Impact of Brief In-class Mindfulness Training Sessions on Trait Mindfulness, Psychological Distress, Physiology, and Learning Outcomes in Undergraduate Students

By

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Abstract

Mindfulness-Based Stress Reduction (MBSR) courses typically consist of 20 hrs of training but smaller doses can be useful in stress reduction (e.g., Boettcher, et al., 2014). To isolate other mindful focus from non-directed silent time, undergraduates were assigned to mindfulness meditation (MM) or control (C) conditions. Twice a week in class, MM listened to a 3-minute-long pre-recorded mindfulness body scan meditation, while C sat silently to control for the directed focus involved in meditating. With a mobile application, students measured their heart rates as an indicator of stress after meditation practice and before exams. We measured their trait mindfulness using the Five-Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2008), and trait anxiety at pretest and then again at the end of 5 and 10 weeks. Participants also reported their valence and arousal before and after each 3-min meditation or silence. Two of our three hypotheses were at least partially supported: group predicted final grades, and time spent meditating or sitting in silence voluntarily outside of class was negatively correlated with heart rate, anxiety, and impulsiveness. Overall trait changes were not induced by our meditation intervention. Qualitative reflections suggest positive changes in experience of everyday life and academic work for some participants, suggesting practical significance of including meditation or another type of break into the classroom if better integrated into the cirriculum.

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List of Abbreviations

ACC	Anterior cingulate cortex
ADHD	Attention-Deficit Hyperactivity Disorder
ADHS	Adult Dispositional Hope Scale
AIC	Akaike's Information Criterion
ALE	Activation likelihood estimation
ANOVA	Analysis of variance
Ar 1	Pre-intervention arousal
Ar 2	Post-intervention arousal
Att	Self-reported attention
Aware	Self-reported awarenss of inner experience
BAI	Beck Anxiety Inventory
BDI	Beck Depression Inventory
C	Control condition
CAMS_R	Cognitive and Affective Mindfulness Scale Revised
CC	Click count
dlPFC	Dorsolateral prefrontal cortex
dMPFC	Dorsal medial prefrontal cortex
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, Volume IV

EEG	Electroencephalogram
FA	Focused attention
Faith	Faithfulness in carrying out the intervention instructions
FFMQ	Five-Facet Mindfulness Questionnaire
FMI	Freiburg Mindfulness Inventory
fMRI	Functional magnetic resonance imaging
GLM	General linear model
GPA	Grade-point average
HR	Heart rate
HRV	Heart rate variability
IBS	Irritable Bowel Syndrome
ID	Identity
IMP	Wide dataset with imputed data
IQR	Interquartile range
IRB	Institutional review board
IRI	Interpersonal Reactivity Index
ISI	Insomnia Severity Index
IWLS	Iteratively-weighted least squares
IWLSR	Iteratively-weighted least squares regression
JSS	Job Stress Survey
KIMS	Kentucky Inventory of Mindfulness
LMER	Linear mixed effects regression
LMS	Langer's Mindfulness Scale

LMS	Learning management system
M	Mean
MAR	Missing at randdom
MBCUL	Mindfulness-Based Coping with University Life
MBI	Mindfulness-based intervention
MBMP	Mindfulness-based medical practice
MBSR	Mindfulness-based stress reduction
MBSR-ld	low-dose mindfulness-based stress reduction
MCAR	Missing completely at random
MCE	Mindfulness Communcation Education
MHPSS	Mental Health Professionals Stress Scale
Min	Self-reported contemplative time outside of class so far in the week
MISS	Wide dataset with missing data
MM	Mindfulness meditation
MMC	Mindfulness meditation course
MNAR	Missing not at random
MOM	Mindfulness-oriented meditation
MPFC	Medial prefrontal cortex
MTS	Mindfulness training skills
NA	Negative affectivity
NHST	Null-hypothesis significance testing
NonJ	Self-reported judgment of inner experience

OLS	Ordinary least squares
OM	Open monitoring
Open	Awareness of external stimuli
p	Probability
PANAS	Positive and Negative Affect Scales
PET	Positron emission tomography
PFC	Prefrontal cortex
PMA	Premotor area
PMS	Philadelphia Mindfulnes Scale
POMS	Profile of Mood States
PSS	Perceived Stress Scale
PTSD	Posttraumatic Stress Disorder
Q-Q	Quartile-quartile plot
QOLI	Quality of Life Inventory
RA	Research assistant
rLMER	Robust linear mixed effects regression
RR	Respiration rate
S-MAAS	State Mindfuln Attention Awareness Scale
SD	Standard deviation
SE	Standard error
SI	Social inhibition
SMA	Supplementary motor area
SMG	Supramarginal gyrus

SMQ	Southampton Mindfulness Scale
SSRI	Selective serotonin reuptake inhibitors
STAI	State-Trait Anxiety Inventory
SWLS	Satisfaction with Life Scale
TCI	Temperatment and Character Inventory
TMS-S	Toronto Mindfulness Scale - State Version
TMS-S	Toronto Mindfulness Scale-State Version
UCLA	University of California, Los Angeles
UK	United Kingdom
Val 1	Pre-intervention valence
Val 2	Post-intervention valence

Introduction to Mindfulness Meditation

Mindfulness and meditation have been defined by spiritual leaders and scientists alike a variety of different ways (Hart, Ivtzan, & Hart, 2013). John Kabat-Zinn (e.g., 2003) uses the term 'mindfulness' as a translation of the Pali term *sati* from Theravada Buddhism. *Sati* is a core component of insight meditation—*vispassana bhavanna*—practiced to cultivate introspection, insight, clarity, and attention in order to reduce psychological distress (Wallace, 2005). Thus, according to Kabat-Zinn, mindfulness involves self-regulation of awareness, attentional deployment to both internal and external stimuli, introspection and metacognition, and a nonjudgmental attitude (Bishop et al., 2004). Kabat Zinn (2003) differentiates the often interchangeably used terms 'mindfulness' and 'meditation' by noting that meditation is a training process aimed at developing mindfulness throughout daily activities in order to reduce distress. Using this conceptual framework, Kabat-Zinn developed secular mindfulness practice courses: Mindfulness-Based Stress Reduction (MBSR; Kabat-Zinn, Massion, Kristeller, & Peterson, 1992).

MBSR courses have enjoyed wide success in recent decades and have been credited with providing relief from symptoms associated with psychological and physical conditions as diverse as mood disorders (Grossmann, Niemann, Schmidt, & Walach, 2004), eating disorders (Bishop, 2002), cardiovascular disease (Canter & Ernst, 2004; King, Carr, & D'Cruz, 2002), and cancer (Coker, 1999; Grossman, Niemann, Schdmit, & Walach, 2004). The most robust finding is distress reduction such as Khoury, Sharma, Rush, and Fournier (2015) found in a meta-analysis of research using MBSR. Mindfulness can also lead to increased grades, possibly by reducing mind-wandering (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). Because anxiety is associated with lower academic performance (e.g., Chapell, et al., 2005), perhaps mindfulness meditation can increase academic performance by reducing distress and physiological arousal. Below we present a study examining the effects of consistent, short sessions of mindfulness practice on trait mindfulness, trait anxiety, and academic performance.

Literature Review

Measuring Mindfulness

Measurement of mindfulness is dependent on its definition, and whether it is conceived of as a state, trait, or procedure (Davidson & Kaszniak, 2015). Hart, Ivtzan, and Hart (2013) wrote a review comparing the leading schools of thought regarding mindfulness. The Langer (1992) and Kabat-Zinn (1994) schools of thought have similar definitions, but differ in philosophies, components of the constructs, goals, measures, audiences, interventions, and outcomes. The Langer school of thought, which they suggest should be labeled "creative mindfulness," features self-regulation of attention, attention to external stimuli, and engaging creatively with those stimuli. On the other hand, "meditative mindfulness" espoused by Kabat-Zinn (1994) involves self-regulation of awareness, attention to both internal and external stimuli, introspection and metacognition, and a nonjudgmental attitude about the perceived stimuli. Langer's (1992) definition is dispositional, although her colleagues' research induces mindfulness as a state, whereas Kabat-Zinn's definition encompasses both a state and a trait, with interventions aimed toward modifying the latter. The core component they have in common is self-regulation, defined as successful control of attention and behavior.

Over the last two decades, many mindfulness questionnaires have been developed, capturing a range from one to five factors. As shown in Table 1, most are trait measures, with the exception of only two state measures to this author's knowledge: the Toronto Mindfulness Scale—State Version (TMS-S; Lau et al., 2006) and the State Mindful Attention Awareness Scale (S-MAAS; Brown & Ryan, 2003). State measures are rare, possibly because their validity as true state measures is in question (e.g., Davidson & Kazsniak, 2015). That is, answering any questions about mindfulness as a state in the present moment necessarily alters the level of mindfulness (which in most models involves attention to inner experience). Levinson, Stoll, Indy, Merry, and Davidson (2014) instead use breath count after a meditation session (corroborated by use of a respiration belt) as an arguably more valid measure of state mindfulness, or at least as a manipulation check in MM studies. As shown in Table 1, trait measures include anywhere from 12-39 items, and many show convergent validity with measures of emotional well-being, adaptive emotion regulation, cognitive flexibility, openness to experience, need for cognition, and self-compassion. Most are negatively correlated with measures of distress such as depression, anxiety (PMS; Cardaciotto et al., 2008;), and dissociation symptoms (SMQ; Chadwick et al., 2008). Some are associated with lower levels of other maladaptive thought patterns such as over- or under-engagement with emotions, avoidant approaches to problems (CAMS_R; Feldman et al., 2007), excessive need for structure (LMS; Boder & Langer, 2001; Langer, 2004), and rumination (TMS; Lau et al., 2006). However, they have differing goals. Some are written to capture a single aspect of mindfulness, conceptualize mindfulness as only one factor, or assess many components of mindfulness. Focuses differ from clinical versus average populations, or measure of experienced versus novice meditators.

The FFMQ (Baer et al., 2006; Baer et al., 2008) is probably the most widely-studied trait mindfulness questionnaire (including by both Langer and Kabat-Zinn's laboratories). Baer and colleagues (2006) developed the 39-item questionnaire by combining items from five other questionnaires: CAMS, FMI, KIMS, MAAS, and SMQ. Its five subscales include Observing (noticing internal and external stimuli), Describing (labeling experiences), Acting with awareness (paying attention in the present), Nonjudging ("coldly" observing inner stimuli), and Nonreactivity (not getting "carried away" by thoughts or emotions). Many other scales assess the attention and awareness portions, but do not account for any emotional components, which some researchers posit are important to mindfulness clinical utility (Siegling & Petrides, 2014). Studies evaluating the FFMQ find correlations with measures of self-regulation (Carmody, Baer, Lykins, & Olendzki, 2009). The FFMQ is also correlated positively with emotional intelligence and openness to experience, whereas it has an inverse relationship with thought suppression and alexithymia (Baer et al., 2006; Baer et al., 2008). Experienced meditators have higher scores on the FFMQ and have greater psychological well-being and less distress (Baer et al., 2006; Baer et al., 2008; Carmody & Baer, 2008), suggesting it measures a positive trait potentially enhanced by long-term meditation training. Furthermore, meditation courses and training programs have been shown to increase mindfulness scores on the FFMQ, supporting Kabat-Zinn's assertion (1992) that mindfulness is a skill practiced during meditation that spills over into other aspects of everyday life. Most comprehensive measure of Eastern conception of mindfulness, and shares 50% variance with Big Five (Neuroticism, Conscientiousness, and Openness; Siegling and Petrides, 2014).

Mindfulness Training

Mindfulness interventions come in a variety of forms. Although Langer's (1992) conception of mindfulness is defined strictly as a trait, interventions based on her school of thought include many brief mindfulness interventions that induce mindful states. Such studies (e.g., Anglin, Pirson, & Langer, 2008; Djikic, Langer, & Fulton-Stapleton, 2008) give specific instructions to participants about how to direct their attention to very specific tasks, such as math problems or sorting faces by many characteristics at once. The interventions—usually around 20 minutes and performed only once—have immediate effects on mental state and have been shown to improve performance in certain tasks, such as erasing the gender gap in math performance (Anglin, Pirson, & Langer, 2008). In another study, Djikic, Langer, and Fulton-Stapleton (2008) used sorting tasks to induce a state of mindfulness of categories into which people are placed. The more mindful (or complex and requiring much attention) the condition in the training task, the less the participants showed activation of negative stereotypes about elders. These data show the Langer conception of mindfulness is associated with greater focus and more accurate perceptions, benefits also touted by its ancient practitioners (Wallace, 2005).

The MBSR program (Kabat-Zinn, 1982, 1994, 2009), briefly described above, provides weeks of meditation training in a traditional Eastern framework, featuring long periods of stillness. The discouragement to change position causes pain in many people, which practitioners are encouraged to notice with mindfulness, nonjudgmentally, without attempting to change it. One way that Kabat-Zinn (1982, 1990 1992; Baer, 2003) proposes mindfulness helps relieve physical and psychological pain is that it allows people to fully experience their distress without escaping it and become less reactive to it, improving functioning in all domains. MBSR induces a state of mindfulness through formal practice that is aimed at increasing trait mindfulness over time, which many have noted serves a mediator between MBSR training and various health outcomes (Shapiro et al., 2011; Bamber and Schneider, 2016).

Psychological Distress Reduction

Carmody and Baer (2009) conducted a review to determine whether shorter interventions than the classic MBSR course could provide relief from distress. Table 2 (reproduced with permission from Table 1 in Carmody and Baer, 2009) summarizes the characteristics of the 28 studies. Demographics included students, working adults, parents, people undergoing psychotherapy, pregnant women, and people with a variety of medical and psychological conditions. Some studies had no control group, while others used wait-list controls, treatment as usual for diagnostic groups, or active controls with educational programs. Psychological distress was measured a variety of different ways. Mean pre-post-test effect sizes collapsed across groups were all across the board, ranging from less than 0.20 to over 1.0. The authors also reviewed the post-test effect sizes between groups. Across 28 studies, at least 22 had an effect size of 0.5 or greater collapsed across groups; between groups, the effect sizes skewed lower, with only 7 out of 16 reporting $d > 0.49$. There was no relationship between time spent in meditation and effect size, as discussed below in the Intervention Duration section. Thus, Carmody and Baer (2009) concluded MBSR has the potential for distress reduction regardless of intervention type, measure of distress, or population sampled.

Virgili (2015) meta-analyzed 19 mindfulness-based intervention (MBI) studies with 1139 participants. Interventions in the examined studies include standard 8-week MBSR, 4-week MBSR, MBMP (Mindfulness-based medical practice), MBSR-ld (low-dose mindfulness-based stress reduction), Mindfulness Communication Education (MCE), interventions labeled mindfulness meditation (MM), mindfulness meditation course (MMC), and mindfulness training skills (MTS). Five studies included wait-list controls, and only four included active controls, ranging from relaxation, leadership training, nutrition education, mindfulness-based art processing, and yoga. Dependent measures included standard questionnaires for clinical depression and anxiety such as the Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI), non-clinical affective measures such as the Positive and Negative Affect Scales (PANAS), Profile of Mood States (POMS), and some more specific questionnaires such as the Mental Health Professionals Stress Scale (MHPSS), and the Job Stress Survey (JSS). Overall, the meta-analysis yielded medium-to-large *Hedge's g* effect sizes for both within- (g = 0.68, 95 % confidence interval (CI) [0.58, 0.78]) and between-group (g = 068, 95 % confidence interval (CI) [0.58, 0.78]) analyses across all studies. They also fund a similar effect size for follow-ups with a median time of 5 weeks after training (g =0.60, 95 % CI [0.46, 0.75]). Similar to other reviews, dependent measure, MBI type, and diagnosis of participants had no relationship with effect size, suggesting robustness of mindfulness training's relationship to lower distress.

A meta-analysis reviewing studies testing effects of MBSR and mindfulness meditation (MM), broadly defined, on stress and anxiety in college students by Bamber and Schneider (2016) included 57 studies. Papers investigated anxiety in 40, self-reported stress in 34, physiological stress in 11, and mindfulness as an outcome in 24 papers. Significant decreases in anxiety and stress were found in 33 (58%) and 25 (44%) studies, respectively. All but two of the

24 showed an increase in mindfulness. Across the studies they meta-analyzed, psychological distress was measured a variety of different ways, similar to both Virgili (2015) and Carmody and Baer's (2009) reviews. They found that mindfulness mediated the relationship between MM and reductions in stress and anxiety. Specifically, MM increased state mindfulness, decreasing both stress and anxiety. After much practice, state mindfulness increases trait mindfulness, which is also associated with lower distress. They concluded that MM is likely effective in reducing stress and anxiety in college students, but that features of MBIs such as frequency, duration, method of instruction, or inclusion of yoga need to be studied further to maximize effectiveness of MBIs.

The meta-analyses reviewed above collectively examined over 100 studies to find broad conclusions about MM's effects on psychological distress. As Carmody and Baer (2009) demonstrated, MBSR courses reduce distress across different populations, measurement of distress, or even intervention duration. Similarly, Virgili (2015) found more broadly-defined mindfulness interventions yielded the same results with medium effect sizes, and Bamber and Schneider (2016) elucidated the role of trait mindfulness in facilitating distress reduction. Taken together, these results reveal the robustness of mindfulness's potential to reduce psychological distress, diagnosis of the meditators, how distress is defined, or how long the training was, and that this effect is achieved through increasing mindfulness as a trait.

Neurophysiological Outcomes

Meditation is used to treat both mental and physical conditions, as well as to increase general well-being (Barnes, Bloom, & Nahin, 2008; Goyal et al., 2010). As reviewed above, mindfulness training reduces psychological distress, which leads many researchers to investigate whether similar changes in physiological stress cooccur. Bamber and Schneider (2016) reviewed autonomic changes associated with mindfulness, with mixed results discussed in detail below. Numerous studies report pain reduction effects (Bernardy, Füber, Kölner, & Häuser, 2010; Bohlmeijer, Prenger, Taal, & Cuijpers, 2010), as well as improvement in several indices of physical health among cancer patients, for example (Ledesma & Kumano, 2009; Matchin, Armer, & Stewart, 2011). Understanding the physiological changes associated with meditating can elucidate the mechanisms by which physical health improvements may occur.

Autonomic activity. A review of studies by Bamber and Schneider (2016) examined changes in perceived stress, anxiety, and physiological measures. They reviewed 10 studies with physiological measures and found inconsistency for a variety of potential reasons.

Three studies tested cortisol levels. Tang et al. (2007) found significantly lower salivary cortisol levels as well as lower anxiety after a math stress task between MM and control groups. Additionally, Turakitwanakan, Mekseepralard, and Busarakumtragul, (2013) found a significant decrease in serum cortisol from pre- to posttest in a single group of participants who underwent mindfulness training. One study by Lynch, Gander, Kohls, Kudielka, & Walach (2011) found psychological differences between students who underwent training in Mindfulness-Based Coping with University Life (MBCUL) and waitlisted controls, including decreases in stress and anxiety, increased mindfulness. They also found a negative correlation between mindfulness and anxiety, as well as between mindfulness and perceived stress. However, those psychological changes were not accompanied by similar physiological changes. They found no differences in either salivary cortisol or alpha amylase (an enzyme often used as a marker for sympathetic activation; Nater, & Rohleder, 2009) among MM, MM sham, and control groups. None of these three studies reported a cortisol change associated with changes in anxiety, stress, or mindfulness. Bamber and Schneider (2016) conclude the inconsistency in cortisol changes could be due to study-specific limitations such as possible placebo effects in and lack of measurement of mindfulness in the case of Tang et al. (2007), a small sample without randomization and high attrition in Lynch et al. (2011), and no control group in Tuakitwanakan (2013). The relationship between mindfulness's psychological effects and cortisol changes remains unclear.

Respiration was investigated in two studies. Delgado, Guerra, Perakakis, Vera, del Paso, and Vila, (2010) found decreases in trait anxiety in both MM and relaxation training groups. Along with those psychological changes, they found the participants trained in mindfulness showed longer inspiration and expiration periods as well as a lower respiration rate (RR). State anxiety decreased in all groups in Shenesey's (2013) study, but there were no anxiety differences among MM, sham MM, and the relaxation group. Similar to the psychological findings, there was a decrease in RR among all groups, but no between-group differences. Bamber and Schneider (2016) attribute the inconsistency in respiration to several threats to internal validity, such as no true control group and potential experimenter bias in Delgado et al. (2010), and lack of measurement of mindfulness and similarity between the levels independent variable (body scan meditation and progressive relaxation) in Shenesey (2013). Mindfulness meditation may slow respiration relative to control conditions, but future investigations using non-treatment control groups and more dissimilar sham conditions may clarify this relationship.

Blood pressure was used as a dependent measure in three studies. Despite finding anxiety reduction in both treatment groups, Zeidan, Johnson, Gordon, and Goolkasian (2010) found no differences among MM, sham MM, and control groups on blood pressure. In a randomized controlled repeated measures study, Leggett (2011) found no significant psychological changes, but a decrease in both systolic and diastolic blood pressure. Chen, Yang, Wang, and Zhang (2013) used a randomized controlled trial with MM and true control groups, finding a decrease in anxiety, as well as lower systolic blood pressure in the MM group. However, they did not find any difference in diastolic blood pressure. Blood pressure measurements were more consistent across groups, despite limitations such as a small sample size, and short intervention period in Chen et al. (2013) and diffusion of treatment in Leggett (2011). Blood pressure may be sensitive to mindfulness training, but its relationship with psychological changes remains unclear.

Five studies measured heart rate (HR) or heart rate variability (HRV). In addition to the BP results above, Zeidan et al. (2010) found that all three groups (MM, sham MM, and control) showed a decrease in HR from pre-post, with the greatest effect for MM. MM and sham MM groups also showed a decrease in state anxiety. In Delgado et al. (2010), trait anxiety decreased pre-post in both MM and relaxation groups, whereas no group differences in HR or HRV were found. Similarly, Chen et al. (2013) found no changes in HR from pre-post in the single MM group. HR decreased from pre-post with no differences among MM, sham MM, and relaxation training groups in Shenesey (2013). Finally, HR and HRV showed no differences in Delgado-Pastor Ciria, Blanca, Mata, Vera, and Vila (2015) among MM, awareness, and attention groups. Study-specific limitations to the preceding studies include small and/or overly homogenous samples (Zeidan et al., 2010; Delgado et al., 2010; Chen), brief interventions or overall training time (Zeidan et al., 2010; Chen), baseline group differences (Zeidan et al., 2010), no true control group (Delgado-Pastor et al., 2015), no follow-up data collection (Delgado et al., 2010), no measurement of mindfulness (Chen; Shenesey 2013). Relaxing types of training such as MM, sham MM, and relaxation may decrease HR, but inconsistency across theoretical approaches, group assignment, control conditions, and psychological measurements obscure the relationship between HR or HRV and mindfulness-associated psychological distress reduction.

As Bamber and Schneider (2016) noted, there is no consensus across studies regarding the relationship between mindfulness and physiological measurements, nor have there been found consistent physiological correlates of mindfulness-associated psychological changes. Mindfulness training seems to increase trait mindfulness, as well as decrease (state and trait) anxiety and perceived stress. However, those changes in self-reported psychological states and traits are not validated by strong findings in the literature regarding expected decreases in sympathetic arousal. That lack of consistency could be due to numerous study limitations commonly found in mindfulness research, discussed further in the section below on criticism of mindfulness research.

Neuroimaging. In addition to peripheral measures of physiological arousal, researchers have sought support for the purported aims of mindfulness meditation through neurofunctional measures as well, such as electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI). Investigating the short-term and long-term brain changes associated with meditating can refine current cognitive models of the effects of mindfulness.

In a 2010 review, Chisea and Seretti (2010) synthesized EEG and fMRI results associated with Zen and Vispassana meditation. Zen meditation is of the breath-focused variety, and in Vipassana practitioners “scan” using focused attention on different parts of the body. Both are often collapsed into the category of mindfulness meditation. EEG results revealed an increase in alpha and theta waves during meditation, as opposed to beta activity (12-30Hz) that is typically detected during alert and attentive wakeful states. Alpha (8-12Hz) and theta (4-8Hz) are typically associated to varying degrees of relaxation and during most types of meditation (Cahn & Polich, 2006). However other evidence suggests that meditation may cause alpha blocking, a decrease in alpha power after meditating (Basar et al. 1997; Niedermeyer, 1997). Chisea and Seretti (2010) suggest alpha blocking during Zen meditation could suggest a relaxed present focus during practice. Thus, EEG results appear to be mixed, and more research is needed to fully understand the relationship between types of meditation and wave changes.

When examining fMRI studies in the same review, Chisea and Seretti (2010) also noted that bilateral activations in the rostral anterior cingulate cortex (ACC) and the dorsal medial prefrontal cortex (dMPFC), possibly reflecting regulation of attentional processes during Zen meditation (Hölzel et al., 2007). Long-term changes associated with Zen meditation showed lower activations in the default mode network while meditating, suggesting a reduction over time in the effort needed to sustain the attentional processes (Pagnoni et al., 2008). Long-term, Vipassana meditation is more associated with interopcetion and attention-related activation, such as in the PFC, the right anterior insula (Lazar et al., 2005; Hölzel et al., 2008, and the right hippocampus (Hölzel et al., 2008). In general, Chisea and Seretti (2010) noted that findings are consistent with the purported aims of two practices. That is, Zen is practiced to increase attentional focus and reduce nonreactivity to inner experience, whereas Vipassana is aimed at increasing nonjudgmental awareness of the body and is commonly used for pain management.

As discussed in the introduction above, meditation is sometimes divided into focused attention (FA) and open monitoring (OM) practices. Despite findings indicating different networks being recruited for different types of meditation, Sperduti, Marginelli, and Piolino (2012) proposed a model of central shared activity between FA and OM meditation. They note that both practices have similar goals, such as relaxation, sustained attention, and detachment from inner experience. In an activation likelihood estimation (ALE) meta-analysis, they found convergent activation in the caudate, entorhinal cortex, and medial prefrontal cortex (MPFC), all consistent with previous meditation literature (Lazar et al., 2000; Ritskes, Ritskes-Hoitinga, Stødkilde-Jørgensen, Bærentsen, & Hartman, 2003; Brefczynski-Lewis et al., 2007; Farb et al., 2007; Lutz, Greischar, Perlman, & Davidson, 2009; Bærentsen et al., 2010; Manna et al., 2010; Newberg et al., 2010). The authors of the review did not find the lateral PFC, ACC, and parietal activation reported in previous studies (such as those reviewed by Cahn & Polich, 2006). This lack of shared activity in commonly reported attention-related areas is attributed to a possible reduction in effort among more experienced meditators (Sperditu et al., 2012), such as that reported above by Chisea and Simonetti (2010). Sperduti et al. (2012) suggest the role of the entorhinal cortex during meditation may be related to its association with emotion regulation, generation of spontaneous thoughts, and monitoring the flow of thoughts. The implication of the caudate they attribute to attention regulation and response inhibition. Broadly speaking, the MPFC activation they found may be associated with self-referential thoughts. Based on these shared activations, they propose that both FA and OM meditation involve thought monitoring, self-monitoring of behavior, and interference control (such as attentional filtering).

In another review, Tomasino, Fregona, Skrap, and Fabbro (2013) used ALE to test differences in activations associated with focused attention and transcendental (mantra-based) meditation. They found focused attention-associated clusters in the medial gyrus, the left superior parietal lobe, and left insula and the right supramarginal gyrus (SMG) (all bilateral). On the other hand, transcendental meditation was more associated with right SMG, bilateral supplementary motor area (SMA), and the left postcentral gyrus activations. There were also differences between short-term and long-term meditators. Naïve meditators showed more PFC activation. The authors posit that areas recruited by beginners, such as the right SMG, may take less effort to sustain attention in experienced meditators.

An ALE meta-analysis of fMRI and positron emission tomography (PET) studies of meditation elucidated dissociable patterns for each of four types of meditation, including focused attention, mantra recitation, open monitoring, and compassion/lovingkindness (Fox et al., 2016). Convergent networks across techniques include insula, premotor area (PMA), SMA, dorsal ACC, and the frontopolar cortex. Specifically, focused attention meditation—most relevant to the current investigation—was associated with activity in the premotor cortex, dorsal ACC, and the dorsolateral PFC (dlPFC). They note these areas are associated with cognitive control functions such as monitoring performance, and regulation of attention and behavior (Carter et al., 1998, Vincent et al., 2008, Dixon and Christoff, 2012, Dixon et al., 2014a). They interpret this pattern as reflective of effortful sustained attention and self-regulation, the aims of most focused attention meditation. There were also notable deactivations, including the posterior cingulate cortex and the posterior inferior parietal lobule (Buckner et al., 2008). Previous research has strongly linked those areas with mind-wandering, episodic memory retrieval, event simulation, and semantic processing (Fox et al., 2015). The authors interpret these deactivations as indicative of reduced generation of and elaboration on spontaneous thoughts. They posit that the deactivations might also signal a suppression of the default mode network when at rest.

Although the peripheral physiological correlates of meditation remain unclear, some evidence suggests that meditation, along with other relaxing practices, may be associated with lower blood pressure, slower respiration, and heart rate changes along with reduction in anxiety. The neuroimaging literature provides more consensus on central networks underlying Zen and other focused meditation practices. Specifically, areas recruited during meditation in naïve practitioners tend to be associated with cognitive control processes such as attentional filtering, sustaining attention, response inhibition, emotion regulation, spontaneous thoughts, and self-referential thinking. Long-term meditators tend to show reduced activation in the same areas compared to beginners, suggesting reduced effort to sustain cognitive control. Overall, the findings are consistent with the goal of meditation to strengthen such skills.

Learning Outcomes

Mindfulness has the potential to improve academic performance through a few different means. Meditation's impact on anxiety and other forms of psychological distress is well documented (see above), and anxiety, especially test anxiety, is associated with lower grades (e.g., Chapell et al., 2005; Khalid & Hasan, 2009). Training programs implemented in the classroom can reduce subclinical anxiety in college students (Brown & Schiraldi, 2013), so perhaps mindfulness training can reduce anxiety and improve grades.

Mindfulness has been shown to improve grades in American elementary school students (Bakosh, Snow, Tobias, Houlihan, & Barbosa-Leiker, 2016). Additionally, Bennett and Dorjee (2016) studied the effects of MBSR training in sixth-form students (students in the UK ages 16-18 undergoing training between high school and college). The training group, compared to the control groups, showed lower depression scores, a reduction in anxiety, and higher grades.

In American college students, Mrazek, Franklin, Phillips, Baird, and Schooler (2013) found that two weeks of mindfulness training as opposed to nutrition training increased practice GRE scores (without vocabulary) by around 16%, probably by reducing mind-wandering. As Byrne, Bond, and London (2013) and Yamada and Victor (2012) posit, mindfulness is associated with increased self-regulation and learning capacity. Nonjudgmental awareness also increases emotion regulation, which can then enhance learning (Byrne et al., 2013; Rosenzweig, Reibel, Greeson, Brainard, & Hojat, 2003; Danitz & Orsillo, 2014). Thus, mindfulness may increase academic performance through both emotional and cognitive routes.

Additionally, meditation may improve attentional performance (Valentine & Sweet, 1999; Jha et al., 2007; Chambers et al., 2008). Experienced meditators perform better than non-meditators on attentional tasks related to unexpected stimuli (Valentine & Sweet, 1999; Jha et al., 2007). Chambers et al. (2008) propose a link between improved attentional performance and the common finding of psychological distress reduction. Furthermore, the improvements in attention are consistent with neurophysiological results reviewed above (Chisea & Simonietti, 2010; Sperduti et al., 2012; Tomasino et al., 2013; & Fox et al., 2016). Taken together the above results indicate that focused attention or mindfulness meditation has the potential to improve academic performance via increases in various cognitive and affective regulation skills. However, the results regarding grades are mixed due to several methodological challenges common to mindfulness studies, as reviewed below in the section on criticism of mindfulness research.

Longitudinal and Trait Outcomes

Much of the research reviewed above concerns short-term effects of meditation. However, the goals of most practitioners are to find longer-lasting changes in their attention and self-regulation. Some previously reviewed neurophysiological results highlight the autonomic and neurofunctional differences between naïve and experienced meditators, but most of the studies in those meta-analyses were correlational. It is necessary to analyze longitudinal data to make any causal claims about meditation practice time and any outcomes. A brief review of longitudinal studies below seeks convergence on trait outcomes associated with meditation.

As noted above in Virgili's (2015) work, there are some long-term effects of mindfulness. In nine studies he reviewed with follow-up data ranging from 4 to 64 weeks, a *g* of 0.60 was maintained. A meta-regression analysis showed that the follow-up interval was unrelated to the effect size. Thus, for up to 20 weeks without assigned maintenance practice, a traditional 8-week MBSR course can have lasting reduction in a variety of psychological distress measures regardless of how much later follow-up data is measured.

A randomized controlled trial of a MBSR intervention tested a variety of outcomes at pretest, post-test, 2-month follow-up, and 12-month follow-up (Shapiro et al., 2011) . At post-test they found an increase in mindfulness measured using the Mindful Attention and Awareness Scale. They also found an increase in subjective well-being measured as a composite of the 20-item Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) and the 5-item Satisfaction with Life Scale (SWLS; Diener, Emmons, Larsen, & Griffin, 1985). Participants also demonstrated increased empathy on the Interpersonal Reactivity Index (IRI; Davis, 1983). At 1-year follow-up, MBSR had larger reductions in stress on the Perceived Stress Scale (PSS; Cohen, Kamarck & Mermelstein, 1983) and larger increases in hope on the Adult Dispositional Hope Scale (ADHS; Lopez, Snyder, & Pedrotti, 2003) relative to controls. However, the interpretation of the results is limited by small effect sizes for most of the measures. Thus, there is mixed support for long-term stress reduction and increases in well-being.

In a study of temperament and character traits, Campanella, Crescentini, Urgesi, and Fabbro (2014) studied the effect of mindfulness on three different treatment groups who reported lack of experience with mindfulness meditation and no familiarity with the Temperament and Character Inventory (TCI; Cloninger et al., 1993). The three treatment groups underwent Mindfulness-Oriented Meditation (MOM) training courses consisting of 8 weekly sessions of 2 hours each. Participants experienced instructions through the active voice guidance of the instructor during weekly sessions, and also were given a CD with a recording of the instructor's voice with identical instructions. Participants took the Italian adaptation of the TCI before beginning training and then 5 weeks into the 8-week course. The control group (who did nothing) also completed the same questionnaire about 75 days apart. Participants reported how many days they used the CD to practice at home. After training they all took the Freiburg Mindfulness Inventory (FMI). All treatment groups experienced the same treatment, just at different scheduled times. At posttest, Groups 1 and 3 showed larger scores in the subscales Self Directedness, Cooperativeness, and Self Transcendence than controls. Groups 1 and 3 also showed character improvement, measured by increases over time in scores on the same scales. There were no significant between-group or within-group effects for Group 2, which the authors attributed to the fact that Group 2 practiced at home significantly less than Group 3 and somewhat less than Group 1. There were no differences between the treatment groups in their FMI scores: Group 2 reported being more mindful but did not show the same levels of character improvement on the personality inventory.

The effects of MBSR on distressed personality traits were investigated by Nyklíček, van Beugen, and Denollet (2013). Participants were residents of the Netherlands fluent in Dutch as a first language who reported personal psychological distress. The researchers measured personality using the Type D Scale-14 (Denollet, 2005), with 7 items each assessing negative affectivity (NA) and social inhibition (SI). People scoring high globally on this scale are considered as having a distressed personality type. Change in the global Type D Scale score after treatment was not significantly different between the intervention group and the wait-list control participants. However, the intervention group did show significant reductions on the subscales, even when controlling for changes in state (rather than trait) negative affect (measured using the PANAS). The authors concluded that MBSR may increase mindfulness and may reduce trait measures of distress in people with Type-D personality.

Overall, some studies report trait changes such as increases in mindfulness and reductions in trait measures of distress. Although mindfulness appears to be correlated with personality traits (Siegling and Petrides, 2014), the personality effects of meditation training are inconsistent across studies. Some have found reductions in anxious personality traits or increases in desirable traits such as cooperativeness. Although follow-up times and effect sizes vary, some trait changes can last up to 1 year after meditation training has been completed. Despite disagreement across studies regarding the specific traits, mindfulness training appears to be associated with lasting increases in well-being and pro-social traits in general.

Intervention Duration

Literature reviewed above suggests trait changes are possible following meditation training. However, some of the disagreement among studies with regard to specific trait outcomes may be due to variability in study design feature such as the duration of training. Classic Kabat-Zinn MBSR courses consist of 26 total hours of guided meditation instruction.

There are typically 8 weekly meetings, running 2.5 hrs each, ending with a weekend day-long session (Kabat-Zinn, 1990). However, other researchers reviewed below have shown smaller doses of mindfulness are useful in distress reduction.

Grossman, et al. (2004) conducted a meta-analysis of the effectiveness of MBSR courses at reducing psychological distress and alleviating symptoms of a variety of physical ailments. The shortest programs studied included 15 total hours of meditation over a period of 6 weeks. They did not report interaction between amount of time and effect size. They also noted the limits of their ability to generalize about long-term effects because all studies they reviewed featured measurement immediately post-training.

In the 30 MBSR studies analyzed by Carmody and Baer (2009), number of weekly sessions ranged from 4-10 and daily session length ranged from 1-2.5 hrs resulting in total in-class hours of practice ranging from 6-28. Not all studies included the weekend-day longer session, but among those that did, they ranged from 3-8 hrs: 17 of the 30 studies did not include the weekend session at all. Seven studies did not assign at-home mindfulness practice. Of the remaining 23 studies, weekly assigned homework meditation minutes ranged from 80-420. Effect size was unrelated to inclusion of a weekend study session, dependent measure of distress, or diagnosis of participants. They found an overall effect size across all studies of $d = 0.63$, similar to findings by other studies. The researchers also found no significant correlation between pre-post effect sizes and in-class hours. They note that the correlation ($r = -0.25$) would probably be significant with a larger sample size, as well as the surprising nature of its direction. MBSR courses with more in-class hours had smaller effect sizes. They attributed this to two outlier studies, which when removed, rendered the correlation statistically and practically insignificant ($r = -0.08$). However, as previously noted, the smallest amount of total meditation time among any of these studies is 6 total in-class hours with 80 minutes per week of assigned meditation homework.

More recently, Boettcher, Åström, Påhlsson, Schenström, Andersson, & Carlbring (2014) conducted an online mindfulness-based treatment intervention for adults meeting diagnostic criteria for any DSM-IV anxiety disorders who were unfamiliar with mindfulness meditation. Participants were assigned to an online mindfulness-training course (MTG) or a control condition (CG) of an online discussion group. MTG was asked to engage with the program at least 6 days per week for 8 weeks, while the CG were asked to participate in online discussion for the same period of time. The researchers offered CG participants the program after follow-up testing. The program measured how many of the online training modules were started but could not measure whether they were adhered to for the full time. Participants began an average of 44 out of 96 mindfulness exercises, an average of 7.3 hours over the entire 8 weeks. Participants had a larger decrease in BAI and Insomnia Severity Index (ISI) scores from pre-post in the experimental group than in the control, with a large effect sizes both within subjects and between groups. Quality of Life Inventory (QOLI) scores also improved more in the experimental group than in the control. Furthermore, number of exercises started had no significant relationship with treatment outcomes. The standard deviation of the time spent on the treatment was 33.3 minutes, but they do not report the range: it is unclear whether such brief interventions can conclusively result in clinically significant anxiety reductions.

Just how brief a frequent dose can be effective is unclear. Colzato, Sellaro, Samara, and Hommel (2015) used only one 20-minute training session to demonstrate changes in attentional filtering and top-down cognitive control. However, their research was unique compared to most reviewed, as they did not use MBSR, but studied the difference between two different types of mindfulness meditation: open monitoring (broad attention to both internal and external stimuli) and focused attention medication (local attention to one internal or external stimulus, such as breathing or a sound).

In their review, Bamber & Schneider (2016) noted a few studies that did not show significant reductions in psychological distress (using MM broadly defined instead of MBSR). Those studies reported abnormally short interventions, such as only one session, 10-minute sessions once per week, or programs lasting only 4 weeks. The current study contains many brief sessions over several weeks culminating in at least a full hour of meditation over a 9-week period. The 3-minute twice-per week participation at the beginning of each class period, though brief, lasted for most of a semester, and is hypothesized to establish meditation as more habitual than previous studies with short interventions.

Criticism of Mindfulness Research

Davidson and Kaszniak (2015) published an article in a special issue of *American Psychologist* reviewing limitations to current mindfulness research. The authors note inconsistency and often lack of clarity at every level of analysis and point in the research process. They call for more clarity in definition; consistency in conceptualization; and clarity about mindfulness as a state, trait, and procedure. Self-report accounts of mindfulness may explain different processes at different times among individuals, because meditation training changes the nature of self-reporting (Varela & Shear, 1999). Davidson and Kazniak (2015) note more detailed descriptions of mindfulness interventions are needed in the literature: participants being assigned to “mindfulness meditation” conditions for a certain period of time may vary widely across studies and it not specific enough. They discuss the conceptual issues of measuring mindfulness, including the limitations in mindfulness questionnaires generalizing well across different populations. The authors recommend caution surrounding the inconsistency of psychophysiological research and the pitfalls of reverse inference in imaging studies. Meditation practice time, which may seem straightforward, is measured inconsistently and often descriptions are not clear enough. Another problem is that very few studies use active comparison conditions alongside classic control groups, which they recommend in order to account for nonspecific features of the interventions. They also recommend how to double-blind the design by not allowing the participants or the instructor administering the intervention to know which treatment is the one of interest (although group membership is cannot be blinded).

It should be noted that although Davidson and Kaszniak (2015) emphasize the importance of active controls, Grossman et al. (2004) noted that the effect sizes for studies with active control (*Cohen's d* = 0.49) were not very different from those that did not control for nonspecific effects (*d* = 58). Thus, sham treatments may not be as important in mindfulness research as previously stated. However, in Grossman and colleagues' (2004) meta-analysis, they caution that there were few studies with active controls, yielding a small overall sample size from which these effect sizes have limited generalizability.

Rationale

Effects of MM reviewed. College students are a highly-stressed population, experiencing stress primarily from academic pressure and thoughts of post-graduation plans (Beiter, et al., 2015). Mindfulness meditation is a simple, universally-available resource with the potential to reduce this distress (e.g., Carmody & Baer, 2009). Mindfulness does not appear to have differing effects for people with or without different diagnoses (Carmody & Baer, 2009), so the research in clinical populations generalizes well to healthy samples and vice versa. Not only does it work well for diverse populations, but MM (including MBSR and other techniques) can have longer-lasting impacts on traits (rather than states) after posttraining measurement (Campanella, Crescentini, Urgesi, & Fabbro, 2014; Nyklíček, van Beugen, & Denollet, 2013; Shapiro et al., 2011; Virgili, 2015). The neurophysiological mechanisms for the demonstrated psychological effects are not well understood. Mindfulness may affect physiology, but the results are ambiguous and inconsistent (Bamber & Schneider, 2016; Davidson & Kaszniak, 2015; Kok et al., 2013; Ospina et al., 2007).

Control condition. Active controls are not common (Davidson & Kaszniak, 2015), and may or may not be necessary to control for the nonspecific treatment effects (Grossman et al., 2004). Active control conditions may be similar to treatment in directing focus. A control condition that does not give any directions about focus can be useful in isolating attentional deployment involved in meditating, whereas other aspects such as nonjudgmentalness are more difficult to isolate. Thus, in the current study, a passive control condition is used similar to the use of resting state data collection in neuroimaging studies to ensure there is enough difference between conditions.

Impacts on learning. Mindfulness meditation is effective not only for stress reduction and change in personality traits but may have effects on learning. Byrne, Bond, and London (2013) and Yamada and Victor (2012) theorize mindfulness components such as awareness, attention, and self-reflection increase self-regulation and learning capacity. Other researchers (Byrne et al., 2013; Rosenzweig, Reibel, Greeson, Brainard, & Hojat, 2003; Danitz & Orsillo, 2014) posit nonjudgmental awareness increases emotion regulation, which then enhances learning. Thus, we measured grades as a post-intervention outcome. To account for cognitive skills, we used the FFMQ, which measures cognitive components of mindfulness that some researchers such as Byrne et al. and Yamanda and Victor link to academic achievement.

Duration. As demonstrated above, MBSR courses as well as other MM intervention are effective at smaller doses than original, including for a total of 6 hours (Boetcher et al., 2014; Carmody & Baer, 2009; Jain et al., 2007; Bamber & Schneider, 2016). Brief mindfulness interventions can produce immediate cognitive changes by inducing a state of mindfulness (e.g., Anglin, Pirson, & Langer, 2008; Djikic, Langer, and Fulton-Stapleton, 2008), and practicing inducing the state leads to changes in traits (e.g., Kabat-Zinn 1982, 1990 1992; Baer, 2003). Homework outside of in-class training may (Campanella, Crescentini, Urgesi, & Fabbro, 2014) or may not be relevant (Carmody & Baer, 2009) to effect on psychological distress. Although we do not plan to measure follow-up data, the fact that effects of a full MBSR course last up to a year later (Shapiro et al., 2011) suggests that frequent brief training sessions may still be able to induce changes in traits, such as trait anxiety or mindfulness, over several weeks' time. Thus, the proposed study seeks to investigate the effects of brief in-class (each class day) formal practice over 10 weeks on mindfulness, anxiety, and grades.

Overview of current study. In order to mitigate some of the challenges outlined above, and to bring clarity to some unresolved issues in the literature, we designed a twice-per-week in-class 3-min mindfulness intervention study. Students were assigned to either listen to a pre-recorded mindfulness body scan meditation or to sit silently for 3 minutes at the beginning of class time 2 days per week. With a mobile application, students measured their heart rates as an indicator of stress after meditation practice and before exams. We measured their trait mindfulness and trait anxiety at pretest and then again at the end of 5 and 10 weeks. Participants also reported their valence and arousal before and after each 3-min meditation or silence. With this design, we aimed to increase external validity by including an in vivo intervention psychophysiological measurement. We also sought to bolster internal validity by using well-established measures of mindfulness and trait anxiety, described in detail in Methods, as well as inclusion of no-treatment control group. Goals of the study also include testing the effects of lower doses of mindfulness on academic, physiological, and cognitive and affective trait outcomes.

Hypotheses

Hypothesis 1. After 5 weeks of participation, we expect MM to have a lower average HR (measured immediately after meditation or silence) than C, and to find an even greater difference at 10 weeks. We expect a similar reduction in anxiety, measured at 5 and 9 weeks.

Hypothesis 2. We predict MM will show increased trait mindfulness at 5-weeks post-test (and even greater at 10 weeks) compared to C, who will show lower to no differences. We also expect FFMQ posttest, heart rate, and anxiety to partially mediate the relationship between meditation and grades. Namely, we predict meditation will lower average HR, increase FFMQ scores, and lower average STAI scores at 5 and 9 weeks, which will then predict final grades (Figure 1).

Hypothesis 3. We expect MM to have higher final grades than C. We also expect to find a linear relationship between time spent in meditation practice outside class and grades (accounting for past GPA as a covariate). We also expect there to be a negative correlation between practice outside of class and heart rate, as well as between "homework" and post-test anxiety.

Methods of the Current Study

Participants

Students in Psychology Research Methods, Cognitive Psychology, Cognitive Neuroscience, Social Psychology, Clinical Psychology, Honors Introduction to Psychology, and two sections of Motor Learning and Performance (a course offered in the School of Kinesiology) participated. Students volunteered and signed consent forms: 181 out of the original 201 participated in at least one survey. Participation numbers varied in each survey, and those patterns are described more below in the Missing Data section of Results. Volunteers were assigned to one of two different conditions: mindfulness meditation (MM) or true control (C; silence). Groups were balanced in terms of anxiety (STAI score) and mindfulness (FFMQ) scores on a pre-test. After random assignment research assistants achieved this by ensuring that there was no systematic relationship between group membership and trait outcomes. They performed t-tests to determine there was no difference between groups on pretest anxiety or mindfulness (as well as the FFMQ subscales). A few participants were reassigned to ensure that balance. The principal investigator remained blind to the group assignment process and confidential participant identifier assignment. Participants in both groups took a pre-test, then MM participants listened to a 3-minute-long pre-recorded message of a body scan meditation, asking them to draw attention to different body parts in sequence and remain in open awareness of whatever they find. The control group sat silently for the same amount of time.

Participants who took the pretest consisted of 117 female students; 8% were first-year students, 18.67% were sophomores, 41.33% juniors, and 2.67% 5^{th}-year ("super") were seniors.

Two reported “other” for classification: one was a non-degree-seeking student, and another was seeking a second bachelor’s degree. Of 144 who disclosed ethnicity, 4 identified as Hispanic/Latino(a). Self-reported race statistics for 160 students were as follows: 12.5% African American/Black, 3.13% East Asian/Asian American, and 80% White/Caucasian. Some students used the option to select multiple racial identifications: one student identified as Asian and White, three as Native American and Black, and three as Native American and White. No students identified as Pacific Islander or South Asian. Of 161 who answered about their meditation history, 49.06% reported having meditated before, while other roughly half of students reported never having meditated. Left-handed students accounted for 10.40% of the sample. The medical questionnaire revealed few serious illnesses: 14 students have had head injuries, none have had stroke or cardiovascular disease, two reported epilepsy or seizures, one reported having had neurological surgery, and 5 reported other neurological problems. Diagnoses of common psychiatric illnesses, including 9 with depressive disorders (most co-morbid with anxiety), 6 with anxiety disorders (all but one co-morbid with depression), 3 with Attention Deficit-Hyperactivity Disorder (ADHD) (one participant with co-morbid anxiety), 2 with Post-traumatic Stress Disorder (PTSD), and 2 with bipolar disorders. Commonly reported medications included oral contraception (10.98%, 18 participants), ADHD medications (12 participants), selective serotonin reuptake inhibitors (SSRIs) (9), anti-histamines (5), acne medications (4), antibiotics (3), synthetic thyroid hormones (3), bupropion (Wellbutrin) (2), unspecified depression medications (4), and unspecified anxiety medications (4). One participant each reported medications reported taking the following medications: medication for irritable bowel syndrome (IBS), anti-nausea medications, Fisteride (to treat prostate conditions and male pattern baldness), Cymbalta for fibromyalgia, Xyrem (narcalepsy), Diazepam (anti-colvulsant), Topomax (migraines), ibuprofen, asthma medication (Montelukast), an unspecified mood stabilizer, an unspecified sleep aid, an unspecified muscle relaxer, unspecified migraine medication, unspecified anti-inflammatories probiotics, melatonin, and glucosamine supplements.

Materials

We measured HR using the Instant Heart Rate mobile app (Azumio, 2017), which has been shown to be a valid and reliable measure of heart rate (Mitchell, Graff, Hedt, & Simons, 2016). At pretest, we administered a demographics questionnaire, a medical screening form, the FFMQ, and the trait form of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Baggm & Jacobs, 1983). We also requested and obtained GPA information from the registrar with permission from the students. We measured trait mindfulness using the FFMQ and STAI before participants begin practicing, and again at the end of the 5- and 9-week study periods. We also noted score in the course at the end of the semester. For the mindfulness intervention, we used a body scan meditation mp3 file from the UCLA Mindfulness Center.

Procedure

A research assistant explained that a study is being conducted to examine the effects of either silence or listening to an audio file before class on their cognition, emotions, and final course grade. Minor deception was used, in that mindfulness was not explained in order to blind participants and the research assistant to which treatment is of interest to the principal investigator and avoid a placebo effect. Participants were given the opportunity to read, ask questions about, and sign an informed consent form to indicate willingness to participate. After returning to class with a signed consent form, participants took the pre-test questionnaires online outside of class, and the researchers requested their cumulative GPAs from the Auburn University Office of the Registrar. Students were then given the first few minutes of class to complete some pre-intervention questions asking about mood and state mindfulness. After either listening to a 3-minute meditation track or sitting quietly, they then answered the same questions as well as reported their heartrate as measured (immediately after participating) by the Instant Heart Rate mobile application. They were asked to participate two class days per week (each class day in Tuesday-Thursday classes, and Monday and Wednesday in Monday, Wednesday, and Friday classes). During the pre-intervention questions each day, we also asked how many minutes of meditation they engaged in the day before. Participants measured their HR immediately following their meditation practice and also immediately before in-class exams (along with one 1-9 question about anxiety level) in order to provide some ecological validity to our assessments. Some courses included only online exams, so those students were encouraged via Canvas LMS announcements to participate at home before starting the exam. Students who arrived at class late were not allowed to enter the classroom to avoid disturbing other participants. After each exam, students were also asked to offer qualitative reflections on their expectations and impression of the course, their thoughts and feelings about exam performance, and their thoughts and feelings about the study. Due to IRB protocol modification approval wait times, the study was started a few weeks after the beginning of the Spring 2018 semester and in-class participation was conducted for 9 weeks instead of the planned 10.

Results

Analytic Strategy

Linear mixed-effects regression (LMER) was chosen for longitudinal data because compared to traditional methods such as repeated measures ANOVA, it can better accommodate missing data, it allows for more control over terms used to model change over time, it is flexible across timing of observations, and it allows for different types of predictors (e.g., dynamic or static, continuous or discrete) (Long, 2012). The current study is also well-suited to this method because of a multi-level nesting structure—participant is nested within group, which is nested within class, nested within teacher, which is nested within research assistant. Thus, we used long format data and modeled participant ID as a random effect. Other random and fixed effects are described in greater detail for each hypothesis below. The 'lmer()' function from the 'lme4' R package (Bates et al., 2018) was used for analysis. Null-hypothesis statistical testing (NHST) was used for coefficients of LMER models and Akaike's Information Criterion (AIC) (Akaike, 1973) was used as a measure of relative effect size. For models excluding any longitudinal variables, the general linear model (GLM) is used in wide format data instead of LMER.

Missing Data

To reduce missing in-class participation data, the variables were collapsed across days within each week. Thus, only 9 observations of variables such as HR or Valence remain instead of 18. Using the complete.case function in R 3.4.4 (Urbanek, Bibiko, & Iakus, 2016), the resulting dataset included revealed 74.91% complete cases of data. Missing data patterns for each variable are presented in Tables 3-6. Missing data assumptions of missing completely at random (MCAR) and missing at random (MAR) were not formally tested due to computing limitations. Specifically, tests for missing mechanisms such as Little's Test for MCAR (Little, 1988)—using packages such as 'BaylorEdPsych' (Beaujean, 2012) or 'MissMech' (Jamshidian, Jalal, & Jansen, 2015)—cannot be completed on datasets as large as the one in the current study. Analyses using missing data are always subject to untestable assumptions (Ugarte, 2009). When using linear mixed effects regression (LMER) as reported below, missing data can be ignored when the missing data mechanism is MCAR or missing not at random (MNAR) (Long, 2012). According to Long, is ignoring missing data is not valid when data are not missing at random. However, he also notes that assuming MAR when that is not the true missing data mechanism probably has much less impact on the validity of inference than other common inaccuracies, such as model misspecification (e.g., leaving out relevant predictors). Thus, we follow Long's recommendation to state that all LMER analyses reported below assume data are MAR and conclusions are valid given that assumption. When using traditional linear model functions in R, rows with a single missing data point are omitted from analysis. Following Long (2012)'s recommendations, we left in rows containing missing data on response variables. He argues that if response variables are analyzed separately, that varying sample sizes are tolerable. However, allowing sample size to vary based on static variables (such as demographics measured only once) is not tolerable. Thus, 'na.omit()' was used to remove cases with missing static variables, as Long recommended.

For analyses that use wide format data (no longitudinal variables), multiple imputation (5 iterations and 5 imputations) was implemented using the R package 'mice' (Buuren & Groothuis-Oudshoorn, 2010). The 5 imputed datasets were then pooled, creating a new dataset with averaged estimated values for the missing observations. Again, formal testing of missing data assumptions is unnecessary, as Enders (2010) posits that multiple imputation can successfully deal with both MCAR and MAR. Henceforth the original wide dataset is referred to as MISS and the pooled imputed dataset as IMP. Hypotheses were tested using both datasets unless otherwise reported. In all analyses using MISS, R automatically excluded missing cases of the variables used. Thus, *n* varies between tests using this dataset. For ordinary least squares (OLS) linear models, effect sizes were calculated using Cohen's f^2, and power was calculated using f^2 in the 'pwr' R package (Champley et al., 2018).

Assumptions

Assumptions of models below include correct specification, residuals with mean of 0, normality of residuals, and constant error variance. Inclusion of predictor variables was evaluated using a multimodel approach. Models with the lowest AIC relative to other candidates were selected for further testing. Normality of residuals was tested by inspecting a Q-Q plot (standardized residuals as a function of theoretical quantiles) for each model and conducting a Shapiro-Wilk test for normality (significance indicating a violated assumption). Constant error variance was tested using scale-location plots (the square root of the residuals as a function of the model's fitted values). Outliers were identified by calculating the median plus and minus twice the interquartile range (IQR): any values more extreme than those fences were changed to the cutoff values. For linear mixed effects models that violated any of the assumptions, robust linear mixed effects regression was used from the 'robustlmm' package (Koller, 2018). Violations of assumptions are reported below for each model, as well as remedial test results if applicable.

Hypothesis 1

We predicted that after 5 weeks of participation, MM would have a lower average HR (measured immediately after meditation or silence) than C, with an even greater difference at 10 weeks. We expected a similar pattern of anxiety reduction at 5 and 9 weeks.

Different models were compared to select appropriate predictors to include alongside Group as a primary fixed effect in predicting HR. Model H1.a1 included Group, Time, and a Group by Time interaction as fixed effects, as well as Time and Subject ID as random effects. Model H1.a2 included participants nested within class into the random effects part of the model. Model H1.a3 included all of the above components, as well RA included as a fixed effect. Lastly, Model H1.a4 included the same predictors as H1.a3 except for Teacher instead of RA. AIC and weight of evidence were compared as measures of relative effect size and model plausibility: Model H1.a4 had the smallest AIC and highest weight of evidence, indicating it was the most plausible model of those compared. Thus, future assumptions testing used model H1.a4. The analysis included 669 observations of the response and data from 130 participants. The mean of the residuals of the model were near zero ($M_{resid} = 1.55*10^{-14}$). According to both a Q-Q plot and a significant Shapiro-Wilk test, the residuals of the model are not normally distributed. The assumption of constant variance is met according to an examination of the square root of the residuals plotted as a function of the model's fitted values. Although LMER may be robust to violated assumptions (Long, 2012), more robust mixed models exist to account for such extreme violations as this one. The package ‘robustlmm’ was used to conduct robust mixed models in order to correct for violated assumptions. Default LMER and rLMER output in R does not produce p-values for t-ratios associated with parameter estimates. In fact, Long (2012) recommends against NHST in such models. Instead, he argues, researchers should focus on the magnitude of the estimates themselves, as well as the t-ratios, to determine practical significance. However, we also conducted significance tests of the t-ratios. When using Group to predict HR, accounting for Time nested within Participant nested within Class as random effects, as well as Teacher as an additional fixed effect, we found no effect of group on HR ($\hat{\beta}$ = -1.77, *SE* = 2.07, p = 0.57). There was also no effect of time with other predictors held constant ($\hat{\beta}$ = 0.24, *SE* = 0.15, p = 0.10). Thus, this part of Hypothesis 1 was unsupported. Regardless of the use of NHST cutoffs, those effects would be negligible.

Next, a similar process was used to search for group differences and model the trajectory of anxiety across time. Model H1.b1 included Group, Time, and a Group by Time interaction as fixed effects, as well as Time and Subject ID as random effects. Model H1.b2 included participants nested within class into the random effects part of the model. Model H1.b3 included all of the above components, as well RA included as a fixed effect. Lastly, Model H1.b4 included the same predictors as H1.b3 except for Teacher instead of RA. AIC and weight of evidence were compared as measures of relative effect size and model plausibility: Model H1.b4 had the smallest AIC and highest weight of evidence, indicating it was the most plausible model of those compared. Thus, future assumptions testing used model H1.b4. The analysis included 352 observations of the response and data from 160 participants. The mean of the residuals of the model were near zero ($M_{resid} = 3.69*10^{-15}$). According to both a Q-Q plot and a significant Shapiro-Wilk test, the residuals of the model are not normally distributed, thus a robust LMER was conducted. There was no difference between groups in terms of anxiety ($\hat{\beta}$ = -0.50, SE = 1.72, p = 0.77), nor did anxiety scores significantly change over time ($\hat{\beta}$ = -0.30, SE = 0.19, p = 0.11). This part of hypothesis 1 is unsupported..

Hypothesis 2

We predicted MM would show increased trait mindfulness at 5-weeks post-test (and even greater at 10wks) compared to C, who will show lower to no differences. We also expected FFMQ posttest, heart rate, and anxiety to partially mediate the relationship between meditation and grades. We expected meditation to lower average HR, increase FFMQ scores, and lower average STAI scores at 5 and 10 weeks, which would then predict final grades (see model in Figure 1).

We first tested group differences in mindfulness using LMER, using the same process as in hypothesis 1. According to the AIC and weight of evidence, the most plausible model included Group, Time, a Group by Time interaction, and Teacher as fixed effects, as well as Time and Subject ID (nested within class) as random effects. The analysis included 352 observations of the response and data from 160 participants. Thus, future assumptions testing used model H1.b4. The mean of the residuals of the model were near zero (M_{resid} = $8.00*10^{-14}$). Assumptions of normality and constant variance were also met. There was no significant effect of Group ($\hat{\beta}$ = -1.03, SE = 2.01, p = 0.61) nor of Time ($\hat{\beta}$ = -0.38, SE = 0.26, p = 0.14). This part of the hypothesis was not supported.

In order to test the multiple mediation model, we began by predicting final grades using Group in the wide format datasets, which revealed non-normal errors and no group differences in either MISS, $t(150)$ =-1.85 (Wald's test $p = 0.066$) or IMP, $t(179) = -0.20$ (Wald's test $p = 0.84$). Thus no more direct effects from the multiple mediation model were tested in either dataset. Hypothesis 2 was not supported, and results were consistent between datasets. Some of the other direct effects of the proposed mediation model necessitate long-format data accounting for the longitudinal nature of collection of variables such as total mindfulness score, anxiety score, and HR. However, our dataset does not support a multi-level mediation model needed to assess changes over time in mediation effects. Such models are overidentified and thus impossible to test.

Hypothesis 3

We predicted MM would have higher final grades than C and that there would also be a linear relationship between time spent in meditation practice outside class and grades (accounting for past GPA as a covariate). Additionally, we expected there to be a negative correlation between practice outside of class and heart rate, as well as between "homework" and post-test anxiety.

We conducted a t-test to test for group differences in grades, which was reported for Hypothesis 2 as well. There were non-normally distributed errors and no significant differences between groups in either dataset. In MISS, multiple iteratively-weighted least squares (IWLS) regression was conducted—to account for non-normally distributed errors and inconstant error variance—using total time spent in meditation or silence outside of class (homework) and GPA to predict final grade. GPA significantly predicted final grade, $\hat{\beta} = 6.23$, $t(141) = 7.43$ (Wald's test $p < 0.001$), but total homework minutes did not, $\hat{\beta} = -0.0006$, $t(141) = -0.76$ (Wald's test p =

0.44). In IMP, the same relationship held for both GPA, $\beta\hat{}$ = 4.56, $t(143) = 3.92$ (Wald's test $p <$ 0.001), and homework, $\beta\hat{}$ = -0.0006, $t(143) = 3.92$ (Wald's test $p = 0.54$).

To test for the strength and direction of relationship between homework and changes in anxiety and HR, Pearson's product-moment correlation (r) was used in the wide format data. Homework was positively correlated with the change in HR from weeks 2-9 in MISS, $r = 0.29$, $t(163) = 3.83$, $p = 0.0002$ ($1\text{-}\beta = 0.96$), but not in IMP $r = -0.070$, $t(179) = 3.83$, $p = 0.35$ ($1\text{-}\beta =$ 0.15). Homework had no relationship with change in anxiety from pre to final post in MISS, $r =$ 0.080, $t(163) = 1.02$, $p = 0.31$ ($1\text{-}\beta = 0.17$), nor in IMP, $r = -0.047$, $t(179) = -0.62$, $p = 0.53$ ($1\text{-}\beta$ $= 0.095$).

Thus, Hypothesis 3 was only partially supported in that GPA predicted final grade, a finding consistent across datasets. Reductions in anxiety were associated with greater practice time as expected, although this relationship was not replicated in the imputed dataset. Homework's relationship with HR was also inconsistent across datasets.

Exploratory Results

Quantitative results. In addition to MISS and IMP, an additional dataset was created using instructor-reported anonymous final grades from students who did not participate, which were added to the existing list of final grades from participants. In total the dataset includes grades for 296 students: 81 in the control group, 73 in the experimental group, and 139 non-participants. No other information was collected or is available about the nonparticipants. Assumptions were tested for an ANOVA of differences among the three groups' final grades. The overall model violated assumptions of normally distributed residuals and constant error variance, so IWLSR was used with two contrast-coded categorial predictors for group comparisons. The control group had a significantly higher final grade than students who did not participate in the study, $t(293) = 2.16$, $p = 0.03$. However, the difference between the meditation group and the non-participants was not significant, $t(293) = 0.47$, $p = 0.64$. The experimental and control groups were not significantly different from each other in terms of final grade, either, $t(293) = -0.92$, $p = 0.36$. There may be a difference in final grade between students who participated and did not participate in the study, but not between study groups.

Additional exploratory analyses involving total self-reported time spent in meditation (the sum of "homework" and minutes in class), click count (the number of times a participant clicked or tapped in attempt to advance the survey past the meditation track or silent instruction page), HR, and FFMQ subscales were conducted. Results are described below for each dataset.

MISS. In the missing dataset, several relationships not initially hypothesized in the proposal were significant. For example, the total amount of self-reported time spent in meditation (or silence) was significantly correlated with observing at week 5, $r = 0.23$, $t(98) = 2.36$, $p = 0.02$ ($1\text{-}\beta = 0.63$), and week 9, $r = 0.23$, $t(97) = 2.33$, $p = 0.021$ ($1\text{-}\beta = 0.63$). Time spent in meditation or silence was also correlated with the difference between FFMQ total score from weeks 5-9, $r = 0.16$, $t(163) = 2.04$, $p = 0.043$($1\text{-}\beta = 0.53$), the difference between observing between weeks 1-5, $r = 0.18$, $t(163) = 2.38$, $p = 0.018$($1\text{-}\beta = 0.64$), and the difference between acting with awareness from weeks 1-5, $r = 0.16$, $t(163) = 2.36$, $p = 0.047$($1\text{-}\beta = 0.53$). Click count at week 9 was significantly positively correlated with time spent in meditation or silence as well, $r = 0.22$, $t(92) = 2.14$, $p = 0.035$($1\text{-}\beta = 0.56$). Additionally, the difference in click count from weeks 1-9 was correlated with time spent in meditation, $r = 0.21$, $t(164) = 2.78$, $p = 0.0061$($1\text{-}\beta = 0.77$), as was the difference in click count from weeks 5-9, $r = 0.25$, $t(164) = 3.33$,

$p = 0.0011$($1\text{-}\beta = 0.90$). Total meditation time was correlated with the change in HR from weeks 1-9 as well, $r = 0.25$, $t(163) = 3.33$, $p = 0.0011$($1\text{-}\beta = 0.90$). Practice time is associated with change in total mindfulness, the observing subscale, the awareness subscale, change in HR from pre-post, and click count (a possible proxy measure of impulsiveness).

Exam day data collection was not included in the multiple imputation because of limitations in computing power and time. Thus, analyses involving HR and self-reported anxiety (on a scale of 1-9, 9 indicating most anxiety possible) on exam days were conducted only using MISS. In classes with only a mid-term and a final exam, mid-term scores were included with exam 2, and final exam scores were included with exam 4 because of their similar timing. When using anxiety before exam 2 to predict exam 4 anxiety, the overall model was significant, $F(1, 47) = 19.12$, $p < 0.001$, $R^2 = 0.29$ (Cohen's $f^2 = 0.41$, $1\text{-}\beta = 0.99$), as was the slope for exam 2 anxiety, $b = 0.59$, $t(47) = 4.37$, $p < 0.001$. All assumptions were met for that regression. However, when using HR before exam 2 to predict HR before exam 4, in a similar regression, two outliers with significant leverage led us to use IWLSR instead. With the more robust regression, exam 2 HR significantly predicted exam 4 HR, $b = 0.93$, $t(28) = 9.18$ (Wald's test $p < 0.03$). No other relationships were found using exam day anxiety and HR scores. Participants' anxiety and HR from previous exams best predicted final exam anxiety and HR.

IMP. In the imputed dataset, many of the effects above dissipated. Total time spent meditating was found to be negatively correlated with STAI score at week 5, $r = -0.21$, $t(179) = -2.90$, $p = 0.0042$ ($1\text{-}\beta = 0.81$), as well as with nonreactivity at 9 weeks, $r = -0.15$, $t(179) = -1.99$, $p = 0.048$ ($1\text{-}\beta = 0.52$). Time spent in meditation or silence was also positively correlated with acting with awareness at week 5, $r = 0.20$, $t(179) = 2.76$, $p = 0.0064$ ($1\text{-}\beta = 0.77$), as well as with the difference between click count from weeks 5-9, $r = 0.22$, $t(179) = 2.85$, $p = 0.0049$ ($1\text{-}\beta =$

0.84). The change in HR from weeks 1-9 was significantly positively correlated with total time spent in silence or meditation, $r = 0.18$, $t(179) = 2.41$, $p = 0.017$ ($1\text{-}\beta = 0.68$). Practice time is associated with anxiety at the first posttest, nonreactivity at final posttest, awareness at the first posttest, the change in click count between posttests, and the change in HR from weeks pre to final posttest. None of the exploratory correlations or linear models were consistent between datasets. Attempts to conduct LMER models exploring changes in exam day HR or anxiety over time resulted in overidentified models.

Long-format data. Using LMER for longitudinal data (dynamic variables), we searched for group differences in other measurements. Notably, we found a significant effect of Time ($\hat{\beta} = -0.06$, $SE = 0.027$, $p = 0.028$, 1058 observations, $N = 153$) on click count when modeling students nested within class as random effects and including a time by group interaction as fixed effects, suggesting that click count slightly decreased over time. Using the same fixed and random predictors, we also found that post-meditation valence increased over time, indicating an elevated mood ($\hat{\beta} = 0.050$, $SE = 0.015$, $p = 0.001$, 1058 observations, $N = 153$). Although there was no significant effect of group on valence ($\hat{\beta} = 0.25$, $SE = 0.17$, $p = 0.15$), there was a group by time interaction ($\hat{\beta} = -0.048$, $SE = 0.023$, $p = 0.037$), indicating that the effect of group decreased with time. Similarly, post-meditation arousal increased over time as well ($\hat{\beta} = 0.083$, $SE = 0.025$, $p = 0.0080$, 1058 observations, $N = 153$) when accounting for the same fixed and random predictors as the above models. Additionally, investigations of the FFMQ subscales revealed some significant differences. When accounting for participants nested within class as random effects as well as teacher, time, group, and a group by time interaction as fixed effects, we found a marginally significant increase in Acting with Awareness over time ($\hat{\beta} = 0.10$, $SE = 0.052$, $p = 0.05$, 352 observations, $N = 160$). For Nonreactivity, a simpler model using only time nested within participants as a random effect and time, group, and their interaction as fixed effects revealed a significant increase over time ($\hat{\beta} = 0.11$, $SE = 0.051$, $p = 0.040$, 347 observations, $N = 161$). Thus, our intervention may have caused small but statistically significant changes in in-class affect and more stable traits.

Qualitative results. Students were invited to provide qualitative reflections following receiving the grade for each exam, as well as during the final posttest of the study. After the second or mid-term exam 12 of 24 respondents reported satisfaction with their exam grade, 19 with the course overall, 10 with the research, and four listed specific effects of participation. After Exam 3, 19 of 48 respondents reported satisfaction with the recent exam grade, 34 with the course overall, and 21 with the research participation, 20 of whom described specific effects of the research (such as aiding focus or increasing feelings of calm). Of the 91 students who offered reflections after the final exam, 49 expressed positivity about the exam and the class, respectively. Many more (58) reported positive thoughts or feelings about the research activity, and 65 described specific perceived effects of the study. Some students reported neutral feelings (few negative) about the research or their classes, and many did not engage in the reflection surveys at all. Overall, most students who wrote reflections looked positively on the research experience, and some reported insights into a relationship between the practice and their course performance or everyday lives.

Discussion

In order to investigate the effects of an in vivo mindfulness practice program on trait changes throughout a semester, we conducted a twice-per-week in-class 3-min mindfulness intervention study. Students either listened to a pre-recorded mindfulness body scan meditation or to sit silently for 3 minutes at the beginning of class time twice per week. Students measured their heart rates as an indicator of stress after meditation practice and before exams using a mobile application. We measured their trait mindfulness and trait anxiety at pretest and then again at the end of 5 and 10 weeks. We aimed to examine the effects of lower doses of mindfulness meditation on academic, physiological, and cognitive and affective trait outcomes.

For Hypothesis 1, we tested the difference between groups in heart rate and across time, while accounting for variability due to a group by time interaction, class, and teacher. Using robust LMER, we found group differences or change over time. We also found the same when predicting anxiety, although the traditional LMER was used due to assumptions having been met. Hypothesis 1 was not supported.

In Hypothesis 2, we predicted that the meditation group would show increased trait mindfulness at 5-weeks post-test (and even greater at 10wks) compared to the silence group, who will show lower to no differences. Using LMER, we tested the difference between groups in mindfulness across time, while accounting for variability due to a group by time interaction, class, and teacher. There was no significant effect of group or time. We also predicted that trait mindfulness posttest, heart rate, and anxiety will partially mediate the relationship between meditation and grades. In other words, we expected meditation to lower average heart rate, increase trait mindfulness scores, and lower average trait anxiety scores at 5 and 10 weeks, all of which would then partially predict final grades (see model in Figure 1). The multiple mediation model was not supported because there were no group differences in final grade and thus no hypothesized main direct effect. Multilevel mediation models were also overidentified and thus unsupported by our dataset. Thus, Hypothesis 2 was not supported.

We predicted the meditation group would have higher final grades than the silence group in Hypothesis 3. We found such no such group differences. We also predicted a linear relationship between voluntary meditation outside of class (homework) and grades, while controlling for cumulative GPA. In both MISS and IMP, GPA did predict final grade as expected, but the homework did not. Additionally, we predicted a negative correlation between practice outside of class and heart rate, as well as between “homework” and post-test anxiety. In the wide-format data (not longitudinal: time points are separate variables), we found a greater reduction in heartrate from the pretest to the first posttest in those who completed more homework in both datasets. In only the imputed dataset, homework was associated with lower anxiety scores at the final posttest. Thus, this part of hypothesis 3 was supported, but results are inconsistent across datasets .

Dynamic Effects

Dynamic effects refer to the use of long-format data and LMER to account for within-subjects variability of time points nested within participants, as well as additional levels of nesting in some models. Using this approach, the main hypotheses were not supported. The mixed models revealed no group differences or changes in time in HR, anxiety, or mindfulness. The intervention could have been generally ineffective at such low doses, or perhaps the conditions were too similar to each other.

As Bamber and Schneider (2016) noted, HR results are often inconsistent across mindfulness and meditation studies. In our case, this may be due to low statistical power because of a large proportion of missing data. However, even when using methods insensitive to missing data, such as LMER and robust LMER, Hypothesis 1 was not significant. Other issues such as technical problems arose with HR measurement throughout the study, and many students used alternative applications or smartwatches to report their HR. It is unknown how many students did this, as many also manually entered their HR instead of providing the requested screenshots of the Instant Heart Rate Application. Additionally, students were at different levels of rest at measurement time. Some had waited for the class for a several minutes, or even in the hall for an hour or more between classes. Others ran to class from across campus. Thus, there was great variability in HR measurement that may have influenced our results.

The lack of differences between groups in posttest anxiety scores may indicate that such a short duration of mindfulness practice does not influence this trait. However, other possibilities include problems with student compliance. Despite our asking them about the faithfulness with which they carried out our instructions, it is difficult to ascertain the seriousness with which the students approached the study. Psychological distress reduction is the most robust finding in mindfulness studies (e.g., Carmody & Baer, 2009), yet our measure of distress showed no difference between groups. Another possibility is that state measures were influenced more so than the trait; however, we did not use the state form of the STAI in order to keep in-class surveys brief and out-of-class surveys few.

Similar limitations may explain our finding no group differences in total trait mindfulness. Previous literature (e.g., Shapiro et al., 2011) has shown a positive relationship between meditation practice and trait mindfulness. Many meta-analyses, such as that of

Grossman and colleagues (2004) find no relationship between the duration of a meditation training program and the effectiveness at reducing distress. However, both the cumulative assigned practice time (54 min) and in-class session (3min) duration in our study fall below the durations studied by the researchers in the literature reviewed above. Perhaps our intervention was below the as-yet-unknown effective minimum dose of mindfulness needed to induce trait effects.

No group differences were found among in-class observed variables, such as click count, valence, and arousal, nor in the FFMQ subscales. However, click count decreased over time, and valence and arousal both increased over time. Acting with Awareness and Nonreactivity both increased over time as well. However, the effects are small. Although they are statistically significant, they may not carry practical benefits worth sacrificing class time.

The paucity of group differences in dynamic variables in our study could be due to a genuine lack of intervention effectiveness. Other possibilities include issues such as too low a dose of the intervention, lack of state anxiety measures, or unaccounted for dispositional variables.

Static Effects

Static variables refer to those measured only once, i.e., wide-format data. More generally, I will continue to use static effects to refer to analyses conducted with the wide format data. Some analyses were performed using time points or difference scores of dynamic variables in the wide dataset because they would be inappropriate in long format, such as with correlations, whose degrees of freedom would be unduly inflated by such an analysis. No group differences in final grade were tested in three wide datasets: MISS, IMP, and the grade-only dataset.

Hypothesized correlation tests and exploratory analyses involving homework, click count (the number of times a participant clicked or tapped in attempt to advance the survey past the meditation track or silent instruction page), heart rate, and mindfulness subscales (observing, describing, acting with awareness, nonjudgment, and nonreactivity) were also conducted in MISS and IMP.

We found a lack of group differences in final grade when testing the assumptions of our multiple mediation model from Hypothesis 2. The amount of meditation assigned or even completed voluntarily may not constitute enough to change grades in the face of the variety of other variables that can account for their variability. We used GPA as a covariate to control for this, but it is only one among many such possible covariates. Adding others made the model unidentified. We did not document differences in teacher style or coursework difficulty, nor are we able to make any conclusions about student motivation or effort. Final grades seem to have been more a result of dispositional factors, as is discussed more below when comparing participants to nonparticipants. However, exploratory analyses comparing participants' grades to anonymous final grades of students in the same classes who did not participate in the study found that the meditation group had higher final grades than students in those classes who did not participate in the study, but there was no significant difference between the experimental and control groups' grades. Participation may have led to increased grades. However, other possibilities may explain the difference between the meditation group and the nonparticipants. For example, dispositional variables such as student motivation or personality variables such conscientiousness may contribute to this difference between experimental participants' and nonparticipants' final grades. We were unable to explore any of those potential relationships due to lack of any other data from non-participants.

MISS. A modest positive correlation was found between homework and the change in total mindfulness score pre-post, as well as from the first posttest to the second. Homework was also correlated positively and to a similar degree with observing at weeks 5 and 9, the difference between observing from pretest to first posttest, and the difference between awareness from the pretest to the first posttest. Homework also correlated with click count at the final posttest, the difference between click count from pre to both the first and second posttests. Homework also correlated positively with the change in heartrate from pretest to final posttest. Thus, with more minutes spent voluntarily meditating or sitting silently outside of class, we find greater change in total mindfulness, greater observing of inner experience, greater increase in observing, as well as a greater increase in awareness. Click count (a possible proxy for impatience) was lower and decreased more in those who spent more time meditating or sitting silently on their own, Finally, heartrate reduced more in those who spent more time in meditation or silence.

Although above we did not find between-group differences in HR, it appears there were still within-subjects differences. The relationship between HR and meditation or silent time outside of class and could reflect changes induced by assigning designated silent or contemplative time. As indicated by the qualitative data discussed below, the assigned contemplative time may inspire some students to seek out the practice more on their own. On the other hand, the lower HR may reflect dispositional differences that are accentuated by being reminded to continue or increase their own calming or contemplative practices. Perhaps lower HR throughout a semester and increased contemplative practice may be due to some personality trait not measured in the study.

Taken together, these correlational findings seem to suggest that contemplative time outside of class plays an important role with cognitive (mindfulness and subscales), affective (anxiety), and physiological (HR) variables. However, as discussed above, they may all be related due to the presence of dispositional variables not measured in this study. Another consideration is that time spent meditating was self-reported and may thus be biased by demand characteristics or some other bias. Nonetheless, this relationship warrants further research to understand the link between these variables and how they could be harnessed to improve student well-being and academic performance.

In addition to correlations, exploratory linear models were conducted as well using exam day data. Exam day data collection had more missing data than the regular twice-per-week collection, due to irregularities in announcements and unreliable research assistant presence in at least one class. Furthermore, compliance was more difficult to obtain in classes with online exams. Because of its pattern of missing data, conclusions drawn from exam day data may have benefitted from multiple imputation. However, limitations in computing power rendered impractical wait times for multiple imputation, so only variables most relevant to the original hypotheses were imputed. Nonetheless, we used the missing dataset to perform some analyses using exam day data, which included heart rate measurement and self-reported anxiety on a scale of 1-9 (9 being the most anxious possible) immediately before taking each exam, starting with Exam 2 of 4 (or in some classes, the midterm). Exam 2 anxiety ratings predicted exam 4 anxiety ratings, and the same relationship held up for respective heart rate on average. The lack of relationship with any other tested variables (such as between HR and anxiety) may reflect the challenges in obtaining exam day data relative to regular in-class data described above. Additionally, students may feel more rushed on an exam day, for example.

IMP. Despite the increased sample size and power, we found fewer significant exploratory results in the imputed dataset. In it, we found greater homework times correlated modestly with lower anxiety. Homework also correlated with lower nonreactivity, which seems counterintuitive, as meditation and mindfulness are supposed to increase a feeling of resistance to impulses and decrease reacting to inner experience. Greater meditation time also was associated with greater acting with awareness at the time of the first pretest, greater reduction in click count between the two posttests, and greater reduction in heartrate between the two posttests in this dataset as well as in MISS.

Some statisticians (such as Graham et al., 2007) recommend a minimum of 30 imputed datasets with at least 10 imputations and caution against bias in imputation. Our 5 imputations of 5 iterations each—restricted by computing limitations—demonstrated consistent results with the original dataset for a priori hypotheses. This suggests our imputed may not have had great bias in estimating the missing values. Thus, future longitudinal investigations into mindfulness could benefit from this approach to missing data. However, exploratory hypotheses showed differences across datasets, which could reflect random variations rather than true effects.

In all, relationships found during exploratory analyses yielded more credence to within-subjects changes in a variety of variables throughout the semester. Specifically, practice time outside of class appears to be linked to many other observed variables, such as heart rate, click count, and some FFMQ subscales. However, the results were less consistent across datasets, warranting caution in interpretation. Future studies could examine these relationships further through a priori hypotheses and more intentional study design surrounding them, especially in the case of the incidentally collected click count.

Qualitative Responses

Reflections by students after each exam and at the conclusion of the study further contextualized some of the quantitative findings. After each exam, students were invited via Qualtrics survey delivered through Canvas announcement by the instructor to offer qualitative reflections on their expectations and impressions of the course, their thoughts and feelings about exam performance, and their thought and feelings about the study. Participation in the reflections increased with each exam, starting with as few as 24 and ending with 91 respondents. In the final reflection, some students in the control group reported using their phones for other purposes during participation, despite being asked not to do so. For example, some mentioned listening to music or playing mobile games. However, the majority of the students in the silence group reported sitting silently and thinking about their days, letting their minds wander, planning, or even praying, and most expressed enjoyment. Yet others who sat silently reported boredom or frustration with sitting still and quiet for 3 minutes: some reported it made them aware of their anxiety, but a few others reported a calming effect. Mentions of feeling calm, relaxed, or focused were much more often found in the meditation group, however, with only a few exceptions. Not all in the meditation group enjoyed hearing the same recording each day. Some respondents expressed a desire for the study to feature a variety of mindfulness activities or speakers, whereas one student reported a comforting feeling of using the same track (i.e., "it grew on me."). One student offered a typical response from those who enjoyed the study and felt it calming, "I have enjoyed this study. I come from a very high energy class before the survey and it is nice to calm down and connect with my surroundings. I also enjoy the sound of the voice. It is quite soothing and helps to calm and allow for directions to be followed." Another wrote about common complaints, "During participation I answered a couple of questions, sat silently for 3 minutes, and then took my heart rate and answered a few more questions. It made me kinda anxious to just sit for three minutes, I almost never am not doing something." Others were neutral, e.g., "I don't think it really changed my experience in this course, and no, it dint impact any other classes." Some other students wrote about a changed perspective toward everyday experiences (although not academic ones), "It did not change my experience of the course, but I did find myself being more aware outside of class. When I would walk to class, I would notice the wind blowing in my face. I came to really enjoy and appreciate my walk to class. I made a point to put my phone in my backpack and just enjoy my time outside."

Future, more sophisticated explorations of these qualitative data could guide alternative interpretations of the quantitative results and suggest avenues for further research. For example, time spent in contemplative practice outside of class correlates modestly with variables representing cognition, affect, and physiology, a finding not hypothesized, yet significant to the overall aims of the project. Future investigations may ask participants for a richer description of their out-of-class practice, such as keeping a meditation journal. The students who reported a more mindful outlook on their daily experiences or increased focus and calm in the classroom have an enriched subjective experience of their semester that they attribute to participation in this research. None reported feeling particularly harmed by the study, but instead often had neutral feelings about its effects. Although some students' reflections indicate personal growth or significance gleaned from the research participation, they were not the norm. Furthermore, the quantitative results suggest effects are possibly too small to justify using class time for such participation.

General Limitations

The participants volunteered from a convenience sample of a participant pool, raising questions of external validity. Students at Auburn University are of relatively homogenous backgrounds with regards to socioeconomic status and ethnicity compared to other institutions in the region. The nature of the institution itself, being a doctoral-granting high-research-activity university, may influence generalizability as well. Some aspects of this study may be replicated at the author's future institution in order to test its generalizability in different student samples.

Other than the limitations to specific inferences discussed above, more general limitations to the study's internal and external validity occurred. The aim of balancing ecological validity with experimental control allowed several sources of variability into the study design that might be less problematic in laboratory studies. Students were nested in different classes taught by different teachers on different days and at different times. Some students were in two or even three courses in which the study was being conducted but were asked to participate in only one.

Due to scheduling availability, two different research assistants (RAs) of different genders recruited for and facilitated participation in different classes: one female RA (who was an undergraduate student) presided over research in Social Psychology and Clinical Psychology, while the male RA (who had already graduated with a bachelor's degree) served as a facilitator in the rest of the classes. There may have been differences in the degree of fidelity to which the RAs carried out principal investigator instructions.

Statistical methods could account for some of these differences, such as including a random effect of time points nested within students, and another indicating students being nested within classes. Additionally, teacher and RA can be added as fixed effects. However, in no case was a single model with all of those effects identified. Teacher or RA could be added as fixed effects in addition to Group, Time, and their interaction, but not both. AIC was used to determine which predictors resulted in the best model fit, but rank deficiency prohibited the addition of other predictors that could have caused variability. No significant differences were found in the above analyses among teachers or between RAs, but the inclusion of teacher specifically accounted for variability that allowed time differences to be revealed.

Longitudinal data collection poses common problems that were also present in our study. Compliance is difficult to achieve. Students were compensated with extra credit commensurate with the percentage available surveys they completed throughout the semester and were reminded by email of whether they had recently participated. The blinding setup made it difficult to communicate with participants in convenient ways, as different survey links for the experimental and control groups were used, necessitating sending survey links to each student individually. Despite instructions to pin the survey link to the top of their inboxes, some students in the qualitative reflections still complained of difficulty in finding the correct link in class.

The pseudo-double blind was limited as well. Some students asked RAs why they were being asked to sit silently. Perhaps through treatment diffusion they had learned from the experimental group students to expect a media file during the 3-minute intervention period. Still, such concerns brought to RAs were relatively rare, so they may not have affected the majority of students.

Some of the above limitations could be mitigated in the future by conducting a similar study in two sections of the same course taught by the same instructor. A third party with experience in mindfulness meditation training could provide in-person guided meditations to both, which may hold student attention better than relying on them to resist distractions while using mobile devices to participate.

Because of the issues with the heart rate collection described above, replications of some of this work may include inviting some study participants into the laboratory for more controlled physiological data collection. Although autonomic assessment in the classroom seems to have wide applicability, it is difficult to obtain reliable measurement across so many different devices. Future grant applications could request standardized devices for students to use during participation to improve HR assessment outside of the laboratory.

Conclusions

Students from psychology and kinesiology undergraduate courses were assigned to practice mindfulness meditation or silence twice a week in class for 3 minutes. Students measured their heart rates on mobile devices as an indicator of stress after meditation practice and before exams. We measured their trait mindfulness and trait anxiety at pretest and then again at the end of 5 and 10 weeks. Group predicted final grades. Additionally, time spent meditating or sitting in silence voluntarily outside of class was negatively correlated with heart rate, anxiety, and click count, a proxy for impulsiveness. Overall, trait changes were not induced by meditating although some exceptions include increases in acting with awareness in the experimental group. Brief sessions of 3 minutes twice per week may be below the as of yet unknown minimum effective dose of meditation. Despite robust distress reduction in the literature, in the current study, group assignment did not appear to affect our measures of distress (HR and STAI), nor did we find significant changes in total trait mindfulness. Additionally, qualitative data lends itself to a variety of exploratory analyses to further contextualize quantitative results, with some conducted and reported above. Some students reflected on subjective improvements of experience of everyday life and coursework, but our results indicate instructors should use caution when including meditation or another type of break into the classroom at the expense of instruction time. Perhaps future researchers and instructors seeking to use mindfulness in the classroom could aim to integrate interventions more with the instructional material or course objectives to avoid allowing quiet time to interfere with class activities.

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Tables

Table 1. Mindfulness Questionnaires

Questionnaire	Authors	Factors	State or Trait	Number of Items	Alpha
Cognitive and Affective Mindfulness Scale Revised (CAMS-R)	Feldman, Hayes, Kumar, Greeson, and Laurenceau (2007)	Four: Attention, Present-focus, Awareness, and Acceptance/Non-Judgment	Trait	12	0.81
Five-Facet Mindfulness Questionnaire (FFMQ)	Baer et al., 2008	Five: Observing, Describing, Acting with Awareness, Nonjudgmentalness, Nonreactivity	Trait	39	0.72-0.92
Freiburg Mindfulness Inventory (FMI)	Bucheld, Grossman, and Walach (2001); Walach, Bucheld, Buttenmüller, Kleinknecht, and Schmidt (2006)	One: Mindfulness	Trait	30	0.93
Kentucky Inventory of Mindfulness Skills (KIMS)	Baer, Smith, and Allen (2004)	Observing, describing, acting with awareness, and accepting without judgment	Trait	39	0.82-0.87
Langer's Mindfulness Scales (LMS)	Boder & Langer (2001); Langer (2004)	Attention and Awareness of Present Moment Experiences	Trait	21	0.85
Mindful Attention Awareness Scale (MAAS)	Brown and Ryan (2003); Carlson and Brown (2005)	Awareness of the present	Trait	15	0.82
Philadelphia Mindfulness Scale (PMS)	Cardaciotto, Herbert, Forman, Moitra, and Farrow (2008)	Present-moment awareness and acceptance	Trait	20	0.87
Southampton Mindfulness Questionnaire (SMQ)	Chadwick et al. (2008)	Single factor: mindfulness	Trait	16	0.85
Toronto Mindfulness Scale-Trait Version (TMS-T)	Davis, Lau, and Cairns (2009)	Curiosity and Decentering	Trait	15	0.95
Toronto Mindfulness Scale—State Version (TMS-S)	Lau et al. (2006)	Curiosity and Decentering	State	15	0.95
State Mindful Attention Awareness Scale (MAAS)	Brown and Ryan (2003)	Same as their trait measure	State	15	0.82

Table 2. Meta-analysis of Mindfulness and Distress Reduction. Reproduced from Table 1 in Carmody and Baer (2009) with written permission from Dr. Carmody.

Table 1
Effect Sizes, Session Data, and Other Characteristics of Published Studies of the Effects of Mindfulness-Based Stress Reduction (MBSR) on Psychological Distress in Adults

Study	*N* for MBSR goup	Participants	Psychological distress measures	Control group	Mean pre-post *d*	Mean between-group *d* at post	Number of sessions	Session length hours	All-day session hours	Total in-class hours	Weekly assigned practice minutes
Anderson et al., 2007	39	Healthy adults	BAI, BDI, PANAS	Wait list	.58	.01	8	2.0	0	16	–
Carlson & Garland, 2005	63	Cancer patients	SOSI, POMS	None	.50	–	8	1.5	3.0	15	270
Carlson et al., 2003	42	Cancer patients	SOSI, POMS	None	.20	–	8	1.5	3.0	15	–
Carmody & Baer, 2008	174	Stress/illness	BSI, PSS	None	.83	–	8	2.5	6.0	26	270
Chang et al., 2004	28	Students	PSS	None	.51	–	8	2.5	0	20	270
Davidson et al., 2003	25	Healthy adults	STAI	Wait list	.64	.42	8	2.5	7.0	27	360
Gross et al., 2004	20	Organ transplant	CES-D, STAI	None	.51	–	8	2.5	0	20	225
Grossman et al., 2007	39	Fibromyalgia	HADS	Support	.62	.36	8	2.5	7.0	27	315
Jain et al., 2007	27	Students	BSI	Wait list relaxation	1.37	.61 .53	4	1.5	6	12	–
Kabat-Zinn, 1982	51	Chronic pain	POMS, SCL-90R	None	.71	–	10	2.0	0	20	270
Kabat-Zinn et al., 1992	22	Anxiety	BAI, BDI, HAM-A&D	None	.97	–	8	2.0	7.5	23.5	270
Klatt et al., 2008	22	Working adults	PSS, PSQI,	Wait list	.61	.10	6	1.0	0	6	80
Koszycki et al., 2007	26	Social anxiety	BDI, social anxiety	CBGT	1.07	-.75	8	2.5	7.5	27.5	180
Kutz et al., 1985	20	Psychotherapy	POMS, SCL-90R	None	.72	–	10	2.0	0	20	315
Marcus et al., 2003	21	Substance use	PSS	None	.14	–	8	2.5	0	20	342
Minor et al., 2006	44	Parents	POMS, SOSI	None	.62	–	8	2.0	0	16	270
Ramel et al., 2004	22	Mood, anxiety	BDI, STAI	Wait list	.34	.44	8	2.0	3.5	19.5	259
Randolph et al., 1999	78	Chronic pain	BSI, POMS	None	.19	–	8	2.0	6.0	22	270
Reibel et al., 2001	104	Mixed medical	SCL-90R, SF36-MCS	None	.57	–	8	2.5	7.0	27	120
Robinson et al., 2003	24	HIV+	POMS, PSS	TAU	.10	.11	8	2.5	8.0	28	315
Rosenzweig et al., 2003	125	Medical students	POMS	Didactic	.21	.20	10	1.5	0	15	120
Roth et al., 1997	79	Mixed medical	BAI, SCL-90R	None	.83	–	8	2.0	0	16	210
Roth & Robbins, 2004	68	Mixed medical	SF36-MCS	No treat	.97	1.11	8	2.0	0	16	222
Sagula & Rice, 2004	39	Chronic pain	BDI, STAI	Wait list	.72	.49	8	1.5	0	12	140
Shapiro et al., 2007	54	Counsg students	PANAS, PSS, STAI	No treatment	.87	.66	8	2.0	0	16	–
Speca et al., 2000	53	Cancer	POMS, SOSI	Wait list	.75	.60	7	1.5	0	10.5	–
Tacon et al., 2004	27	Breast cancer	STAI (state)	None	1.38	–	8	1.5	0	12	–
Tacon et al., 2003	9	Heart disease	STAI (state)	Wait list	.94	1.34	8	2.0	0	16	–
Vieten & Astin, 2008	13	Pregnant women	CES-D,PANAS, PSS,STAI	Wait list	.82	.17	8	2.0	0	16	140
Williams et al., 2001	35	Healthy/stressed	SCL-90R	Education	.47	.47	8	2.5	8.0	28	420

Note. CBGT = Cognitive behavioral group therapy; HIV = human immunodeficiency virus; TAU = treatment as usual; BAI = Beck Anxiety Inventory; BDI = Beck Depression Inventory; BSI = Brief Symptom Inventory; CES-D = Center for Epidemiologic Studies Depression Scale; HADS = Hospital Anxiety and Depression Scale; HAM-A = Hamilton Rating Scale for Anxiety; HAM-D = Hamilton Rating Scale for Depression; PANAS = Positive and Negative Affect Scales; POMS = Profile of Mood States; PSQI = Pittsburgh Sleep Quality Index; PSS = Perceived Stress Inventory; SCL-90R = Symptom Checklist 90 Revised; SF36-MCS = Short Form 36 Mental Component Summary; SOSI = Symptoms of Stress Inventory; STAI = State Trait Anxiety Inventory.

Table 3. Missing data counts for GPA, final grade, class, and teacher. Participants are students participating in different courses: “class,” and “teacher” refer to the course in which they participated and the instructor of that course. The total number of participants was 181.

Variable	**Number Missing**
GPA	35
Grade	23
Class	0
Teacher	0
Total	181

Table 4. Missing data counts FFMQ items at the pretest, first posttest, and final posttest. The total number of participants was 181.

Number of Missing Cases

Item	**Pretest**	**Posttest 1**	**Posttest 2**
1	20	80	82
2	20	80	83
3	20	80	82
4	20	80	82
5	21	80	82
6	20	80	82
7	20	81	82
8	20	80	82
9	21	80	84
10	21	80	83
11	20	80	83
12	20	80	83
13	20	80	84
14	20	80	83
15	20	80	83
16	20	80	83
17	21	80	83
18	21	80	83
19	20	80	84

20	21	80	83
21	20	81	83
22	20	80	84
23	20	80	84
24	20	81	83
25	20	81	83
26	20	81	83
27	20	82	83
28	20	81	84
29	20	81	83
30	20	81	83
31	21	81	84
32	21	81	83
33	21	81	84
34	21	81	83
35	21	81	83
36	21	81	83
37	22	81	83
38	21	81	83
39	21	81	84

Table 5. Missing data counts for STAI items at the pretest, first posttest, and final posttest. The total number of participants was 181.

Number of Missing Cases

Item	**Pretest**	**Posttest 1**	**Posttest 2**
1	21	82	83
2	21	82	83
3	21	82	83
4	22	82	83
5	22	82	83
6	21	82	84
7	21	82	83
8	21	82	83
9	21	82	83
10	22	82	83
11	21	82	83
12	21	82	83
13	21	82	83
14	22	82	83
15	21	82	84
16	21	82	83
17	21	82	83
18	21	82	83
19	21	82	83
20	21	82	83

Table 6. Missing data counts and percentages for in class participation. Val1 and 2 indicate valence before and after meditating, respectively. Ar1 and 2 indicate arousal before and after meditating, respectively. Min is self-reported contemplative practice outside of class so far in the week, HR is heart rate, Att refers to self-reported attention, and NonJ is self-reported nonjudgment of inner experience. Aware is self-reported awareness of inner experience, Open refers to awareness of external stimuli, and Faith refers to self-reported faithfulness in carrying out the instructions. The total number of participants was 181.

Number of Missing Cases

Variable	**Wk 1**	**Wk 2**	**Wk 3**	**Wk 4**	**Wk 5**	**Wk 6**	**Wk 7**	**Wk 8**	**Wk 9**
Val 1	49	38	50	45	51	62	53	90	87
Ar 1	49	38	50	45	51	62	53	90	87
Min	52	39	51	46	53	63	55	91	88
Clicks	51	39	51	45	51	62	53	90	87
HR	97	94	102	97	100	105	101	124	120
Val 2	53	40	52	45	51	62	53	90	87
Ar 2	53	40	52	45	51	62	53	90	87
Attn	53	40	52	45	51	62	53	90	87
NonJ	53	40	52	45	52	62	53	90	87
Aware	53	40	52	45	51	62	54	90	87
Open	53	40	52	45	51	62	53	90	87
Faith	53	40	52	45	51	62	53	90	87

Table 7. Exam day data for Exams 2, 3, and 4. In classes with only a mid-term exam and a final exam, the mid-term is placed in the Exam 2 category, and final in Exam 4 due to their proximity in time to those exam numbers in the other courses. Self-reported anxiety was on a scale of 1-9 (9 being the most anxious possible). HR refers to pre-exam heart rate measurement. The total number of participants was 181.

Number of Missing Cases

Variable	**Exam 2**	**Exam 3**	**Exam 4**
Anxiety	131	151	81
HR	139	163	96

Table 8. Means and standard deviations for experimental and control groups in the dataset with missing cases (MISS), the imputed dataset (IMP), and the dataset including only anonymous grade data for participants and non-participants.

		Group					
		Control		**Experimental**		**Non-Participants**	
Dataset	**DV**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
GRAD	Grade	89.26568	7.957721	87.67608	8.894844	84.05461	13.46905
MISS	Grade	89.88248	7.187717	86.92175	9.637043		
IMP	Grade	85.54727	10.80744	85.38732	11.30029		
MISS	Wk 5 HR	79.86585	13.62444	77.61429	11.61457		
IMP	Wk 5 HR	79.20312	12.78663	78.91176	14.04609		
MISS	Wk 9 HR	79.16667	13.50245	80.58929	12.78747		
IMP	Wk 9 HR	81.88542	15.47859	83.48824	15.41258		
MISS	WK 5 Anxiety	49.39286	5.269737	48.56098	8.792181		
IMP	Wk 5 Anxiety	49.16667	12.78663	47.16471	14.04609		
MISS	Wk 9 Anxiety	50.22807	4.582644	50.22807	9.092695		
IMP	Wk 9 Anxiety	50.04167	15.47859	49.57647	15.41258		
MISS	Wk 5 FFMQ	121.1607	10.4877	116.2439	12.14656		
IMP	Wk 5 FFMQ	121.6771	6.018684	118.5294	7.773347		
MISS	Wk 9 FFMQ	120.9649	11.8502	116.2105	19.66085		
IMP	Wk 9 FFMQ	121.4688	5.086446	118.6471	7.515661		

Figures

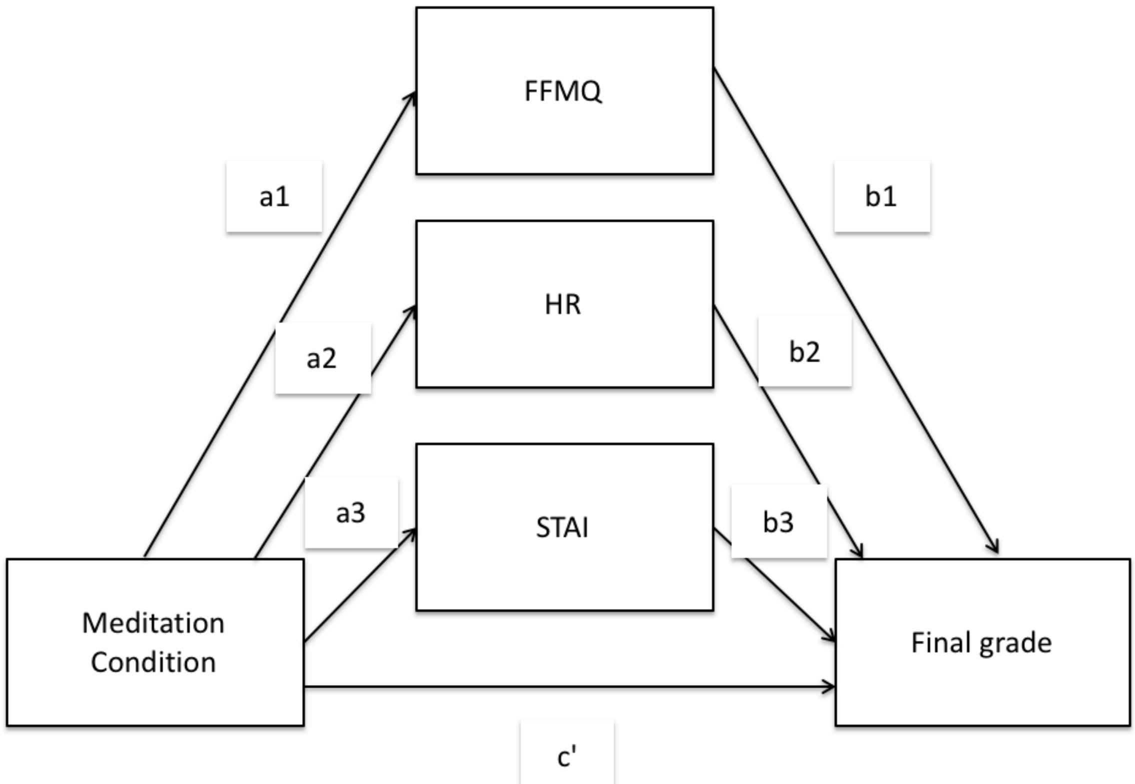

Figure 1. Hypothesized multiple mediation model

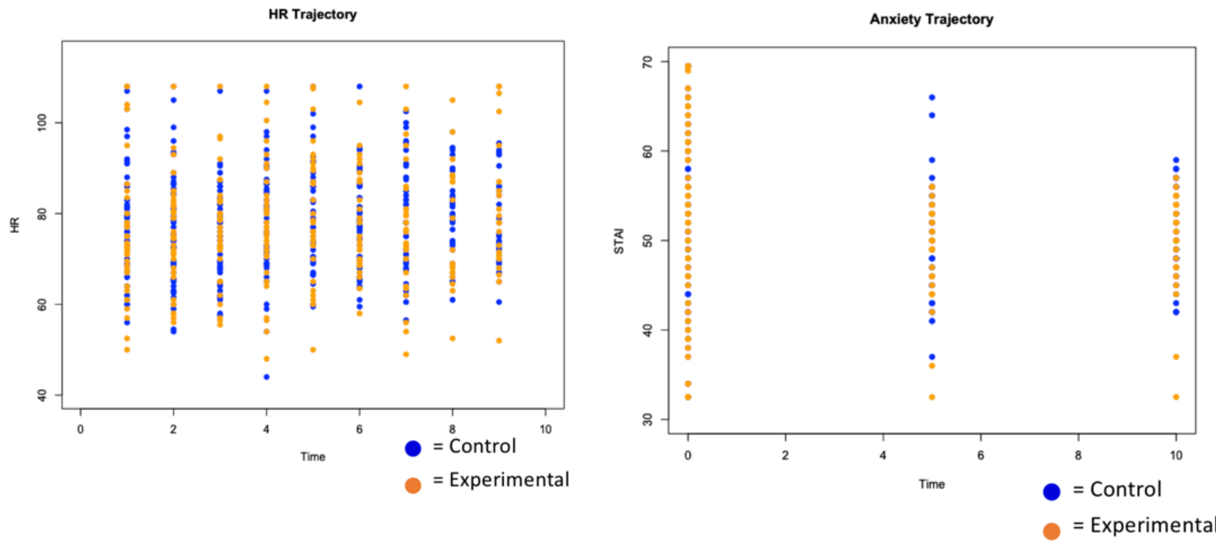

Figure 2. Hypothesis 1 results: plots of time by HR and anxiety from the longitudinal dataset, labeled by group.

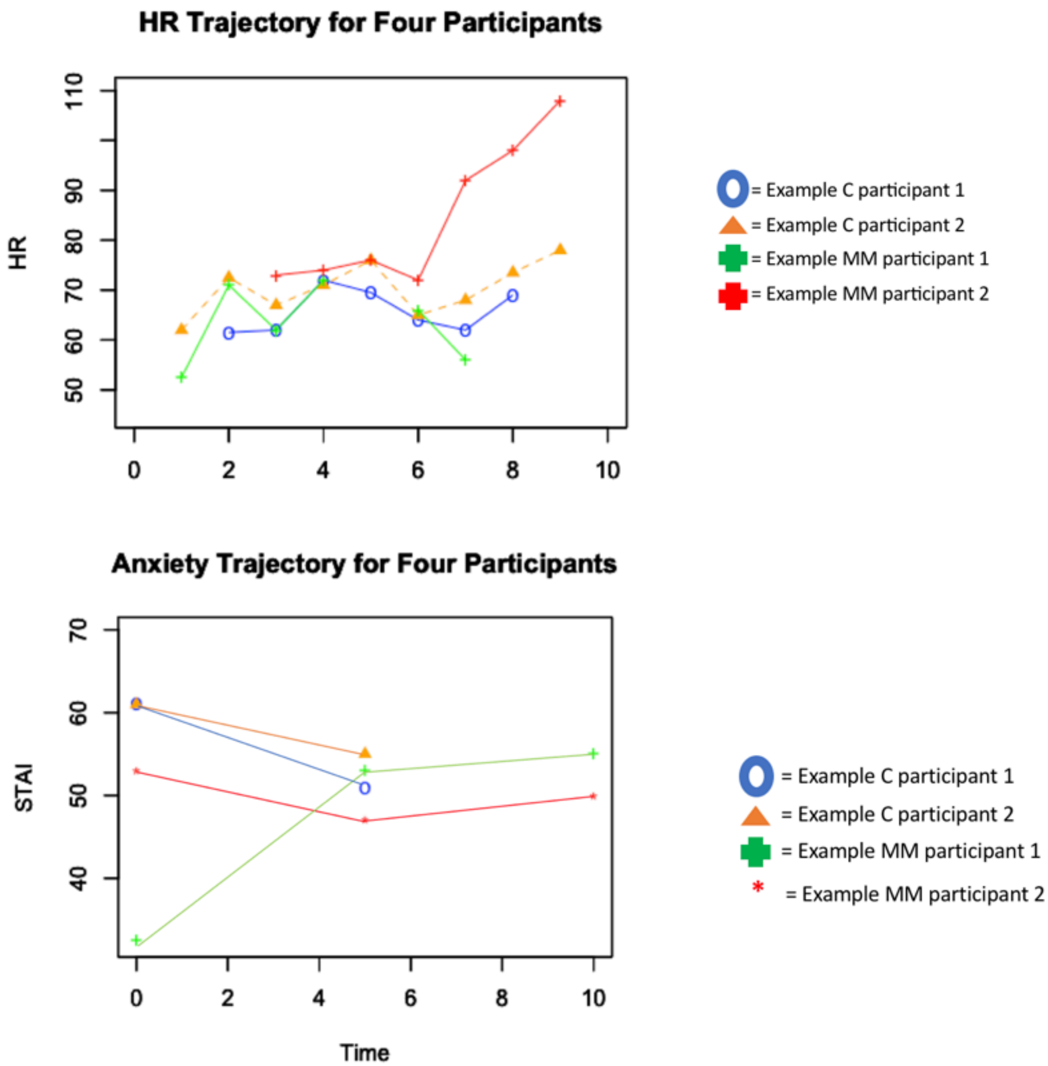

Figure 3. Hypothesis 1 results: trajectories of example participants' HR and anxiety.

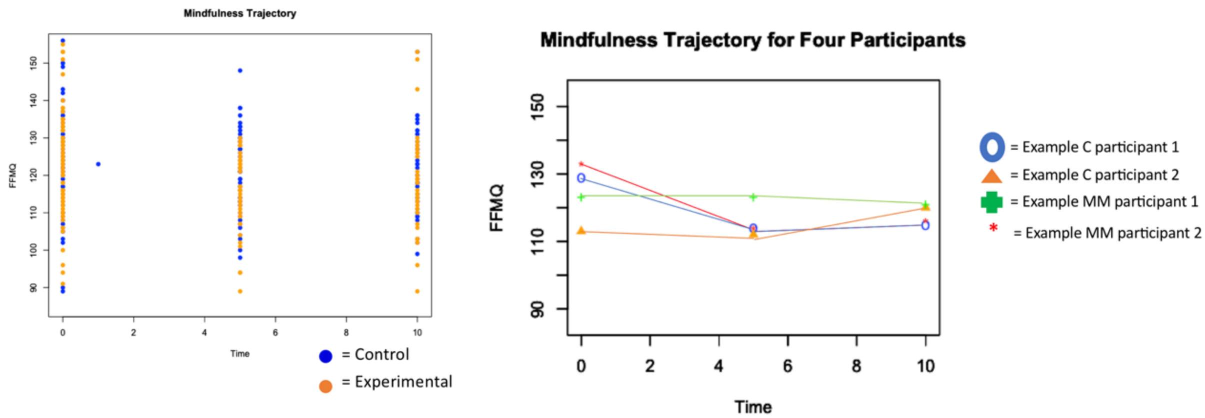

Figure 4. Hypothesis 2 results: plot of time by mindfulness from the longitudinal dataset, labeled by group, and a plot of trajectories for example participants' mindfulness.

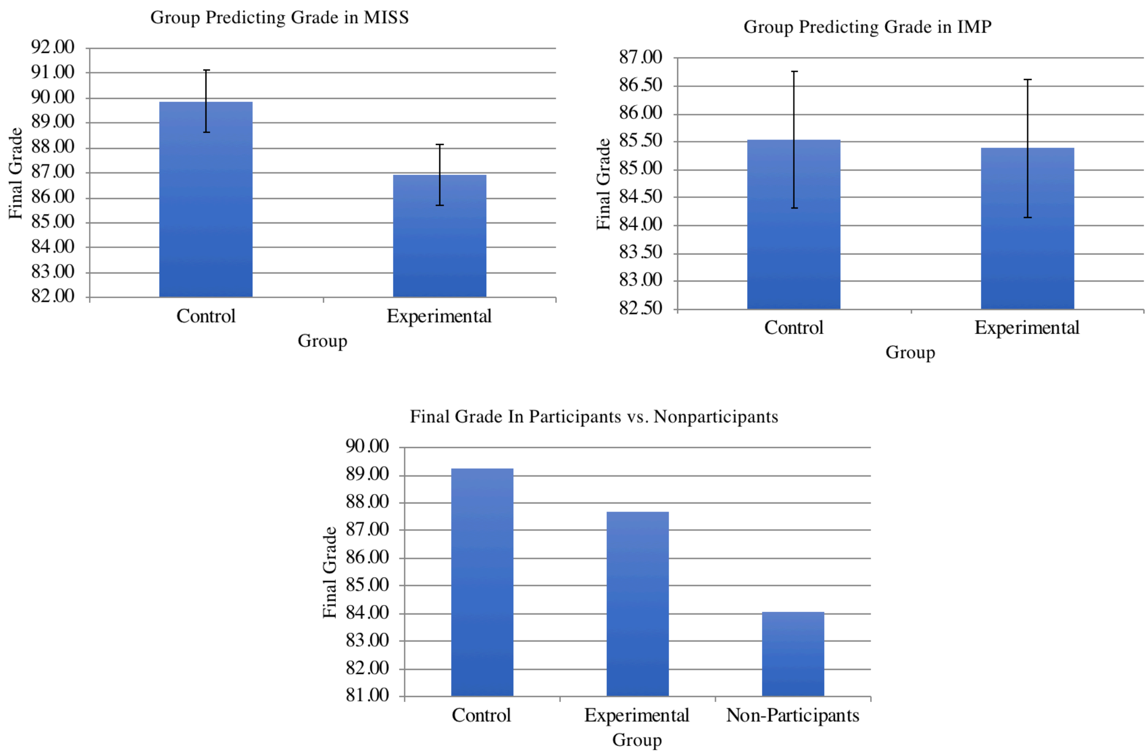

Figure 5. Hypothesis 3 and exploratory results: group comparisons of final grade in the missing and imputed datasets (Hypothesis 3), and participant groups compared to nonparticipants in the anonymous grade-only dataset (exploratory).

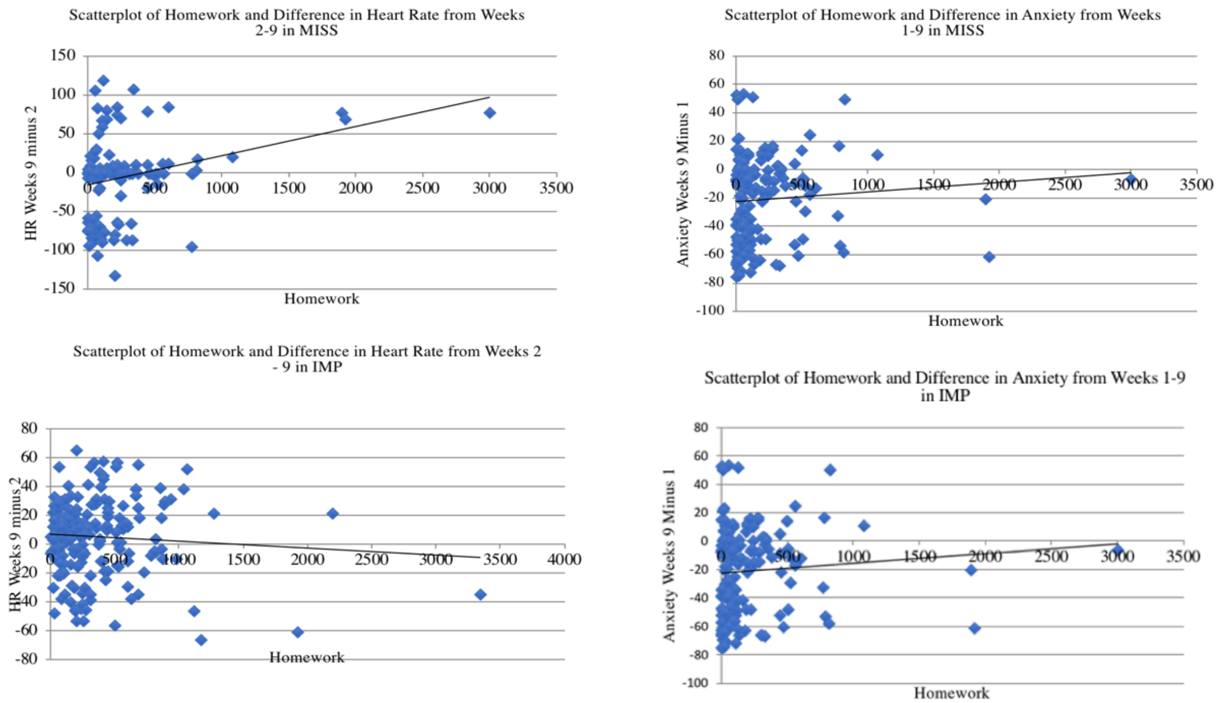

Figure 6. Hypothesis 3 correlational results in both the missing and imputed datasets.

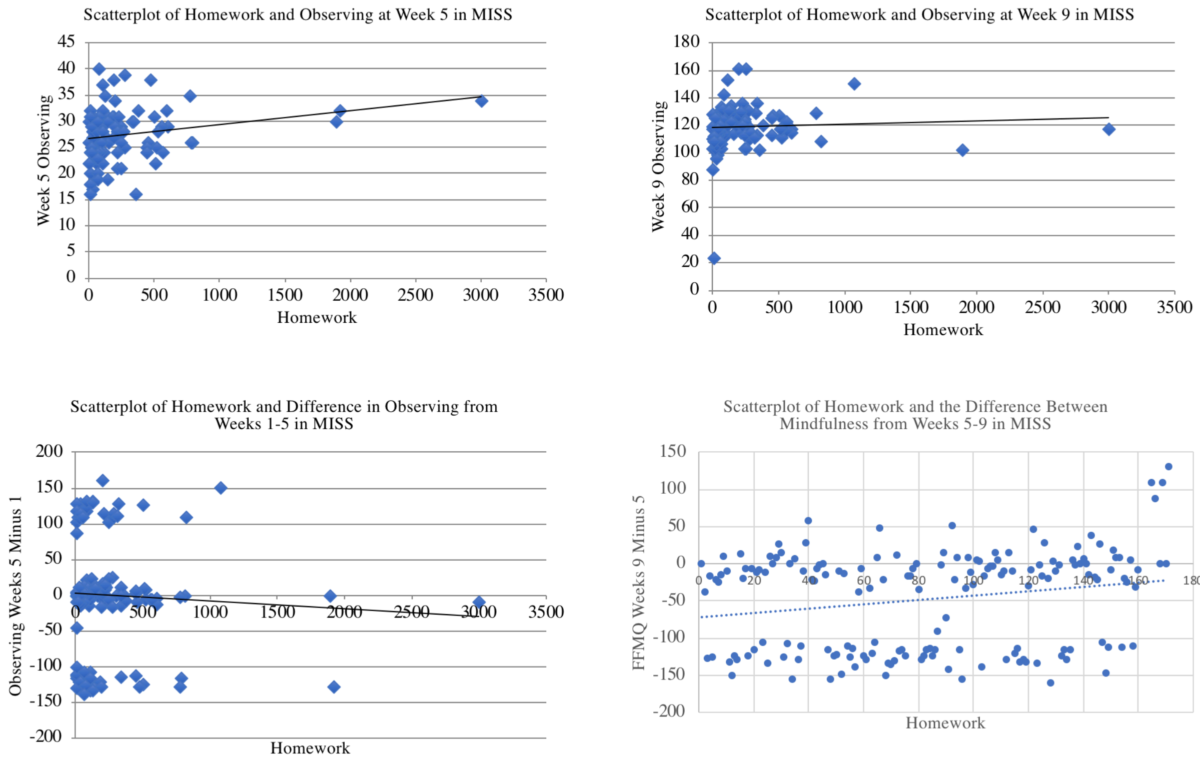

Figure 7. Exploratory correlational results in the missing dataset.

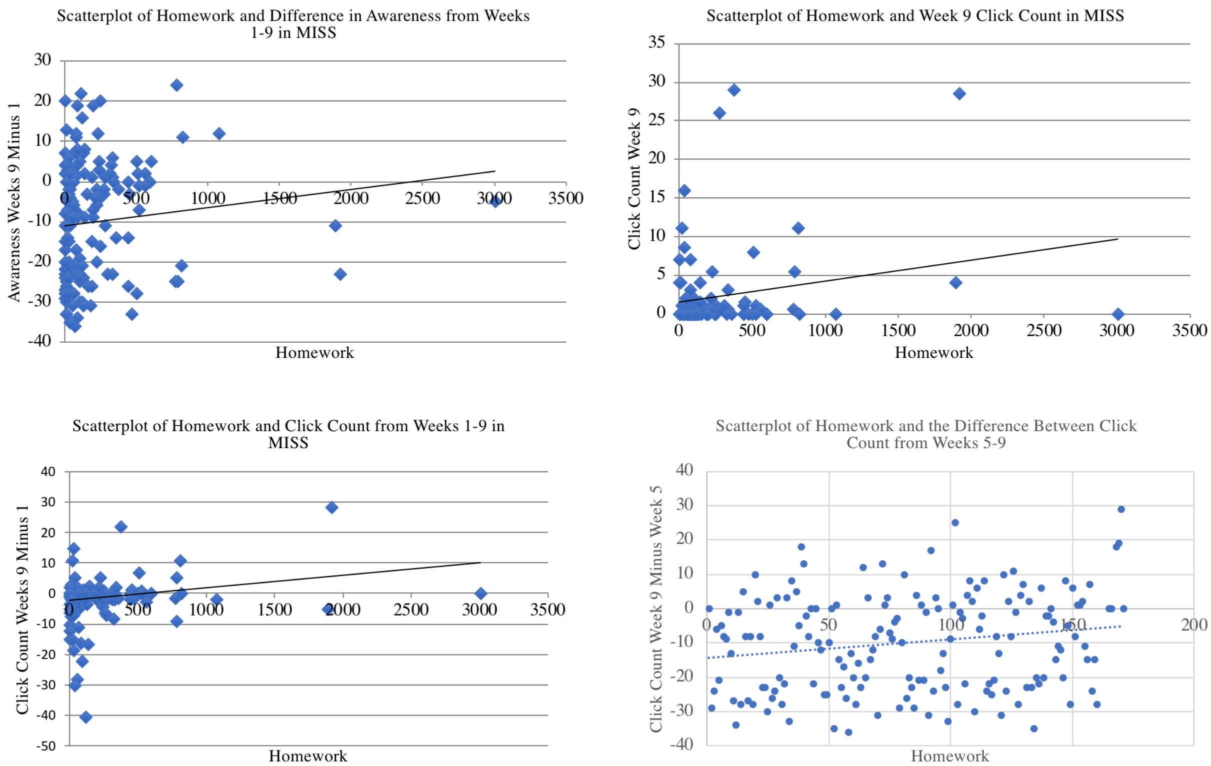

Figure 8. Exploratory correlational results in the missing dataset.

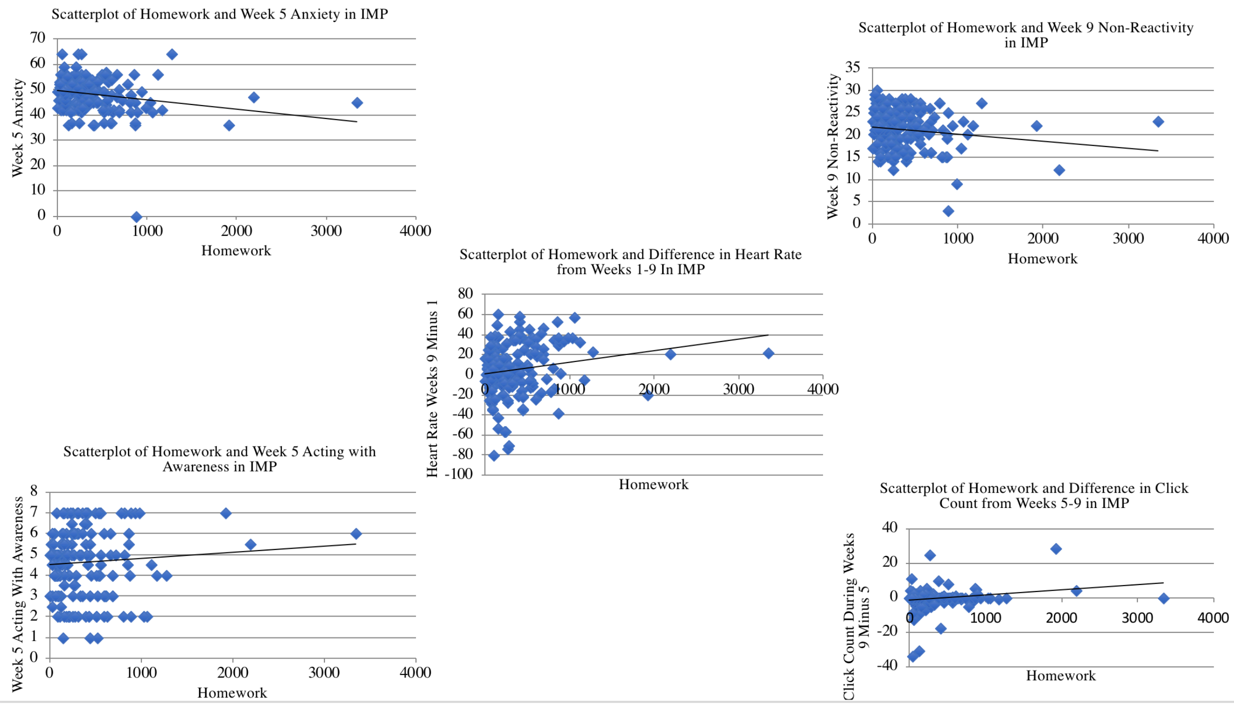

Figure 9. Exploratory correlational results in the imputed dataset.

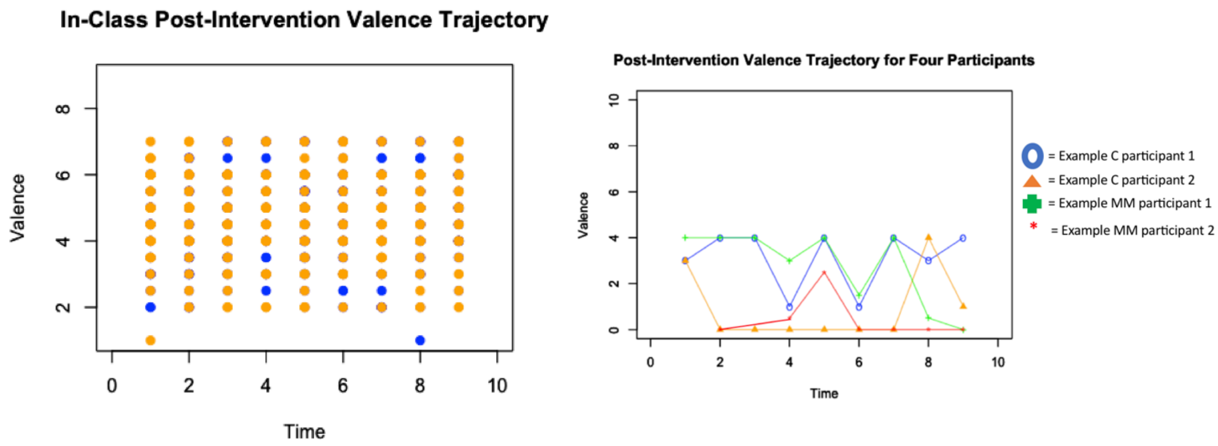

Figure 10. Exploratory LMER results in the longitudinal dataset: plot of time by valence from the longitudinal dataset, labeled by group, and a plot of trajectories for example participants' valence.

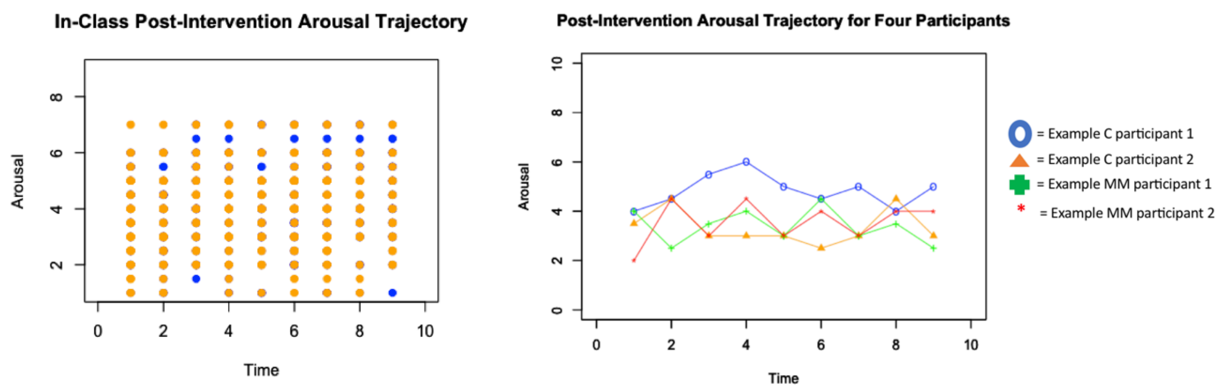

Figure 11. Exploratory LMER results in the longitudinal dataset: plot of time by arousal from the longitudinal dataset, labeled by group, and a plot of trajectories for example participants' arousal.

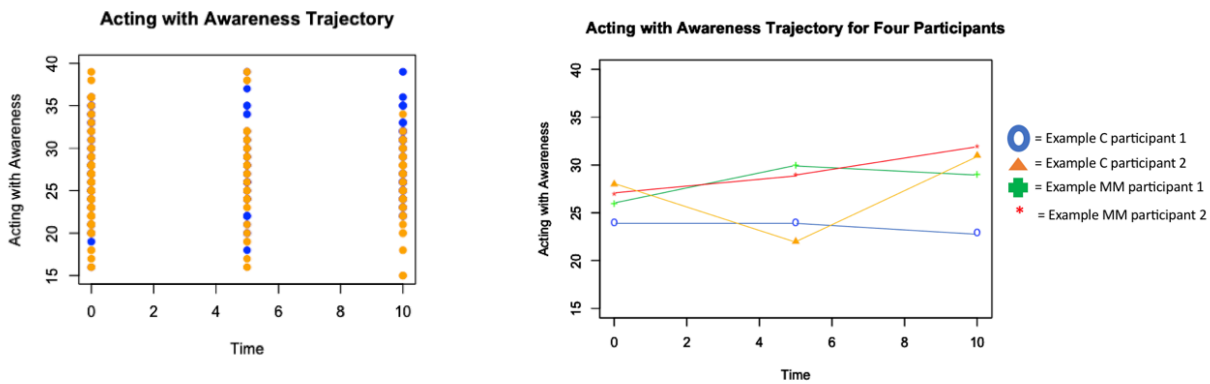

Figure 12. Exploratory LMER results in the longitudinal dataset: plot of time by acting with awareness from the longitudinal dataset, labeled by group, and a plot of trajectories for example participants' acting with awareness.

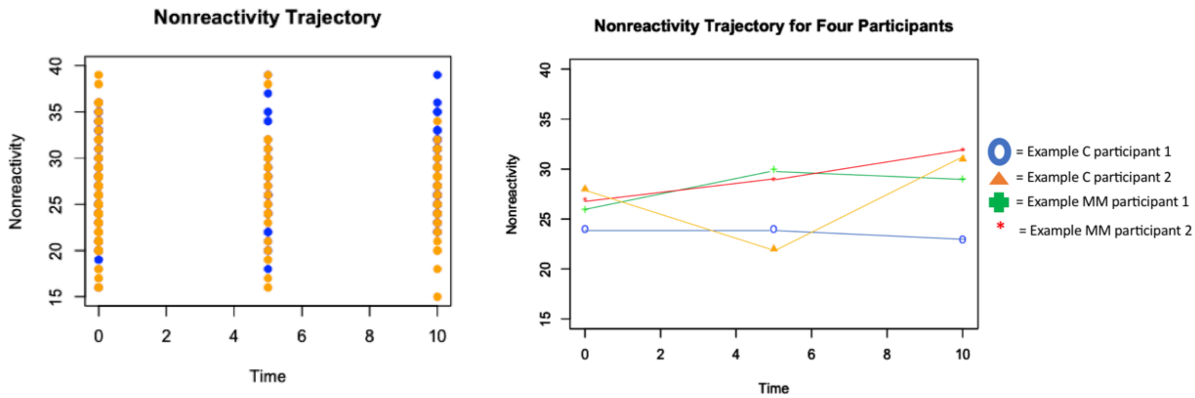

Figure 13. Exploratory LMER results in the longitudinal dataset: plot of time by nonreactivity from the longitudinal dataset, labeled by group, and a plot of trajectories for example participants' nonreactivity.

Appendix A: Pilot Data Collection Materials

Demographics Questionnaire

1. What is your age (in years)?
2. What classification are you?
3. What is your race?
4. What is your ethnicity?
5. Have you ever meditated?
   a. If so, how long ago did you learn to meditate?
   b. About how many minutes do you spend meditating per week?

Mental Health Questionnaire

Have you ever experienced or been diagnosed with any of the following, or are you experiencing any of the following at present: (Please choose the appropriate response and explain "yes" answers below.

		Yes	No
1.	Severe head trauma/injury	O	O
2.	Stroke	O	O
3.	Epilepsy or seizures	O	O
4.	Neurological surgery	O	O
5.	Other neurological problems	O	O
6.	Cardiovascular disease	O	O
7.	Psychiatric illness	O	O
8.	Are you currently taking any prescription or over-the-counter medications?	O	O

Please explain "Yes" responses

____

____

____

9. When was the last time you consumed caffeine?

10. When was the last time you consumed nicotine?

Five Facet Mindfulness Questionnaire

Please rate each of the following statements using the scale provided. Write the number in the blank that best describes your own opinion of what is generally true for you.

1	2	3	4	5
never or very rarely true	rarely true	sometimes true	often true	very often or always true

1. When I'm walking, I deliberately notice the sensations of my body moving.

2. I'm good at finding words to describe my feelings.

3. I criticize myself for having irrational or inappropriate emotions.

4. I perceive my feelings and emotions without having to react to them.

5. When I do things, my mind wanders off and I'm easily distracted.

6. When I take a shower or bath, I stay alert to the sensations of water on my body.

7. I can easily put my beliefs, opinions, and expectations into words.

8. I don't pay attention to what I'm doing because I'm daydreaming, worrying, or otherwise distracted.

9. I watch my feelings without getting lost in them.

10. I tell myself I shouldn't be feeling the way I'm feeling.

11. I notice how foods and drinks affect my thoughts, bodily sensations, and emotions.

12. It's hard for me to find the words to describe what I'm thinking.

13. I am easily distracted.

14. I believe some of my thoughts are abnormal or bad and I shouldn't think that way

15. I pay attention to sensations, such as the wind in my hair or sun on my face.

16. I have trouble thinking of the right words to express how I feel about things

17. I make judgments about whether my thoughts are good or bad.

18. I find it difficult to stay focused on what's happening in the present.

19. When I have distressing thoughts or images, I "step back" and am aware of the thought or image without getting taken over by it.

20. I pay attention to sounds, such as clocks ticking, birds chirping, or cars passing.

21. In difficult situations, I can pause without immediately reacting.

22. When I have a sensation in my body, it's difficult for me to describe it because I can't find the right words.

23. It seems I am "running on automatic" without much awareness of what I'm doing.

24. When I have distressing thoughts or images, I feel calm soon after.

25. I tell myself that I shouldn't be thinking the way I'm thinking.

26. I notice the smells and aromas of things.

27. Even when I'm feeling terribly upset, I can find a way to put it into words.

28. I rush through activities without being really attentive to them.

29. When I have distressing thoughts or images I am able just to notice them without reacting.

30. I think some of my emotions are bad or inappropriate and I shouldn't feel them.

31. I notice visual elements in art or nature, such as colors, shapes, textures, or patterns of light and shadow.

32. My natural tendency is to put my experiences into words.

33. When I have distressing thoughts or images, I just notice them and let them go.

34. I do jobs or tasks automatically without being aware of what I'm doing.

35. When I have distressing thoughts or images, I judge myself as good or bad, depending what the thought/image is about.

36. I pay attention to how my emotions affect my thoughts and behavior.

37. I can usually describe how I feel at the moment in considerable detail.

38. I find myself doing things without paying attention.

39. I disapprove of myself when I have irrational ideas.

STAI

DIRECTIONS: A number of statements which people have used to describe themselves are given below. Read each statement and then choose the number next to the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

1	2	3	4
not at all			very much

1. ____ I feel calm.
2. ____ I feel secure.
3. ____ I am tense.
4. ____ I feel strained.
5. ____ I feel at ease.
6. ____ I feel upset.
7. ____ I worry over possible misfortunes.
8. ____ I feel satisfied.
9. ____ I feel frightened.
10. ____ I feel comfortable.
11. ____ I feel self-confident.
12. ____ I feel nervous.
13. ____ I am jittery.
14. ____ I feel indecisive.
15. ____ I am relaxed.
16. ____ I feel content.

17. ____ I am worried.

18. ____ I feel confused.

19. ____ I feel steady.

20. ____ I feel pleasant.

Daily Manipulation Check

Before Meditation

1. What is your current mood?
2. About how many minutes did you spend in meditation yesterday?

After Meditation

1. What is your current mood?
2. What is your current attention level?
3. What is your current level of nonjudgment?
4. What is your current level of awareness of your body?
5. What is your current level of open awareness (outside of your body)?
6. How faithfully do you feel you followed the instructions in the script?