR_{rest}]$), the percentage of maximum $\dot{V}O_2$ ($\%\dot{V}O_{2max}$; estimated based on HR_{rest} and HR_{max} [Uth, Sorensen, Overgaard, & Pedersen, 2004]), total oxygen consumption for the trial (VO_{2T}), and VO_{2T} normalized to BW (VO_{2T}/BW). The psychophysical dependent measures were RPE of the carrying arm (RPE [A]), of the back (RPE [BK]), and of the whole body (RPE [WB]) (Mital & Manivasagan, 1983; Yoon & Smith, 1999). RPEs were obtained after each trial using the 15-point Borg Scale (Appendix 8; Borg, 1970). Participants were familiarized with the Borg Scale beforehand.

3.3.3. Independent and Dependent Variables

Three independent variables were investigated: age, obesity, and load magnitude. Each of the first two variables included two levels (young/older, and obese/non-obese, respectively). The load magnitude variable included four levels (*No-load*, *Light*, *Heavy*, and *Self-selected*). All nine dependent variables were analyzed at each combination of levels of the independent variables.

3.3.4. Statistical Analysis

The data were visually inspected to determine if the assumptions of using analysis of variance (ANOVA; e.g., normality plots, histograms, residual plots, outlier checks) were met. Moreover, Shapiro-Wilk tests were conducted to evaluate the normality of the residuals. The tests suggested the data were normally distributed. Parametric and nonparametric Levene's tests were conducted to evaluate equality of variances for the physiological responses and walking speed, and psychophysical responses, respectively. Results suggested that all of the data had sufficiently equal variances ($p > 0.05$).

The statistical significance of the main effect of each of the three independent variables (age, obesity, and load magnitude), and the interaction of these variables on the dependent variables was determined using ANOVA following a split-split-plot factorial design. The design was performed using a statistical analysis software (Statistix 8.0; Analytical Software; Tallahassee, FL, Maryland, USA). Tukey honestly significant difference (HSD) post-hoc tests were used to assess all pairwise comparisons for load magnitude, if this main effect was significant. An alpha value of 0.05 was employed for all analyses. It should be noted that only statistically significant effects are reported in the Results section for brevity. ANOVA results (F values, degrees of freedom, p values, and effect sizes [η^2]) for all dependent variables are presented in Appendix 1.

3.4 Results

3.4.1. Physiological Responses

The interaction between age and load was observed to be statistically significant for HR, %HRR, and $\%\dot{V}O_{2max}$ ($p = 0.01$, $p = 0.01$, and $p = 0.03$, respectively). All three dependent measures increased with the increase of load magnitude (from *No-load* to *Heavy*) for both young and older groups (Figures 3.1 and 3.2). However, carrying the *Self-selected* load resulted in a slight increase in all three measures among the young groups compared with carrying the *Heavy* load, while older groups experienced a noticeable decrease. Nevertheless, it should be noted that the young groups self-selected heavier loads than the older groups (10.45 kg [greater than the *Heavy* load] versus 7.85 kg [smaller than the *Heavy* load], respectively; Table 3.1). Consistent results were observed regarding the effect of the interaction between obesity and load on $\%\dot{V}O_{2max}$ ($p < 0.01$). Furthermore, VO_{2T} and VO_{2T}/BW generally increased as the load magnitude increased ($p < 0.01$ for both).

VO_{2T} for the two obese groups were much larger than the corresponding measures for the non-obese groups at the four loading conditions ($p < 0.01$; Figure 3.1). For instance, VO_{2T} (liter [L]) for the *Heavy* load condition was 1.9 for the OO, 1.8 for the YO, 1.4 for the ONO, and 1.4 for the YNO. However, when normalized to BW (VO_{2T}/BW), differences between groups were smaller and results did not follow any particular trend ($p = 0.17$). Moreover, VO_{2T}/BW was observed to be significantly smaller among the obese groups when a load was carried, despite being larger for the *No-load* condition ($p = 0.01$; Figure 3.2). In addition, a statistically significant interaction between age and obesity was observed for $\%\dot{V}O_{2max}$ ($p = 0.01$; Figure 3.3). Age had a larger effect on the obese groups than the non-obese groups.

3.4.2. Walking Speed

A statistically significant interaction was observed between age and load for walking speed ($p = 0.04$). The two older groups walked with greater speed compared to the two young groups for the *No-load* condition (Figure 3.2). However, carrying a load resulted in an increase in walking speed among the young groups, and a decrease among the older groups, compared with walking with *No-load*. Changes in speed were less pronounced among the older groups. For example, the largest difference between the walking speed (m/s) while carrying *No-load* and the walking speed while carrying any other load was, on average, 0.05 (m/s) for the young groups and 0.02 (m/s) for the older groups.

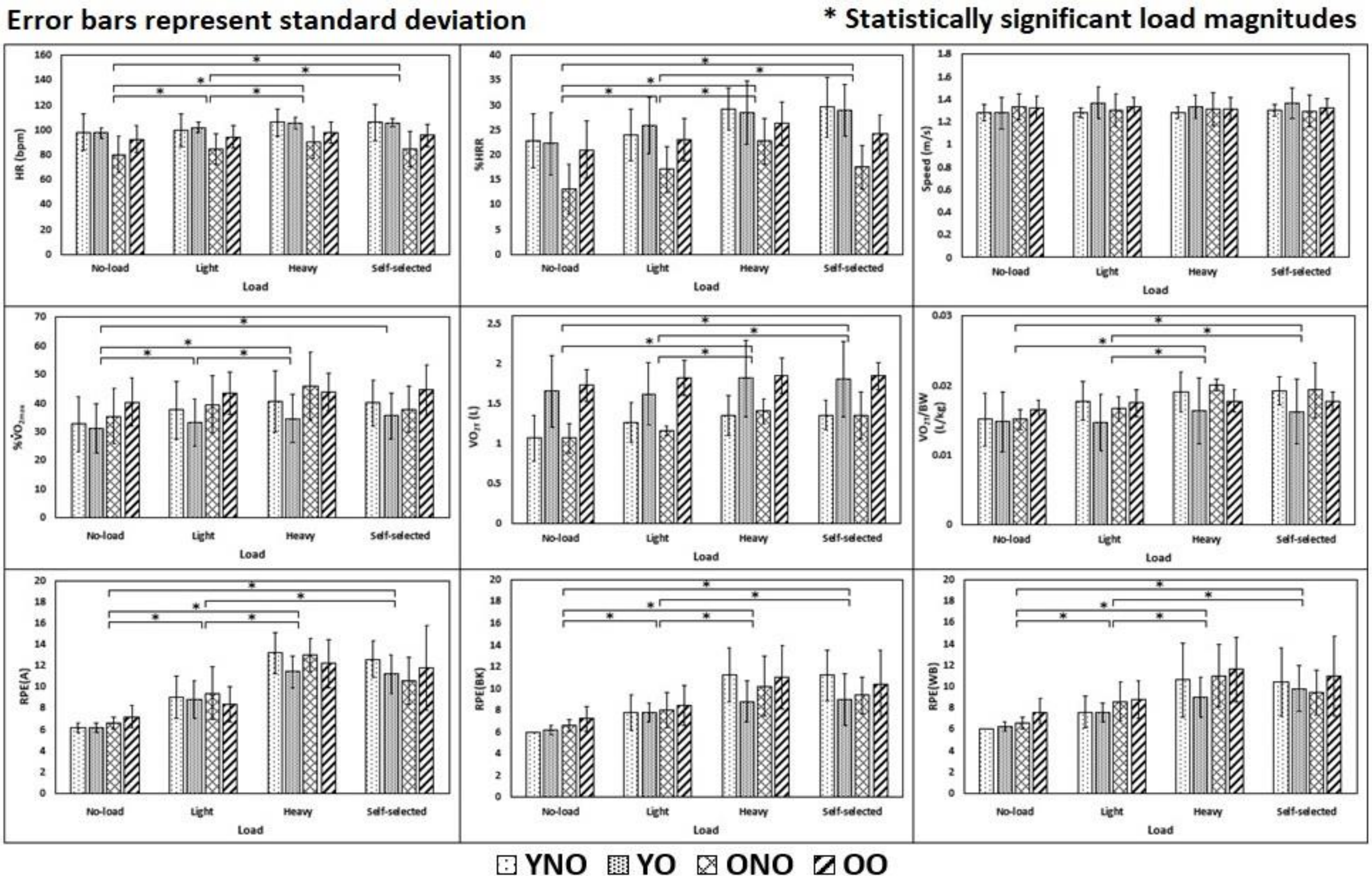
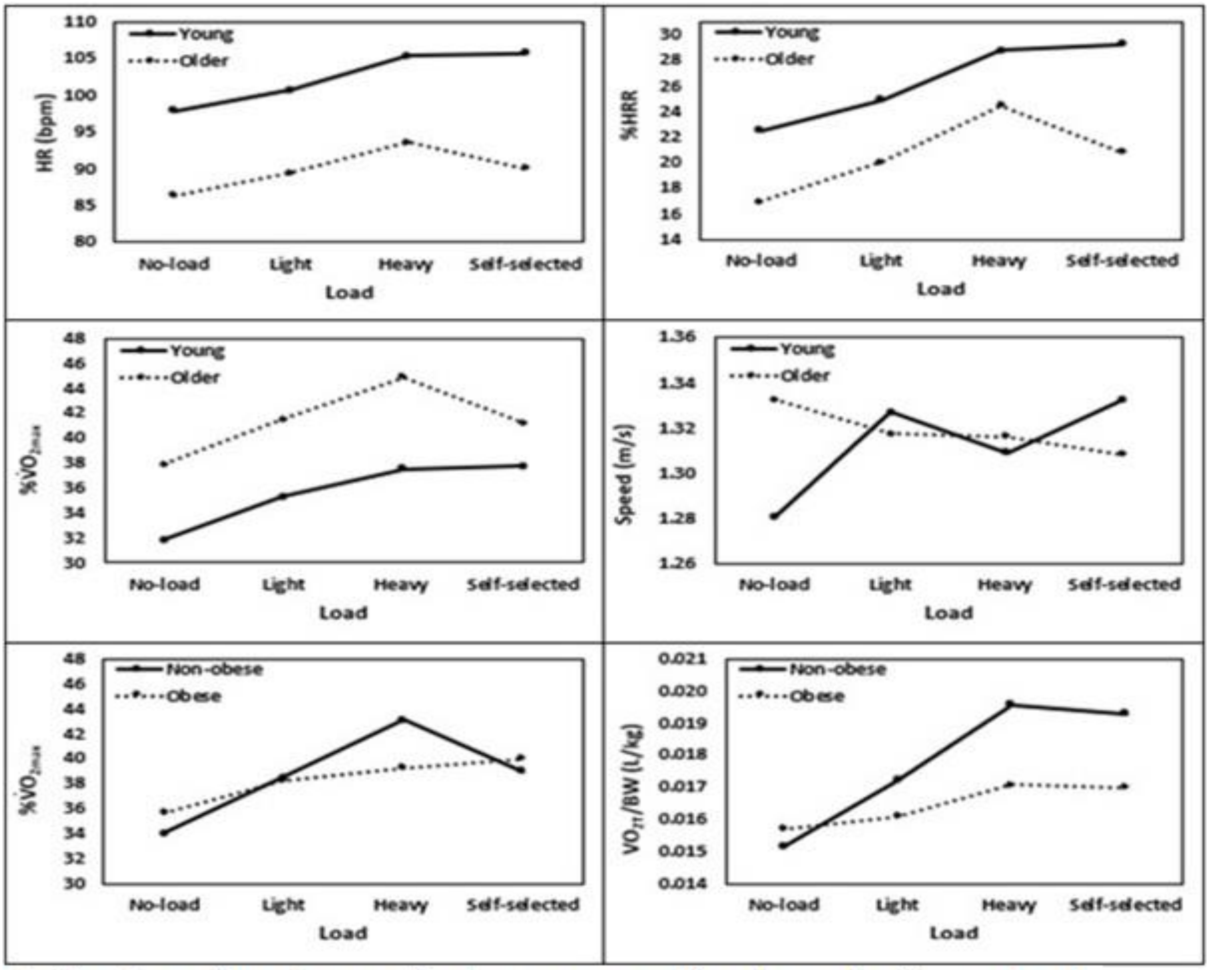


Figure 3.1. All dependent variables at different load condition



Self-selected **loads may be larger or smaller than the** ***Heavy*** **load.**

Figure 3.2. Significant interactions of age and load as well as obesity and load

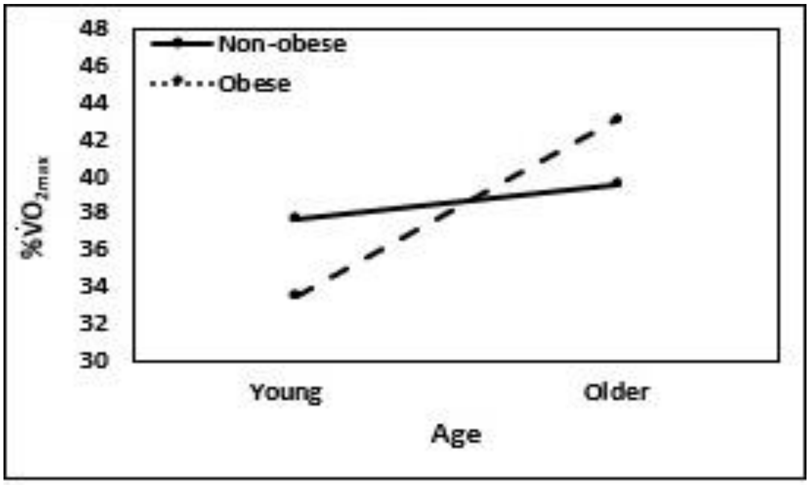


Figure 3.3. Significant interaction of age and obesity with respect to $\%\dot{V}O_{2max}$

3.4.3. Ratings of Perceived Exertion

Load had a statistically significant main effect on RPE(A), RPE(BK), and RPE(WB). In general, all three responses increased with increasing carried loads ($p < 0.01$ for all; Figure 3.1) over the four loading conditions. The largest RPE for all groups across all four loading conditions was RPE(A) when participants carried the *Heavy* load (YNO = 13.2; YO = 11.4; ONO = 13; OO = 12.2). In most cases, RPE(BK) and RPE(WB) were smaller than the corresponding RPE(A) while a load was carried (*Light*, *Heavy*, and *Self-selected*).

3.4.4. Self-selected loads

Three of the four participant groups (YNO, ONO, and OO) carried a *Self-selected* load between the *Light* and *Heavy* load conditions (10.0 kg, 7.3 kg, and 8.4 kg, respectively). The fourth group (YO) carried a load slightly heavier than the *Heavy* load (10.9 kg). All of the physiological and psychophysical responses for the *Self-selected* load were, to a large extent, comparable to the corresponding values at either the *Heavy* load or the *Light* load for the four participant groups, particularly the young groups. The *Self-selected* load was not statistically significantly different from the *Heavy* load in affecting any of the dependent variables. The *Self-selected* load was also not statistically significantly different from the *Light* load in affecting $\%\dot{V}O_{2max}$ or walking speed.

3.5 Discussion

Despite the statistically significant interaction between age and load on HR, %HRR, and $\%\dot{V}O_{2max}$, the older groups had smaller HR and %HRR than the younger groups for the four load conditions. In addition, the largest $\%\dot{V}O_{2max}$ experienced by the older groups (while carrying the

Heavy load) did not exceed 45%. Accordingly, loads up to approximately 10 kg as recommended in previous research (Lind & McNicol, 1968; Ganguli & Datta, 1977; Kilbom et al., 1992) do not appear to lead to substantive changes in the physiological responses of older, healthy individuals (up to 64 years old) carried one time for a distance of up to 90 m. However, it should be noted that the *Heavy* load might not be the most comfortable load to carry in one-hand by an older individual, particularly the ONO. In this study, the older groups self-selected smaller loads to carry than those selected by the young groups (Table 3.1); the ONO self-selected the smallest load on average. This may explain the large absolute differences between the average RPEs reported after carrying the *Heavy* versus the *Self-selected* load in the ONO, compared with the corresponding differences in the three other groups (RPE[A]: 2.4 versus 0.2-0.6; RPE[BK]: 0.8 versus 0-0.6; RPE[BK]: 1.6 versus 0.2-0.8, respectively).

The effect of obesity on VO_{2T} was thought to be mainly attributable to the increased BW among the obese groups. The size of fat cells generally increases with obesity (Kabon et al., 2004; Jansson, Larsson, Smith, & Lönnroth, 1992). Since the increase in fat cells size is not accompanied with an increase in blood flow (Kabon et al., 2004; Jansson et al., 1992), hypoperfusion, and hence hypoxia, of fat tissues may occur among obese people (Kabon et al., 2004; Di Girolamo, Skinner, Hanley, & Sachs, 1971). In this study, the loads carried by the two obese groups represented smaller percentages of BW compared with the non-obese groups, suggesting that the increase in some of the physiological responses in the obese groups may be attributed to the walking process itself. For instance, the differences between the resting $\dot{V}O_2$ (ml/min) and $\dot{V}O_2$ (ml/min) for the *No-load* condition in all four groups were considerably larger than the corresponding differences in $\dot{V}O_2$ (ml/min) for the *No-load* and the *Heavy* load, particularly for the two obese groups (YNO: 556.1 and 226.2; YO: 899.3 and 146.5; ONO: 540.2 and 270.8; OO: 933.0 and 145.3, respectively).

The significant effects of obesity on the non-normalized oxygen consumption measure (VO_{2T}) reflects that the tested load conditions were more demanding for the obese groups than for the non-obese groups. Obesity is known to have a negative effect on endurance as well as contribute to fatigue (Cavuoto & Nussbaum, 2014). In this study, the obese groups had larger resting and walking/carrying $\dot{V}O_2$ than the non-obese groups. This may be attributed to a greater mass of adipose tissue (Fonseca et al., 2018; Leibel, Rosenbaum, & Hirsch, 1995). These results suggest that the tested load carrying conditions, although possibly not considered highly physiologically demanding tasks according to recommended classifications (USDHHS, 1996), could be more stressful for obese people over a complete work shift than non-obese people. The situation could be particularly pronounced for the OO as compared to the YO. For example, the significant interaction between age and obesity on $\%\dot{V}O_{2max}$ indicated that the OO group were challenged more by greater physiological stresses when compared to the other three groups (Figure 3.3). However, more research is recommended to examine this load limit for longer carrying distances, or complete work shifts, particularly for obese individuals.

With regard to psychophysical responses, carrying the *Heavy* load was considered to be a fairly light to somewhat hard task by the majority of participants regardless of age or obesity classification (according to the RPE responses; Borg, 1970). Although perceived to not be very demanding, this load could cause soreness of the arm muscles during repetitive tasks. Muscle activity and local muscle fatigue would be expected to be larger in one-handed carrying than in other methods of load carrying (Legg, 1985). Accordingly, it is recommended to avoid one-handed carrying tasks by distributing the load between two hands or carrying it on the back, if possible. Distribution of the load should enable individuals to carry heavier loads than those that could be carried in one hand (Yoon & Smith, 1999; Nottrodt & Manley, 1989), without being exposed to excessive physiological demands (Lind & McNicol, 1968; Jackson et al., 1973; Legg, 1985; Ganguli & Datta, 1977).

This study provides baseline information for developing one-handed carrying guidelines for obese and older workers. To our knowledge, no previous research has examined the effects of age and obesity on the physiological responses in females during one-handed carrying (Badawy et al., 2018). Future work should examine the effect of gender on physiological and psychophysical responses during one-handed carrying. Furthermore, the effects of one-handed carrying on gait parameters (spatiotemporal, kinematic, and kinetic) in older and obese people has not been sufficiently studied. Previous research has suggested that one-handed carrying results in an increase in the hip and low back joint forces as well as muscle activity when compared to other methods of carrying (Neumann & Cook, 1985; Neumann, Cook, Sholty, & Sobush., 1992; Neumann, 1996; Bergmann, Graichen, Rohlmann, & Linke, 1997; Cook & Neumann, 1987; McGill, Marshall, & Andersen, 2013). However, the literature lacks similar research that focuses on older and obese populations. For instance, it is possible that carrying a *Heavy* load in one hand may result in an increased risk of slips and falls in older people, due to instability of individuals from asymmetric gait patterns (An, Yoon, Yoo, & Kim, 2010) and/or a shift in the center of gravity laterally (Neumann & Cook, 1985).

This work has several limitations. First, the participants carried the load for a relatively short distance (90 m). The objective was to select a walking distance that would not be too short nor too long, such that differences in responses would be detected without exposing older and/obese participants to excessive workload that may contribute to an injury. Second, the apparatus used in measuring oxygen consumption added slightly more weight to participants and may have obstructed some of their natural movements. Third, the *Self-selected* load was limited to 20 kg to meet Institutional Review Board recommendations. It is unknown how large the *Self-selected* load would have been if the participants were provided with loads exceeding 20 kg. Fourth, HR_{max} and $\dot{V}O_{2max}$ measures used in this study were determined using the equations obtained from the literature (Tanaka et al., 2001; Uth et al., 2004). Ideally, recordings of practical HR_{max} and $\dot{V}O_{2max}$ would have represented a better estimation of participants' physiological capacity. Fifth, differences in fitness levels between participants were not considered as inclusion criteria. Accordingly, the impact of fitness differences across age and obesity levels could not be assessed.

Key Points

- Load magnitude and obesity had a practically meaningful effect on all physiological and psychophysical responses whereas age had no practically meaningful effect on most of the responses.
- While the physiological responses did not increase considerably with age, the older groups self-selected smaller loads to carry than those selected by the young groups.

- A load carried in one-hand is more physiologically demanding for obese people, particularly older obese individuals, despite the load representing a smaller percentage of their total BW in comparison with non-obese people.
- While it may be considered a light to moderately intense task from a physiological perspective, it is unknown if carrying the *Heavy* load for very long distances and/or repetitive tasks would expose people to injury risk.
- Future research is needed to examine the effects of one-handed carrying tasks among older and obese people when carrying heavier loads at any load carrying distances greater than 90 m.

Chapter 4

Trunk Muscle Activity among Older and Obese People during One-handed Carrying

4.1 Abstract

Manual material handling (MMH) is associated with the development of work-related musculoskeletal disorders (MSDs). One-handed carrying is a particularly challenging form of MMH. Age and obesity have been increasing among the general and working populations in the United States and worldwide. While older and obese workers are more susceptible to MSDs in comparison to younger, healthy workers, the effects of one-handed carrying on trunk muscle activity among these populations have not been adequately studied. In this paper, we evaluate the effects of age and obesity on trunk muscle activity of six trunk muscle pairs during one-handed carrying of different loads. The results suggest that older and obese individuals may not exhibit considerably larger muscle activity than young and non-obese individuals. Muscle activity was mainly driven by the effect of load magnitude. Further research is needed to evaluate the effects of age and obesity during one-handed carrying of heavier loads and longer carrying distances/durations.

4.2 Introduction

Humans are living and working longer than ever before. In 2017, the global proportion of people aged 60+ years was 13% and growing at a rate of 3% per year (UNDESA, 2017). The number of people aged 65+ years in the United States is expected to double by 2050 in comparison to 2012 (Ortman, Velkoff, & Hogan, 2014). People aged 55+ years are expected to represent 24.8% of the working population in the United States by 2024; an increase from 21.7% in 2014 (Toossi, 2015).

Obesity rates are also increasing worldwide. The global prevalence of overweight and obese adults increased 27.5% between 1980 and 2013, with rate increases higher among men aged 45-55 years and women aged 55-60 years than among younger individuals (Ng et al., 2014). Similarly, the prevalence of obesity in American adults increased 9.1% between 1999-2000 and 2015-2016 (Hales, Carroll, Fryar, & Ogden, 2017). The prevalence of obesity among American adults was higher in 2015-2016 for people aged 60+ years than for those aged 20-39 years (Hales et al., 2017).

Previous research has indicated that older and obese populations may be more susceptible to work-related musculoskeletal disorders (MSDs) in comparison to other populations (Kouvonen et al., 2013; BLS, 2015; Schulte et al., 2007). For instance, obese people could be more susceptible to risk associated with low back pain and intervertebral disc disorders, in comparison to non-obese people (Sheng et al., 2017; Roffey, Budiansky, Coyle, & Wai, 2013; Peng, Pérez, & Gabriel, 2018). In addition, older people appear to have higher rates of low back pain than younger populations (Hoy et al., 2012; Wong, Karppinen, & Samartzis, 2017). There are several potential explanations for the increased risk of MSDs among obese and older populations. For instance, obese people experience more load on body joints than non-obese individuals due to excessive body weight (BW; Frilander et al., 2015). In addition, older people generally have less muscle mass and more body fat than younger people (Villareal et al., 2004; Beaufrere & Morio, 2000). This situation is exacerbated when obesity is combined with being older. Older obese people tend to have lower muscle strength than older non-obese people (Villareal et al., 2004).

Manual material handling (MMH) is associated with the development of work-related MSDs (Xu, Cheng, & Li-Tsang, 2013; Nelson et al., 2006). One-handed carrying has been identified as a particularly challenging form of MMH, due in part to the large forces generated by some trunk muscles during one-handed carrying (Cook & Neumann, 1987; McGill, Marshall, & Andersen, 2013). Despite the increased risks associated with age and obesity, the effects of one-handed carrying on trunk muscle activity among older and/or obese individuals have not been adequately studied (Badawy et al., 2018).

Cook & Neumann (1987) observed that one-handed contralateral (the opposite body side of the carried load) and anterior load carrying methods resulted in considerably higher muscle activity from the erector spinae muscles among young participants (21-36 years) than the muscle activity of the same muscles during no load, posterior, or ipsilateral (the same body side of the carried load) carrying. However, the effects of different methods of load carrying on other trunk muscles were not studied.

McGill et al. (2013) studied the effects of load magnitude and load location (one versus two hands) on spinal muscle activity, compression forces, and shear forces (L4/L5 vertebral segment) among young healthy males (22.7 ± 2.1 years). Results of the study indicated that both muscle activity and spinal forces were larger while a load was carried in one hand when compared to evenly splitting the load between two hands, or in some situations, even carrying the same load in each hand (twice the load in total).

Rohlmann et al. (2014) completed the only study we are aware of that considered older individuals during one-handed carrying. Participants with implanted vertebral body replacement carried different loads in one hand, in two hands, or on the back. The increase in spinal loading on the implant was examined. Results were consistent with those observed by Cook & Neumann (1987), and McGill et al. (2013). The force on the implant did not increase while carrying 20 kg in both hands (10 kg in each hand), compared with carrying 10 kg in one hand.

Notwithstanding the valuable information gathered through these three studies, few conclusions may be drawn regarding the effects of one-handed carrying on muscle activity among obese and older persons. None of the three studies discussed the effect of obesity during one-handed carrying. Moreover, identifying the effect of age was not the main objective of the only study that included older participants (Rohlmann et al., 2014); understanding the effect of age was not possible because the study included only older participants. The objective of the present study was to examine changes in trunk muscle activity with respect to load magnitude among obese and older people during one-handed carrying to address this gap in the scientific literature. We hypothesized that obese and older individuals would exhibit increased muscle force exertion in comparison to non-obese and young individuals.

4.3 Method

4.3.1. Participants

Twenty (20) right-handed, male participants were recruited for this study (Appendices 5 and 6). All participants reported that they had 1) a body mass index (BMI) < 25 kg/m^2 or BMI ≥ 30 kg/m^2; 2) No history of physician-diagnosed cardiovascular diseases or MSDs in the neck, shoulder, extremities, or low back regions; 3) No chronic pain in the neck, shoulder, extremities, or low back in the 6 months preceding the study; and 4) No adhesive allergies (Appendix 7). After providing their informed consent, all participants had a Dual-energy X-ray absorptiometry (DEXA) scan to estimate their percentage of body fat (Appendix 4).

Participants were divided into four groups with respect to age and obesity (Young/Non-obese [YNO]: 19-35 years of age, BMI < 25 kg/m^2; Young/Obese [YO]: 19-35 years of age, BMI ≥ 30 kg/m^2; Older/Non-obese [ONO]: 55-64 years of age, BMI < 25 kg/m^2; Older/Obese [OO]: 55-64 years of age, BMI ≥ 30 kg/m^2). All study procedures were approved by the Auburn University Institutional Review Board. Descriptive statistics (means and standard deviations) of age, weight, height, and BMI, and of each group are presented in Table 4.1.

Table 4.1. Mean and standard deviation of personal data of each group of participants

Group	**n**	**Age (years)**	**Weight (kg)**	**Height (cm)**	**BMI (kg/m^2)**	**%Body fat**
YNO	5	25.4 ± 2.1	70.7 ± 5.3	173.2 ± 5.8	23.7 ± 0.7	15.2 ± 4.2
YO	5	29.1 ± 4.5	113.0 ± 19.4	179.3 ± 4.6	35.0 ± 4.7	39.4 ± 7.0
ONO	5	59.7 ± 3.5	70.2 ± 6.6	175.3 ± 4.4	22.9 ± 0.9	16.0 ± 5.6
OO	5	60.1 ± 0.8	104.2 ± 4.6	180.3 ± 3.6	31.9 ± 1.4	34.0 ± 4.8

4.3.2. Pre-experiment Protocol

Twelve paired surface electromyography (EMG) electrodes (EMG Pre-Amplifier SX230, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK) were placed bilaterally on six trunk muscles. These muscles were the right and left rectus abdominis, external oblique, internal oblique, latissimus dorsi, upper (thoracic) erector spinae, and lower (lumbar) erector spinae (McGill, 1991; McGill et al., 2013). Placement of the electrodes (location and orientation) was consistent with the guidelines in McGill (1991), McGill et al. (2013), and Escamilla et al. (2006). Before placing the electrodes, the skin was cleansed with alcohol wipes. If needed, a small electric hair trimmer was used to remove patches of hair where the sensors were applied for participant comfort as well as to improve the quality of the recorded signals. A die cut medical grade double-sided adhesive tape (T350, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK) was used to apply the electrodes on the muscles. The electrodes were connected to analog input sockets of one of two portable, programmable data acquisition units (DataLOG MWX8, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK). Two ground reference cables (R506, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK) were attached to the clavicle bones using disposable EMG electrodes with a 4-mm snap connector (SEN3001, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK). Each of the two ground reference cables was connected to either of the digital sockets of one of the two data acquisition units. The two data acquisition units were placed in a bag worn anteriorly and secured to the participant's waist ("fanny pack"). The raw EMG signals were digitized at 1000 Hz and streamed via Bluetooth to a computer for analysis.

For normalization, short standing and sitting rest periods (1 minute each) were captured. Then, participants performed three out of four exercise strategies (sit-up [one task], standing [four tasks], and twisting [six tasks]) developed by McGill (1991). The fourth strategy (hanging) was excluded as it was deemed too strenuous for older and/or obese participants. Additionally, for the twisting exertions, two research assistants provided resistance to restrain the participant. One research assistant provided resistance to the shoulders from the front and the other from the back. Each of the three strategies (comprising 11 tasks in total) was performed three times, resulting in a total of 33 exertions. The maximum exertion of each of the tested muscles over all of the 33 exertions was used to calculate the maximum voluntary isometric contraction (MVC) for this particular muscle. Each MVC exertion lasted a maximum of four seconds, or sometimes less if the participant could not withstand exerting maximum force for four seconds. Data recording was managed using Biometrics software (version 9.01, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK).

4.3.3. Experiment

The experiment took place in the Auburn University Biomechanical Engineering Laboratory. Participants were asked to perform three replicates of three walking trials (total of 9). These trials included walking while carrying different loads in the dominant/preferred [right] hand (0 kg [*No-*

load], 5.67 kg [*Light*], and 10.21 kg [*Heavy*]) for a distance of approximately 6 m. An adjustable dumbbell (from 5 to 52.5 lb, in 2.5 lb increments) was the load used in the study. Loading amounts during walking trials were randomized. To avoid fatigue and/or muscle soreness, a resting period of at least 1 minute separated the trials.

4.3.4. Data Processing

A MATLAB script (Mathworks Inc., 2017a, USA) was implemented to calculate the percentage of MVC (%MVC) of each muscle for each experimental condition. A 4th order Butterworth (59.5-60.5 Hz) filter was applied to attenuate powerline noise occurring at 60 Hz (Willigenburg, Daffertshofer, Kingma, & van Dieën, 2012). A high-pass filter at 30 Hz cut-off frequency was applied for electrocardiography noise attenuation (Drake & Callaghan, 2006). Then, the data were full-wave rectified and low pass filtered with a cut-off frequency of 2.5 Hz to match the frequency response of trunk muscles (McGill et al., 2013; Brereton & McGill, 1998).

The smallest EMG value for each muscle of all the walking and resting files (11 files) was considered the absolute minimum for that specific muscle. These minimum values were considered the base EMG noise (EMG_{Noise}). The middle three seconds of each MVC exertion were considered for calculating the MVC (Douphrate et al., 2017). The %MVC was calculated for each of the 12 muscles in all 9 walking trials. The %MVC of each muscle was calculated using Eq. 4.1, where EMG_i is the EMG for a sample i of the data in the walking files and EMG_{MVC} represents the peak MVC across all 33 MVC files (Douphrate et al., 2017; Thorn et al., 2007).

$$\%MVC = \sqrt{EMG_i^2 - EMG_{Noise}^2} \Big/ \sqrt{EMG_{MVC}^2 - EMG_{Noise}^2} \qquad Eq.(4.1)$$

The %MVC for the stance phase of each limb of one step during an established gait (after participants walked for 3 steps) was calculated. The stance phase of each limb was identified using ground reaction forces collected using two force plates (AMTI BP400600, 2000 lb. capacity; Advanced Mechanical Technology, Inc., Watertown, MA, USA). Data from the force plates were collected using Nexus software (Version 2.6.1; Vicon Motion Systems Ltd, Oxford Industrial Park, Oxford, UK). EMG and force plate data were synchronized using a synchronization cable (SYNC5, Biometrics Ltd, Nine Mile Point Ind. Est, Newport, UK). Data during the stance phase were normalized to 101 time points (t = 0% to 100%). Resulting values for each of the three trials for the different carrying conditions *No-load*, *Light*, and *Heavy* were averaged. The averages of resultant values for each participant group were calculated. Two of the three *Heavy* load trials for one participant of the ONO group were unusable due to a data storage error, and hence excluded. Both peak and average %MVC at each of the two gait phases were considered for analysis.

4.3.5. Independent and Dependent Variables

Three independent variables were examined; age (young/older), obesity (obese/non-obese), and load magnitude (*No-load*, *Light*, and *Heavy*). Dependent variables included the peak and average %MVC during the stance phase as well as walking speed.

4.3.6. Statistical Analysis

The data was visually inspected (e.g., normality plots, histograms, residual plots, outlier checks) and tested for analysis of variance (ANOVA) assumptions (normality of residuals and equality of variance) using SPSS statistics software (SPSS Inc, release 14.0, Chicago, IL, USA) and Statistix 8.0 statistical software (Analytical Software; Tallahassee, FL, Maryland, USA). Most of the EMG dependent variables (20 out of 24) violated at least one of the two tests. Accordingly, the data were Log transformed. The transformed data were normally distributed according to Shapiro-Wilk tests, and had sufficiently equal variances according to Levene's test. Accordingly, the transformed data were considered for the statistical analysis.

The statistical significance of the main and interaction effects of the independent variables on the dependent variables were tested using ANOVA following a split-split-plot factorial design. Tukey honest significant difference (HSD) post-hoc tests were conducted to compare each pair of the 3-level load conditions, when significant, using an alpha value of 0.05 (set beforehand). ANOVA and Tukey tests were conducted using Statistix 8.0. ANOVA results for muscle activity as well as the statistically significant interaction effects for all dependent variables (muscle activity and walking speed) are presented in appendices 2 and 3.

4.4 Results

4.4.1. Muscle Activity during the Stance Phase of the Left Limb (Unloaded Side) versus the Stance Phase of the Right Limb (Loaded Side)

Results suggest that only small differences existed between the peak and average %MVC during the stance phase of the loaded side versus the peak and average %MVC during stance phase of the unloaded side. For instance, the differences between the average and peak %MVC for the two muscles most affected by load carrying in this study (left external oblique and left lower erector spinae) for all groups while carrying the *Heavy* load during the left and right stance phase varied from 0.08% to 2.25% and from 0.02% to 2.97%, respectively (Table 4.2). Consistent results were observed for all of the tested muscles. Accordingly, only peak and average %MVC during the stance phase of the right limb (referred to as peak and average %MVC for the rest of this study) will be discussed moving forward.

Table 4.2. Peak and average %MVC for two muscles while carrying the *Heavy* load

Group	**Left External Oblique**				**Left Lower Erector Spinae**			
	Average %MVC	**Average %MVC**	**Peak %MVC**	**Peak %MVC**	**Average %MVC**	**Average %MVC**	**Peak %MVC**	**Peak %MVC**
	Left Stance	**Right Stance**	**Left Stance**	**Right Stance**	**Left Stance**	**Right Stance**	**Left Stance**	**Right Stance**
YNO	14.34	15.03	18.91	17.43	17.67	16.49	26.71	23.74
YO	9.22	11.47	14.3	14.2	16.16	15.49	21.33	22.11
ONO	18.16	19.57	22.7	23.37	17.36	15.88	34.14	34.16
OO	11.77	12.70	16.00	16.69	21.45	21.37	32.96	34.06

4.4.2. Effect of the Independent Variables on Muscle Activity

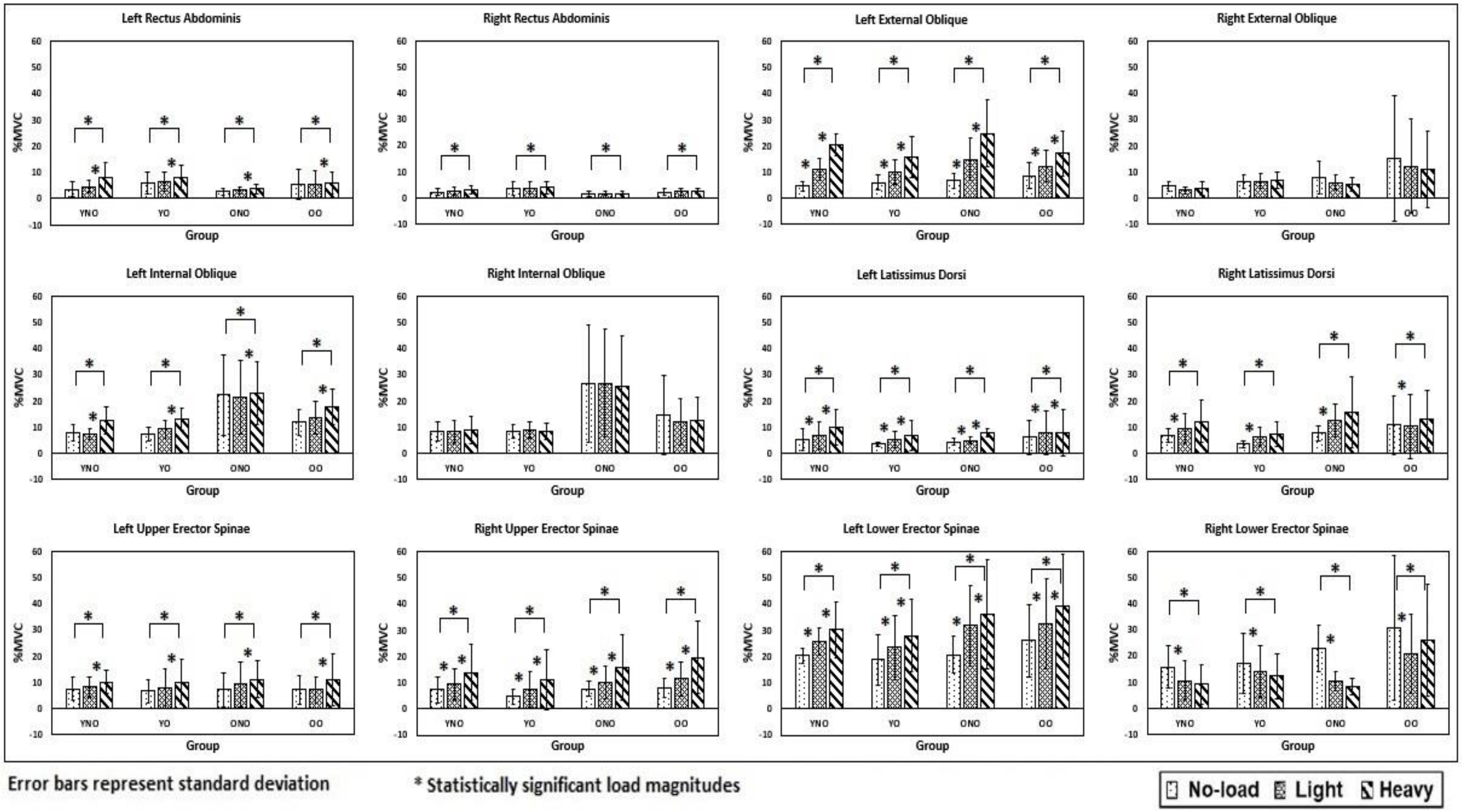
Increases in peak and average %MVC with increases in load were generally larger for the left external oblique, left lower erector spinae, and right upper erector spinae in comparison to all other muscles (Figures 4.1 and 4.2). For instance, differences in peak %MVC for all groups for these muscles due to carrying the *Heavy* load when compared to the *No-load* carrying condition varied between 8.6%-18.2%, 9.2% -15.4%, and 6.6%-11.7%, respectively. Differences in peak %MVC for the right latissimus dorsi and left internal oblique were relatively comparable for some of the groups (e.g., right latissimus dorsi for the ONO: 8.0%, left internal oblique for the

OO: 6.1%). Considerably smaller increases, or sometimes a decrease, in peak muscle activity was observed for the remainder of the muscles considered on both sides of the body. Despite the small change for some of the muscles, load had a statistically significant effect on most peak and average %MVC measures of all the tested muscles (21 out of 24; Table 4.3). Results of the Tukey follow-up tests are presented in Figures 4.1 and 4.2. For all significant pairs, there was a general trend of an increase in muscle activity due to load carrying, except for the right external oblique and right lower erector spinae where a decrease in muscle activity occurred.

Results indicate that muscle activity was, in general, greater for the left (contralateral to load) than for the right (ipsilateral to load) muscles for three of the six muscle pairs (rectus abdominis, external oblique, and lower erector spinae) when a load was carried (Figures 4.1 and 4.2). Consistent results, with some exceptions, were observed for the internal oblique. However, it should be noted that differences in muscle activity between the left and right sides of the rectus abdominis and internal oblique were smaller in comparison with those observed for the external oblique and lower erector spinae. In some situations, carrying a load resulted in less muscle activity for the right sides of the external oblique, internal oblique, and lower erector spinae in comparison to walking with *No-load*. Conversely, increases in muscle activity of both sides of the upper trunk muscles (latissimus dorsi and upper erector spinae) were observed when a load was carried. However, the increase was larger for the right side (side closest to the carried load).

Since the largest increases in muscle activity were observed for five muscles (left lower erector spinae, left external oblique, left internal oblique, right latissimus dorsi, and right upper erector spinae), differences in peak %MVC between groups for these specific muscles are discussed in detail. For simplicity, only comparisons between the peak and average %MVC for the *No-load* and *Heavy* conditions are presented.

For two of the five muscles (left external oblique and right latissimus dorsi), the two non-obese groups experienced the largest increase in peak %MVC (YNO: 15.8% and 5.5%, YO: 9.5% and 3.8%, ONO: 18.2% and 8.0%, OO: 8.6% and 2.4%, respectively). The interaction between obesity and load was statistically significant in affecting both peak and average %MVC for the left external oblique; whereas the peak %MVC for the right latissimus dorsi was statistically significantly larger for the older groups than for the young groups (Table 4.3). The two obese groups experienced the largest increase in peak %MVC for the left internal oblique (YNO: 4.6%, YO: 5.5%, ONO: 0.5%, OO: 6.1%, respectively). However, the peak %MVC was statistically significantly larger for the non-obese groups than for the obese groups, and for the older groups than for the young groups. The peak %MVC for this muscle was the largest for the ONO and the smallest for the YNO. Despite both peak and average %MVC for the left internal oblique were observed to be considerably large for the older groups, muscle activity was mainly driven by walking and not carrying (the largest increase in peak %MVC varied between 0.5% and 6.1%). The peak %MVC for the left lower erector spinae and right upper erector spinae were larger for the two older groups (YNO: 10.1% and 6.7%, YO: 9.2% and 6.6%, ONO: 15.4% and 8.1%, OO: 13.2% and 11.7%, respectively). However, differences were statistically insignificant. While some other statistically significant interaction effects were observed, differences were practically small (for example, Right Rectus Abdominis). ANOVA results for both peak and average %MVC of each tested muscle are presented in Appendix 2.



Error bars represent standard deviation

* Statistically significant load magnitudes

Figure 4.1. Peak %MVC for all three load conditions

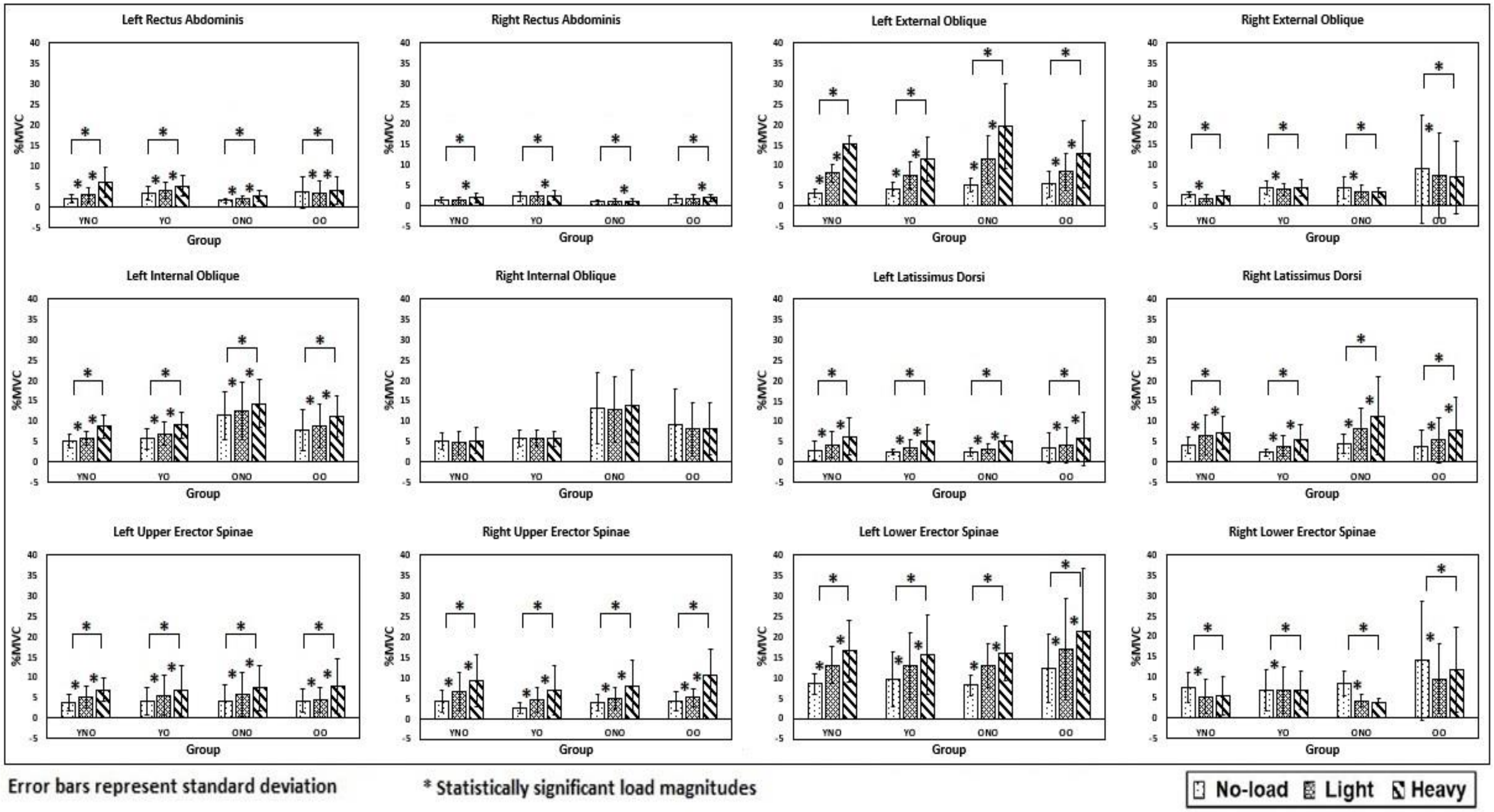


Figure 4.2. Average %MVC for all three load conditions

4.4.3. Walking Speed

The YNO group walked the fastest for all of the three load carrying conditions, whereas the YO group walked the slowest (Figure 4.3). The average walking speed for the *Heavy* load condition was 1.32 m/s for the YNO, 1.16 m/s for the YO, 1.23 m/s for the ONO, and 1.26 m/s for the OO. Nevertheless, load condition appeared to have a negligible (insignificant) effect on walking speed. The maximum difference between any two of the three load conditions for all participant groups was 0.04 (m/s). The increase in load magnitude resulted in a decrease in walking speed for the two older groups. However, walking speed for the two young groups followed no pattern. For the YNO, speed increased for the *Light* load then decreased for the *Heavy* load, in comparison with the *No-load* condition. Conversely, the YO experienced less speed during the *Light* load and more speed while the *Heavy* load was carried, in comparison with the *No-load* condition. The interaction between age and obesity was statistically significant for walking speed (p = 0.03) where age resulted in a decrease in the speed for the non-obese groups and an increase for the obese groups.

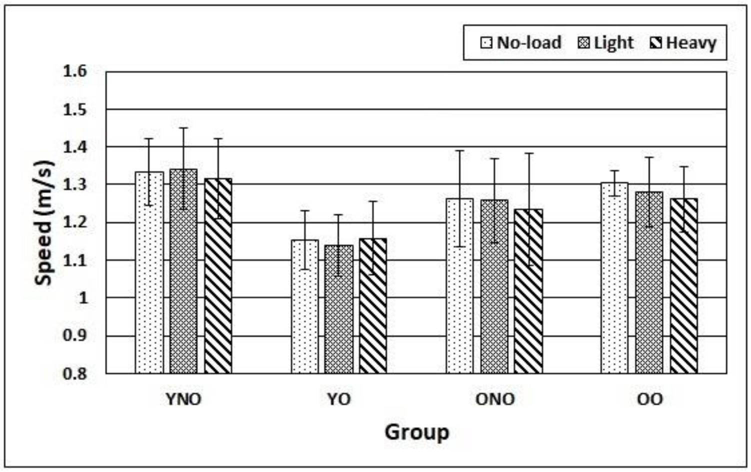


Figure 4.3. Walking speed at different load conditions

Table 4.3. *p*-values for peak and average %MVC

Dependent Variables	**Peak/ Average**	**Load**	**Age**	**Obesity**	**Age X Load**	**Age X Obesity**	**Obesity X Load**	**Age X Obesity X Load**
Left Rectus Abdominis	Peak	< **0.01**	0.33	0.26	0.21	0.90	0.15	0.14
	Average	< **0.01**	0.29	0.25	**0.03**	0.76	< **0.01**	0.14
Left External Oblique	Peak	< **0.01**	0.34	0.48	0.23	0.90	< **0.01**	0.92
	Average	< **0.01**	0.42	0.27	0.11	0.61	< **0.01**	0.79
Left Internal Oblique	Peak	< **0.01**	**0.03**	0.16	**0.01**	**0.03**	**0.03**	0.14
	Average	< **0.01**	0.08	0.35	0.15	0.17	0.55	0.29
Left Latissimus Dorsi	Peak	< **0.01**	0.83	0.66	0.49	0.76	0.08	0.61
	Average	< **0.01**	0.95	0.84	0.39	0.98	**0.02**	0.71
Left Upper Erector Spinae	Peak	< **0.01**	0.86	0.77	0.48	0.93	0.76	0.77
	Average	< **0.01**	0.88	0.89	0.27	0.93	0.36	0.26
Left Lower Erector Spinae	Peak	< **0.01**	0.50	0.69	0.59	0.50	0.71	0.98
	Average	< **0.01**	0.70	0.99	0.88	0.43	0.43	0.92
Right Rectus Abdominis	Peak	**0.01**	0.18	0.22	0.27	0.99	0.75	0.20
	Average	< **0.01**	0.28	0.10	0.55	0.92	0.15	**0.02**
Right External Oblique	Peak	0.12	0.64	0.33	0.82	0.55	0.43	0.52
	Average	< **0.01**	0.62	0.19	0.39	0.49	0.33	0.39
Right Internal Oblique	Peak	0.99	0.15	0.17	0.80	0.10	0.10	0.67
	Average	0.57	0.18	0.51	0.84	0.11	0.78	0.58
Right Latissimus Dorsi	Peak	< **0.01**	**0.03**	0.29	0.48	0.73	0.71	0.12
	Average	< **0.01**	0.12	0.26	0.84	0.96	0.43	0.62
Right Upper Erector Spinae	Peak	< **0.01**	0.28	0.76	0.87	0.43	0.38	0.93
	Average	< **0.01**	0.60	0.70	0.40	0.42	0.50	0.72
Right Lower Erector Spinae	Peak	< **0.01**	0.39	0.30	0.59	0.52	**0.02**	0.61
	Average	< **0.01**	0.56	0.29	0.40	0.45	**0.01**	0.86

* Significant effects are presented in bold.

4.5 Discussion

Despite the statistically significant interaction between age and load, as well as the significant main effect of age on the average and/or peak %MVC for some muscles, results of this study suggest that differences in trunk muscle activity between younger and older working age people are practically small given the loads considered. Similarly, the statistically significant interaction between obesity and load on the peak and/or average %MVC of some muscles indicate that muscle activity was comparable for both the obese and non-obese groups when a load was carried; the one exception to this was the right lower erector spinae (ipsilateral to the carried load). However, muscle activity for this muscle was smaller when a load was carried, compared to the *No-load* condition. Accordingly, the results suggest a lack of support for our hypothesis that older and/or obese individuals would exhibit increased muscle force exertion in comparison to young individuals while carrying a load in one hand. Specifically, obese individuals may even exert less effort than non-obese individuals as the carried load represents a smaller percentage of their relative BW. In addition, the conclusion suggesting that older and obese people may carry a load up to approximately 10 kg without experiencing substantially more trunk muscle activity is limited to the specific loads carried for this study. It is unknown if practically significant differences in trunk muscle activity would be observed if heavier loads were carried by older and/or obese people versus young and/or non-obese people.

Despite the significant effects of load magnitude on most of the muscles in this study, the tested loads appear to be acceptable to be carried in one hand for the majority of working age people from a “muscle activity” perspective. The peak %MVC due to carrying the *Heavy* load for all groups varied from 27.8% to 39.2%, suggesting that such a task would be considered “Light” work

(USDHHS, 1996). However, further research is needed before it could be determined if the *Heavy* load would be considered a "safe" load to carry in one hand, particularly for extended carrying durations and distances. First, the impact of unilateral carrying of such a load on the arm muscles and joints is unknown. To our knowledge, the literature is this area is sparse (Badawy et al., 2018). Second, carrying a load in one hand has been demonstrated to increase spinal loading in comparison with distributing the load in two hands, or even carrying twice the load in both hands (McGill et al., 2013). Accordingly, more research is needed to examine the impact of such load on spinal moments and forces, since one-handed carrying is not a preferred method for load carrying from a biomechanical perspective. Third, the long-term effect due to one-handed carrying needs to be studied, particularly among the older and obese populations since these populations are more susceptible to MSDs (Kouvonen et al., 2013; BLS, 2015; Hoy et al., 2012; Wong et al., 2017; Schulte et al., 2007).

Previous research has suggested that, in general, mean amplitude muscle activity increases with an increase of walking speed (Anders et al., 2007). Accordingly, the non-statistically significant effect of load magnitude on walking speed suggests that the change in muscle activity due to carrying a load was not biased by differences in walking speed during each load condition. Differences in speed between groups were mainly driven by participants' manners of ambulation regardless of the carried loads.

Results also suggest that two left side muscles (external oblique and lower erector spinae) and two right side muscles (latissimus dorsi and upper erector spinae) are the four main trunk muscles most involved in one-handed carrying of the tested muscles. The increase in peak and average %MVC of the left external oblique and left lower erector spinae may be because the muscles on the left side exert more force to counteract the load at the right side. Furthermore, the increased average and peak %MVC of the right latissimus dorsi and right upper erector spinae may be due to an increased upper back muscle force necessary to keep the trunk upright while walking.

In general, it is suggested that a load should be distributed between hands, if possible, to avoid imbalance due to one-handed carrying. This suggestion is in agreement with the conclusions drawn in the literature regarding carrying a load in one hand (Cook & Neumann, 1987; McGill et al., 2013). However, it should be noted that results regarding the right upper back muscles (latissimus dorsi and upper erector spinae) were not in agreement with those reported by McGill et al. (2013). In McGill et al. (2013), the right upper back muscles exerted considerably less muscle activity than the left upper back muscles while a load was carried. In our study, the right upper back muscles exerted more force. For instance, the average %MVC measure for the left and right upper back muscles due to carrying 10 kg in one hand were 6.8 - 8.8% and 2.1 - 2.9% in McGill et al. (2013), respectively. In the current study, the corresponding average %MVC measures due to carrying the *Heavy* load were 2.4 - 7.8% and 2.3 - 11.3%.

The difference in results could be because of the different gait segments considered for analysis in each study. McGill et al., (2013) considered the period where the right limb is off the ground whereas as in our study we analyzed the whole stance phase. Further research is needed to understand the patterns of change in trunk muscle activity along the entire gait cycle.

This work has three main limitations. First, the exclusion of one of the MVC exercise strategies (hanging) could have affected the results in this study. It is unknown how inclusion of this normalization exercise may have affected the MVC results. However, even though this strategy could have resulted in an MVC value greater than the value obtained from the three other strategies, this would still enhance the conclusion of the study that the tested load conditions would be acceptable to carry, since %MVC results would have been less. Second, the sample size for each group was rather small. The complexity and duration of the experiment represented two main obstacles against recruiting more people, particularly in the older groups. Third, differences in fitness levels between participants were not considered as inclusion criteria. Accordingly, the impact of fitness differences across age and obesity levels could not be assessed.

The following items highlight the main findings of this paper:

- Comparable differences in muscle activity were observed among individuals with different ages and/or BMIs. One-handed carrying of a load up to 10 kg may be considered acceptable for the majority of working age people from a "muscle activity" perspective. Further research is needed to evaluate the short-and-long-term effects of one-handed carrying on muscle activity and loading of different body segments/joints, particularly during extended carrying durations and distances.
- Differences in speed between groups were mainly driven by participants' manners of ambulation regardless of the carried loads.
- Load was an important factor, affecting most of the peak and average %MVC measures for all the tested muscles.

- Muscle activity was generally greater on the contralateral side of the body than the ipsilateral side across all groups, except for the upper trunk muscles (upper erector spinae and latissimus dorsi). For some muscles, muscle activity for the ipsilateral side during carrying a load was less than the corresponding muscle activity during walking with *No-load*.

Chapter 5

Effects of Age and Obesity on Trunk Kinetics and Kinematics during One-handed Carrying

5.1 Abstract

The proportion of older and obese people are increasing in both the general and working populations in the United States. Older and obese populations are more susceptible to work-related musculoskeletal disorders (MSDs) in comparison with healthy, younger populations. Manual Material Handling (MMH) is also associated with the development of work-related MSDs. Although previous research has suggested that one-handed carrying is a particularly undesirable method of MMH, the effects of one-handed carrying on trunk kinetics and kinematics among older and/or obese people have not been adequately studied. The objective of this study was to examine the effects of age and obesity on trunk angles and moments about the approximate location of the L4/L5 vertebral segment during one-handed carrying of various load magnitudes. Twenty (20) participants divided into four age (young and older) and obesity (obese and non-obese) categories carried different loads (*No-load* [0 kg], *Light* [5.67 kg], and *Heavy* [10.21 kg]) in one hand for approximately 6 m. Three-dimensional (3D) trunk angles and moments about the approximate L4/L5 location were calculated using Visual3D. Results suggested that carrying a load in one hand plays a substantial role in changing trunk kinematics and kinetics, but is not dependent on age or

obesity. Absolute moments were greater among the obese groups, however these moments were mitigated when normalized to body weight and height (%BW*Ht). Age did not exacerbate the effects of load on the trunk.

5.2 Introduction

More than twelve percent (12.3%) of the world's population in 2015 was aged 60+ years (UNDESA, 2015a). This percentage is expected to increase 56% by 2030 and 130% by 2050 (UNDESA, 2015a; UNDESA, 2015b). In the United States, the proportion of the population aged 65+ years is expected to reach approximately 20.9% in 2050; double the percentage reported in 2012 (Ortman, Velkoff, & Hogan, 2014). Accordingly, the percentage of older people in the American working population is expected to increase somewhat as well (Toossi, 2015).

In addition to aging, obesity rates are also increasing worldwide. A global increase of 27.5% in the prevalence of overweight and obese adults was reported between 1980 and 2013. Obesity also increased 9.1% among American adults between 1999-2000 and 2015-2016 (Hales, Carroll, Fryar, & Ogden, 2017). In 2030, over 50% of American adults are expected to be obese (Wang et al., 2008; Finkelstein et al., 2012). On average, people aged 45+ years have experienced higher rates of increasing obesity than younger individuals both worldwide (Ng et al., 2014; Hales et al., 2017) and among the American working population (Gu et al., 2014; Luckhaupt, Cohen, Li, & Calvert, 2014).

Work-related musculoskeletal disorders (MSDs) are more prevalent among older and obese people in comparison with healthy, younger populations (Kouvonen et al., 2013; BLS, 2015; Schulte et al., 2007). For example, low back pain has been associated with age (Hoy et al., 2012; Wong, Karppinen, & Samartzis, 2017), and obese people appear to be at higher risk of low back pain in comparison to non-obese people (Sheng et al., 2017; Roffey, Budiansky, Coyle, & Wai, 2013; Peng, Pérez, & Gabriel, 2018). The situation may be exacerbated for individuals who are both older and obese as they tend to have lower muscle strength than older, non-obese people (Villareal et al., 2004). Accordingly, the changing composition of the working population evokes the necessity of a deeper understanding of work-related health outcomes among these populations.

Previous research has indicated a strong association between manual material handling (MMH) and the development of work-related MSDs (Xu, Cheng, & Li-Tsang, 2013; Nelson et al., 2006). While one-handed carrying is a particularly undesirable method of MMH since it is more physiologically and biomechanically demanding than other methods of load carrying (e.g., two-handed, anterior, posterior; Cook & Newmann, 1987; McGill, Marshall, & Andersen, 2013; Lind & McNicol, 1968; Ganguli & Datta, 1977), to the best of our knowledge, the effects of one-handed carrying on the loading of the back was studied in only two studies (McGill et al., 2013; Rohlmann et al., 2014). McGill et al. (2013) suggested that larger compression and shear forces on the L4/L5 vertebral segment of the spine were observed among young, healthy male participants (aged 22.7 ± 2.1 years) carrying a load in one hand than when the load was evenly split between two hands, or even when carrying the same load in both hands (twice the carried load). Rohlmann et al. (2014) studied the effects of different load carrying methods (in one hand, in two hands, and on the back) among older individuals (aged 66.2 ± 3.8 years) with implanted vertebral body replacements. Spinal loading on the implants were larger when 10 kg were carried in one hand than when 20 kg were carried in both hands (10 kg in each hand). While these two studies considered spinal loading during one-handed carrying, trunk kinematics and kinetics have not been described and are associated with spinal loading during MMH, and low back disorders (Lee & Nussbaum, 2013; Marras, 2000). In addition, although the study conducted by Rohlmann et al. (2014) included older participants, the effect of age was not studied. Furthermore, obesity was not studied in either of the two studies. Accordingly, few conclusions can be drawn regarding the effects of one-handed carrying on the back among obese and older individuals. Moreover, although previous research has suggested that the maximum load to be carried in one hand should not exceed 10 kg in males and 7 kg in females (Lind & McNicol, 1968; Ganguli & Datta, 1977; Kilbom, Hagg, & Kall, 1992), the effects of these load limits on trunk biomechanics among older and obese individuals have not been adequately studied (Badawy et al., 2018).

The objective of this study was to examine changes in trunk angles and moments about the approximate location of the L4/L5 vertebral segment, among older and obese individuals during one-handed carrying of various magnitudes of load. To the best of our knowledge, the current study is the first to evaluate the effects of age and obesity on trunk kinematics and kinetics during one-handed carrying (Badawy et al., 2018). The work provides insights that may be helpful for establishing one-handed carrying guidelines for the changing working population.

5.3 Method

5.3.1. Participants

Twenty (20) right-handed, male participants were recruited for this study. Five eligibility criteria were considered: 1) Age of 19-35 or 55-64 years; 2) A body mass index (BMI) < 25 kg/m^2 or BMI ≥ 30 kg/m^2; 3) No history of physician-diagnosed cardiovascular diseases or MSDs in the neck, shoulder, extremities, or low back regions; 4) No chronic pain in the neck, shoulder, extremities, or low back in the 6 months preceding the study; and 5) No adhesive allergies. Eligible participants were divided into four groups with respect to age and obesity (Young/Non-obese [YNO]: 19-35 years of age, BMI < 25 kg/m^2; Young/Obese [YO]: 19-35 years of age, BMI ≥ 30 kg/m^2; ONO: 55-64 years of age, BMI < 25 kg/m^2; OO: 55-64 years of age, BMI ≥ 30 kg/m^2). After providing informed consent, all participants had a Dual-energy X-ray absorptiometry (DEXA) scan to estimate their percentage of body fat. All study procedures were approved by the Auburn University Institutional Review Board. Descriptive statistics (means and standard deviations) of age, weight, height, and BMI, and %Fat of each group are presented in Table 5.1.

Table 5.1. Mean and standard deviation of personal data of each group of participants

Group	**n**	**Age (years)**	**Weight (kg)**	**Height (cm)**	**BMI (kg/m^2)**	**%Body fat**
YNO	5	25.4 ± 2.1	70.7 ± 5.3	173.2 ± 5.8	23.7 ± 0.7	15.2 ± 4.2
YO	5	29.1 ± 4.5	113.0 ± 19.4	179.3 ± 4.6	35.0 ± 4.7	39.4 ± 7.0
ONO	5	59.7 ± 3.5	70.2 ± 6.6	175.3 ± 4.4	22.9 ± 0.9	16.0 ± 5.6
OO	5	60.1 ± 0.8	104.2 ± 4.6	180.3 ± 3.6	31.9 ± 1.4	34.0 ± 4.8

5.3.2. Pre-experiment Protocol

The participants arrived at the Auburn University Biomechanical Engineering (AUBE) Laboratory where the experiment took place. Seventy-nine reflective markers were placed on participants using hypoallergenic tape. A previously validated reflective marker-based point cluster technique was used to collect kinematic data (Andriacchi et al., 1998; Andriacchi & Dyrby, 2005; Dyrby & Andriacchi, 2004). Marker placement was completed by one researcher and verified by a second researcher to ensure that anatomical landmarks were properly located. A static standing calibration trial was performed immediately after placing the markers. Kinematic data were collected using a 10-camera motion capture system (Vicon, Vantage V5 Wide Optics cameras, each with 22 high-powered IR LED strobe at 85 nm; Vicon Motion Systems Ltd, Oxford Industrial Park, Oxford, UK), and ground reaction force data were collected using two force plates (AMTI BP400600, 2000 lb. capacity; Advanced Mechanical Technology, Inc., Watertown, MA, USA). Data from the motion capture system and the force plates were collected and synchronized using Nexus software (Version 2.6.1; Vicon Motion Systems Ltd, Oxford Industrial Park, Oxford, UK).

5.3.3. Experiment

Participants were asked to perform three carrying conditions, each replicated three times (a total of nine trials). These conditions included walking across the lab (approximately 6 m) while carrying different loads in the dominant/preferred [right] hand (0 kg [*No-load*], 5.67 kg [*Light*], and 10.21 kg [*Heavy*]). All nine walking trials were randomized. The trials were separated by a resting period of at least 1 minute to avoid fatigue and/or muscle soreness. Participants were instructed on the starting location(s) of each trial such that each foot contacted only one force plate, while maintaining normal gait pattern.

5.3.4. Data Processing

A skeletal model of each participant, scaled to their weight and height, was constructed using Visual3D (C-Motion, Germantown, MD, USA). A pipeline was constructed to calculate the kinematic and kinetic results of the trunk along the gait.

Joint angles were calculated according to the Joint Coordinate System provided by Grood & Suntay (1983). Body segments were described according to the International Society of Biomechanics recommendations (Wu et al., 2002). Visual3D used the static trial to establish a coordinate system and location of center of mass for each segment. The shoulder markers (placed on the acromion) were used to create the distal joints of the trunk segment and the two iliac crest markers were used to create the proximal joints. Markers on the clavicle, sternum, right scapula, and tenth vertebral body were also tracked. Using these markers, a three-dimensional (3D) coordinate system was created for the trunk segment. The 3D angles between the trunk coordinate system and the lab coordinate system were considered the trunk angles.

To calculate reaction moments, a bilateral Newton-Euler model that includes the lumbar and thoracic segments was used (Seay, Selbie, & Hamill, 2008). A joint was created between the pelvis and the trunk which represents the waist for all angle and moment calculations (Seay et al., 2008). Based on palpation of the lower back of participants (particularly among female participants and participants with high BMI), Chakraverty, Pynsent, & Isaacs (2007) suggested that the iliac crest is in line with L3 or the L3/L4 joint. However, based on imaging, the line passing through the two iliac crest markers were found to pass through the L4 or L4/L5 joint. Accordingly, it is assumed that the waist moments in the current study are calculated about the L4/L5 spinal level.

Trunk angles and moments about the L4/L5 vertebral segment during the stance phase of each limb (right [loaded side] and left [unloaded side]) were calculated; data of one step during an established gait (after participants walked for 3 steps) was considered. The stance phase of each limb was identified using the collected ground reaction force data. Data during each stance phase (loaded and unloaded) were normalized to 101 time points (t = 0% to 100%). Resulting values for each of the three trials for the different carrying conditions *No-load*, *Light*, and *Heavy* were averaged. The averages of resultant values for each participant group were calculated. Two of the three *Heavy* load trials for one participant of the ONO group were unusable due to data collection error, and hence excluded.

5.3.5. Independent and Dependent Variables

Three independent variables were examined: age (young/older), obesity (obese/non-obese), and load magnitude (*No-load*, *Light*, and *Heavy*). Thirty-six dependent variables were analyzed. These included 3D trunk angles (tilt [extension/flexion], obliquity [ipsilateral/contralateral], and rotation [ipsilateral/contralateral]) and 3D reaction moments at the L4/L5 vertebral segment (tilt [extension/flexion], obliquity [ipsilateral/contralateral], and rotation [ipsilateral/contralateral]). Both absolute reaction moments and moments normalized to body weight and height (%BW*Ht) were considered. Normalized moments were analyzed to identify the effects of the independent variables regardless to differences in weight between groups (Blazek, Asay, Erhart-Hledik, & Andriacchi, 2013). A description of the 3D motions is presented in Table 5.2.

Table 5.2. Descriptions of 3D motion of the trunk

Motion	**Description**	**Sign**
Extension	Leaning toward the back	+
Flexion	Leaning toward the front	-
Ipsilateral obliquity	Side leaning toward the load	+
Contralateral obliquity	Side leaning away from the load	-
Contralateral rotation	Rotating the front of the body away from the load	+
Ipsilateral rotation	Rotating the front of the body toward the load	-

5.3.6. Statistical Analysis

The data were visually inspected (e.g., normality plots, histograms, residual plots, outlier checks) and tested for analysis of variance (ANOVA) assumptions (normality of residuals and equality of variance) using Statistix 8.0 statistical software (Analytical Software; Tallahassee, FL, Maryland, USA) and SPSS statistics software (SPSS Inc, release 14.0, Chicago, IL, USA), respectively. Only 15 out of 36 dependent variables passed both Shapiro-Wilk and Levene's tests. Different data transformations were evaluated for the remaining 21 variables; no unique transformation method performed adequately enough for all of them. A combination of transformation methods that resulted in the minimum number of violations (1 out of 36 variables) was implemented. It should be noted that the original data for this variable that did not pass the assumptions (peak absolute ipsilateral obliquity moment during the stance phase of the loaded side) passed Shapiro-Wilk test, but failed Levene's test. However, it was decided to consider the original data for that specific variable while running the statistical analysis, provided that three-way ANOVA is robust to violations of assumptions.

The statistical significance of the main and interaction effects of the independent variables on the dependent variables were tested using ANOVA following a split-split-plot factorial design.

Tukey honest significant difference (HSD) post-hoc tests were conducted to compare each pair of the 3-level load conditions, when significant, using an alpha value of 0.05. ANOVA and Tukey tests were conducted using Statistix 8.0. In order to present all data during the stance phase of both the loaded and unloaded sides, only statistically significant effects are discussed. Main effects were not discussed if the interaction effect was significant.

5.4 Results

Results of Tukey honest significant difference (HSD) post-hoc tests of each pair of the load condition are presented in Figures 5.1, 5.2, and 5.3. It should be noted that the patterns of significant interaction effects were sometimes different for the original data than for the transformed data. Accordingly, while describing the significant interaction effects, the transformed data is considered.

5.4.1. Peak Trunk Angles

Loaded Side (Stance Phase)

Load carrying resulted in a statistically significant alteration of the 3D trunk angles. All participant groups tended to have less extension angle ($p < 0.01$), less ipsilateral obliquity angle ($p < 0.01$), and less contralateral rotation angle ($p < 0.01$) during load carrying (Figure 5.1). In general, the participant groups walked with their trunk flexed, bent away from the load, and rotated toward the load, compared with the *No-load* condition.

Unloaded Side (Stance Phase)

Results for the unloaded side were generally consistent with those of the loaded side. The only exception was a statistically significantly effect of age and load on ipsilateral obliquity angle ($p = 0.04$). The young groups experienced lower ipsilateral obliquity angles while carrying the *Heavy* load compared to carrying the *Light* load, whereas the older group experienced greater angles.

5.4.2. Absolute Peak L4/L5 Moments

Loaded Side (Stance Phase)

A statistically significant effect of load magnitude on extension moment was observed ($p = 0.04$). Carrying the *Heavy* load resulted in an increased extension moment compared with the corresponding moment that resulted from walking with *No-load* for all participant groups except for the YO group (Figure 5.2).

Unloaded Side (Stance Phase)

Carrying either the *Light* or the *Heavy* loads resulted in an increased contralateral rotation moment, compared with the *No-load* condition ($p < 0.01$). Moments were greater for the obese groups than for the non-obese groups for all three load conditions ($p < 0.02$). Furthermore, a statistically significant interaction between obesity and load was observed for the ipsilateral obliquity moment ($p = 0.02$); moments among the obese groups were more sensitive to change while the *Heavy* load was carried.

5.4.3. Normalized Peak L4/L5 Moments

Loaded Side (Stance Phase)

Consistent with the results for the absolute moments, the change in trunk angles due to load carrying resulted in increased flexion moment (except for the YO group; $p = 0.04$), increased ipsilateral obliquity moment ($p < 0.01$), decreased contralateral obliquity moment ($p < 0.01$), and increased contralateral rotation moment ($p < 0.01$), compared to walking with *No-load* (Figure 5.3). A statistically significant interaction between obesity and load was observed on the ipsilateral rotation moment ($p < 0.01$) where the obese groups experienced the largest moments when they carried the *Light* load and the smallest moments when they carried the *Heavy* load.

Unloaded Side (Stance Phase)

In most cases, carrying a load resulted in an increased flexion moment ($p = 0.01$), an increased contralateral rotation moment ($p < 0.01$), and a decreased ipsilateral rotation moment ($p = 0.03$). Although both the obese and non-obese groups experienced increased ipsilateral (and decreased contralateral) obliquity moments while a load was carried, considerably larger increases/decreases were observed among the non-obese groups ($p < 0.01$ and $p = 0.03$, respectively). Age resulted in a decrease in the extension moments among the non-obese groups, but an increase among the obese groups ($p = 0.01$). Age also resulted in a decrease in the ipsilateral rotation moment for the obese groups, but an increase among the non-obese groups ($p = 0.03$).

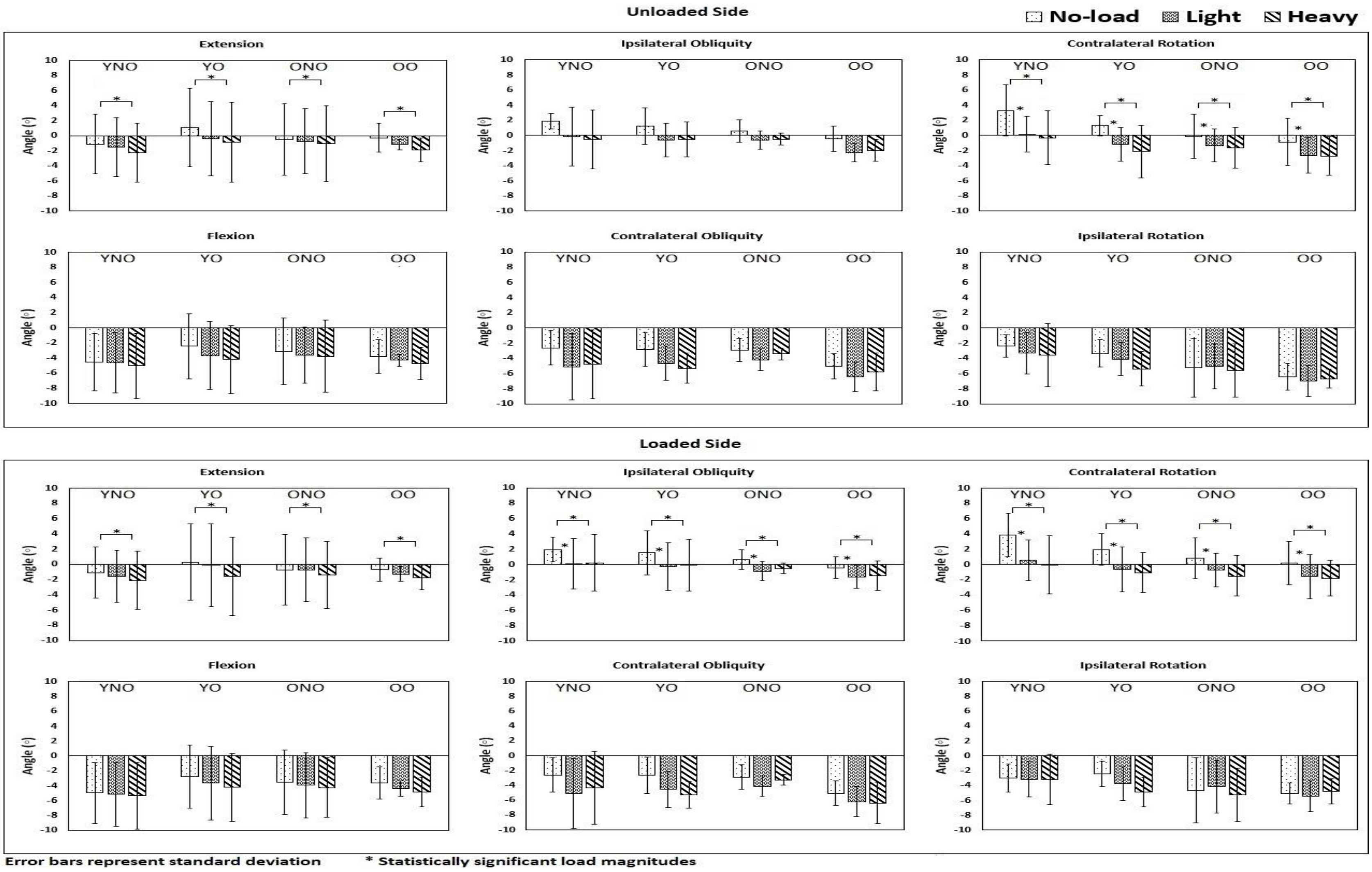
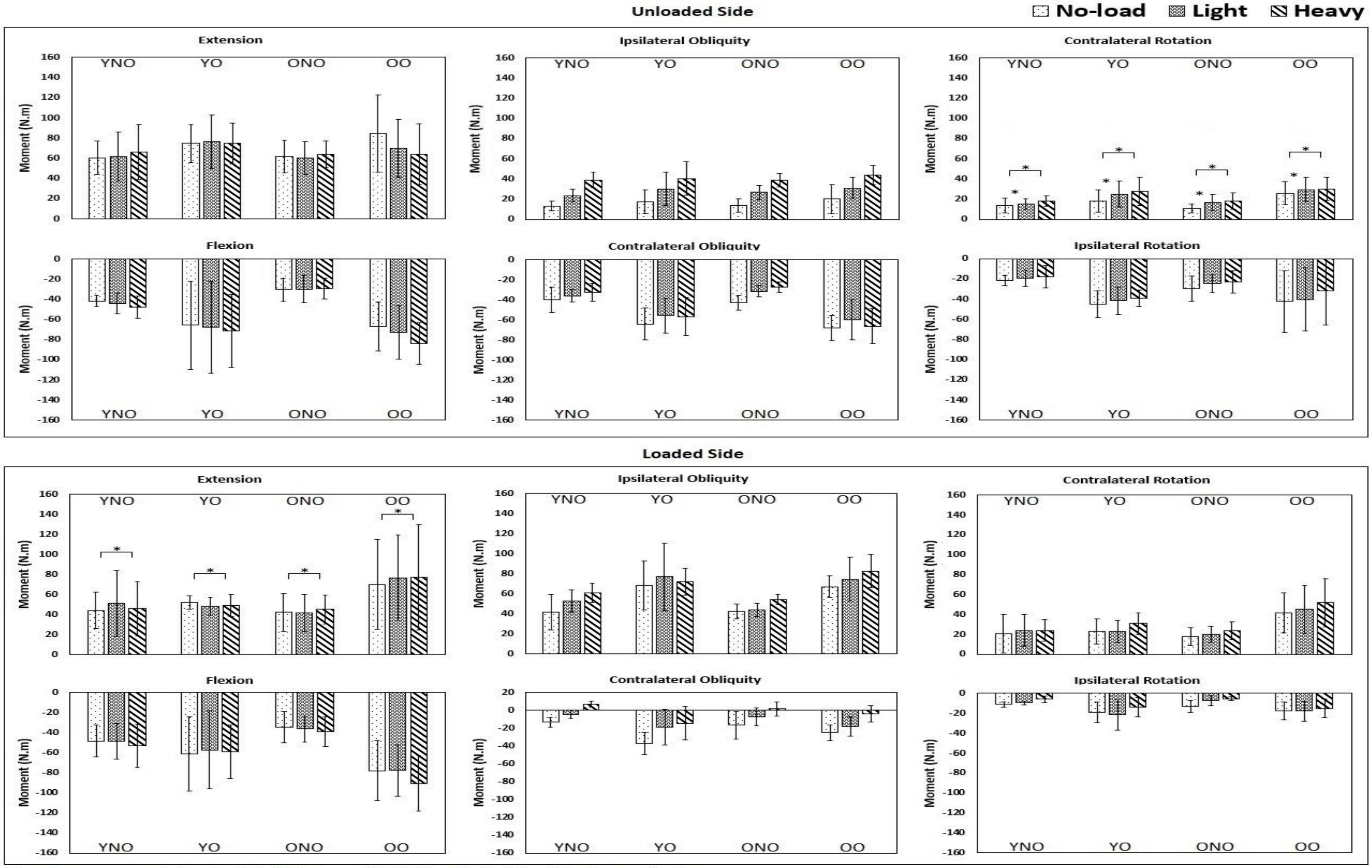


Figure 5.1. Peak trunk angles at three load conditions



Error bars represent standard deviation * Statistically significant load magnitudes

Figure 5.2. Absolute peak L4/L5 moments at three load conditions

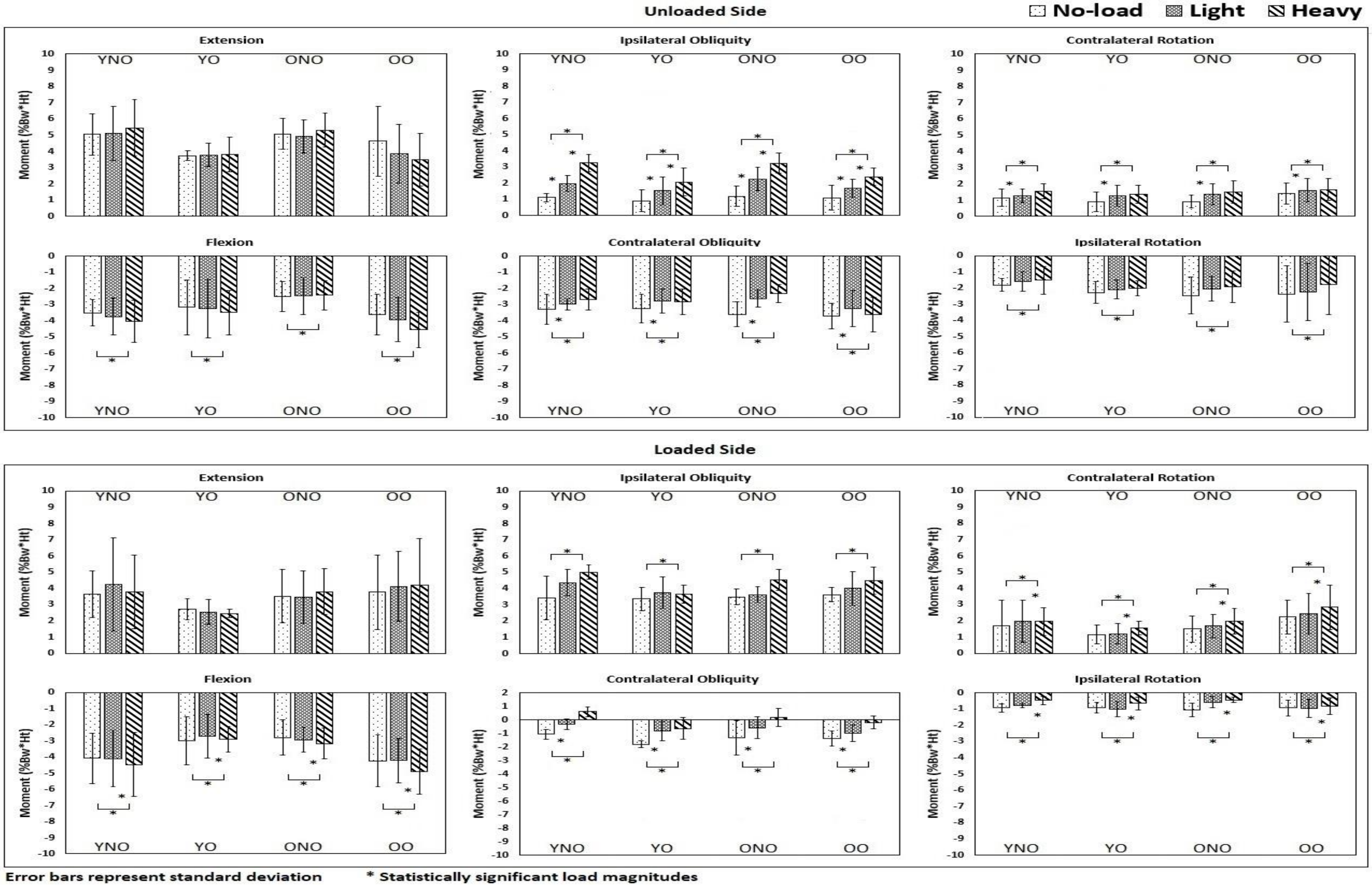


Figure 5.3. Normalized peak L4/L5 moments at three load conditions

5.5 Discussion

Results of this study indicate that carrying a load in one hand has an important role in changing trunk kinematics and kinetics, but the effects are not dependent on age, nor obesity. The obese groups experienced greater absolute moments, however these moments were mitigated when normalized to BW*Ht. Consistently, moments observed for the older groups were relatively comparable to those observed for the young groups.

In general, all participant groups walked with their trunk flexed and rotated toward the load across loaded trials. Participants also tended to lean toward their unloaded (non-dominant) side to counteract the load added to their dominant hand. Participants may have flexed their trunks to maintain their stability by keeping their center of mass closer to the ground. Contralateral bending during load carrying was approximately identical to the corresponding bending for the *No-load* condition only during the double support component of the gait cycle, suggesting that having both feet on the ground enabled participants to balance their body without excessive lateral bending. In addition, results indicated that all participants rotated their trunks toward the load only from the mid-stance of the limb on the loaded side to the mid-stance of the limb on the unloaded side (generally when the limb contralateral to the body was off the ground). Relatively no differences were observed beyond that region, in comparison to walking with *No-load*. Moreover, due to shifting the center of mass while carrying a load, ipsilateral rotation increased, and contralateral rotation became more restricted.

The change in trunk angles during load carrying was accompanied by a change in moments about the L4/L5 vertebral segment. The increased extension (decreased flexion) trunk angle was generally accompanied by an increased L4/L5 extension moment. Consistent results were also observed for the obliquity and rotation moments. While the load magnitude had a statistically significant effect on many of the tested absolute and normalized moments, increases in all 3D moments due to carrying the *Heavy* load across the four groups were relatively small when compared to walking with *No-load* (not exceeding 25.62 N.m and 2.14%BW*Ht, respectively). However, the effects of such increases in moment on the internal loading of the spine remains unknown. In addition, the magnitude of the moments may be misleading while trying to understand the impact of one-handed carrying of a load. The ground reaction force is generally oriented towards (or closer to) the center of mass of the body, resulting in a small lever arm and hence a small moment. For instance, the carried load and the weight of the upper body will cause two forces acting on both sides of the body when people lean toward the contralateral side of the carried load to maintain stability of their body. These forces have the potential to cause excessive loading of the lumbar spine, despite small moment magnitudes. The situation is exacerbated with increased carried load magnitude since larger changes in trunk kinematics would be anticipated for maintaining balance of the body along the gait. One-handed carrying, a method of asymmetric load carrying, has been previously suggested to increase trunk muscle activity and spinal loading when compared with carrying a comparable load in a more symmetrical manner (e.g., splitting between two hands; McGill et al., 2013; Cook & Newmann, 1987). Accordingly, it is suggested that carrying heavy loads may be associated with MSDs of the lumbar spine due to the asymmetric load application. Consequently, it is recommended to avoid one-handed carrying of heavy loads as much as possible, since that method of load carrying has the potential to result in unmaintained neutral posture of the trunk.

The obese groups experienced greater absolute moments than the non-obese groups during all the three load conditions (*No-load*, *Light*, and *Heavy*), although they carried a smaller percentage of their body weight (%BW). Normalizing the moments to BW*Ht resulted in fewer changes in moments among the obese people due to load carrying, compared to walking with *No-load*. In many cases, normalized moments among the obese groups were comparable to, if not smaller than, the corresponding moments among the non-obese groups. Accordingly, results suggest that obesity may not be a detrimental factor in affecting moments about the L4/L5 vertebral segment, particularly since neither obesity nor the interaction between obesity or any other independent variable had statistically significant effects on any of the 3D trunk angles. In fact, obese people could have a relative advantage during load carrying because of their heavier bodies (when solely considering the kinetics and kinematics of carrying). However, the impact of the carried load on the joints needs to be assessed in future studies.

Despite the statistically significant interaction of age and obesity on both the normalized extension and normalized ipsilateral rotation moments on the unloaded side, the maximum differences in moments between groups could be considered practically negligible (1.43%BW*Ht and 0.51%BW*Ht, respectively). Consequently, it could be stated that people with different ages (up to 64 years) could be under comparable changes in trunk angles and moments about the L4/L5 vertebral segment during one-handed carrying of a load up to approximately 10 kg. Therefore, older people may not be at an increased risk of MSDs during one-handed carrying of the *Light* and *Heavy* load when solely considering kinetics and kinematics. However, no conclusive statement may be made for many reasons, one being that their aged body structures may have less ability to support the same load as younger people. For instance, advanced age is a known risk factor for vertebral compression fracture (Old & Calvert, 2004). In addition, muscle mass and strength generally decrease with age (Villareal et al., 2004; Beaufrere & Morio, 2000).

In conclusion, one-handed carrying of a load of up to 10 kg had a substantial effect on the trunk motion of participants and could contribute to the development of MSDs during carrying tasks. Consistent with recommendations provided in previous research, results of this experiment suggest avoiding one-handed carrying. Unlike load magnitude, age and obesity did not exacerbate the effects of load on the trunk. Obese people actually appear to have an advantage in terms of kinematics and kinetics while carrying a fixed load magnitude, since the load represents a smaller percentage of their BW than it does for non-obese people.

This research has three main limitations. First, the sample size in each participant group is relatively small. The experiment's duration and complexity impaired the ability to recruit more participants, particularly older individuals. Second, the tested loads were examined for short carrying distances (approximately 6 m). More research is needed to evaluate the effect of fatigue on the distribution of spinal loading during prolonged carrying tasks. Third, differences in fitness levels between participants were not considered as inclusion criteria. Accordingly, the impact of fitness differences across age and obesity levels could not be assessed.

Future research is needed to examine the effects of one-handed carrying on the ground reaction force among different age and obesity populations. It is assumed that the ground reaction force will provide a better understanding of the change in the lumbar spine kinetics due to carrying a load in one hand. In addition, the simultaneous change in both trunk kinematics and kinetics during one-handed carrying needs to be studied. The present study focused mainly on the magnitude of change in kinetics and kinematics by examining peak trunk angles and moments. Although the present study provided a description of the change pattern in trunk angles along the gait cycle, the corresponding change in the moments about L4/L5 remains understudied. In addition, more research is needed to examine the effects of one-handed carrying on the biomechanics of the lower extremity. Previous research has suggested that increasing in hip muscle activity/joint forces occur on the side of the body contralateral to the carried load (Neumann & Cook, 1985; Neumann, Cook, Sholty, & Sobush, 1992; Neumann, 1996; Bergmann, Graichen, Rohlmann, & Linke, 1997). However, the effects of age and obesity were not the main objectives of these studies. In addition, to our knowledge, no work has been completed to examine these effects on the biomechanics of the knee nor the ankle.

Chapter 6

Conclusions

6.1 Key Findings

The systematic review suggested that one-handed carrying is more physically demanding than other methods of load carrying. Physiological responses to carrying a load in one hand were comparable to the corresponding responses to carrying the same load in two hands (two times the load). Muscle activity and joint forces also increased during one-handed carrying. The greatest effect happened on the body side contralateral to the carried load. Some studies suggested that a load carried in one hand should not exceed 9-10 kg for men and 6-7 kg for women. However, more research on the effects of age and obesity during one-handed carrying are needed to determine if these results hold for people with different ages and obesity levels.

Although they carried a smaller percentage of their total body weight (BW), physiological responses to one-handed carrying were larger among obese people, particularly older obese individuals, in the first experiment. Results suggest that obese people may experience fatigue during one-handed carrying earlier than non-obese people while carrying the same load magnitude. In addition, the older groups self-selected smaller loads to carry than those selected by the young groups, suggesting that the *Heavy* load may not be a comfortable load to carry by older people. However, no practically meaningful increases in their physiological response were observed when they carried different loads. In addition, ratings of perceived exertion (RPE) values increased with an increased load magnitude for all participant groups. RPEs of the arm (RPE[A]) were generally greater than RPEs of the back (RPE[BK]) and RPEs of the whole body (RPE[WB]).

Load magnitude affected muscle activity among all groups in the second experiment. Consistent with findings from the literature, muscle activity was generally greater on the contralateral side of the body than the ipsilateral side across all groups. However, differences in muscle activity between groups for different load conditions were generally less pronounced than differences within groups (between load conditions). In addition, load magnitude had a relatively small effect on walking speed, suggesting that differences in speed were mainly driven by participants' manners of ambulation regardless of the carried loads.

Changes in trunk kinetics and kinematics were mainly attributed to load magnitude, not age nor obesity in the third experiment. While absolute moments were greater among the obese groups, these moments were mitigated when normalized to BW and height (BW*Ht). Age did not exacerbate the effects of load on the examined angles and moments. Nevertheless, it is unknown if older people will be at risk of musculoskeletal disorders (MSDs) or not, provided that muscle mass and strength generally decrease, and vertebral compression fracture increases with age.

6.2 Limitations

The main limitations of the present work are as follows. First, the sample size considered was relatively small. Second, the tested loads were examined for relatively short carrying distances. Third, differences in fitness levels between participants were not considered as inclusion criteria. Accordingly, the impact of fitness differences across age and obesity levels could not be assessed. Fourth, only male participants were included. The addition of gender as another independent variable, while a necessary topic for future research, was not possible given resource limitations. Other limitations from each chapter are listed below:

1) Chapter 2: Articles on one-handed carrying were included in the systematic literature review only if they were written in English and published in peer-reviewed journals.
2) Chapter 3: The *Self-selected* load was limited to 20 kg. Participants may have self-selected heavier loads, if they were provided with heavier dumbbells.
3) Chapter 4: First, the estimation of the maximum voluntary contraction (MVC) of each participant could have been affected by the exclusion of one of exercise (hanging).
4) Chapter 5: Only peak values of angles and moments were analyzed. Other metrics need to be analyzed to better understand the change in angles and moments along the gait.

6.3 Future Research

Future research is warranted to address the limitations of this study and fill the remaining gaps in the literature regarding one-handed carrying, particularly among older and obese people. The effects of one-handed carrying tasks among older and obese people while carrying heavier loads for longer carrying periods/distances need to be studied. In addition, while the design of the conducted experiments was conservative regarding the tested loads in order not to expose the older participants to elevated risk of injury, the findings of the present work suggest testing the performance of older people while carrying heavier loads for prolonged distances as the loads considered here appear to not be associated with undue risk. Furthermore, the current study needs to be extended to examine the effects of one-handed carrying on the physiological, psychophysical, biomechanical responses of old and/or obese females. Previous research has suggested that one-handed carrying capacity among young females was smaller than the corresponding capacity among young males (Mital & Manivasagan, 1983). However, the gender effect among older participants remains unknown. The literature also lacks recommendations regarding other carrying factors that may affect responses during one-handed carrying (e.g., working temperature, characteristics of the load to be carried, characteristics of walking surface, history of load carrying tasks, etc.).

While the findings of the trunk muscle activity study suggest that muscle activity increases for all participant groups on the contralateral side of the body with increased load magnitude, a future study is suggested to examine the effects of extended load carrying on muscle fatigue, and hence on the change of the biomechanics of carrying. Muscle fatigue may change the rate of muscle recruitment, and hence may affect load distribution.

Despite results of the trunk kinematics and kinetics study suggesting that one-handed carrying, as an asymmetric method of load carrying, plays an important role in trunk motion, the impact of asymmetric carrying on the risk of slips and falls remains understudied. Accordingly, more research is warranted to fill this gap in the literature, particularly with the continuously increasing age of the working population. Moreover, ground reaction force may represent a better metric to evaluate the impact of one-handed carrying on the moments about L4/L5 vertebral segment. One potential explanation for the small differences in the observed moments with respect to different load conditions is that ground reaction force is generally oriented towards (or closer to) the center of mass of the body, resulting in a small lever arm and hence a small moment, regardless of the carried load. This is because the participants tend to counteract the carried load by changing the kinematics of the trunk to balance their body along the gait. Furthermore, evaluating the simultaneous change in trunk kinematics and kinetics during one-handed carrying represents a potential research study. While it was beyond the main objective of the current study, the trunk kinematics and kinetics experiment briefly described trunk angles patterns at important sections of the gait cycle. The corresponding change in the moments about L4/L5 remains understudied and warrants future research. In general, the literature on one-handed carrying lacks an inclusive study that describes the motion pattern of the body during each phase of the of the gait cycle.

A few studies have examined the effects of one-handed carrying on the biomechanics of the lower extremity. These studies focused on the effects on hip muscle activity/joint forces (Neumann & Cook, 1985; Neumann, Cook, Sholty, & Sobush, 1992; Neumann, 1996; Bergmann, Graichen, Rohlmann, & Linke, 1997). However, the effects of age and obesity were not the main objectives of these studies. In addition, to our knowledge, no work has been completed to examine these effects on the biomechanics of the knee or the ankle, neither among old and obese individuals, nor among young healthy people.

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Appendices

Appendix 1: ANOVA Results for Dependent Variables in Chapter 3

Dependent Variables	**Main and Interaction Effects***																				
	Load (p; $F_{3,48}$; η^2)			**Age (p; $F_{1,4}$; η^2)**			**Obesity (p; $F_{1,8}$; η^2)**			**Age X Load (p; $F_{3,48}$; η^2)**			**Age X Obesity (p; $F_{1,8}$; η^2)**			**Obesity X Load (p; $F_{3,48}$; η^2)**			**Age X Obesity X Load (p; $F_{3,48}$; η^2)**		
HR (bpm)	**< 0.01**	**38.89**	**0.05**	0.12	3.98	0.26	0.23	1.67	0.04	**0.01**	**4.07**	**0.01**	0.25	1.56	0.04	0.24	1.45	0	0.35	1.11	0
%HRR	**< 0.01**	**44.17**	**0.16**	0.06	7.03	0.2	0.17	2.26	0.05	**0.01**	**4.08**	**0.02**	0.17	2.3	0.05	0.22	1.54	0.01	0.25	1.43	0.01
%VO_{2max}	**<0.01**	**33.32**	**0.06**	0.45	0.71	0.1	0.77	0.09	0	**0.03**	**3.21**	**0.01**	**0.01**	**11.51**	**0.04**	**< 0.01**	**7.13**	**0.01**	0.07	2.57	0
VO_{2T} (L)	**< 0.01**	**17.67**	**0.06**	0.83	0.05	0	**< 0.01**	**39.04**	**0.45**	0.97	0.08	0	0.56	0.36	0	0.11	2.14	0.01	0.15	1.88	0.01
VO_{2T}/BW (L/kg)	**< 0.01**	**16.76**	**0.14**	0.53	0.48	0.02	0.17	2.31	0.04	0.97	0.08	0	0.32	1.14	0.02	**0.01**	**4.48**	**0.04**	0.29	1.3	0.01
Speed (m/s)	0.64	0.57	0	0.91	0.02	0	0.51	0.44	0.02	**0.039**	**3**	**0.02**	0.71	0.15	0.01	0.13	1.99	0.01	0.78	0.36	0
RPE(A)	**< 0.01**	**57.8**	**0.62**	0.74	0.13	0	0.47	0.57	0.01	0.55	0.71	0.01	0.47	0.57	0.01	0.42	0.96	0.01	0.41	0.99	0.01
RPE(BK)	**< 0.01**	**33.84**	**0.41**	0.54	0.45	0.01	0.79	0.07	0	0.69	0.49	0.01	0.26	1.5	0.03	0.44	0.92	0.01	0.17	1.73	0.02
RPE(WB)	**< 0.01**	**27.29**	**0.36**	0.19	2.48	0.03	0.84	0.04	0	0.55	0.71	0.01	0.45	0.63	0.02	0.68	0.5	0.01	0.67	0.52	0.01

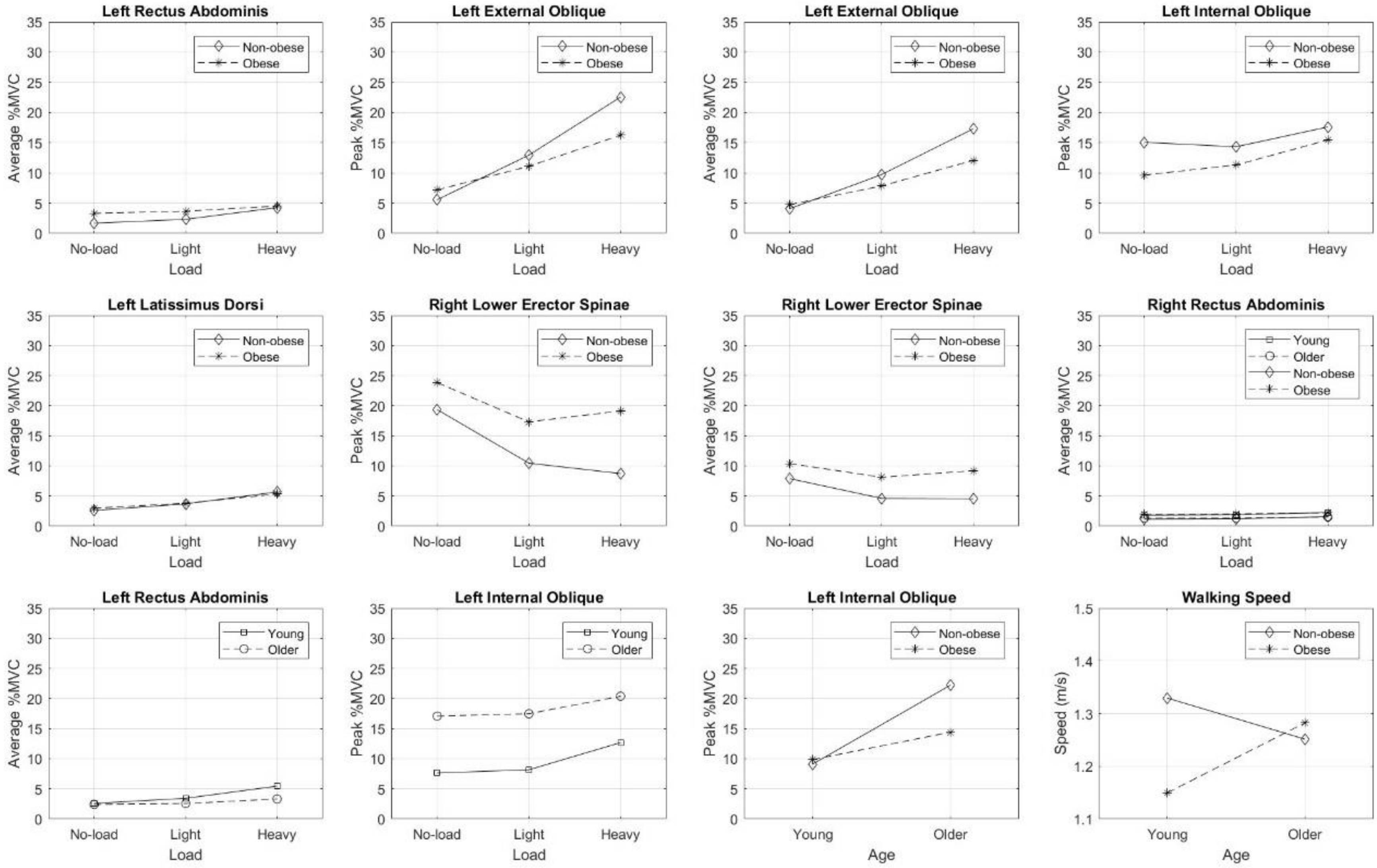
*** Significant effects are presented in bold.**

Appendix 2: ANOVA Results for Muscle Activity (Chapter 4)

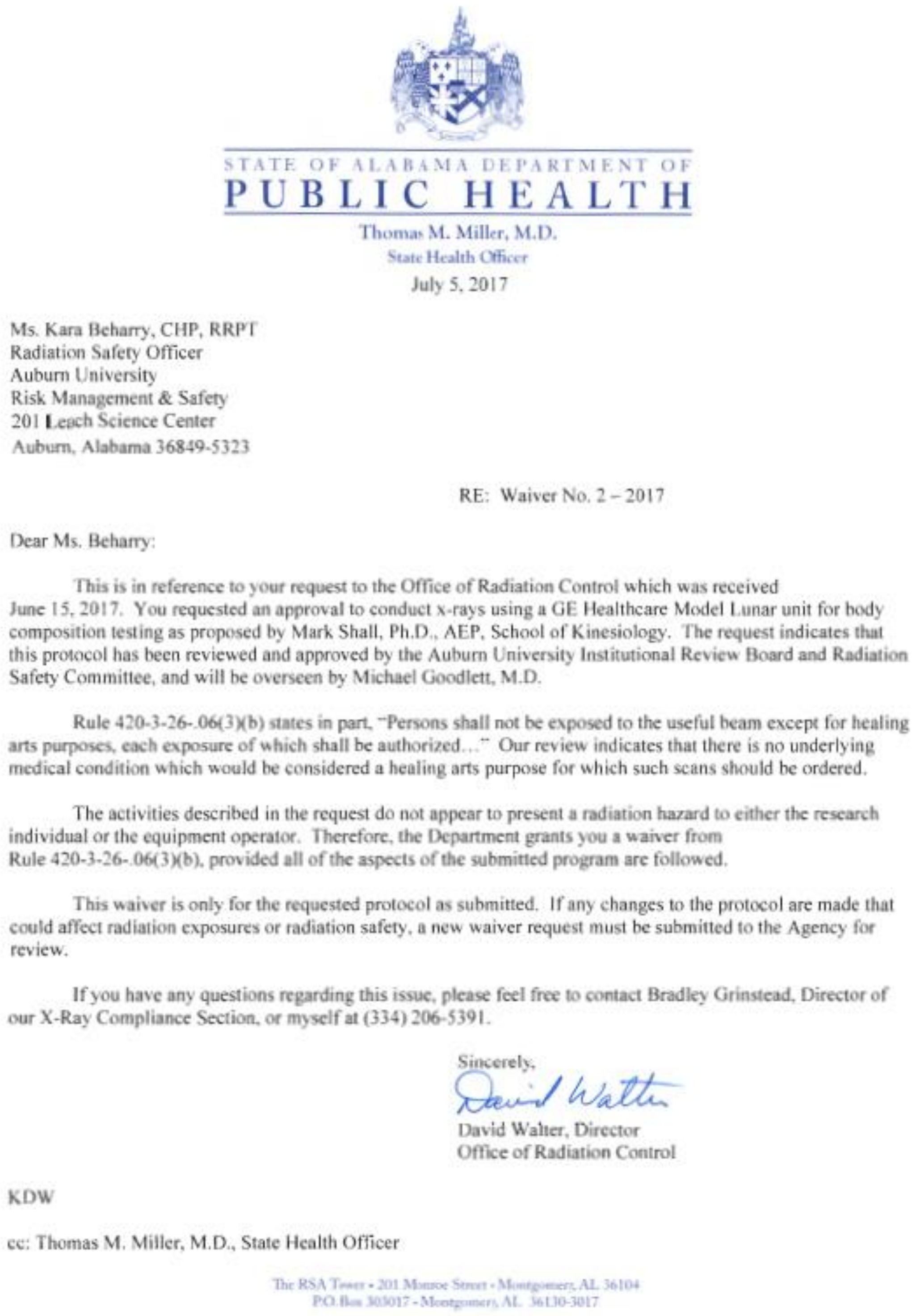
Dependent Variables	**Log$_{10}$ (Peak %MVC)***																				
	Load (p; $F_{2,32}$; η^2)			**Age (p; $F_{1,4}$; η^2)**			**Obesity (p; $F_{1,8}$; η^2)**			**Age X Load (p; $F_{2,32}$; η^2)**			**Age X Obesity (p; $F_{1,8}$; η^2)**			**Obesity X Load (p; $F_{2,32}$; η^2)**			**Age X Obesity X Load (p; $F_{2,32}$; η^2)**		
Left Rectus Abdominis	**< 0.01**	**20.11**	**0.08**	0.33	1.25	0.07	0.26	1.48	0.06	0.21	1.62	0.01	0.90	0.02	0	0.15	2.02	0.01	0.14	2.11	0.01
Left External Oblique	**< 0.01**	**174.04**	**0.46**	0.34	1.16	0.02	0.48	0.54	0.01	0.23	1.53	0	0.90	0.02	0	**< 0.01**	**11.84**	**0.03**	0.92	0.09	0
Left Internal Oblique	**< 0.01**	**40.68**	**0.09**	**0.03**	**10.10**	**0.29**	0.16	2.35	0.14	**0.01**	**5.36**	**0.01**	**0.03**	**6.43**	**0.03**	**0.03**	**3.91**	**0.01**	0.14	2.091	0
Left Latissimus Dorsi	**< 0.01**	**27.71**	**0.09**	0.83	0.05	0.01	0.66	0.21	0.01	0.49	0.73	0	0.76	0.10	0	0.08	2.73	0.01	0.61	0.5	0
Left Upper Erector Spinae	**< 0.01**	**25.59**	**0.06**	0.86	0.03	0	0.77	0.09	0.01	0.48	0.75	0	0.93	0.01	0	0.76	0.27	0	0.77	0.26	0
Left Lower Erector Spinae	**< 0.01**	**22.50**	**0.09**	0.50	0.56	0.04	0.69	0.17	0.01	0.59	0.54	0	0.50	0.49	0.02	0.71	0.35	0	0.98	0.03	0
Right Rectus Abdominis	**0.01**	**5.29**	**0.01**	0.18	2.58	0.12	0.22	1.78	0.10	0.27	1.36	0	0.99	0	0	0.75	0.29	0	0.20	1.69	0
Right External Oblique	0.12	2.26	0.01	0.64	0.26	0.02	0.33	1.08	0.05	0.82	0.20	0	0.55	0.39	0.02	0.43	0.86	0	0.52	0.67	0
Right Internal Oblique	0.99	0.01	0	0.15	3.20	0.17	0.17	2.25	0.05	0.80	0.22	0	0.10	3.49	0.07	0.10	0	0	0.67	0.40	0
Right Latissimus Dorsi	**< 0.01**	**12.39**	**0.08**	**0.03**	**10.78**	**0.05**	0.29	1.30	0.08	0.48	0.67	0	0.73	0.13	0.01	0.71	0.35	0	0.12	2.28	0.01
Right Upper Erector Spinae	**< 0.01**	**32.43**	**0.16**	0.28	1.58	0.06	0.76	0.10	0	0.87	0.14	0	0.43	0.70	0.03	0.38	1.00	0	0.93	0.08	0
Right Lower Erector Spinae	**< 0.01**	**19.77**	**0.10**	0.39	0.91	0.07	0.30	1.21	0.03	0.59	0.54	0	0.52	0.46	0.01	**0.02**	**4.25**	**0.02**	0.61	0.51	0
*** Significant effects are presented in bold.**																					

Dependent Variables	**Log$_{10}$ (Average %MVC)***																				
	Load (p; $F_{2,32}$; η^2)			**Age (p; $F_{1,4}$; η^2)**			**Obesity (p; $F_{1,8}$; η^2)**			**Age X Load (p; $F_{2,32}$; η^2)**			**Age X Obesity (p; $F_{1,8}$; η^2)**			**Obesity X Load (p; $F_{2,32}$; η^2)**			**Age X Obesity X Load (p; $F_{2,32}$; η^2)**		
Left Rectus Abdominis	**< 0.01**	**55.98**	**0.13**	0.29	1.50	0.08	0.25	1.55	0.07	**0.03**	**3.95**	**0.01**	0.76	0.10	0	**< 0.01**	**8.07**	**0.02**	0.14	2.09	0
Left External Oblique	**< 0.01**	**282.83**	**0.48**	0.42	0.80	0.02	0.27	1.37	0.02	0.11	2.39	0	0.61	0.28	0	**< 0.01**	**14.98**	**0.03**	0.79	0.24	0
Left Internal Oblique	**< 0.01**	**55.29**	**0.12**	0.08	5.63	0.17	0.35	0.98	0.02	0.15	1.99	0	0.17	2.27	0.03	0.55	0.61	0	0.29	1.28	0
Left Latissimus Dorsi	**< 0.01**	**67.38**	**0.14**	0.95	0	0	0.84	0.04	0	0.39	0.97	0	0.98	0	0	**0.02**	**4.78**	**0.01**	0.71	0.34	0
Left Upper Erector Spinae	**< 0.01**	**59.94**	**0.11**	0.88	0.03	0	0.89	0.02	0	0.27	1.36	0	0.93	0.01	0	0.36	1.06	0	0.26	1.41	0
Left Lower Erector Spinae	**< 0.01**	**45.72**	**0.13**	0.70	0.17	0.02	0.99	0	0	0.88	0.12	0	0.43	0.70	0.02	0.43	0.88	0	0.92	0.08	0
Right Rectus Abdominis	**< 0.01**	**18.37**	**0.02**	0.28	1.54	0.08	0.10	3.47	0.17	0.55	0.60	0	0.92	0.01	0	0.15	2.04	0	**0.02**	**4.42**	**0**
Right External Oblique	**< 0.01**	**7.86**	**0.02**	0.62	0.29	0.03	0.19	2.02	0.08	0.39	0.97	0	0.49	0.53	0.02	0.33	1.14	0	0.39	0.98	0
Right Internal Oblique	0.57	0.57	0	0.18	2.57	0.16	0.51	0.48	0.01	0.84	0.17	0	0.11	3.30	0.07	0.78	0.25	0	0.58	0.56	0
Right Latissimus Dorsi	**< 0.01**	**33.93**	**0.16**	0.12	4	0.02	0.26	1.44	0.09	0.84	0.18	0	0.96	0	0	0.43	0.86	0	0.62	0.49	0
Right Upper Erector Spinae	**< 0.01**	**41.54**	**0.23**	0.60	0.31	0.01	0.70	0.16	0.01	0.40	0.95	0.01	0.42	0.73	0.03	0.50	0.71	0	0.72	0.33	0
Right Lower Erector Spinae	**< 0.01**	**14.68**	**0.06**	0.56	0.40	0.03	0.29	1.29	0.04	0.40	0.94	0	0.45	0.64	0.02	**0.01**	**5.88**	**0.02**	0.86	0.15	0
*** Significant effects are presented in bold.**																					

Appendix 3: Statistically significant interaction effects (Chapter 4)



Appendix 4: Dual-energy X-ray Absorptiometry (DEXA) Scan Approval Letter



STATE OF ALABAMA DEPARTMENT OF
PUBLIC HEALTH
Thomas M. Miller, M.D.
State Health Officer

July 5, 2017

Ms. Kara Beharry, CHP, RRPT
Radiation Safety Officer
Auburn University
Risk Management & Safety
201 Leach Science Center
Auburn, Alabama 36849-5323

RE: Waiver No. 2 – 2017

Dear Ms. Beharry:

This is in reference to your request to the Office of Radiation Control which was received June 15, 2017. You requested an approval to conduct x-rays using a GE Healthcare Model Lunar unit for body composition testing as proposed by Mark Shall, Ph.D., AEP, School of Kinesiology. The request indicates that this protocol has been reviewed and approved by the Auburn University Institutional Review Board and Radiation Safety Committee, and will be overseen by Michael Goodlett, M.D.

Rule 420-3-26-.06(3)(b) states in part, "Persons shall not be exposed to the useful beam except for healing arts purposes, each exposure of which shall be authorized…" Our review indicates that there is no underlying medical condition which would be considered a healing arts purpose for which such scans should be ordered.

The activities described in the request do not appear to present a radiation hazard to either the research individual or the equipment operator. Therefore, the Department grants you a waiver from Rule 420-3-26-.06(3)(b), provided all of the aspects of the submitted program are followed.

This waiver is only for the requested protocol as submitted. If any changes to the protocol are made that could affect radiation exposures or radiation safety, a new waiver request must be submitted to the Agency for review.

If you have any questions regarding this issue, please feel free to contact Bradley Grinstead, Director of our X-Ray Compliance Section, or myself at (334) 206-5391.

Sincerely,

David Walter

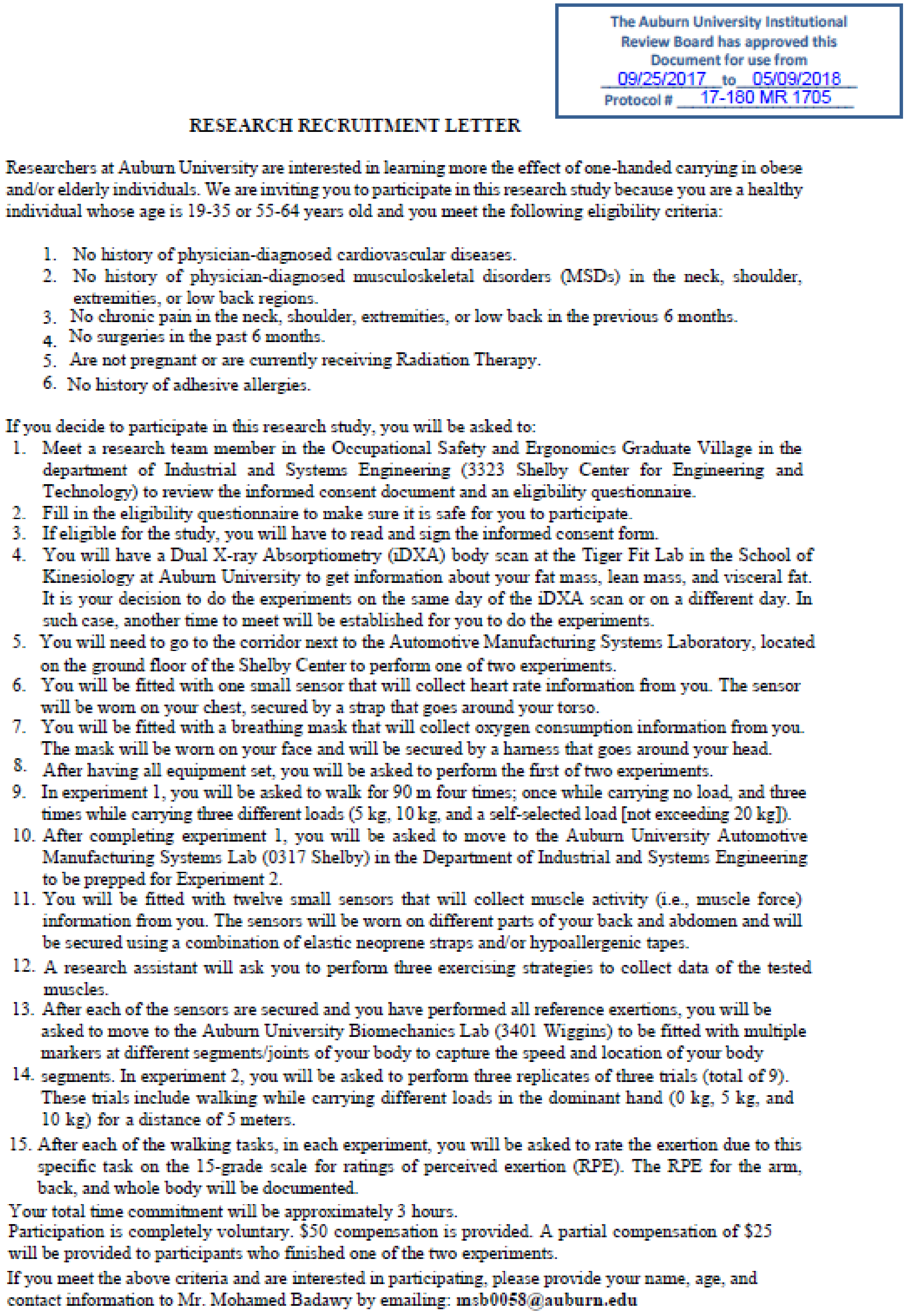
David Walter, Director
Office of Radiation Control

KDW

cc: Thomas M. Miller, M.D., State Health Officer

The RSA Tower • 201 Monroe Street • Montgomery, AL 36104
P.O. Box 303017 • Montgomery, AL 36130-3017

Appendix 5: Research Recruitment Letter



The Auburn University Institutional
Review Board has approved this
Document for use from
09/25/2017 to 05/09/2018
Protocol # 17-180 MR 1705

RESEARCH RECRUITMENT LETTER

Researchers at Auburn University are interested in learning more the effect of one-handed carrying in obese and/or elderly individuals. We are inviting you to participate in this research study because you are a healthy individual whose age is 19-35 or 55-64 years old and you meet the following eligibility criteria:

1. No history of physician-diagnosed cardiovascular diseases.
2. No history of physician-diagnosed musculoskeletal disorders (MSDs) in the neck, shoulder, extremities, or low back regions.
3. No chronic pain in the neck, shoulder, extremities, or low back in the previous 6 months.
4. No surgeries in the past 6 months.
5. Are not pregnant or are currently receiving Radiation Therapy.
6. No history of adhesive allergies.

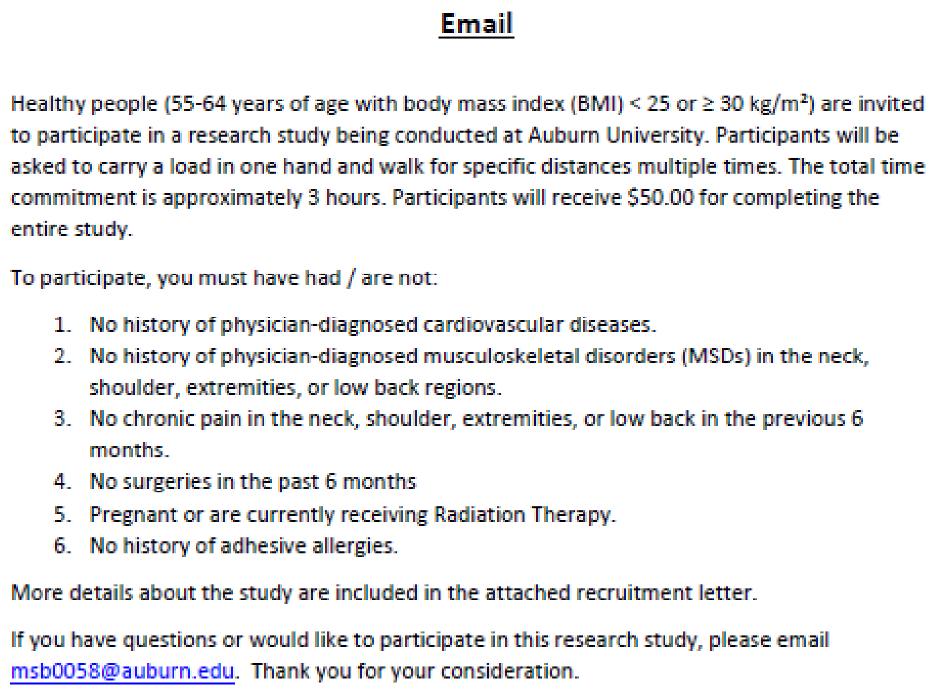
If you decide to participate in this research study, you will be asked to:

1. Meet a research team member in the Occupational Safety and Ergonomics Graduate Village in the department of Industrial and Systems Engineering (3323 Shelby Center for Engineering and Technology) to review the informed consent document and an eligibility questionnaire.
2. Fill in the eligibility questionnaire to make sure it is safe for you to participate.
3. If eligible for the study, you will have to read and sign the informed consent form.
4. You will have a Dual X-ray Absorptiometry (iDXA) body scan at the Tiger Fit Lab in the School of Kinesiology at Auburn University to get information about your fat mass, lean mass, and visceral fat. It is your decision to do the experiments on the same day of the iDXA scan or on a different day. In such case, another time to meet will be established for you to do the experiments.
5. You will need to go to the corridor next to the Automotive Manufacturing Systems Laboratory, located on the ground floor of the Shelby Center to perform one of two experiments.
6. You will be fitted with one small sensor that will collect heart rate information from you. The sensor will be worn on your chest, secured by a strap that goes around your torso.
7. You will be fitted with a breathing mask that will collect oxygen consumption information from you. The mask will be worn on your face and will be secured by a harness that goes around your head.
8. After having all equipment set, you will be asked to perform the first of two experiments.
9. In experiment 1, you will be asked to walk for 90 m four times; once while carrying no load, and three times while carrying three different loads (5 kg, 10 kg, and a self-selected load [not exceeding 20 kg]).
10. After completing experiment 1, you will be asked to move to the Auburn University Automotive Manufacturing Systems Lab (0317 Shelby) in the Department of Industrial and Systems Engineering to be prepped for Experiment 2.
11. You will be fitted with twelve small sensors that will collect muscle activity (i.e., muscle force) information from you. The sensors will be worn on different parts of your back and abdomen and will be secured using a combination of elastic neoprene straps and/or hypoallergenic tapes.
12. A research assistant will ask you to perform three exercising strategies to collect data of the tested muscles.
13. After each of the sensors are secured and you have performed all reference exertions, you will be asked to move to the Auburn University Biomechanics Lab (3401 Wiggins) to be fitted with multiple markers at different segments/joints of your body to capture the speed and location of your body
14. segments. In experiment 2, you will be asked to perform three replicates of three trials (total of 9). These trials include walking while carrying different loads in the dominant hand (0 kg, 5 kg, and 10 kg) for a distance of 5 meters.
15. After each of the walking tasks, in each experiment, you will be asked to rate the exertion due to this specific task on the 15-grade scale for ratings of perceived exertion (RPE). The RPE for the arm, back, and whole body will be documented.

Your total time commitment will be approximately 3 hours.
Participation is completely voluntary. $50 compensation is provided. A partial compensation of $25 will be provided to participants who finished one of the two experiments.

If you meet the above criteria and are interested in participating, please provide your name, age, and contact information to Mr. Mohamed Badawy by emailing: **msb0058@auburn.edu**

Appendix 6: Research Recruitment Email



Email

Healthy people (55-64 years of age with body mass index (BMI) < 25 or ≥ 30 kg/m^2) are invited to participate in a research study being conducted at Auburn University. Participants will be asked to carry a load in one hand and walk for specific distances multiple times. The total time commitment is approximately 3 hours. Participants will receive $50.00 for completing the entire study.

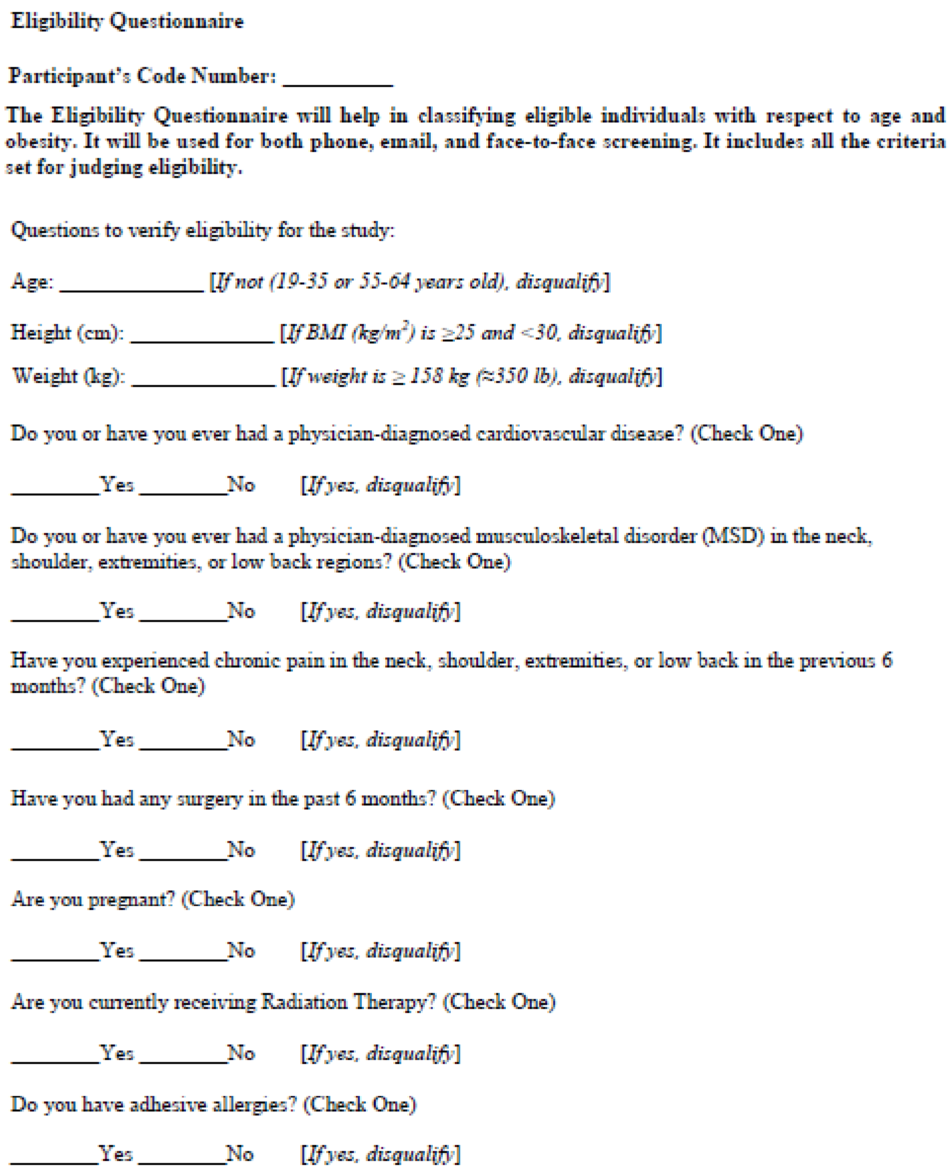
To participate, you must have had / are not:

1. No history of physician-diagnosed cardiovascular diseases.
2. No history of physician-diagnosed musculoskeletal disorders (MSDs) in the neck, shoulder, extremities, or low back regions.
3. No chronic pain in the neck, shoulder, extremities, or low back in the previous 6 months.
4. No surgeries in the past 6 months
5. Pregnant or are currently receiving Radiation Therapy.
6. No history of adhesive allergies.

More details about the study are included in the attached recruitment letter.

If you have questions or would like to participate in this research study, please email msb0058@auburn.edu. Thank you for your consideration.

Appendix 7: Eligibility Questionnaire



Eligibility Questionnaire

Participant's Code Number: __________

The Eligibility Questionnaire will help in classifying eligible individuals with respect to age and obesity. It will be used for both phone, email, and face-to-face screening. It includes all the criteria set for judging eligibility.

Questions to verify eligibility for the study:

Age: _____________ *[If not (19-35 or 55-64 years old), disqualify]*

Height (cm): _____________ *[If BMI (kg/m^2) is ≥25 and <30, disqualify]*

Weight (kg): _____________ *[If weight is ≥ 158 kg (≈350 lb), disqualify]*

Do you or have you ever had a physician-diagnosed cardiovascular disease? (Check One)

________Yes ________No *[If yes, disqualify]*

Do you or have you ever had a physician-diagnosed musculoskeletal disorder (MSD) in the neck, shoulder, extremities, or low back regions? (Check One)

________Yes ________No *[If yes, disqualify]*

Have you experienced chronic pain in the neck, shoulder, extremities, or low back in the previous 6 months? (Check One)

________Yes ________No *[If yes, disqualify]*

Have you had any surgery in the past 6 months? (Check One)

________Yes ________No *[If yes, disqualify]*

Are you pregnant? (Check One)

________Yes ________No *[If yes, disqualify]*

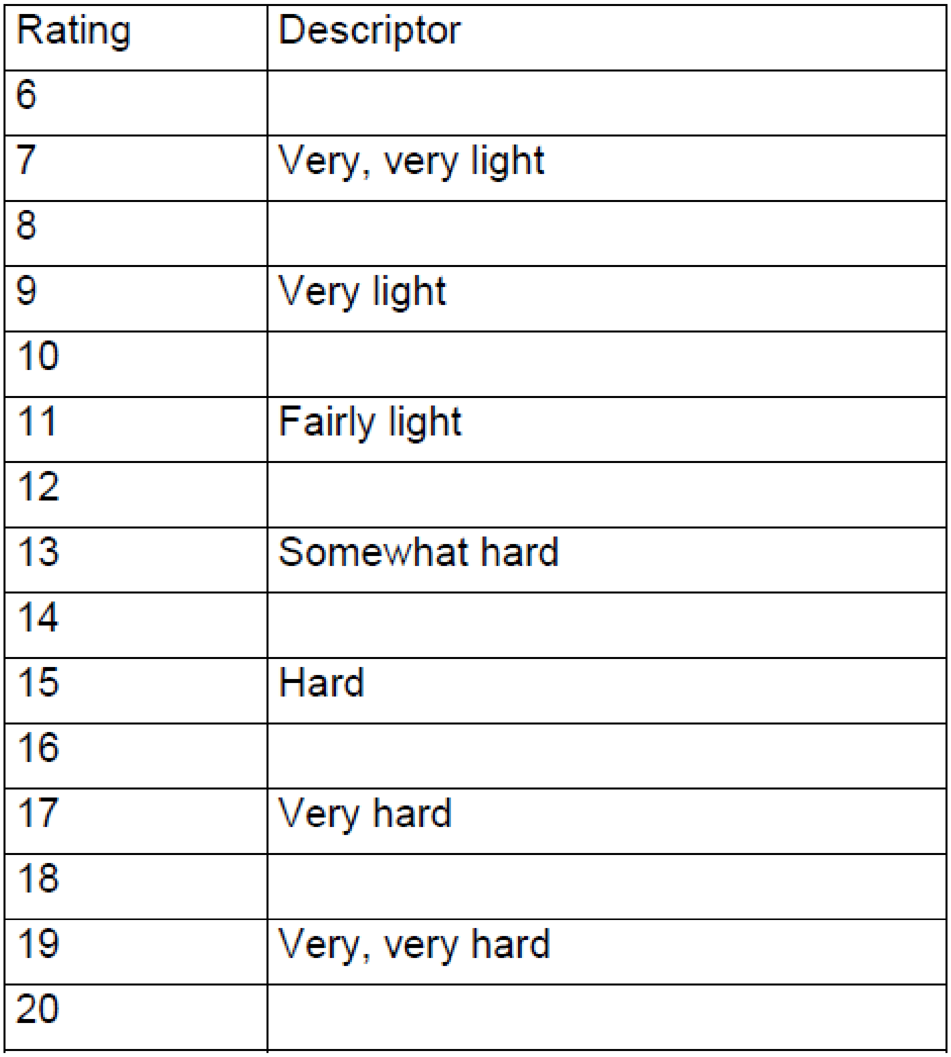
Are you currently receiving Radiation Therapy? (Check One)

________Yes ________No *[If yes, disqualify]*

Do you have adhesive allergies? (Check One)

________Yes ________No *[If yes, disqualify]*

Appendix 8: The 15-grade Scale for Ratings of Perceived Exertion (RPE)



Rating	Descriptor
6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	