Winter 12-20-2017

Exploring Mindfulness Training Effects on Cognition and Psychological Wellbeing in Young and Older Adults

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by

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A thesis presented to
The Graduate School
of Washington University in
partial fulfillment of the
requirements for the degree
of Master of Arts

December 2017
St. Louis, Missouri

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Acknowledgments

Thesis Committee: Drs. Todd Braver, Deanna Barch, and Ryan Bogdan

I would first like to thank my advisor Dr. Todd Braver for his guidance and mentorship with this thesis. I would also like to give special thanks to Dr. Tim Bono for his help and support with data collection from his class, and Dr. Eric Lenze for sharing his pilot data and allowing me to analyze and include them in my thesis. I would also like to thank Dr. Doug Schultz and Dr. Mike Cole for their collaboration and support with neuroimaging data analysis. I would like to thank Dr. Jo Etzel for her constant support and suggestions with any technical issues I encountered along the way.

Finally, I would like to thank my parents for their continuous love and encouragement.

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December 2017

ABSTRACT OF THE THESIS

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Washington University in St. Louis, 2017

Professor Todd Braver, Chair

Previous investigations have revealed a range of cognitive, physiological, and psychological benefits following mindfulness training in young, middle-aged, and older adults. The aim of this thesis was to provide new insights into three issues that have not been adequately addressed in the extant literature. First, the application and integration of mindfulness training within conventional educational contexts is limited. In study 1, I provide evidence of the utility and effectiveness of mindfulness training incorporated as a part of traditional college curriculum. Second, although mindfulness training has been shown to offset age-related cognitive declines, studies have yet to combine mindfulness training with other forms training to together capitalize training-induced benefits against prominent cognitive declines for older adults. In Study 2, mindfulness training was combined with physical exercise, which is another promising training that enhances cognitive functions, to together promote cognitive benefits in in older adults. Third, individual differences in dispositional qualities of mindfulness have been linked with variability in cognitive performance, yet the underlying neural basis through which trait mindfulness relates to cognition remains elusive. In Study 3, a novel index based on network

neuroscience methods is utilized to shed lights on putative neural correlates that might give rise to the relationship between trait mindfulness and cognitive functions.

Chapter 1: Introduction

The ability to pay attention is a fundamental human characteristic, but the ability to direct and sustain one's attention in a purposeful manner requires additional effort. In particular, given that our minds have a natural tendency to wander away from what is happening in the present moment, specific training may be needed to overcome this tendency. Mindfulness is thought to be a state of mind that emphasizes the importance of living in the present; specifically, it refers to a state of lucid awareness of one's internal and external experiences, including thoughts, emotions, actions or surroundings as they occur at any given moment. In the last twenty years, and even more so in the last decade, there has been a burgeoning interest in the psychological construct of mindfulness, as well as in the training of mindfulness, based on evidence that mindfulness can benefit cognitive, psychological and physiological health in a range of diverse populations (Kabat-Zinn, 1990; Chiesa, Catati, & Serretti, 2011).

Although contemporary conceptualizations of the word "mindfulness" have taken many forms within the scientific community, the most widely accepted and scientifically operationalized definition involves two pivotal components: 1) a conscious awareness of, and attention to, present moment experiences, and 2) an open, nonjudgmental and nonreactive attitude towards present moment experiences (Kabat-Zinn, 1990; Hölzel et al., 2011). For personality psychologists, mindfulness (or trait mindfulness) is a dispositional quality associated with a wide degree of individual variations, which can arise from a complex interaction of genetic predisposition and environmental factors (Brown & Ryan, 2003; Davidson, 2010). From an interventionist perspective, mindfulness is a natural characteristic that can be strengthened through repeatedly inducing a state of mindfulness via specific exercises and training (mindfulness training). Such interventions could range anywhere from several days (short-term) to several months (long-term), or even several years of practices for dedicated practitioners (Davidson, 2010; Tang & Posner, 2013). Accordingly, the science of mindfulness contains two different yet related lines of research: investigations of trait mindfulness and mindfulness training, both of which have been empirically shown to be closely associated with positive aspects of cognitive, psychological and physiological well-being (Davidson, 2010).

Despite over two decades of research effort on mindfulness training and the related construct of trait mindfulness, there are still unexplored territories that may provide new avenues of investigation for the field of mindfulness research. For instance, the incorporation of mindfulness training into the college curriculum seems intuitively promising as a possible training strategy by which to further enhance cognitive functioning and psychological well-being in students. Yet such education-based training approaches have not been tested until recently, with only one published study in the literature (Morrison, Goolsarran, Rogers, & Jha, 2013). Furthermore, there have been no examinations of the potential benefits of combining mindfulness training with other well-established training protocols (e.g., physical exercise). Lastly, the neural correlates of individual differences in trait mindfulness are beginning to be explored within the literature (Creswell, Way, Eisenberger, & Lieberman, 2007; Modinos, Ormel, & Aleman; 2010; Kong, Wang, Song, & Liu, 2016), but prior work has not exploited the network neuroscience approaches and methods that are becoming increasingly dominant within this domain (Medaglia, Lynall, & Bassett, 2015; Bassett & Sporns, 2017), and which may most sensitively capture relevant brain-behavior relationships. The purpose of this thesis is to provide examples of such investigations through three independent and preliminary studies. At the outset, it should be noted that these studies were conducted either based on convenience samples or on existing data that were collected previously. As will be noted in the discussion, this research strategy carries with it important limitations in the design of each study in terms of its ability to address the relevant questions of interest. Nevertheless, valuable and practical insights can still be drawn from these studies to benefit future research on mindfulness, and to open up the scientific community to new research possibilities.

1.1 Mindfulness Training

A brief introduction on mindfulness training will be provided in this section before delving into specific empirical studies on mindfulness training and trait mindfulness. Mindfulness training encapsulates a modernized subgroup of meditation practices primarily derived from the Eastern Buddhist traditions and philosophy. Although in the past these practices had been developed in conjunction with religious-based traditions (e.g., as a part of monastic training), their primary themes translate very well into modern mainstream society and associated secular therapeutic traditions. These themes include enhancing favorable qualities and capacities such as emotional balance, mental clarity, embodied awareness and acceptance (Williams & Kabat-Zinn, 2013). Not surprisingly, beginning from the early 1970s, there has been a rapidly growing interest in Buddhist contemplative practices among the general public and scientists alike, especially in the set of practices commonly referred to as mindfulness meditation. Recently there has been a strong push to produce Westernized adaptations of mindfulness meditation, from which standardized mindfulness programs have been developed that not only contain the core techniques of mindfulness meditation, but also incorporate other related exercises and activities (e.g., yoga) that collectively promote the capacity of mindfulness (Chiesa et al., 2011). As a result, almost all of the current mindfulness training programs are amalgamations of different mindfulness-based and mindfulness-related practices and techniques drawing from relevant traditions and lineages, with the exception of less well-known programs that restrict their focus to practicing one or two meditation techniques.

Despite the heterogeneous nature of mindfulness training, most programs do share core commonalities such as the goal of enhancing mindfulness, while de-emphasizing the direct ties with classical Buddhist teachings and principles in order to make the training more palatable for a secular audience. The primary emphasis is to establish mindful awareness as a universal human characteristic that everyone possesses to one degree or another, and that being mindful does not mean that one needs to self-identify as a Buddhist (Kabat-Zinn, 2003). The two earliest standardized and well-known adaptations of mindfulness practices for Western audiences are Mindfulness-based Stress Reduction (MBSR) (Kabat-Zinn, 1990) and Mindfulness-based Cognitive Therapy (MBCT) (Segal, Williams, & Teasdale, 2002). Both of these programs were predominately driven by the clinical needs of finding effective treatments to ameliorate stress-related problems and emotional disturbances, and with the goal of integrating mindfulness training into mainstream medicine and science (Williams & Kabat-Zinn, 2013). Other similar and systematic mindfulness programs tailoring specific populations and settings have also been developed and applied over the last three decades to contribute to this growing effort of promoting individual well-being at many different levels. Therefore, the history and development of contemporary mindfulness training can be best characterized as reflecting a confluence of factors, including guidance from basic science and medical therapeutic techniques with the goal of adapting contemplative practices from Buddhist traditions.

There is no single way to train and practice mindfulness, just like there is no single solution to every problem. Since the birth of Buddhism and its subsequent teachings, many meditative techniques have been introduced to facilitate the attainment of a stable and focused awareness of the present moment. Similarly, contemporary mindfulness programs also involve a range of meditative techniques, of which three widely practiced techniques specifically targeting mindfulness will be briefly discussed next. In the first technique, focused attention meditation, the standard practice is to simply close the eyes and gently observe the sensation of one's breathing (or another chosen object) as a means of maintaining attentional focus. The key is not to judge or analyze this experience, but instead to just sustain this constant awareness (Lutz, Slagter, Dunne, & Davidson, 2008). It should be noted that, in any form of mindfulness training, mind-wandering or loss of attention focus is perceived as a natural phenomenon, and in fact another target of awareness. Whenever mind-wandering occurs, individuals are asked to gently bring back their attention to where it was before it drifted away. The second common approach entails an open and nonreactive observation of the present moment experiences (sensations, thoughts, feelings), where there is no specific object of focus, instead the focus is on anything that is taking place in the present moment. This type of practice is called open monitoring meditation (Lutz et al., 2008). Lastly, there is the third technique, loving-kindness meditation, which involves using imagery or words to elicit a state of friendliness, compassion, and kindness towards oneself and others (Hofmann, Grossman, & Hinton, 2011). Importantly, this practice should not be thought as simply repeating phrases or imagining scenes, but instead as a technique that bolsters mindful awareness on current emotional experience, namely, feelings of love and kindness that may fluctuate from moment to moment (Hofmann et al., 2011). Hence, the primary distinction among these three techniques lies within the choice of focus object, which could range from bodily sensations, to imagery and thoughts. Additionally, as a part of mindfulness training, other mindfulness-related activities have been developed to facilitate and complement the practice of mindfulness techniques, some of these include but not limited to mindful walking (noticing the sensation of each step while walking) and mindful eating (paying attention to the taste and texture of food).

1.2 Current Research on Mindfulness

While an exhaustive review of the previous scientific literature on mindfulness is beyond the scope of this thesis, a general review highlighting representative findings is provided in this section in order to provide an overview of the current state of the field. Specifically, a wide range of benefits with respect to mindfulness training will be discussed first, followed by a brief overview of literature on trait mindfulness at the end of the section.

Currently, two types of research designs are commonly used in studies on mindfulness training: 1) cross-sectional designs that compare long-term or experienced meditators against non-meditators who matched in age and other relevant variables, and 2) longitudinal designs that administer mindfulness training to a group of non-meditators for a period of time (short-term or long-term) and compare pre to post changes either with participants in a wait-list control group or in an active control group that receive comparable training such as relaxation training and health education (Tang et al., 2015). Additionally, participants are randomly assigned to either the mindfulness condition or a control condition. Typically, most studies employ random assignment (randomized controlled trial), since it is considered to be the most rigorous research design to examine training effects. Nonetheless, there are still a considerable amount of studies that employ quasi-experimental designs in which participants are self-selected to be in the mindfulness condition due to their specific needs or interests.

1.2.1 Cognitive Benefits of Mindfulness Training

Three cognitive domains are typically enhanced following mindfulness training: attention, memory, and executive functions. Based on the previous discussion of mindfulness, it is unequivocal that attention control is a primary focus of mindfulness training, since cultivating mindfulness requires attention to notice mind-wandering, reorient cognitive focus back to the target of concentration, and sustain concentration throughout the practice (Lutz et al., 2008; Tang & Posner, 2009). Interestingly, these active ingredients of mindfulness training involving attention correspond nicely with existing components of attention and attention networks based on previous work in cognitive neuroscience: 1) maintaining a vigilant and alert state (sustained attention, alerting network), 2) directing and orienting to sensory events (selective attention, orienting network), and 3) detecting and resolving conflict signals (executive attention, executive control network) (Posner & Petersen, 1990, 2012; Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Posner & Rothbart, 2007; Malinowski, 2013).

Many studies have already shown that mindfulness training can improve behavioral measures of these three aspects of attention. Salutary benefits in sustained attention have been shown in terms of better overall performance and enhanced vigilance during a visual continuous performance task (CPT) for participants who underwent a three-month mindfulness training, but not for waitlist controls (MacLean et al., 2010). Notably, participants in this study were between 21 and 70 years old, and age was not a predictor of any training-related changes, which may suggest that sustained attention improvement following mindfulness training could be generalizable across both young and older adults. For selective attention, Hodgins and Adair (2010) found that long-term meditators, ranging from 21 to 79 years old, exhibited better selective attention than age-matched non-meditators, as indicated by greater flexibility in directing and re-directing visual attention when presented with invalid cues in a cued-response task. Similarly, Jha and colleagues (2007) also observed improved ability in the orienting component of selective attention (using the attention network task) in young adults who underwent 8-weeks of mindfulness training. For executive attention, the ability to detect and resolve conflict was found to be enhanced in one study for young adults who received a 5-day mindfulness training when compared with those who underwent relaxation training (Tang et al., 2007). Similarity, a separate report using the same research design and training duration also found enhanced conflict resolution by showing significantly reduced Stroop effect only for mindfulness training group, but not for relaxation group (Fan, Tang, Tang, & Posner, 2015). Therefore, it is evident that mindfulness training, as well as long-term experience with mindfulness practices, can have positive effects on core aspects of attention in both young, middle-aged and older adults.

Akin to attention, memory can be divided into several broad categories, yet the most relevant aspect of memory in mindfulness research is working memory, the ability to maintain and manipulate information over short periods of time for ongoing mental processes (Baddeley, 2012). Although working memory may not seem directly related to mindfulness, conceptually, the ability to maintain present moment awareness on external and internal environment is pivotal for successful working memory. In addition, previous research has repeatedly demonstrated the critical role of attention and the detrimental cost of mind-wandering (both areas showed benefits after mindfulness training) in influencing working memory ability (McVay & Kane, 2009; Unsworth, Fukuda, Awh, & Vogel, 2014; D'esposito, & Postle, 2015). Thus, an area of central research interest is to determine whether working memory performance can be improved through potentially strengthening attention control and reducing mind-wandering via mindfulness training.

A study by Zeidan and colleagues (2010) in young adults suggests that 4 days of mindfulness training can significantly and differentially improve performance in an adaptive n-back working memory task relative to a control group that engaged in audiobook listening during the training period. Intriguingly, this improvement in working memory was accompanied by enhanced executive attention as assessed in two separate tasks (verbal fluency and digit symbol substitution) (Zeidan et al., 2010). Furthermore, another study using 2 weeks of mindfulness training found that improved working memory capacity, as measured by the Operation Span task, was mediated by reduced mind-wandering, specifically among participants who were prone to distraction at baseline in a group of college students (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). However, the examination of working memory in older adults is limited, with only one report, which showed non-significant changes in working memory between an 8-week mindfulness training group and an active control group for participants ranging from 55 to 75 years old (Malinowski, Moore, Mead, & Gruber, 2015). These lines of evidence suggest that mindfulness training can positively bolster working memory performance in young adults, putatively through bolstering attention control capacity and by mitigating the amount of task-unrelated distraction, whereas in older adults, the potential benefits on working memory are less clear.

One of the prominent components of executive function is inhibitory control, which is the capacity to voluntarily regulate and inhibit prepotent responses in order to maintain and execute appropriate behavior that is consistent with internal goals (Diamond, 2013). As mentioned above, Stroop interference, an index of inhibitory function, can be significantly reduced (better inhibition) after 5 days of mindfulness training as compared with an equal amount of relaxation training in healthy college students (Tang et al., 2015). Additionally, a study conducted by Heeren and colleagues (2009) demonstrated that inhibition of cognitively prepotent responses (fewer errors) in the Hayling task (Meulemans, Steyaert, & Vincent, 2001) was greatly improved after 8 sessions of mindfulness training as compared to those in a matched wait-list control group in participants ranging from 27 to 75 years old. Relatedly, better cognitive flexibility, another aspect of executive function, was found in this study in the mindfulness training group as indicated by superior performance from pre to post-training in three different verbal fluency tasks (semantic, phonemic, verbs), but not in the control group (Heeren et al., 2009).

In sum, these promising lines of evidence support the notion that mindfulness training can have beneficial effects on critical aspects of cognition related to attention control in both young and older adults. Needless to say, these abovementioned benefits are essential to academic performance and success for students across all ages. However, for young adults, the application of mindfulness training in educational settings as a means of enhancing cognitive function is still fairly limited. Most often, these types of training courses are offered as separate extracurricular activities that are independent of the school curriculum, which inevitably creates considerable difficulties for students to participate, since additional effort and time commitment is needed to engage in extended mindfulness practice and training. In older adults, the engagement in mindfulness training as a means of ameliorating age-related cognitive decline could be particularly important for their life quality and activities of daily living. This suggests a need to come up with effective ways to further enhance existing mindfulness programs, and to bolster their associated benefits in older adults, as a tool for combating age-related impairments in cognition.

1.2.2 Psychological Benefits of Mindfulness Training

In addition to cognitive components involving attention control, mindfulness also has an affective component. In particular, a core benefit of mindfulness is thought to be in the domain of emotion regulation, as one learns to develop an accepting and nonreactive attitude towards present moment experiences (Tang et al., 2015). It is the development of this attitude that may have critical relevance for ameliorating emotional dysfunction. Additionally, decreased mind wandering, a frequent result of mindfulness training, is also highly correlated with less rumination, further suggesting the potential benefit of mindfulness training for psychological well-being (Ottaviani et al., 2014). Not surprisingly, consistent findings on emotional benefits of mindfulness training have been demonstrated in previous literature across young and older adults.

Both MBSR and MBCT have frequently been implemented as therapeutic treatments to address depression and anxiety. For example, studies comparing MBCT to treatment as usual have found significant reductions in the risk of depression relapse in young and middle-aged adults who have had three or more previous major depressive episodes (Ma & Teasdale, 2004; Teasdale et al., 2000). Several additional meta-analyses regarding the effects of mindfulness training on anxiety-related symptoms also indicate a positive trend after a period of mindfulness training, although there is not full consensus regarding whether mindfulness training is superior to other well-accepted control interventions, such as cognitive behavioral therapy (Strauss et al, 2014; Goldin et al., 2016). Furthermore, studies specifically targeting older adults with emotional problems have demonstrated similar benefits after an 8-week standardized MBSR program (O'Connor, Piet, & Hougaard, 2014; Lenze et al., 2014). In healthy populations, improvement in positive mood and reduction in negative affect has been found in multiple studies following mindfulness training, as measured by self-report questionnaires in young adults (Jain et al., 2007; Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010; Robins, Keng, Ekblad, & Brantley, 2012; Tang et al., 2007; Ding et al., 2013). Additionally, two studies by Gallegos and colleagues have each found improvement in psychological well-being for measures such as depressive symptoms and positive affect in healthy older adults (2013a; 2013b). These findings suggest that mindfulness training can effectively induce positive emotional changes in both healthy and young and older adults, as well as ameliorate depressive and anxiety symptoms. However, a similar issue exists as discussed in previous section, that is, how to better integrate and apply mindfulness training in young and older adults to suit their particular needs and to improve cognition and mental health.

1.2.3 Trait Mindfulness and Cognition

In this section, previous findings on trait mindfulness in relation to psychological well-being and cognitive functions are briefly discussed. As brought up in the introduction, trait mindfulness reflects an innate level of present moment awareness and attention with a nonjudgmental and accepting attitude. Some theorists have recently hypothesized that mindfulness training programs which repeatedly induce mindfulness states may lead to more stable and trait-level changes in mindfulness (Kiken, Garland, Bluth, Palsson, & Gaylord, 2015). Consequently, considering individual differences in trait mindfulness at baseline might be critical in predicting post training-related outcomes.

Currently, trait mindfulness is commonly assessed in the form of self-reported questionnaires. However, it should be noted that different theoretical characterizations of mindfulness have led to the development of a variety of mindfulness scales. As of now, there are roughly 8 distinct self-reported scales available to measure trait mindfulness. However, since mindfulness has only recently been thought of as a trait construct within personality psychology, it is not that surprising that a consensus personality inventory has yet to emerge (Anicha, Ode, Moeller, & Robinson, 2012).

When investigating trait mindfulness, researchers typically focus on examining individual variations of this dispositional quality in relation to measures of psychological health and cognitive functions. A consistent finding is that trait mindfulness is positively correlated with personality dimensions related to positive affect, such as optimism, and negatively correlated with traits related to negative affect such as anger, depression and anxiety (Wallace & Shapiro, 2006). However, only a few studies have examined the relationship between individual differences in trait mindfulness and cognitive abilities. Several preliminary findings have suggested that people who have higher trait levels of mindfulness exhibit better performance in cognitive tasks involving visual sustained attention, such as different variants of the continuous performance task (Schmertz, Anderson, & Robins, 2009; Ruocco & Direkoglu, 2013), and working memory (Anicha et al., 2012; Ruocco & Direkoglu, 2013). Although these studies seem to support a promising association between trait mindfulness and cognitive functions, the underlying mechanisms by which these relations are established remain elusive. Relatedly, studies that seek to explore the neural basis of trait mindfulness have been scarce, and are more oriented toward aspects of emotion and individual well-being (Creswell, Way, Eisenberger, & Lieberman, 2007; Modinos, Ormel, & Aleman; 2010; Kong, Wang, Song, & Liu, 2016), rather than cognitive functions. For instance, trait mindfulness has been implicated in affect labeling task, and is associated with greater prefrontal activation, but less bilateral amygdala activity during the labeling of negative affective stimuli (Creswell et al., 2007). Similar attempts have been made since then to link trait mindfulness with brain function, yet evidence is still lacking regarding the neural correlates of trait mindfulness during cognitive task engagement.

1.2.4 Summary

To date, multiple lines of evidence using randomized controlled trials have demonstrated a variety of cognitive, physiological and psychological benefits following both short-term and long-term periods of mindfulness practice in diverse populations, including children, young and older adults, as well as in both healthy and clinical samples (Tang, Hölzel, & Posner, 2015; Gu, Strauss, Bond, & Cavanagh, 2015). While these valuable studies seem to cover almost all interesting research areas, new directions of research that go beyond and extend upon these existing approaches and designs can be still be explored and expanded to shed lights on our current scientific and practical understanding and knowledge of mindfulness training.

In particular, it is becoming increasingly apparent that mindfulness training-induced benefits are widespread, and are highly relevant for individual well-being and success in life. Yet, the actual real world applications of mindfulness training have mostly been limited to clinical treatment or for self-growth and self-development. In the last decade, some considerable development has been made in the educational world to promote well-being and health in students via mindfulness training. However, as reviewed in the previous sections highlighting benefits of mindfulness training, there is still work to be done in order to better integrate mindfulness training into educational settings that can best benefit the lives of students. Likewise, combining mindfulness training with other promising forms of training to further enhance and strengthen training effects is another unexplored domain. Notably, for populations such as older adults who may suffer from age-related declines in daily functioning, employing mindfulness training alone may not be sufficient to suit their needs. Finally, individual differences in how well one responds to mindfulness training has not been extensively investigated, especially with respect to how pre-existing differences in trait level of mindfulness may influence cognitive functioning and associated neural substrates in individuals without any training in mindfulness. Thus, the current state of research on mindfulness is full of new possibilities and avenues of investigation that can be built based on prior research, which is also the central goal of this thesis.

1.3 Issues in Mindfulness Research

Even given the large and growing scientific literature demonstrating positive impacts of mindfulness training and trait mindfulness on cognition and emotion, several critical issues remain unaddressed. The first issue in mindfulness research pertains to the application and integration of mindfulness training into standard educational settings, particularly for students during important educational transition periods such as the first-year of college. Although a proliferation of research studies have demonstrated the positive effects of mindfulness training in young adults, namely, college students, almost all of these studies examined intensive mindfulness programs that were totally separated from the standard college curriculum. Thus, the utility and practicality of this type of intervention program seems to be less pronounced in common educational settings. As mentioned in previous sections, many of the positive qualities associated with mindfulness practices are highly critical to success in college years, such as enhanced working memory and sustained attention, as well as reduced mind-wandering – which is known to hamper academic performance (Mrazek et al., 2013). However, college students frequently do not have the same kind of luxury as adults do to engage in a standardized mindfulness program that demands a lot of time commitment and persistence outside of classroom. Relatedly, even in previous studies implementing mindfulness-based programs in college students to promote psychological well-being, the training is typically offered as an option that is separated from the university curriculum (Oman, Shapiro, Thoresen, Plante, & Flinders, 2008; Dvorakova et al., 2017), or in some instances, requires an extracurricular commitment that one signs up for in order to get paid for participation. Until recently, only preliminary efforts have been made to incorporate mindfulness training into a standard college curriculum. One recent study by Morrison and colleagues (2014) administered a brief mindfulness training (5-10 mins per session) spanning over 7 weeks to college students who enrolled in a seminar-style class. This setup makes mindfulness training both feasible and educational to students by integrating it within a common curriculum that does not require additional commitment and effort, except by attending classes as they always do. Interestingly, the researchers assessed performance on a sustained attention task that taps into mind-wandering, and found that students in the mindfulness seminar group showed greater improvements following training relative to those in a wait-list control group. This finding provides encouraging evidence that brief mindfulness training offered within a regular class setting can induce beneficial outcomes in aspects of attention critical to academic success. However, no significant effects were found in working memory for these students.

Additionally, the study contains one methodological constraint, which should be addressed by further studies in order to validate the utility and effectiveness of mindfulness training in educational setting. Specifically, training-related outcomes in the mindfulness group were compared to that of a wait-list control group. Yet the use of wait-list control may confound the observed results, since extraneous factors such as intellectual development, knowledge accumulation and life experiences during the course of the semester could contribute to the enhancement in task performance. Thus, to extend and build upon this finding by Morrison and colleagues, and to examine the utility and effectiveness of mindfulness training within a traditional educational context, we set up a similar seminar style class in our *Study 1*, by not only incorporating mindfulness training, but also exposing students to scientific discussion and reflection of mindfulness research, and encouraging them to think critically about what those findings mean. Additionally, we also had a comparable control group, in which first-year college students attended a class that emphasized strategies and concepts related to psychological growth and development over the course of college years. Finally, we assessed a battery of cognitive tasks, as well as a range of self-report questionnaires that provide valuable information on students' psychological health and well-being.

The second issue focuses on developing and strengthening existing mindfulness training programs in order to maximally enhance cognitive functions in older adults, who typically suffer from age-related declines in cognition. Although the past literature has demonstrated promising psychological benefits following mindfulness training in older adults (Gard, Hölzel, & Lazar, 2014), findings related to cognitive benefits seem rather mixed (Berk, van Boxtel, & van Os, 2017), which suggests that the nature of cognitive declines in older adults are more severe, such that alternative strategies are needed to combine mindfulness training with other forms of effective training to together promote substantial benefits in cognitive functions. Among a variety of training and intervention programs, physical exercise is the most plausible candidate given its complementary nature (one is more static, the other is more mobile), as well as mounting evidence that indicates physical exercise training leads to improvements in the cognition of older adults (Hillman, Erickson, & Kramer, 2008). Notably, in one large-scale study, older adults who underwent one year of physical exercise training showed better memory performance at post-assessment, accompanied by an increase in the size of hippocampus (Erickson et al., 2010). Typically, shrinkage in hippocampus and decline in memory ability are key characteristics of aging, but this finding suggests that physical exercise may be able to reverse aging-related declines in cognition and brain. Additionally, another study showed improvement in cognitive functions including processing speed, executive functions and working memory for older adults who participated in a 12-week physical training compared to those in a wait-list control group (Langlois et al., 2013). Therefore, combining two training approaches that both have been shown to effectively enhance cognitive functions may be ideal to induce observable cognitive enhancement in older adults. However, no such studies of this type have been reported; instead researchers have investigated the effects of each training on cognitive functions separately. Thus, in *Study 2*, we analyzed data from a feasibility trial using combined physical exercise training and mindfulness training in a group of older adults over a period of six months. In particular, neuropsychological assessments of cognitive function were administered with the NIH toolbox at baseline, 3 months, and 6 months to test for the presence of longitudinal improvement.

Lastly, the third issue concerns the neural correlates of individual differences in trait mindfulness and how this may influence cognitive functions. Individual variability is universal in almost all domains of psychological investigation, thus it is critical to examine individual variability to determine the degree with which it may interact and influence the construct of interest or the dependent variable we seek to observe. As mentioned more extensively in the above section, research on the underlying neural correlates of individual variability in trait mindfulness during cognitive tasks is currently lacking. Hence, the purpose of *Study 3* is to address this question in a subset of individuals who participated in the Human Connectome Project. In particular, these participants underwent task fMRI data for several cognitive tasks including working memory, relational reasoning and language processing, providing an appropriate range of tasks for our purposes. On a post-hoc basis, a subset of individuals were recruited to complete two of the most widely administered and accepted scales of trait mindfulness – Mindful Attention Awareness Scale (Brown & Ryan, 2003) and Five Facets Mindfulness Questionnaire (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). Critically, we examined the neural correlates of the relationship between trait mindfulness and cognitive performance using a novel measure of brain function, the efficiency of brain network reorganization (Schultz & Cole, 2016), which indexes the degree of brain network connectivity similarity across resting and task states. This measure has been recently found to predict better cognitive performance (Schultz & Cole, 2016). Yet this type of network-based perspective on brain function has not previously been considered in the context of trait mindfulness. Nevertheless, it seems highly reasonable to consider dispositional levels of mindfulness as a global index of information processing and brain function that should be studied at the brain network level, given that brain network properties are putative candidates from which personality traits arise. Therefore, we first tested whether individual differences in trait mindfulness was related to levels of cognitive task performance, and then further explored whether trait mindfulness was related to the efficiency of brain network reorganization, to determine whether this could be a source of individual differences in cognition.

Chapter 2: Effects of Brief Mindfulness Training in Young Adults

2.1 Materials and Methods

Participants. This study was conducted with a quasi-experimental design. Participants were first-year undergraduate students of Washington University in St. Louis, who self-enrolled in a 1-hour credit seminar class occurring during Fall 2016 academic semester. The students ranged in age from 17 to 19 years old (mean age = 17.96). The experimental group consisted of students who registered for the "Mindfulness: Science and Practice" (N=24). The control group consisted of students who registered for a different seminar: the "Psychology of Young Adulthood: College Years" (N=149). Participants in the control group received compensation ($10) at baseline, as well as at the end of semester for completing a battery of cognitive assessment ($10 plus a $5 bonus). However, they did not receive any form of compensation for filling out behavioral questionnaires, which was a part of their class requirement. Students in the mindfulness class did not receive any form of compensation, since completion of both the questionnaires and cognitive tasks was required for the class and discussed as part of the educational experience. All protocols were approved by the Washington University Institutional Review Board. Informed consents were obtained from all participants.

2.1.1 Procedure

Both classes met on a one-time-per-week basis and were each led by a primary instructor. For the mindfulness class, the seminar took place at a residential hall in the evening, whereas the psychology class was held in a regular classroom setting during daytime hours. At baseline and at the end of the semester (two time points), behavioral assessments were conducted, that included self-report questionnaires collected through the Research Electronic Data Capture program (REDCap; a set of electronic data capture tools hosted at Washington University), along with a battery of cognitive tasks administered through the Inquisit Web software program (developed by the Millisecond Company, and consisting of a prebuilt library of psychometric assessments for cognitive, neuropsychological, and online research). It should be noted that students did not complete these cognitive tasks or questionnaires in a laboratory setting, but rather in a more natural setting during their leisure time.

Mindfulness Seminar Curriculum. The overarching goal of the mindfulness seminar was to introduce students to the science and practices of mindfulness. Thus, the curriculum was divided into two parts: learning and understanding the science of mindfulness, and practicing mindfulness. The science component of the course mainly involved reading and discussing assigned research articles and findings related to mindfulness. The practice component of the course consisted of practicing different mindfulness meditation techniques, and engaging in activities that promoted mindful awareness, such as mindfulness eating, walking, and drawing. In particular, these mindfulness exercises and activities were primarily based on the curriculum of an evidence-based mindfulness program called Learning to BREATHE (L2B), which has been shown to improve psychological well-being primarily in adolescents (Broderick, 2013; Metz et al., 2013), but also more recently in first-year college students (Dvorakova et al., 2016). Mindfulness techniques that were taught during class-time practice sessions included body scanning, loving-kindedness, and open monitoring of thoughts and sensations. Students were encouraged, but not required, to practice outside of class time. Some adaptation was made to the L2B curriculum in consultation with developers of the L2B program at Penn State University.

A typical one-hour class session began with a 5-10 min long mindfulness practice that was either externally guided (by the instructor or a taped audio) or self-guided, then students were divided into groups for discussion of research articles. Following discussion, each group summarized the key findings and shared thoughts with rest of the class. Students then moved on to mindfulness activities and concluded the class session. If time permitted, the class session concluded with a 5-10 mindfulness meditation. There were 14 class sessions in total. During the first three weeks of the class, students met twice weekly to learn and consolidate their mindfulness techniques (discussion of research articles was not involved); the rest of the semester (8 weeks) required only one meeting per week.

Psychology Seminar Curriculum. This one-hour course met once a week over the span of 14 weeks, and has been taught for many years at Washington University to first-year undergraduate students. The major aims were to foster psychological growth and development for students specifically during their college years, and to discuss topics relevant to the developmental, social, personal, and cognitive issues that confront young adults during this time period. In some ways, this class can be considered to be analogous to a positive psychology course, and as such served as an appropriate comparison for the present study, since the conceptual emphasis was similar while the didactic approach was fairly different and complementary. The class was mainly taught in lecture style, with in-class discussion and activities. In particular, the scientific basis of covered concepts and empirically supported strategies for promoting psychological growth and development were among the top emphases of this course. Ultimately, the goal of the course was to provide students with relevant knowledge that could be used to facilitate academic success, personal development, and a more rewarding social and academic experience over the course of college and beyond.

2.1.2 Behavioral Questionnaires

Trait Mindfulness. The Mindful Awareness Attention Scale (MAAS) was used to assess individual differences in trait mindfulness, which is the ability to pay attention and be openly aware of the present moment in a calm and non-judgmental way. The questionnaire has 15 Likert-scale items that range from 1 (Almost Always) to 6 (Almost Never), tapping into the degree to which an individual goes about daily activity in a mindful vs. mindless way. The MAAS has been validated previously in numerous studies and populations as a reliable measure of trait mindfulness (Brown & Ryan, 2003; Van Dam, Earleywine, & Borders, 2010).

Self-Compassion. The Self-Compassion Scale (SCS) contains 12 items that measures one's tendency to be accepting, understanding, and caring towards oneself when facing failures, struggles, and negative emotions in life (Neff, 2003; Raes et al., 2011). Scores for each item can range from 1 (Almost Never) to 5 (Almost Always).

Self-Control. The 13-item Self-Control Scale (SCTRL) assesses the ability of people to control their own behavior and actions in relative autonomy without getting hampered by external distraction and impulses (Tangney, Baumeister, & Boone, 2004). A Likert scale from 1 (Not at all) to 5 (Very much) was used to rate each described statement.

Satisfaction with Life. The Satisfaction with Life scale measures one's cognitive perception and judgment of his or her life with 5 brief questions (Diener et al., 1985). Sample questions include "If I could do my life over, I would change almost nothing", and "The conditions of my life are excellent". A Likert scale from 1 (Strongly Disagree) to 7 (Strongly Agree) was used.

Sleeping Quality. The Pittsburgh Sleep Quality Index is a subjective questionnaire that assesses 7 aspects of sleep over the past one month: sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction (Buysse et al., 1989). Each of these subscales ranges from 1 (0 to 3) and are usually summed together to get a total score. Higher scores indicate poorer sleeping quality.

Anxiety. The Generalized Anxiety Disorder Scale (GAD) is a 7-item measure designed to assess the frequency of experiencing anxiety-related symptoms such as worrying and feeling restless in the previous two weeks (Spitzer et al., 2006). Item score ranges from 0 (Not at all) to 3 (Nearly every day).

Depression. The Patient Health Questionnaire (PHQ) was used to assess depressive symptoms such as anhedonia and feeling down during the previous two weeks (Kroenke & Spitzer, 2002). This 8-item questionnaires has been commonly used as a screening scale for depression. Each question was rated from 0 (Not At all) to 3 (Nearly every day).

2.1.3 Cognitive Tasks

Attention Network Test (ANT): This task is thought to measure the function of three core attention networks (alerting, orienting, executive control) (Fan et al., 2002). Specifically, participants were presented with arrows either above or below a fixation cross shown on screen, and they were asked to determine the pointing direction of the center arrow. The task has three flanker conditions: 1) neutral, when the center arrow is not flanked by arrows but by straight lines, 2) congruent, when the center arrow is flanked by arrows pointing to the same direction, and 3) incongruent, when the center arrow is flanked by arrows pointing to the opposite direction. In addition, there were four cue conditions (no cue, center cue, double cue, spatial cue) that may alert participants that targets are about to come on screen and potentially where on the screen (above or below the cross). The center cue and double cue indicated targets are about to appear on screen, but did not provide any location information, whereas spatial cues indicated where arrows are about to show up on screen. The frequency of each cue and flanker condition appeared in trials was equal. The task comprised one block of 24 practice trials with feedback and two additional test blocks of 64 trials. Reaction time (RT) and accuracy were both recorded for later calculation of the efficiency of three attention networks. Specifically, these efficiencies are defined as the following: alerting effect=RT no cue – RT center cue, orienting effect=RT center cue – RT spatial cue, conflict effect=RT incongruent – RT congruent.

Sustained Attention to Response Task (SART): The SART is a type of Go/NoGo task in which the nogo stimulus is presented very infrequently, thereby leading to an autonomic tendency to press the go key if sustained attention is not present to detect and monitor responding (Robertson et al., 1997). In this task, participants were presented with a single digit 1-9 in the middle of the screen in varying font sizes. The digit then disappeared and was replaced by a circle with an X. Next, participants were asked to press a predefined key if any digit other than 3 was presented and to withhold a response if digit 3 was presented. There were 225 trials and the digit 3 appeared in 11% (25) of the trials. Reaction time (RT) and accuracy were both recorded for later calculation of percent of errors in nogo trials, commonly referred to as commission errors, and RT variability in correct go trials, which is the coefficient of variability in RT (CVRT), calculated by dividing the mean RT with the standard deviation of RT.

Operation Span Task (OSPAN): The OSPAN is a standard task for measuring a form of working memory span by asking participant to perform simple mathematical operations while trying to remember the order of a list of letters (Conway et al., 2005). In particular, participants were presented with a sequence of letters ranging from 3 to 7 letters that need to be recalled at the end. The presentation of each letter on screen was preceded by a math problem (“3*4-8=?”) followed by a proposed solution (“5”), and participants needed to indicate if this answer is correct by clicking “True” or “False”. After presentation of all letters in the sequence, recall was assessed by asking participants to select letters in the correct order of which they were presented from a letter matrix. Participants first practiced 3 trials in the practice session, followed by 15 trials in the test session. The importance of accuracy in math calculation and recall order was stressed throughout the task by immediately showing the percentage of correct responses following each math problem and recalled set. Participants were also told beforehand that they need to solve these math problems as quickly and accurately as possible, and to maintain at least 85% of accuracy, otherwise their data could not be used for analyses. The sum of all correctly recalled sets was recorded, as well as the total number of letters recalled in the correct position.

AX-Continuous Performance Test (AX-CPT): The AX-CPT is a variant of the continuous performance task designed to measure cognitive control, which is the ability to flexibly vary and adapt ongoing information processing and behavior based on current goals that are being actively maintained in mind (Servan-Schreiber, Cohen, & Steingard, 1996). We used a standard version of AX-CPT (Braver et al., 2001; Marcora, Staiano, & Manning, 2009), but replaced distractors with a fixation cross and changed the display time of both cue and probe to 500ms. For this task, participants viewed sequences of stimuli shown on screen in the following order: cue (a letter), a 1000ms delay with no stimuli (a fixation cross), probe (a letter), and were asked to respond if the pair of letters is a target (cue=A, probe=X), but not other combinations when the probe could be any letter other than X (invalid probe), and the cue could be any letter other than A (invalid cue). Thus, four types of trials were possible: AX (target), AY (represents A and an invalid probe), BX (represents an invalid cue and X), BY (represents an invalid cue and an invalid probe). There were 100 trials in total with 70 target trials, 30 non-target trials (10 AY trials, 10 BX trials, and 10 BY trials). Participants were asked to press the “/” key as quickly and accurately as possible if the target pair AX appears, and press the "." key if the non-target pair appears. Reaction time and accuracy were record for each trial type.

2.1.4 Data Analyses

All questionnaires and task measures were scored and calculated based on published scoring guides and past literature, which can be found in references stated above in section 2.1.2 and 2.1.3. Data were visually inspected for any outliers and violation of normality assumptions. Pairwise deletion was used for missing data.

For questionnaires, non-normality was observed in the GAD (anxiety) and SWL (satisfaction with life) for the psychology seminar, thus outliers were identified and removed from further analyses if values were two standard deviations above or below the mean. PHQ (depression) and PSQI (sleeping quality) were skewed for both classes and non-normality could not be addressed using either log or square root transformation. Regardless, both questionnaires were still included for further analyses given their relevance, but results should be interpreted with caution. Independent samples t-tests were conducted for all questionnaires to examine if there are any baseline differences between the mindfulness class and the psychology class. Significant ($p < .05$) baseline differences were found in MAAS (mindfulness), PHQ (depression), and PSQI (sleeping quality). Specifically, trait mindfulness in the positive psychology class (same as national average) was higher than that of the mindfulness class (lower than national average), and students in the mindfulness class had worse sleeping quality and more depressive symptoms than those in the psychology class.

For task measures, non-normality was observed in coefficient of variability in reaction time (CVRT) for SART, and reaction time of AX, AY, and BX trial types in AX-CPT for both groups. Applying log or square root transformation did not fix non-normality. Thus, results for these measures should be interpreted with caution. There were significant differences in reaction time of AX and AY trial types between the two classes at baseline, as indicated by independent samples t-tests, such that the psychology class had faster reaction time for both AX and AY trial types than the mindfulness class ($p < .05$).

2.2 Results

Our primary goal was to test for any changes in cognitive task and self-report measures from pre-test (beginning of class) to post-test (end of class) for both groups, then compare these changes between groups. Typically, repeated measures analysis of variance (RM-ANOVA) is conducted to examine between and within group differences for this type of design. However, given the small sample size of the mindfulness class, as well as considerable differences in sample sizes between these two classes, conventional tests of significance are less meaningful and important for the present study. Thus, for all behavioral assessments, we report and interpret the results in terms of effect sizes for both groups. Regardless, standard RM-ANOVA approaches were performed, and results can be found in the supplementary files. A descriptive statistics table is provided below for all measures. It should also be noted that different sample sizes across tasks were due to failure of some students to complete certain tasks.

Table 1. Descriptive Statistics for Study 1

Questionnaires	**Group**	**Session**	**N(% Male)**	**Mean**	***SD***
Dispositional Mindfulness	Mindfulness	Pre	19 (42.1%)	3.593	0.664
		Post		3.849	0.570
	Psychology	Pre	112 (25.9%)	3.842	0.665
		Post		3.860	0.715

Generalized Anxiety Disorder	Mindfulness	Pre	22	8.09	4.888
		Post	(45.5%)	5.50	3.529
	Psychology	Pre	118	6.71	4.478
		Post	(27.1%)	6.54	4.429
Satisfaction with Life	Mindfulness	Pre	22	14.18	5.207
		Post	(45.5%)	15.59	6.170
	Psychology	Pre	120	14.08	5.911
		Post	(26.7%)	14.03	5.363
Self-Control	Mindfulness	Pre	21	39.52	8.238
		Post	(42.9%)	37.19	10.21
	Psychology	Pre	116	42.47	8.297
		Post	(25.9%)	40.83	8.863
Self-Compassion	Mindfulness	Pre	22	2.792	0.666
		Post	(45.5%)	2.822	0.768
	Psychology	Pre	115	2.932	0.651
		Post	(27.8%)	3.006	0.619
Sleeping Quality	Mindfulness	Pre	22	6.59	2.520
		Post	(45.5%)	6.91	3.100
	Psychology	Pre	109	5.31	2.490
		Post	(23.9%)	5.62	2.490
Patient Health Questionnaire	Mindfulness	Pre	22	7.73	5.110
		Post	(45.5%)	8.68	4.325
	Psychology	Pre	118	5.71	4.261
		Post	(26.3%)	7.01	4.462

Tasks	*Variable*	*Group*	*Session*	*N (% Male)*	*Mean*	*SD*
Operation Span	Total Span	Mindfulness	Pre	19 (36.8%)	50.79	19.03
			Post		53.37	13.35
		Psychology	Pre	14 (35.7%)	50.50	17.25
			Post		50.50	17.32
Sustained Attention to Response Task	% Commission Error	Mindfulness	Pre	15 (33.3%)	53.33	25.51
			Post		49.07	29.45
		Psychology	Pre	17 (29.4%)	35.53	23.79
			Post		31.53	27.20
	Coefficient of Variability	Mindfulness	Pre	15 (33.3%)	0.316	0.090
			Post		0.297	0.114
		Psychology	Pre	17 (29.4%)	0.215	0.066
			Post		0.192	0.070
Attention Network Test	Alerting	Mindfulness	Pre	14 (35.7%)	64.93	35.48
			Post		68.61	39.52
		Psychology	Pre	15 (33.3%)	55.36	25.21
			Post		43.86	31.16
	Orienting	Mindfulness	Pre	14 (35.7%)	18.30	18.55
			Post		12.85	26.70
		Psychology	Pre	15 (33.3%)	21.09	12.07
			Post		20.40	16.17
	Executive	Mindfulness	Pre	13 (38.5%)	74.59	27.47
			Post		62.44	25.80

	Executive	Psychology	Pre	15	78.11	18.45
			Post	(33.3%)	65.44	28.66
AX-Continuous Performance Task	AX Error	Mindfulness	Pre	18	0.029	0.028
			Post	(33.3%)	0.056	0.079
		Psychology	Pre	15	0.016	0.025
			Post	(26.7%)	0.017	0.027
	AY Error	Mindfulness	Pre	18	0.050	0.071
			Post	(33.3%)	0.106	0.147
		Psychology	Pre	15	0.027	0.046
			Post	(26.7%)	0.100	0.141
	BX Error	Mindfulness	Pre	18	0.056	0.086
			Post	(33.3%)	0.106	0.166
		Psychology	Pre	15	0.067	0.098
			Post	(26.7%)	0.040	0.106
	BY Error	Mindfulness	Pre	18	0.022	0.043
			Post	(33.3%)	0.033	0.112
		Psychology	Pre	15	0.020	0.041
			Post	(26.7%)	0.000	0.000
	AX RT	Mindfulness	Pre	18	539.5	141.7
			Post	(33.3%)	534.0	151.9
		Psychology	Pre	15	443.9	117.4
			Post	(26.7%)	454.9	103.6
	AYRT	Mindfulness	Pre	18	669.8	149.8
			Post	(33.3%)	666.1	264.0

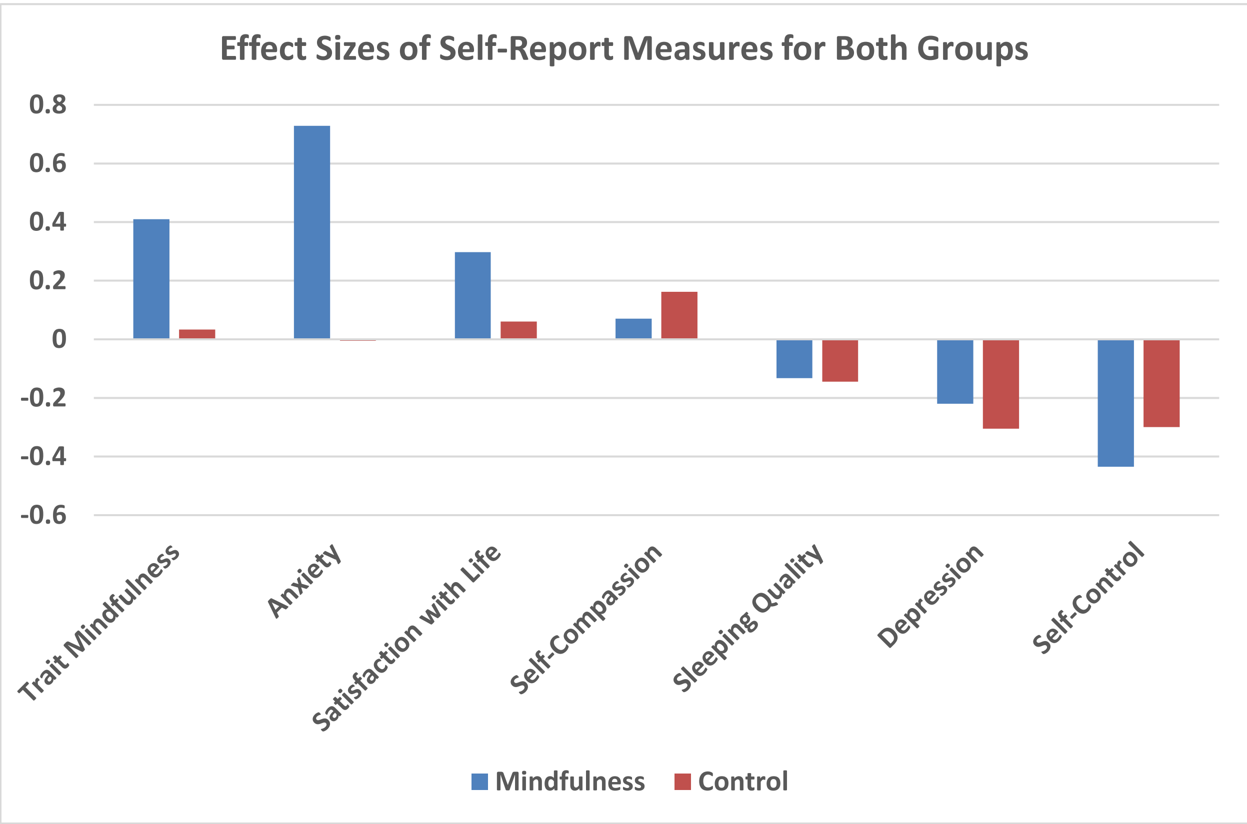
AX-Continuous Performance Task	AYRT	Psychology	Pre	15 (26.7%)	529.8	81.61
			Post		546.6	91.23
	BXRT	Mindfulness	Pre	18 (33.3%)	553.7	175.4
			Post		514.7	180.4
		Psychology	Pre	15 (26.7%)	370.2	154.0
			Post		376.1	151.2
	BYRT	Mindfulness	Pre	18 (33.3%)	540.2	169.7
			Post		590.3	216.5
		Psychology	Pre	15 (26.7%)	357.1	155.5
			Post		399.1	142.0

There are many ways to calculate effect sizes. Here, we present the more intuitive Cohen's d_z, an effect size that is commonly used in paired t-tests to compare changes in behavioral outcomes from baseline to conclusion of the class between these two groups. For the ease of interpretation, we modified the direction of signs, such that positive values indicate better cognitive function, faster reaction times, and greater psychological well-being at the post-test assessment relative to pre-test, whereas negative signs indicate the opposite.

Self-Report Measures

For the self-report measures, the mindfulness class exhibited positive changes in most questionnaires, consistent with benefits related to psychological well-being. Specifically, towards the end of the semester, students in mindfulness group exhibited small to moderate improvements in trait mindfulness (Cohen's dz=0.410), symptoms of generalized anxiety disorder (Cohen's dz=0.729), satisfaction with life (Cohen's dz=0.297), and self-compassion (Cohen's dz=0.070). Further, in the first three measures, the observed improvements were larger than those found in the control group (positive psychology class). The exception was for the self-compassion measure, in which the control group showed a slightly stronger (but still small) effect size (Cohen's dz=0.162). Interestingly, participants in both groups reported less self-control, poorer sleeping quality and more depressive symptoms (PHQ) at post-assessment, but the two groups differed very little in these three change measures, as shown in Table 1. Figure 1 provides a summary of effect sizes for all self-report measures.

Figure 1. Effect Sizes of Self-Report Measures for Both Groups in Study 1



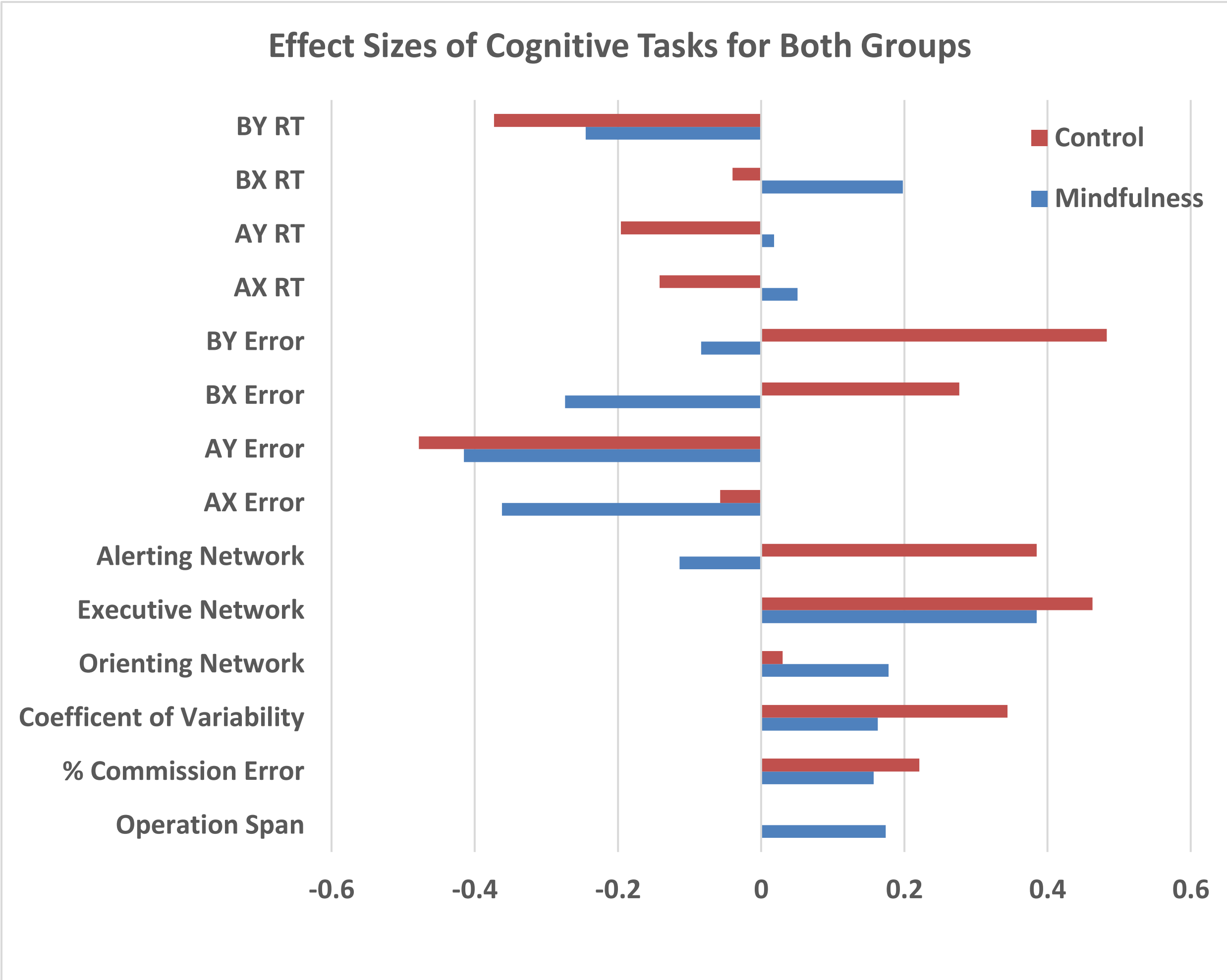
Cognitive Measures

Compared to pre-assessment, students in the mindfulness group exhibited improvement in working memory capacity as indicated by a small positive effect size in the operation span task (Cohen's dz=0.174). Similar magnitudes of positive effect size were also observed in the two indices of the SART related to mind-wandering: commission errors (Cohen's dz=0.157) and

CVRT (Cohen's dz=0.163). For the ANT, small to moderate effect size improvements were found in two of the measures of attention network functioning, executive control (Cohen's dz=0.385) and orienting (Cohen's dz=0.178). The exception was found in the alerting measure, for which a small negative effect size was observed, indicating a slight reduction in alerting efficiency (Cohen's dz= -0.114). In the AX-CPT, effects were mixed, in that small reaction time improvements were found in 3 of the 4 reaction time measures (AX, AY, BX) with BY as the only exception, but these were mirrored by higher error rates on all trial types (i.e., negative effects).

When comparing the two groups, there was less evidence for specificity in any of these effects. Although larger effect sizes were observed in the mindfulness group compared to the control group in the operation span and the ANT orienting measure, in the SART indices and ANT executive control and alerting measures, greater positive effects were observed in the control group. Likewise, although the AX-CPT reaction time effects were larger in the mindfulness group, only the control group showed benefits in terms of error rates (for BX and BY trial types). See Figure 2 below for effect sizes of all cognitive measures.

Figure 2. Effect Sizes of Cognitive Measures for Both Groups in Study 1.



Mindfulness and Cognitive Improvements

We explored whether individual differences in trait mindfulness served as a moderator of cognitive performance effects. It should be noted that here correlation coefficients, which are the equivalent for effect sizes, were not interpreted in the same fashion as they were in the above section. In particular, a negative correlation coefficient simply suggested a negative relationship between two variables, and vice versa for positive correlations, but did not imply improvement or reduction in psychological well-being and cognitive performance.

In a first analysis, correlations were computed between baseline trait mindfulness and each of the cognitive measures, focusing on pre-test values, but collapsing across participant groups to increase the sample size. Fourteen correlational analyses were conducted and four indices in AX-CPT showed significance, AX error ($r = -0.422$, $p=0.003$), BX error ($r = -0.366$, $p=0.010$), BY error ($r = -0.468$, $p=0.001$) and BY RT ($r = -0.342$, $p=0.016$), but only three indices, AX error, BX error, and BY error, survived FDR correction ($p<0.05$). These results suggest that participants with higher baseline trait mindfulness generally made less errors in AX-CPT. As a secondary analysis, we also examined if there were any relationships between baseline trait mindfulness and changes in each of the cognitive measures across participant groups, but no meaningful correlations were found.

Interestingly, in the mindfulness group, there was a significant negative correlation between baseline trait mindfulness and improvements in trait mindfulness following training ($r = -0.607$, $p<0.008$), suggesting that students with a lower level of baseline trait mindfulness showed greater mindfulness increases with training. Consequently, in a second analysis, we tested for any possible relationship between change in trait mindfulness and change in cognitive performance within the mindfulness group. To reduce multiple comparisons, we focused on three cognitive measures that showed relatively greater effect size after training, efficiencies of executive network and orienting network, as well as operation span. However, there were no meaningful correlations detected, as correlation coefficients were not significant and close to zero. We also examined for any possible relationship between baseline trait mindfulness and change in cognitive performance (the same three cognitive measures as in previous analysis) within the mindfulness group. Again, no meaningful relationships were detected for these measures ($p>0.05$).

2.3 Discussion

We employed a quasi-experimental design with one mindfulness group and one control group to examine the utility and effectiveness of brief mindfulness training on cognitive functions and psychological well-being within an education context. In particular, consistent with prior literature on cognitive effects of mindfulness training, improvements were observed in working memory capacity (Mrazek et al., 2013), along with better attentional functions in orienting network (Jha et al., 2007). Although improvements in the executive attention network were also found, the results indicated that the increase in attentional efficiency was not unique to mindfulness group, as similar patterns were also found in the control group. This pattern is somewhat contrary to what was observed in prior studies (Tang et al., 2007; van den Hurk et al., 2010), where mindfulness training typically induced stronger changes in the executive attention network at post-assessment. However, the current results may not be that surprising, given that the amount of training students received in the present study is not comparable to previous studies that had a greater total number of hours of mindfulness training. However, the lack of positive benefits observed in the mindfulness group for the attentional alerting network do stand in stark contrast to previous studies that showed enhanced function (Tang et al., 2007; Jha et al., 2007) after mindfulness training.

Another surprising aspect of the findings was that the two indices of sustained attention in the SART task, though showing improvements in the mindfulness group, actually exhibited larger positive effects for the control group. These two indices are thought to reflect the presence of mind-wandering (Robertson et al., 1997; Bastian & Sackur, 2013; Mrazek, Smallwood, & Schooler, 2012), and indeed several prior reports have shown selective benefits on these exact measures following mindfulness training. Yet this pattern did not replicate in the current study.

Finally, the pattern of AX-CPT results are also puzzling and somewhat random. Specifically, students in mindfulness class showed overall more errors and shorter reaction time at post-assessment, while students in control class exhibited more errors in two specific trial types and had overall longer reaction time, which were all unexpected regardless of whether or not training was applied to these students, since their performance should remain relatively close to what it was at baseline.

There are several possible explanations that might account for these deviant patterns. First of all, it should be noted that the distributions of measures in AX-CPT and SART were mostly skewed due to between-subject variability (distributions plots can be found in the supplementary files), which may give rise to some of the perplexing trends. Secondly, given the nature of class design and structure, most of the students did not complete the cognitive tasks within a standard laboratory setting, and instead they used their leisure time to finish these tasks in an unsupervised and uncontrolled manner, which could lead to increased noise and possible contamination of the data. Additionally, for students in the control group, data analyses were only conducted on participants who completed the entire cognitive task battery, which means that those participants who completed just one or two tasks were excluded from analyses. The reason for this strategy was due to our compensation scheme, such that participants were only compensated if they completed all tasks; consequently, we were required not to keep data from participants that were not compensated. Therefore, it is plausible that those who persisted and finished all cognitive tasks may have had inherent differences in their level of motivation, persistence, and cognitive ability, which could all potentially contribute to these observed task outcomes to some extent.

However, our assessment of psychological well-being was less affected by these abovementioned extraneous factors, since both classes had to complete the self-report questionnaires as part of their class requirement. Moreover, the questionnaire responses were also likely to be less vulnerable to environmental distractions and noise than the cognitive tasks. Based on our data, we found that subjective reports of mindfulness capacity and life satisfaction in college students were elevated after a period of brief mindfulness training, whereas students in control group did not have a similar level of improvement in these indexes. Although, we did not find any positive impact of mindfulness training on symptoms of depression, self-report anxiety symptoms did decrease more in mindfulness group than in control group, which is consistent with previous studies that showed improvement in anxiety after mindfulness training (Dvorakova et al., 2017). A deviant trend of poorer sleep quality at post-assessment was observed for both groups, but this could possibly be due to the fact that our post-assessment was conducted towards the end of semester during finals period, a time that students were likely to have disrupted patterns of sleep.

Together, the findings indicate that although the cognitive benefits of brief mindfulness training within an education context were rather moderate and mixed, there was an overall improvement in measures of psychological health for students who underwent mindfulness training. This pattern suggests that incorporating mindfulness training into the college educational system is indeed both feasible and promising. Lastly, given that the two groups were non-randomized and had baseline differences in measures such as trait mindfulness, symptoms of generalized anxiety and depression, as well as sleeping quality, the groups may not have been equivalent in psychological well-being at baseline, which could have potentially influenced the outcomes of assessments. Nevertheless, the potential positive effects of mindfulness training on students' cognitive functions and psychological well-being warrant further larger-scale investigation, given that the current study provides only a preliminary exploration, with few results reaching statistical significance. A more in-depth discussion on how to move forward with this type of mindfulness research in educational settings, and to address existing practical constraints for future studies, is provided in the General Discussion section.

Chapter 3: Effects of Mindfulness Training and Physical Exercise in Older Adults

3.1 Materials and Methods

This study examined the effects of combining both physical exercise and mindfulness training into a 6-month training program on cognitive functions and psychological well-being in older adults. As discussed in previous sections, this approach of combining two promising trainings to together capitalize the benefits on cognition and psychological well-being has not been applied in prior research. Thus, the goal of the current study was to investigate the feasibility and utility of such approach in groups of older adults.

Participants. 26 non-demented healthy older adults aged between 65 and 84, underwent a 6-month of combined acute physical exercise and mindfulness training at two separate study sites. In particular, 14 participants received training at University of California San Diego, while the other 12 participants were trained at Washington University in St. Louis. This pilot dataset was collected as a part of feasibility study for the MEDEX (Mindfulness, Health Education and Exercise) project that seeks to promote cognition and potentially reverse age-related cognitive declines using mindfulness and physical exercise training. Since this was a pilot feasibility study, the dataset only contains groups of older adults who were recruited to receive and had finished the combined training as a means of potentially addressing age-related decline in aspects of cognition such as memory and attention.

3.1.1 Procedure

All participants underwent physical exercise and mindfulness training at training facilities with guided and certified instructors, as well as completing at-home practices and exercises by themselves for a period of 6 months. Specifically, participants came in once weekly to receive mindfulness training and twice weekly to receive exercise training. The NIH Toolbox for Assessment of Neurological and Behavioral Function (www.nihtoolbox.org) and NIH Patient Reported Outcomes Measurement Information System (PROMIS; www.nihpromis.org) were used to assess participants at baseline (prior to receiving training), 3-month (mid-training) and 6-month (after the completion of training) for any improvement in cognition and psychological well-being.

Mindfulness Training. The standardized Mindfulness Based Stress Reduction (MBSR) program developed by Jon Kabat-Zinn, PhD. at the University of Massachusetts was selected to be the primary mindfulness training method. The program is led by two certified and experienced MBSR instructors in a group-based and classroom setting, and consists of an introductory meeting, followed by eight weekly 2.5-hour classes plus a retreat. The curriculum includes instruction in mindfulness meditation practices, gentle mindful movement, and additional exercises such as yoga and various techniques of meditation to enhance mindfulness in everyday life. *A Mindfulness-Based Stress Reduction Workbook* was used as a companion guide. Participants also received daily homework to practice mindfulness by themselves using a CD, and were encouraged to continue this even after the completion of 8 weekly classes for the first two months.

Physical Exercise. A multi-component intensity-based exercise training protocol was developed and used to improve aerobic fitness and insulin sensitivity in older adults, as well as to improve strength and balance and reduce indices of frailty. The training consisted of two classes per week, totaling up to 1.5 hours, under the guidance of three trained exercise instructors. Each session included aerobic exercises and resistance training and exercises involving balance, mobility, and flexibility, which are an essential part of an exercise program in this age group. Participants were also prescribed an hour of at-home exercise to complete twice weekly. The aerobic component consisted of walking and/or using exercise DVDs. In addition, a rotation of exercise cards for strength and balance-training exercises practiced in class were provided to participants so that they can safely practice at home.

3.1.2 Behavioral Questionnaires

As a part of NIH PROMIS self-report measures of mental health, a 7-item short questionnaire was used to assess symptoms of anxiety; for depression, an 8-item questionnaire was included in the assessment. Additionally, sleep disturbance was measured using an 8-item questionnaire that surveys any problems with sleep over the past 7 days.

Trait mindfulness was assessed using the Revised 12-item Cognitive and Affective Mindfulness Scale (Feldman, Hayes, Kumar, Greeson, & Laurenceau, 2007), which is a uni-dimensional questionnaire that measures mindfulness during general daily occurrences on four components related to mindfulness (attention, awareness, present-focus, and acceptance).

3.1.3 Cognitive Tasks

A set of cognitive tasks were collected using the NIH Toolbox task battery, and details about scoring procedures and norms are available at (https://nihtoolbox.desk.com/customer/portal/articles/2437205-nih-toolbox-scoring-and-interpretation-guide). Among a variety of neuropsychological measures, five tasks tapping into different aspects of cognitive functions were included in the analyses. The first one is the flanker task, which measures attention and inhibitory control by asking participants to attend to a particular stimulus (target) and rapidly respond appropriately to it while inhibiting responses to flanking (non-target) stimuli. Typically, the target stimulus is an arrow pointing to a specific direction, whereas non-target stimuli are the ones that either point to the same direction as the target stimulus (congruent), to an opposite direction (incongruent), or to neither (neutral). Participants are asked to make responses by indicating the direction of the target arrow. The second one is dimensional change card sort task, which measures cognitive flexibility by asking participants to match a series of bivalent test cards to target cards either by one dimension (color) or by the other dimension (shape), with the relevant dimension switching randomly (and cued with each trial). The third task assesses working memory by presenting participants with randomly intermixed pictures of foods and animals (with set size progressively increasing across trials), and asking them to internally reorder and recall the items according to category and size (i.e., smallest to largest, food then animals). The fourth task measures episodic memory by asking participants to recall a series of illustrated objects and activities that are presented in a particular order on the computer screen, with again the number of illustrated objects and activities gradually increasing. The fifth task assesses processing speed, by asking participants to rapidly discern whether two visual patterns were the same or not, making as many keypress choices as possible in a 90-second period.

3.1.4 Data Analyses

Behavioral questionnaires were scored based on published scoring guides found in www.nihpromis.org. For cognitive tasks, scores for each task were automatically generated from the NIH Toolbox and used in subsequent analyses. Notably, we used age adjusted scores for all tasks except the flanker task and dimensional card sort task. For these latter two tasks, the computed scores, instead of age adjusted scores, were used for analyses, since the computed scores take into account both accuracy and reaction time, which are known to be critical for these two tasks. We also included a fluid cognition composite score, which reflects the capacity of novel information learning and problem solving that is independent of previous knowledge. The composite score reflects the summed performance across the abovementioned five cognitive tasks.

Data were examined for any violation of normality assumptions. Outliers were observed in the flanker task and list sorting working memory task, but not in any self-report questionnaires. Therefore, for these two tasks, data were analyzed with and without including the outliers. Individual paired t-tests were conducted for participants who successfully completed all three time points, in order to test for any changes in cognitive and behavioral measures from baseline to the 3-month assessment, and from baseline to the 6-month assessment.

3.2 Results

A descriptive statistics table of all participants in this study is provided below before any discussion of the results. It should be noted that higher scores in each of these questionnaires reflects higher level in that scale, which means higher score in anxiety would indicate higher level of anxiety, while higher score in mindfulness would indicate greater level of trait mindfulness. For cognitive tasks, higher scores indicate better performance.

Table 2. Descriptive Statistics for Study 2

Questionnaires	**Session**	**N**	**Mean**	***SD***
Anxiety	Baseline	26	14.92	5.075
	3-month	26	14.27	4.075
	6-month	25	14.16	5.281
Depression	Baseline	26	12.88	4.457
	3-month	26	13.23	5.301

	6-month	25	13.24	5.532
Sleep Disturbance	Baseline	26	20.58	5.714
	3-month	26	19.69	6.253
	6-month	25	19.44	7.018
Dispositional Mindfulness	Baseline	26	37.08	5.878
	3-month	26	37.35	4.939
	6-month	25	38.72	6.031
Tasks	**Session**	**N**	**Mean**	***SD***
Fluid Cognition	Baseline	23	108.5	14.18
	3-month	25	109.0	15.16
	6-month	24	113.3	15.56
Episodic Memory	Baseline	25	106.7	16.87
	3-month	25	114.2	20.21
	6-month	25	117.7	20.81
Processing Speed	Baseline	25	104.3	16.80
	3-month	25	101.5	19.51
	6-month	25	105.1	23.44
Cognitive Flexibility	Baseline	25	7.754	0.9305
	3-month	25	7.586	0.8241
	6-month	25	7.728	0.7867
Inhibitory Control	Baseline	25	8.109	0.7185
	3-month	25	8.038	0.7785
	6-month	25	8.037	0.8075

Working Memory	Baseline	25	109.7	15.62
	3-month	25	110.7	12.75
	6-month	24	110.3	13.69

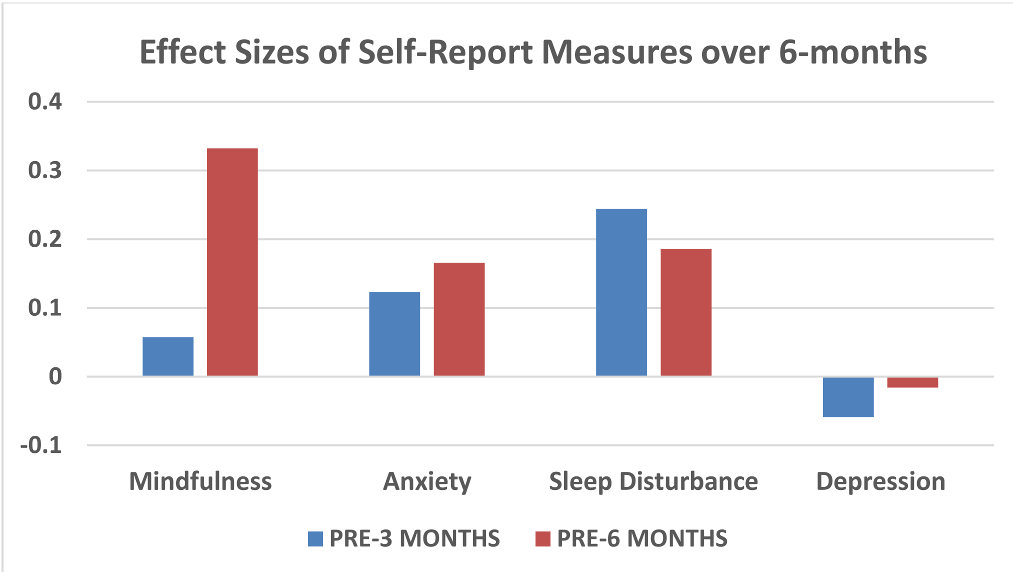
Self-report Measures

It should be noted that we again modified the direction of signs for effect sizes, such that positive values indicate improvement in tasks or psychological well-being, whereas negative signs indicate the opposite.

As expected, there was a moderate increase in self-report trait mindfulness, but with only a small effect (Cohen's dz=0.057) registered at the 3-month assessment, and a larger benefit observable (Cohen's dz=0.332, p=0.110) at the 6-month assessment (see Figure 3 for effect sizes). However, paired t-tests yielded non-significance.

For the self-report mental health and sleep disturbances, 25 out of 26 participants completed data for all three time points. Based on the national PROMIS scoring norms, the mean scores of anxiety, depression and sleep disturbance of these participants were all close to national averages (within 1 SD). Examining the individual scales, anxiety decreased (positive effect size since this was improvement in psychological well-being) from baseline to 3-month assessment and stayed relatively constant at 6-month post-assessment, although the observed changes were not significant in either paired t-tests ($p>0.05$). Similarly, symptoms of sleep disturbance reduced (positive effect size) following training, though the results were again not significant. In contrast, there was a slight increase in symptoms of depression (negative effect size) over the 6-month period, but the results were again not significant. Figure 3 below shows the changes in terms of effect size.

Figure 3. Effect Sizes of Self-Report Measures over 6-month in Study 2



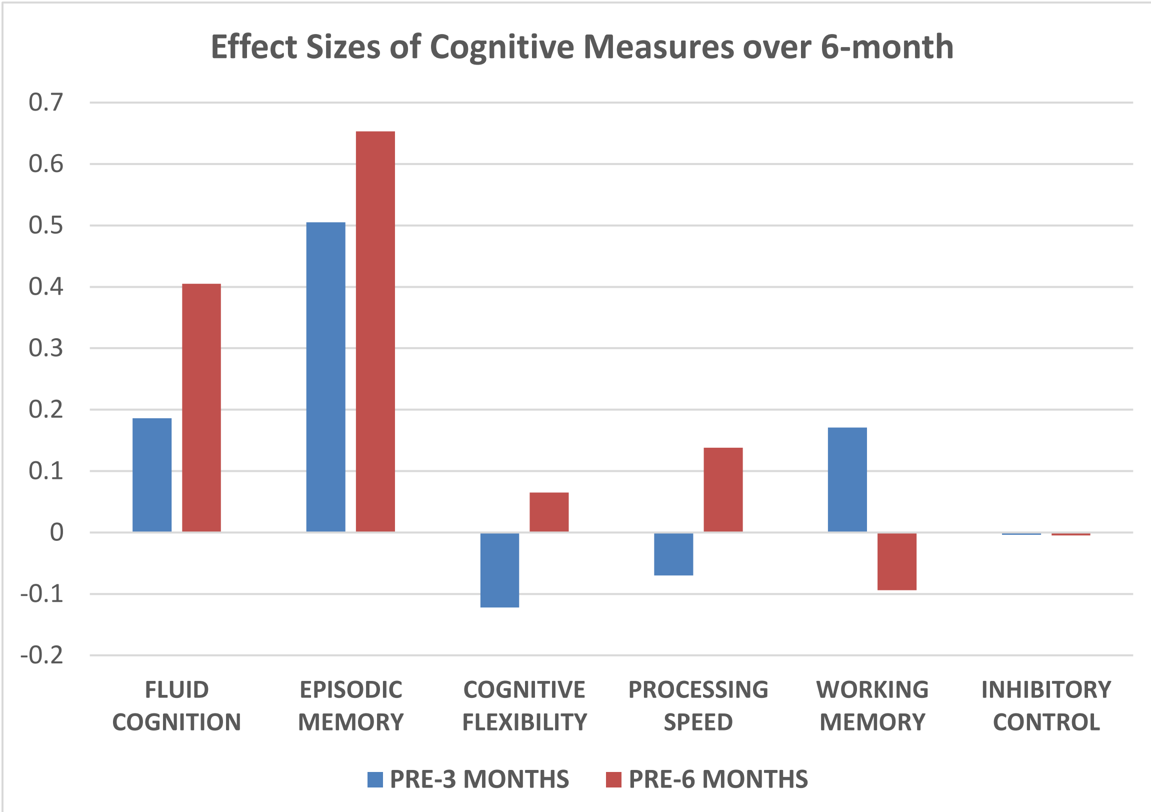
Cognitive Measures

For cognitive measures, means of all six measures were compared with national norms. Participants in the study scored very close to the national averages (within 1 SD). The fluid cognition composite score, which was based on the performance of five different tasks (flanker, dimensional change card sort, list sorting, processing speed, and picture sequence memory) as mentioned previously (N=22 with complete scores for all measures), showed gradual improvement, with a moderate increase present by 6-month (Cohen's dz=0.405). This 6-month effect was considerably greater than that of 3-month (Cohen's dz=0.185), even though both results were not statistically significant ($p>0.05$).

Focusing in on the individual tasks that comprised the composite score, similar trends were observed. The largest effect was observed in episodic memory as measured by the picture sequence task (N=25), with a moderate enhancement from baseline to the 3-month assessment ($t(24)=2.477$, $p=0.021$; Cohen's dz=0.505), as well as from baseline to the 6-month assessment (t(24)=3.306, p=0.003; Cohen's dz=0.653). Both results remained statistically significant even after correction for multiple testing (p=0.05/2).

For cognitive flexibility (N=25) and processing speed (N=25), performance first decreased from baseline assessment to the 3-month assessment (p>0.05), but then increased from the 3-month assessment to the 6-month assessment (p>0.05), to roughly back to where it was at baseline (p>0.05). The measure of working memory capacity, showed the opposite pattern, with task performance improving non-significantly from baseline to the 3-month assessment (N=25, with outliers; N=24, without outliers), but then decreased slightly and non-significantly from the 3-month assessment to 6-month assessment (N=24, with outliers; N=23, without outliers) both with and without outliers. Likewise, the improvement in working memory from baseline to the 6-month assessment (N=24, with outliers; N=23, without outliers) was not significant (p>0.05). Finally, the flanker task measuring inhibitory control (N=25, with outliers; N=24, without outliers) appeared to exhibit almost no change in performance over the course of 6-month training, with or without outliers. Figure 4 below shows the changes in terms of effect size.

Figure 4. Effect Sizes of Cognitive Measures for Both Groups in Study 2



Mindfulness and Cognitive Measures

We conducted exploratory correlational analyses to examine the relationship between trait mindfulness and cognitive functions. The first analysis examined the relationships between individual differences in baseline trait mindfulness and cognitive performance prior to training. However, only performance in list sort working memory task yielded a marginal significant and positive correlation with baseline level of trait mindfulness (r=0.379, p=0.062). Yet, when outlier was removed from the sample, this marginal significance no longer held. The second analysis examined whether baseline levels of trait mindfulness predicted any of the cognitive effects observed following training. Interestingly, baseline mindfulness was found only to be positively and significantly correlated with improvement in episodic memory performance from baseline to the 3-month assessment (r= 0.522, p=0.007), but not with improvement from baseline to the 6-month assessment (r=0.122, p=0.560) or changes in other tasks performance (p>0.05). Consequently, in a last analysis we examined whether training-related improvements in trait mindfulness predicted the magnitude of training-related cognitive benefits. Surprisingly, only one significant and negative correlation was observed for improvement in episodic memory performance from pre to 3-month (r= -0.492, p=0.012), such that individuals showing larger improvements in trait mindfulness tended to show reduced benefits in episodic memory. For other cognitive tasks, no significant correlations were found with change in trait mindfulness.

3.3 Discussion

In this preliminary feasibility study, standardized mindfulness training was combined with multi-component, intensity-based physical exercise training to together promote cognitive and psychological well-being in older adults concerned about age-related declines in many critical aspects of daily functioning. The most consistent improvements were seen in anxiety related symptoms; additionally, less sleep disturbance and higher trait mindfulness were also observed over the 6-month period of training. In particular, these effects were evident at 3-month and stayed relatively unchanged at 6-month post-assessment. However, depression related symptoms seemed to increase slightly over the course of training, which is somewhat contrary to what had been observed in prior reports. Yet, the effect sizes of these changes in depression were close to zero, suggesting that the minor fluctuations could be spurious. For example, the slight changes in depression ratings could be due to measurement noise, such as unexpected life events that participants might had encountered during times that were close to assessments. An obvious alternative interpretation is that they reflect a null effect of the training intervention on depression; however, this seems less likely, given previous evidence that demonstrated emotional benefits of either mindfulness training or physical exercise training in older adults with worries and affective problems (O'Connor, Piet, & Hougaard, 2014; Lenze et al., 2014; Netz, Wu, Becker, & Tenenbaum, 2005).

In addition to these moderate yet positive changes in mental health, some salutary effects on cognitive functioning were also observed in the present study. Overall, based on effect sizes, the positive improvements were most pronounced in episodic memory, and in the composite fluid cognition measure. These lines of evidence are in line with previous research that indicates mindfulness training could enhance these cognitive capacities (Moore et al., 2009; Zeidan et al., 2010), except that prior researchers did not find strong evidence supporting the effects of mindfulness training on episodic memory. However, research has shown that physical activity is positively associated with episodic memory performance in older adults (Hayes et al., 2015), which might explain this observed improvement in episodic memory after training intervention. There were also slight enhancements in the cognitive flexibility, processing speed and working memory measures, but the effect sizes (<0.2) were weaker than that found in fluid cognition and episodic memory. Additionally, one surprising finding was the no improvement in inhibitory control, an index that has been repeatedly shown in previous studies to enhance after mindfulness training (Heeren et al., 2009; Tang et al., 2015).

Together, these results suggest that combining mindfulness training with physical exercise training could positively enhance general cognitive abilities and mental health over the course of a 6-month training period; nevertheless, the effects were small in magnitude and were mostly not statistically reliable. In particular, these preliminary results should be interpreted with caution and scrutiny, since several limitations exist in the present study.

The first limitation is the lack of a control group, which makes a direct comparison of effect sizes impossible. Second, although we did observe positive trends for almost all measures of psychological and cognitive well-being, these results were not statistically significant, which could either suggest that the effects were not robust enough due to relatively small sample sizes or that what we have observed here is simply due to chance or practice effects. Third, it is also possible that after the first two months of guided mindfulness training, individual at-home practices may not be equally effective as face to face practice with instructors, thus contributing to non-significant results in training-related outcomes. All of these explanations are likely, and should be considered carefully when interpreting the results. As such, further discussions concerning these issues raised above will be provided in the General Discussion section.

Nevertheless, the present study is unique in that it is among the first to employ a combination of two effective and promising training interventions: mindfulness with physical exercise, to together combat age-related declines in cognition, along with promoting psychological health in older adults. Furthermore, the study also demonstrated the feasibility of providing these two forms of training simultaneously to older adults. These promising trends offer novel possibilities and evidence for future large-scale studies that may be able to comprehensively and rigorously investigate the effects and benefits in combining training methods to boost training-related outcomes in cognition and behavior. Indeed, the next step would be to compare the results of this study with the full-scale MEDEX project that includes not only a mindfulness training plus physical exercise group, but also three other comparison groups: health education, mindfulness training alone, and physical exercise alone, to together examine if the combination of two trainings is superior and more effective than conditions involving only one training approach.

Chapter 4: Trait Mindfulness and Brain-Behavior Relationship

4.1 Introduction

The goal of this study was to investigate the putative neural correlates that give rise to the relationship between individual differences in trait mindfulness and cognitive functions found in previous studies. One pivotal component in answering this research question is the selection of an appropriate neural index, since it is essential to have an index that can best relate to variability in trait mindfulness and cognitive performance at the neural level. Intuitively, personality measures such as trait mindfulness should reflect a relatively stable and global disposition that individuals possess with varying degree, which in turn requires a neural index that can be equally reflective of global qualities or characteristics of brain states within each individual, in order to examine our brain-behavior question.

In the current study, we chose the efficiency of brain network reorganization as a promising neural index, which assesses how well individuals update their brain network organization as measured by the similarity of functional connectivity (FC) patterns from rest to task state in response to task demands. The rationale behind selecting this index was threefold. First, this index is sensitive to individual differences in our variable of interests, namely, cognitive performance. As shown in a study by Schultz and Cole (2016), higher efficiency, meaning greater similarity of FC patterns between rest and task state, was positively associated with cognitive tasks performance, as well as with general intelligence. Second, general intelligence is similar to trait mindfulness, such that they both could reflect the level of global and intrinsic ability within individuals, which suggests a plausible relationship between trait mindfulness and this efficiency index. Third, trait mindfulness is conceptually related to the efficiency of network reorganization. In particular, trait mindfulness reflects a state of mind where individuals constantly possess a present moment awareness and attention in response to external stimuli, which could facilitate individuals becoming promptly aware of and update their brain network organization into an optimized state space that does not require moving as much from one state space to another when there is a task demand. Thus, it is possible that being highly mindful could entail being highly efficient in terms of moment-to-moment network reorganization. Based on these abovementioned reasons, employing this efficiency index seemed like a suitable and promising approach for our investigation.

4.2 Materials and Methods

Participants. Participants were recruited from the subject pool of Washington University-Minnesota Consortium Human Connectome Project (HCP) (Van Essen et al., 2013) for a study on cognitive control and mindfulness training. In particular, mailed questionnaires and consents were sent to these participants, who were mostly local community adults living in St. Louis and surrounding areas. All behavioral questionnaires related to individual differences were collected either through the Research Electronic Data Capture (REDCap) electronic data capture tools hosted at Washington University, or via paper questionnaires that were mailed to participants' home address. Each participant could choose from the following two options: 1) complete questionnaires online or 2) fill them out on paper and return through the regular mail. Among all contacted participants, we were able to acquire behavioral questionnaires from 48 people (24 males, 24 females). All neuroimaging data of these participants had been collected prior to the study, as part of the HCP, making this a convenience sample and follow-up investigation.

Informed consents were obtained from all participants and a $25 compensation was provided to each participant who completed the new questionnaires.

Behavioral Questionnaires. A battery of behavioral questionnaires was collected, but for the purpose of this study, we will only focus on two trait mindfulness questionnaires: Five Facet Mindfulness Questionnaire (FFMQ) and Mindful Attention Awareness Scale (MAAS). Both FFMQ (Baer et al., 2006) and MAAS (Brown & Ryan, 2003) have been validated previously as reliable measurements of trait mindfulness in multiple studies across different countries and populations (Carlson & Brown, 2005; Hansen et al., 2009; Baer et al., 2008). The MAAS is a 15-item scale designed to assess open awareness of and attention to what is taking place in the present. The FFMQ consists of 39 questions tapping into five independent and core facets of trait mindfulness: nonjudging, nonreactivity, observing, describing, and acting with awareness. Additionally, the NEO Five-Factor Inventory, a quick and accurate measure of the big five factors of personality, was also included for later comparisons, having been collected and computed previously as a part of the standard HCP protocol.

MRI Acquisition. Functional images were acquired using echo-planar BOLD sequence with a 32 channel head coil on a modified 3T Siemens Skyra scanner with TR=720 ms, TE=33.1 ms, flip angle=52°, BW=2290 Hz/Px, in-plane FOV=208 x 180 mm, 72 slices, 2.0 mm isotropic voxels, and a multiband acceleration factor of 8 was used (Ugurbil et al., 2013). Further details regarding these protocols and procedures were described previously in Smith et al. (2013). Data were collected across two consecutive days. For each day, two sessions of 28 min of resting state fMRI data were acquired (56 min total), and each was separated and followed by a session of 30 min of task fMRI data collection (60 min total). The task fMRI component of the HCP comprised seven tasks in total, and each task was completed over two consecutive fMRI sessions. Detailed description regarding these task paradigms can be found in Barch et al. (2013).

Tasks. The seven distinct tasks that were completed inside the scanner, included tasks of emotion perception, language processing, relational reasoning, reward learning, motor responses, social cognition, and working memory. These tasks engaged different aspects of cognitive and emotional processes and have been found in the prior literature to reliably activate well-defined brain networks and functional regions (Barch et al., 2013). In the current study, we focus on the n-back working memory task given our specific interest in the neural correlates of trait mindfulness in relation to cognitive performance during working memory, following up on previous findings reported by Schultz and Cole (2016).

4.2.1 Behavioral Data Analyses

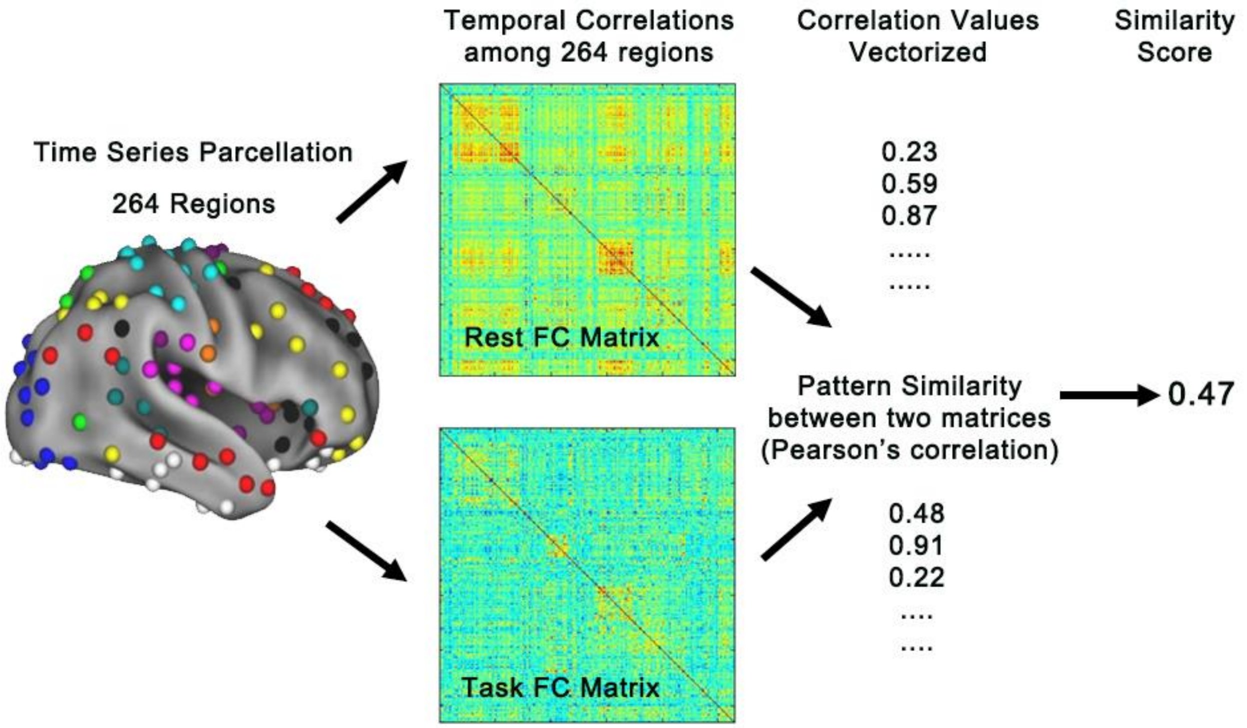
Questionnaires were scored for each participant following instructions from published scoring guides (Brown & Ryan, 2003; Baer et al., 2006). The final score of MAAS was obtained by simply averaging the scores of all 15 items. For FFMQ, some items were reverse scored based on guidelines, and five individual facet scores were calculated by taking the sum of all items in that facet. A total FFMQ score was also calculated by summing all five facets scores. Participants who missed more than three items in the MAAS were excluded from analysis (one met this criteria). For FFMQ, there was only one missing item for one participant and the average scores of that item from all other participants was taken and imputed for that item. We ran analyses in two ways, either with the imputation or without imputation (throwing out the entire case), but the results did not change whether we did one way or the other. For the NEO-FFI, we used factor scores of neuroticism and conscientiousness calculated by the HCP as comparison measures in our subsequent analyses.

4.2.2 Neuroimaging Data Analyses

fMRI preprocessing. Data were minimally preprocessed by the HCP pipelines, which include standard preprocessing procedures such as motion and distortion correction, spatial normalization and intensity normalization. Additional details on HCP minimal preprocessing pipelines can be found in Glasser et al. (2013). For subsequent processing and analyses, we replicated the exact approaches used by Schultz & Cole (2016). The first step involved removing nuisance variables such as the 12 motion parameters, white matter and ventricle signals, and their derivatives from the time series using linear regression in AFNI (Cox, 1996). These nuisance signals were generated previously within the HCP preprocessing pipelines (Glasser et al., 2013). Linear detrending was applied to the time series and all data were spatially smoothed (FWHM=4 mm). We did not apply the typical whole brain global signal regression and temporal filtering on the resting state fMRI data in order to maintain consistency with the Schultz & Cole (2016) approaches. The rationale behind this choice was to process resting state data and task data in the same manner to reduce potential differences, and thereby allow unbiased comparisons between resting state and task state functional architecture in later analyses. Next, using in-house scripts provided by Schultz & Cole, spatially smoothed time series were parcellated into a set of 264 regions (ROIs) encompassing 14 functional networks in MATLAB (The MathWorks), which would enable us to investigate brain functional organization at the network-level. These 264 putative regions were identified and classified into 14 functional networks by Power et al. (2011) based on task-based neuroimaging meta-analyses. These identified functional networks form coherent subgraphs that are in good agreement with known functional brain systems (Power et al, 2011). After parcellation, voxels within each of these 264 regions were averaged across the time series for later calculation and construction of functional connectivity matrices for both resting state and task fMRI data. To increase the reliability of task functional connectivity (FC) estimates, we also removed average task-related signals from the task data by using the residuals of a standard general linear model regression of task events, following previous approaches (Cole et al., 2014). Next, we performed these exact same steps again on resting state fMRI data for the purpose of analyzing task and resting state data in the same way. Although regressing out task-related signals from resting state data should not affect our results (since they are considered to be orthogonal to the resting state signal fluctuations), we compared the results without task-related signal regression with results that underwent regression; not surprisingly, there were no differences detected. We then calculated Pearson's correlations between all pairs of 264 ROIs for each participant and for each task, in order to construct FC matrices. This step returned 7 FC matrices per participant. For instance, if the reasoning task consisted of 200 time points (fMRI scan images), then the resting state matrix was calculated using the same number of time points as in reasoning task, which in this case was 200 (starting from the first rest scan to the 200th). Finally, Pearson's correlation values were all normalized using a Fisher's Z transformation.

FC Similarity. Our goal was to assess the similarity of FC patterns between resting state and task state as a measure of functional network update or reconfigurations from one state to another. Prior work in mathematics and other fields has established that pattern similarity can also be regarded as the inverse of distance in state space (Cha, 2007). Therefore, a high degree of pattern similarity between the resting state and a given task state was interpreted as reflecting greater efficiency in brain network organization, such that there was less of a shift need to move participants from the rest state to the given task state. To quantify the similarity of FC patterns, we calculated a single similarity score for each participant based on Pearson's correlation, that is, a correlation coefficient was calculated between the values of the task FC matrix and the values of the resting state FC matrix. We first isolated the upper triangle of each FC matrix by removing redundant connections in the lower triangle and self-connections on the diagonal. We then vectorized these remaining values for each rest FC matrix and task FC matrix before calculating a Pearson's correlation between them as our similarity score. Below is Figure 5 which summarizes these abovementioned steps.

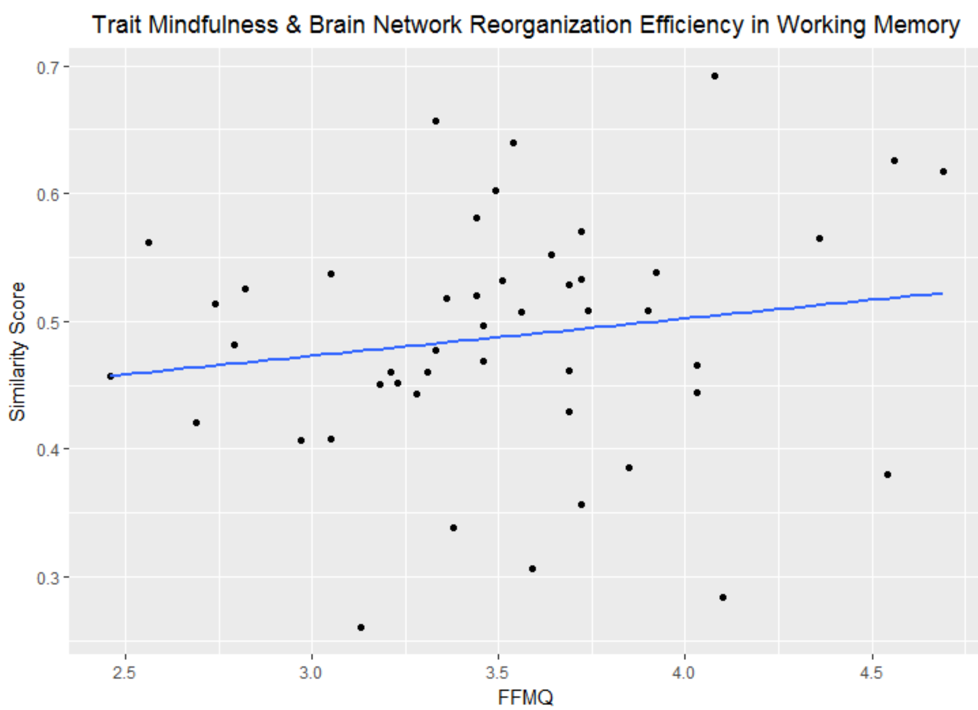
Figure 5. Flow Chart of Brain Network Reorganization Efficiency Calculation



4.3 Results

A first goal was to replicate previous findings regarding the positive association between trait mindfulness and cognitive performance in working memory. To accomplish this, we took individual scores of trait mindfulness in MAAS (Mindful Attention Awareness Scale) and FFMQ (Five Facet Mindfulness Questionnaire), and conducted two separate correlational analyses with participants' overall accuracy in working memory task (up to 2-back). However, no significant correlations between trait mindfulness and working memory performance were detected ($r=-0.259$, $p=0.076$ for MAAS; $r=-0.047$, $p=0.754$ for FFMQ). Second, we went on to examine whether or not an association exists between trait mindfulness and brain network reorganization efficiency (the similarity score between rest and task FC patterns) in working memory task. Again, we did not observe any significant correlations between the MAAS (r=0.004, p=0.979) or FFMQ (r=0.157, p=0.291) and the efficiency of brain network reorganization from resting state to task state. It should be noted that, when initial analyses were conducted on a starting dataset of 36 participants, a significant positive correlation was observed for the FFMQ (but not MAAS) and brain network update efficiency. However, when the sample size increased to 48 participants, the significant finding was no longer present, even though the trend was still in the positive direction (see Figure 6 below).

Figure 6. The Relationship of Trait Mindfulness and Brain Network Reorganization Efficiency

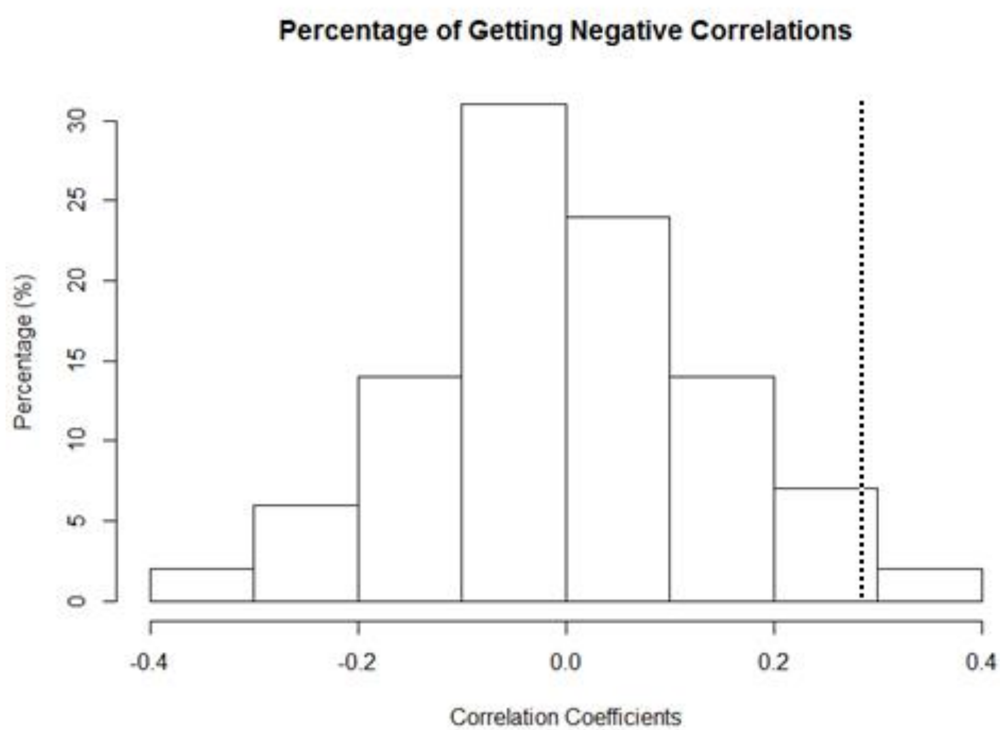


Although we did not observe any significant correlations between trait mindfulness and the efficiency of brain network update, it is possible that trait mindfulness may not be a sensitive individual difference index. Thus, for a comparison, we substituted in two more standard personality measures for trait mindfulness, conscientiousness and neuroticism, which have been shown to strongly associate with trait mindfulness based on prior literature (Giluk, 2009), to test whether these measures would show any relationship with brain network reorganization efficiency, or with n-back working memory performance. Perhaps not surprisingly, none of the computed correlations were statistically significant, with conscientiousness showing a negative correlation at r=-0.143, p=0.333, and neuroticism showing a correlation at r=0.009, p=0.954.

Because of these null results in the primary question of interest, we also examined whether we could replicate the Schultz and Cole (2016) finding of a positive association between brain network reorganization efficiency and task performance within our current sample. It is important to note that although both our study and that conducted by Schultz and Cole (2016) involved analyses of participants from the full HCP dataset, our sample of 48 participants constituted an almost fully non-overlapping subset of HCP participants from the 100 HCP participants examined by Cole and Schultz (2016). This is because our sample was one of convenience, consisting of local (Missouri area) participants willing to complete follow-up questionnaires, whereas Cole and Schultz (2016) used an existing sub-sample provided in the HCP release (100 unrelated participants).

Thus, a key question was whether, in our sample of 48 participants, we would observe the same positive correlation between brain network reorganization efficiency (i.e., pattern similarity between resting state and the n-back task) and n-back task performance. Surprisingly, we did not replicate this effect, but instead observed a non-significant and negative correlation (r=-0.132, p=0.372), in which participants with greater efficiency in brain network updates tended to perform worse in working memory task, contrary to what had been found in Schultz and Cole (2016). Attempting to understand this puzzling result, we went a step further to explore the probability of getting a negative correlation between these two measures using the original dataset from Schultz and Cole. Based on the sampling distribution of correlation coefficients that we generated by randomly pulling out subsets of 48 participants from the 100 participants in Schultz and Cole's study (100 correlation tests computed), we found that negative correlations were obtained over 50% of the time, and that replicating a positive and significant correlation was also very unlikely (see Figure 7 below, where dashed line indicates the cutoff for significant positive correlations). Thus, we conclude that it was not that unusual or anomalous to have observed a negative correlation in our new sample of 48 participants, even when trying to replicate the observed significant positive correlation reported by Schultz and Cole (2016).

Figure 7. Percentage of Getting Negative Correlations between Working Memory Performance and Brain Network Reorganization Efficiency



4.4 Discussion

In this study, we aimed to explore the neural correlates of how individual differences in trait mindfulness relate to variability in cognitive task performance such as working memory, since previous research has not provided a coherent explanation as to why higher trait mindfulness might be associated with better working memory capacity. The preliminary results did not support our hypothesis that trait mindfulness would be associated with either working memory performance, or more importantly, with brain network reorganization efficiency, using the novel measure developed by Schultz and Cole (2016). In their recent study, Schultz and Cole (2016) found that this novel measure was positively associated with better performance on the n-back task, and also more generally higher intelligence. Even though a weak positive association was found between this bran network measure, and one of the measures of trait mindfulness (FFMQ), the result was not statistically reliable, and could be spurious, given that it fluctuated downward as the sample size increased from 36 to 48 participants. These lines of evidence seem to suggest that individual variability in trait mindfulness is not reliably associated with the efficiency of updating brain network organization from the resting state to a task state. Furthermore, our results also call previous claims into question regarding whether higher trait mindfulness is reliably related to higher working memory capacity.

Nonetheless, several issues need to be carefully considered before we make the conclusion that no relationship exists among these variables based on our finding of non-significance. First, given the small sample size of our dataset, it is possible that the effect size of this relationship among trait mindfulness, working memory and brain network reorganization efficiency is not large enough to be reliably detected in a group of 48 participants, and that substantially bigger sample sizes may be needed for the results to reach statistical significance.

Second, it is possible that there may be some noise within this efficiency of brain network reorganization index, such that it may not be sensitively capturing brain network characteristics that are relevant for trait mindfulness and working memory. Third, our validation steps also demonstrated that even the previously reported finding of Schultz and Cole (2016), is not so robust as to be reliably detected in a smaller sample. Specifically, our sampling distribution analysis indicated when trying to replicate the finding in a subset of 48 participants, a negative correlation would be observed over half the time, and only rarely (3% of the samples) would a significant positive correlation be detected. The implication of this analysis is that it suggests a large sample size is necessary to detect relevant positive associations of this type (which exhibit only small effect sizes), or alternatively, it could suggest that the previous report of a positive correlation may have been driven largely by a subgroup of participants that exhibited patterns of association in the positive direction, but not by the entire 100 participants.

Taken together, these results suggest that future studies using large sample sizes are warranted to more strongly validate the claim that individual variability in trait mindfulness is related to individual differences in working memory capacity. Additionally, selecting other more sensitive neural indexes, such as graph theoretical metrics and multivariate pattern analyses, in addition to this brain network reorganization efficiency index, may be critical for the investigation of neural correlates of trait mindfulness and cognitive performance. Again, further discussions regarding the abovementioned issues will be provided in the General Discussion section.

Chapter 5: General Discussion

Previous research endeavors have devoted considerable efforts into investigating effects of mindfulness training on cognitive functions, psychological, and physiological health in a range of populations. Although important scientific advances have been made by uncovering these benefits and their associated underlying mechanisms, the application and utility of mindfulness training in contexts other than standardized training settings have been less explored. Additionally, incorporating and combining mindfulness with other forms of training and curriculum to together promote and enhance the outcomes of training have not been carefully examined. Lastly, there has been no clear explanation provided to date as to the neural mechanisms by which individual differences in trait mindfulness might give rise to differential cognitive performance.

Through a series of three preliminary studies, we were able to explore these less investigated domains. First, we studied the utility and effectiveness of mindfulness training within an educational context adapted to a standard college curriculum (i.e., a semester-long seminar class), but moreover adapted the mindfulness practices to better fit the needs of college students. We found that compared with students in a control class who were taught strategies that promote psychological growth and development during college years, students in the mindfulness class exhibited greater psychological well-being in areas such as anxiety, dispositional mindfulness and satisfaction with life. Furthermore, students in the mindfulness class also showed some promising trends in improving cognitive functions such as working memory and selective attention. However, several practical and methodological issues exist in the present study, which should be taken into careful consideration when interpreting results, as well as when planning for future studies.

The first issue is the small sample size of the mindfulness group, with around 24 students enrolled in the class and an even smaller sample size for individual cognitive tasks due to some students not completing the entire task set. One straightforward solution is simply increasing the sample size to where we should be able to have enough power in order to detect an effect based on effect sizes reported in prior mindfulness meta-analyses (Hofmann et al., 2010; Lao, Kissane, & Meadows, 2016), and to where incomplete data is less of a problem given the large N. However, practically, having more than 25 students with only one instructor per group is not ideal for training quality. In fact, previous studies have mostly adopted a sample size of under 30 per group for mindfulness training studies. Thus, although we are aware of the sample size limitation that inevitably influenced our ability to detect significant effects, we were unable to address this issue in this preliminary study without sacrificing the quality of training. Yet, there are few alternative solutions to this issue including: 1) conducting training in multiple groups at different times of the day, 2) having more than one instructor available who is willing and able to teach and train students, and 3) having more teaching assistants but just one instructor to guide a larger group of students. One difficulty with training groups involving a sample size greater than 25 is that the instructor is not able to manage, monitor and respond to everyone in the class. Having a number of trained teaching assistants available would address these concerns regarding training quality, while allowing for a simultaneous increase in overall sample size.

The second issue relates to the non-laboratory assessment of training outcomes, which would definitely increase the likelihood of noise in our cognitive data, since students completed those tasks during their leisure time. Even though this set-up may not have been optimal from an experimental perspective, it did represent a sensible compromise, given the constraints of providing mindfulness training within standard educational setting. Specifically, these assessments were not solely meant for research purposes, but were also a part of educational experience provided to students in the class. Thus, allowing students to complete these tasks outside of class time instead of coming into laboratory was the most efficient and reasonable approach to simultaneously collect data and educate students. Nevertheless, in order to rigorously examine and evaluate training effects on students' behavioral outcomes for future studies, we could modify the current assessment approach by 1) setting up a specific time period outside of class for students to complete these behavioral measures, and 2) asking students to report the amount of distraction while they complete these assessments.

The third issue concerns the quasi-experimental nature of the research design, which was again inevitable within the educational context, since the students who chose to sign up for this class were ones already interested in mindfulness training; thus, they could not be randomly assigned to other conditions. This challenging issue will always exist, which means a comparable control group is required to match the mindfulness group in terms of motivation and interests. In our current study, the positive psychology class served as such control group, with only one caveat of a significantly larger sample size than that of the mindfulness group, which could be addressed in future studies by undertaking the solutions mentioned above regarding sample size.

Although there were limitations in terms of sample size and research design, Study 1 was able to provide valuable initial insights into how to incorporate mindfulness training within current college educational systems, and how to improve existing programs to capitalize the benefits of mindfulness training within these systems. Therefore, finding the optimal balance between: 1) providing valuable educational experiences and training to students; and 2) conducting scientifically rigorous research studies to evaluate training effects, will be critical for future studies of mindfulness training within educational settings.

In Study 2 we explored the effectiveness and feasibility of combining mindfulness training with physical exercise training, as a means of collectively strengthening training-related benefits in older adults, a population that is sensitive to age-related declines in cognition. These two trainings have each been separately tested in prior literature. This literature has demonstrated salutary effects of both mindfulness training and physical exercise training on cognitive function. Thus, in study 2, preliminary data from the MEDEX project was used to examine the combined effects of training on cognitive and psychological health. We found that episodic memory and overall fluid cognition were moderately enhanced after a 3-month combined training and were maintained at 6-month post-assessment. Additionally, psychological well-being in domains such as anxiety and trait mindfulness also gradually improved over the 6-month period as a result of training; an exception was in sleep disturbance, since improvement was observed after 3-month training, which had a greater effect size than that of 6-month training.

However, the results of the current study are surprising in that most effect sizes were relatively small and that several findings did not replicate what had been found in previous studies. Naturally, it is reasonable to hypothesize that combining two promising trainings should induce greater effects on behavioral outcomes, yet the results proved otherwise. In particular, for psychological well-being, previous meta-analysis of mindfulness training alone has shown an effect of 0.22 [95% CI, 0.02-0.43] at 3-6 months for improved anxiety, 0.23 [0.05-0.42] at 3-6 months for depression, and insufficient evidence of any effect on sleep (Goyal et al., 2014). Although the effect sizes of both anxiety (0.12 at 3-month, 0.17 at 6-month) and depression (0.02 at 4-month, 0.24 at 6-month) fall almost within this confidence interval, these effects were on the lower ends of the CI and did not seem to suggest any superior effects of combining both physical exercise and mindfulness training. For cognitive measures, we did not replicate a consistent improvement in working memory or any improvement in inhibitory control, as had been shown in previous studies of mindfulness training (Lao et al, 2016). Additionally, we did not observe any meaningful improvement in cognitive flexibility (effect sizes: 0.12 at 3-month, 0.06 at 6-month), which is contrary to reports that showed medium to large effect sizes in cognitive flexibility (Lao et al., 2016). Therefore, these small effect sizes increase uncertainty regarding the robustness and reliability of previous reports, and even towards the utility of adding physical exercise with mindfulness training, given that there were virtually no added benefits. Yet, as mentioned briefly in previous section, it is worth considering that the current study did not maintain face-to-face mindfulness training throughout the 6-month period, but instead asked participants to self-practice mindfulness at home after the 8-week MBSR training. This could be potentially problematic for training outcomes, since it is difficult to ensure adherence and the quality of individual practices without on-site instructions and monitoring. As such, diminishing training-related effects as a result of non-supervised mindfulness practices could possibly contribute to these small effect sizes observed at 3-month and 6-month. One solution to this would be to conduct face-to-face training sessions throughout the 6-month period and to better match with the protocol of physical exercise training, for which participants come to the gym throughout the 6-month period.

Finally, in Study 3, we explored whether the putative association between individual differences in trait levels of mindfulness and variability in working memory capacity can be explained in terms of specific neural correlates. To test this, we employed a novel neural index that accounts for the similarity of functional connectivity patterns in brain networks organization between resting state and task specific state, which has been shown to associate with intelligence level and task performance. This global index is thought to reflect the efficiency in brain network reorganization from resting state to task state, which might help us tapping into individual differences at a more comprehensive level without the need to select specific brain regions as the focus of analysis. Consequently, this approach can be used to investigate whether trait mindfulness, an innate characteristic that is somewhat similar to general intelligence, could also be related to this index of general brain organization. Likewise, such an account provides a natural explanatory and mediating framework for understanding how trait mindfulness could be associated with enhanced cognitive function. However, we did not find any association between trait mindfulness and this neural reorganization efficiency index, when looking at similarity between the resting state and a working memory task state. Further, we did not observe a significant positive association between trait mindfulness and working memory capacity as previous studies claimed. Lastly, we did not replicate the finding from one report by Schultz and Cole (2016) who established this index and its positive relationship to general intelligence and cognitive performance. Our subsequent analyses showed that these non-replications were actually not surprising given the limitation of our small sample size on statistical power. Likewise, simulation analyses suggested that even a negative association between brain reorganization efficiency and working memory performance was not statistically unlikely given this small sample size.

However, we need to consider the possibility that, despite evidence showing that this neural index of the efficiency of network reorganization may be the most sensitive and ideal neural correlate of this relationship between trait mindfulness and working memory performance, there might be other more suitable alternatives. For instance, one emerging neuroimaging analysis method based on network neuroscience, the graph theoretical approaches, could calculate brain network metrics that reflect a variety of brain network properties and characteristics. For example, global efficiency as a graph theory metric could be a good alternative, in that it describes the overall efficiency of information transfer among brain regions across different networks, and has been shown to positively relate to individual differences in IQ (Bullmore and Sporns, 2012), a measure that is comparable to trait mindfulness. Moreover, recent advances in multivariate pattern analysis (MVPA) have increasingly helped cognitive neuroscientists to uncover and characterize distinct psychological states based on functional connectivity or activation patterns in the brain, which could in fact capture more fine-grained global network properties that may give rise to the relationship between individual differences in trait mindfulness and cognitive performance. Both of these promising methods remain to be further applied and tested in mindfulness research, as studies have not begun to widely exploit these valuable neuroimaging analyses.

Aside from the limitations and issues discussed above for these three studies, several additional explanations can be offered regarding the pattern of general non-replication that was observed across all three studies. The most worrisome one points to the general increased awareness regarding non-replication patterns in the field of social science (often referred to as "the replication crisis"). Here a common culprit that has been raised is the so-called "file-drawer problem", in which researchers selectively publishing only significant and positive findings, which tends to cause inflation in the actual effect size of an experimental effect. Thus, it is possible that the actual effect of mindfulness training on behavioral outcomes might not be as robust as we previously thought. Indeed, the only solution to this problem would be to conduct more large-scale studies with large sample size and more comprehensive behavioral batteries as a means of determining and validating the actual effects of mindfulness training, and of the combination of mindfulness training with other forms of training, such as physical exercise.

Secondly, confirmation bias, the tendency to search for and interpret findings in ways that can support one's own preexisting beliefs or hypotheses, is also likely to exist in mindfulness training research, as many researchers themselves are ardent practitioners of mindfulness who tend to strongly believe in the benefits of mindfulness training. This may lead to interpretations that could exaggerate the observed training effects on psychological well-being and cognitive functions, and should always be dealt with extra cautions and self-scrutiny from the researchers who conduct this type of studies. One of the common practices to avoid such bias is to conduct data analyses and perhaps even interpretations of results by someone who is blind to the conditions or to what type of training each group receives. Subsequently, one can compare these results with that of one's own to detect if there are any biases in the way one performs analyses and forms interpretations. However, confirmation bias is an issue that every researcher would face in his or her daily research and the best way to avoid such bias would be to always keep it in mind while conducting studies and interpreting results.

While being critical of the results from these three studies, which may not seem to strongly support the benefits of mindfulness, it is important to remember that there is still not enough of literature regarding the cognitive effects of mindfulness training or physical exercise training on a variety of subdomains in cognition to draw conclusive conclusions. Further, the extant literature on the effects of mindfulness training includes many different forms and styles of mindfulness training, which makes the interpretation of results even harder to generalize and compare across studies. For example, it is very likely that one training method which solely engages in focused attention technique might be particularly effective in certain behavioral domains that are attention related, but might not be with domains that are primarily emotion related. Likewise, while loving-kindness is a method that fosters compassion toward oneself and others, it might not be as equally effective as the focused attention technique in enhancing attentional ability. In fact, one study has already shown that there are distinct neural correlates and differential task performance associated with forms of mindfulness techniques, such that practicing focused attention technique benefited attention task performance, but practicing loving-kindness technique did not result in this effect (Lee et al., 2012). Therefore, separating and determining the contribution of each mindfulness techniques may be critical for future research, as well as understanding the effects of mindfulness training on a variety of behavioral domains. Therefore, at this stage, it is still too early to draw any firm conclusions regarding whether mindfulness training, or in fact, combining mindfulness training with physical exercise training, has significant benefits on psychological well-being and cognition. Again, these results provide only preliminary evidence regarding the feasibility of combining the two training practices, suggesting that there are at least some promising effects associated with them. More large-scale studies will be needed to validate and extend these preliminary findings.

In conclusion, our three studies were drawn from convenience sampling, which inevitably limits us from making strong conclusions based on our findings and resulted in non-significance in all of our results. Nonetheless, these three studies did provide preliminary insights and highlighted limitations that can be better addressed in further investigations with larger sample sizes and more rigorous designs. Although the field of mindfulness research has advanced quite a bit since the early 1970s, the research designs, methods and understanding of mindfulness training and its applications still require improvement and development. Joining efforts across multiple disciplines such as psychology, neuroscience, biology and engineering, would be the next step in advancing mindfulness research.

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