The Effects of Mindfulness on Mind-Wandering and ERP Measures of Attention

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Abstract

The present study aimed to examine whether a brief mindfulness breathing exercise would reduce the amount of mind-wandering and used the P300 portion of the ERP peak as a neural measure of attention. Participants (N = 24) listened to a brief recording designed to elicit mindfulness or a control recording and then completed a sustained attention task while EEG was recorded. Though mindful breathing reduced self-reported mind-wandering, P300 peaks to stimuli were not affected by mindfulness or mind-wandering. Future studies should further examine these questions with a larger sample size.

Keywords: mind-wandering, mindfulness, P300, ERP
In recent years there has been an increase in research about mind-wandering, “a situation in which executive control shifts away from a primary task to the processing of personal goals” (Smallwood & Schooler, 2006, p. 946). Mind-wandering has not been studied in depth due to the difficulty with studying an internal process that often happens subconsciously. With the development of technology such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) that allow researchers to observe what parts of the brain are activated and when, the study of mind-wandering has come to be a major topic in psychology and neuroscience. It is important to study mind-wandering because it is estimated that people spend up to half of their waking time mind-wandering (Smallwood & Schooler, 2015). Previous research has focused on how mindfulness interventions can help reduce mind-wandering and keep people focused on the task at hand. The current study aims to investigate the effects of mindfulness intervention on mind-wandering and uses EEG as a measure of attentional control.

**Key Features of Mind-Wandering**

Mind-wandering occurs when attention is focused internally and not externally (Smallwood & Schooler, 2015). This means that the mind is not primarily occupied by thoughts due to stimuli in the external world, but instead is focused on internal self-generated thoughts. A person is mind-wandering when “attention switches from a current task to unrelated thoughts and feelings” (Smallwood & Schooler, 2015, p. 487). Because the thoughts that occur during mind-wandering are not due to external stimuli and are unrelated to the task being performed, these thoughts are called task-unrelated thoughts (TUTs).
Mind-wandering is important in many areas of life. For example, in terms of mental health, people who have the tendency to mind-wander and focus on aspects of the past in their mind-wandering often are unhappy and unsatisfied with life (Smallwood & Schooler, 2015). However, other studies have found that if thoughts are excessively constrained (which would mean mind-wandering does not occur), this could be indicative of ruminative thoughts, which is a common symptom of depression and anxiety (Andrews-Hanna, Irving, Fox, Spreng, & Christoff, 2018). In addition to anxiety and depression other mental disorders have been associated with the amount that the mind wanders. Excessive mind-wandering may characterize attention deficit-hyperactivity disorder (ADHD), obsessive compulsive disorder (OCD) or types of psychosis, such as mania (Andrews-Hanna, et al., 2018).

Mind-wandering is also relevant in occupational and educational contexts. It impairs abilities in many tasks important to education such as reading comprehension, actively listening to lectures, and test-taking (Smallwood & Schooler, 2015). Another negative consequence of mind-wandering is that it has a very large detrimental effect on driving abilities. A study asked accident victims about circumstances before the crash and found that although a variety of factors (alcohol consumption, external distraction, negative affect, psychotropic drug use, and sleep deprivation) contributed to who was responsible for the crash, being focused on internal thoughts was the best predictor of accident responsibility (Smallwood & Schooler, 2015).

Although a lot of research has focused on the negative effects of mind-wandering, mind-wandering could have positive effects as well. One example of this is that mind-wandering about future events is associated with improved subsequent mood (Andrews-Hanna, et al., 2018). In addition, people generate a greater quantity of creative ideas while mind-wandering; however, these ideas may not be higher in creativity (Smallwood & Schooler, 2015). This study
exemplifies that mind-wandering may be an important factor in creative thinking. Overall, mind-wandering has been associated with multiple aspects of everyday life, so examining this process and how it occurs may have important clinical and practical applications.

**Challenges in Studying Mind-Wandering**

While the fact that mind-wandering happens internally is one of the reasons it is difficult to experimentally study it, this is certainly not the only difficulty in studying mind-wandering in a meaningful way. There are three major issues in the investigation of mind-wandering: 1) one cannot have complete experimental control over the process, 2) self-generated thoughts happen internally and do not depend on external stimuli, and 3) potential reactivity and validity of self-report evidence (Smallwood & Schooler, 2015). The lack of experimental control occurs because one cannot precisely induce mind-wandering in the ways that one may be able to manipulate external task performance. However, manipulations can be done to influence the likelihood of mind-wandering. For example, if one makes the task in the experiment easy and not cognitively demanding, people are more likely to mind-wander.

The second issue is that it is difficult to experimentally monitor internal thoughts. There are two ways that this is done: firstly, researchers use self-report during the task or after the task, and second, they use imaging technology, such as fMRI or EEG to see the activity of the brain. Recent developments in the quality of this type of technology have made imaging easier and better than ever, giving us information on parts of systems of the brain that are involved in mind-wandering. Therefore, EEG and fMRI technology give researchers valuable additional information about the phenomenon of mind-wandering. Using imaging and self-report in conjunction is useful because if mind-wandering correlates with certain activation in imaging
methods, then one can test the validity of the self-report method against the neural measures, which explains how the third issue of validity is addressed.

Self-report is an important way to measure what occurs during mind-wandering. There are four main methods of experience sampling (self-report) data that are used to measure mind-wandering. The first type is the probe-caught method, which is the most commonly used method to investigate mind-wandering. This method consists of a probe which will interrupt the task and asks participants to indicate whether they were mind-wandering or not in the time directly preceding the probe. These probes occur in an unpredictable order so participants are not able to guess when they will be probed (Smallwood & Schooler, 2015).

The second form of experience sampling is the self-caught method. This method asks participants to indicate they are mind-wandering if it happens and they are aware that they are mind-wandering (Smallwood & Schooler, 2015). This method is not sufficient to be used alone because people who are mind-wandering often are so absorbed on their own internal thoughts they do not think about the fact that they are mind-wandering and do not realize they are doing it. If this method is used along with another method, like the probe-caught method, it can be a useful tool.

The third common experience sampling method is the retrospective method. This method asks participants to indicate how much they think that they mind-wandered during the task via a post-task questionnaire. This preserves the natural time course of the task, as interruptions do not occur (Smallwood & Schooler, 2015). However, sometimes people may have trouble estimating the amount of time they mind-wandered after the task, as opposed to indicating mind-wandering during the task.
The fourth method is the open-ended method. This method asks participants to describe the experience of the tasks (Smallwood & Schooler, 2015). The benefit of this method is that it does not constrain participants into labeling what they experienced as mind-wandering or not; however, it is more time consuming and difficult for experimenters to code. Each of the common experience sampling methods has benefits and drawbacks. It is useful to use multiple methods to make sure that mind-wandering is not tied to a specific method and to test reliability across methods. The present study will use both the probe-sampling method and the retrospective method, along with neuroscience measures.

**Neuroscience Methods of Studying Mind-Wandering**

In addition to using self-report experience sampling measures, neuroscientific methods are useful investigative tools. Neuroscientific methods can provide insights into how mind-wandering unfolds, supplementing what we can learn from self-report methods. The two neuroscientific methods that have been used most commonly to study mind-wandering are functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). FMRI uses blood oxygen level dependent (BOLD) signals to show images of brain activity (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009). When an area is activated, oxygenated blood will flow to that area and it will be highlighted in an fMRI image. A benefit of this method is that the BOLD signals have a high level of spatial accuracy. One is able to tell exactly what portions of the brain are being activated using this method; however, because it takes time for the blood to flow to the activated part of the brain, the temporal accuracy is not very good (Christoff et al., 2009). Conversely, in EEG the electric current in the brain is measured; because the electrodes pick up the activity immediately, the temporal accuracy of this method is very good. However, the spatial accuracy for this method is not as specific. EEG will be used in the present study
because the temporal accuracy will allow us to see what is happening in the brain as it unfolds during mind-wandering.

fMRI studies of mind-wandering have implicated a network in the brain called the default mode network (DMN) (Christoff et al., 2009). The DMN includes structures such as the hippocampus and the medial prefrontal cortices, which makes sense as mind-wandering often involves episodic memory and future planning, which is known to involve both of these structures. The DMN exhibits “elevated activity during periods of task-unrelated self-generated thought” (Smallwood & Schooler, 2015, pg. 488). The aforementioned study also found that neural recruitment in both the DMN and executive networks (dorsal anterior cingulate cortex and bilateral dorsolateral prefrontal cortex) was most pronounced when people lacked awareness of the external world (Cristoff et al., 2009). This suggests that the DMN is important for mind-wandering and that executive control also may play a role in mind-wandering as well.

While FMRI has contributed, another useful investigative tool useful in examining what is occurring in the brain during mind-wandering is EEG. EEG uses electrodes on the scalp to detect electric currents in the brain and produces a chart with peaks and dips in activity that reflect neuro-cognitive processes time-locked to specific mental events. The cap is made up of electrodes in different locations on the scalp so that one can record electrical activity from different sites. In the present investigation we plan to look at the P300 event related potential (P300 ERP). The P300 ERP occurs about 300 milliseconds after a stimulus is presented and indexes the amount of attention the stimulus is given (Schröder, Kajosch, Verbanck, Kornreich, & Campanella, 2016). The P300 ERP will be used to monitor attention and mind-wandering during a sustained attention task.
This study will be using a method called triangulation, which means that we will be examining the mental process of mind-wandering using a combination of self-report and physiological and behavioral measures (Smallwood & Schooler, 2015). Adding ERP to this study adds a physiological measurement, which is useful because mind-wandering is a very internal process. Previous studies have found that certain aspects of the EEG/ERP waves are related to mind-wandering (Barron, Riby, Greer, & Smallwood, 2011; Compton, Gearinger, & Wild, 2019). In using the ERP P300 in combination with self-report methods we are able to better assess make progress in associating the subjective experience of mind-wandering to particular neural markers of cognitive processing. In this case we use the neural markers of attention engagement.

**Mind-Wandering and Attention**

**Mind-Wandering and Executive Functioning**

Experts in the field of mind-wandering disagree on how mind-wandering and executive functioning are linked. While some argue that mind-wandering is a result of a failure in executive functioning others believe it is due to successful allocation of attention by the executive functioning system (McVay & Cane, 2010). People who see mind-wandering as a failure in executive functioning argue that because mind-wandering is often detrimental, it must occur because executive functioning fails in keeping the brain on-task. People who have better executive functioning then, would be able to avoid mind-wandering better than those with lower executive functioning. Alternatively, because mind-wandering can be beneficial in certain situations, the alternate viewpoint argues the executive functioning system would know when it has extra resources and would use those resources to mind-wander and pay more attention to
internally generated thoughts. This could be useful because mind-wandering can be helpful in areas like creativity or future planning.

To assess the relationship between mind-wandering and executive functioning, some researchers have investigated the role of individual differences in working memory capacity. McVay and Kane (2012) argue that working memory capacity is responsible for variation in mind-wandering. They assert that the amount of working memory capacity can affect if one is able to mind wander in a useful way or not. Working memory capacity (WMC) refers to the ability to hold information so that it is immediately available and can be used or transformed into a useful form. People vary in WMC, such that a person with a high WMC can hold a lot information in their working memory, while a person with low WMC cannot hold much information. This variance is related to attentional processes that regulate thought and action. This means that WMC involves direction of attention to important stimuli. WMC is related to mind-wandering because mind-wandering is dependent on direction of attention as well.

Because WMC is related to attention, and people with higher WMC likely have higher executive functioning, it makes sense that individuals with higher WMC would have more control over when mind-wandering occurs, compared to lower WMC individuals. McVay and Kane (2012) tested peoples’ WMC and then had them perform cognitively challenging and cognitively undemanding task and kept track of how much people mind-wandered during these tasks. They found that that WMC is related to differences in mind-wandering during cognitively challenging tasks. People with higher WMC capacity mind-wandered more during the undemanding “easy” task. This contradicts the hypothesis that mind-wandering is a result of executive functioning failure. Instead, it supports the ideas that mind-wandering can be used in beneficial ways. When someone has a large amount of executive resources, at least in terms of
WMC, they are able to know that in a nondemanding task that some of those executive resources can be directed towards beneficial goal-oriented mind-wandering, and this is an efficient use of cognitive resources.

Yet, another study found that people high in WMC mind-wander less than people with lower WMC scores (Mrazek, Smallwood, Franklin, Chin, Baird, & Schooler, 2012b). Participants completed a test that measured their WMC, followed by both an effortful (difficult) task and a sustained attention task (easy, boring) task. They found that overall people with high WMC mind-wandered less in both the effortful and sustained attention task. This could be explained by the point of view that mind-wandering is tied to a failure of executive function. People with higher WMC may have higher executive functioning overall, which could be why they are able to have the executive control to defend against TUTs. As explained above, while one study focused on WMC seemed to support the idea that mind-wandering is useful and not due to a failure of executive functioning, the findings from Mrazek et al. (2012b) seem to show the opposite, that mind-wandering is associated with lower executive functioning capabilities.

In sum, while there is evidence supporting the hypothesis that mind-wandering is due to executive failure, there is also evidence to support the opposite, that mind-wandering is sometimes useful. It is likely that mind-wandering is due to a combination of factors and could sometimes be due to failures in executive functioning and at other times be a result of allocation of attention by the executive control system. When a task demands a large amount of cognitive attention to do well, such as reading something for school, mind-wandering would be detrimental and therefore a result of a failure of executive functioning. Conversely, if a task is easy and does not require much attention to do well, such as folding laundry, the executive functioning system may recognize this and direct attention internally to important tasks such as planning the future.
Because both of these cases happen, it seems mind-wandering can be elicited by both adaptive and maladaptive processes. Further research is necessary to distinguish these two.

The Perceptual Decoupling Hypothesis of Mind-Wandering

Decoupling is an idea that attempts to pinpoint more precisely the cognitive process that is occurring during mind-wandering. Decoupling refers to when executive resources are redirected away from the external environment and into internal thoughts (Kam & Handy, 2013). The decoupling conception of mind-wandering fits well with neural evidence of DMN activation during mind-wandering, because the DMN regions of the brain are known to be involved in internally-directed thought. Instead of distractibility being the cause of mind-wandering (executive functioning failure), the executive resources are just being directed elsewhere, and less attention is given to the external world. Kam and Handy (2013) argue that not only are thoughts decoupled from the external world, but sensory decoupling occurs as well. This means that overall the senses are less sensitive to information from the external world because attention and cognitive resources are very much internally focused.

One way to measure whether attention is decoupled from the external environment is by using ERP measures such as the P300. The P300 ERP, extracted from EEG recordings, occurs approximately 300 milliseconds after the presentation of a stimulus, and the amplitude of the peaks can be used to index attention (with higher peaks meaning more attention was given to the stimulus and lower peaks meaning less attention was given to the stimulus) (Luck & Kappenman, 2012). Because the P300 peaks give researchers a way to measure the amount of attention given to an external stimulus, studies measuring the P300 could provide evidence for or
against the perceptual decoupling hypothesis. If the perceptual decoupling hypothesis is true, presumably the P300 peaks would be reduced during mind-wandering.

Studies have examined how the P300 ERP is related to mind-wandering. One study measured EEG while participants completed a task on the computer (Smallwood, Beach, Schooler, & Handy, 2008). They also took subjective and behavioral measures of mind-wandering. The results showed that the P300 ERP was reduced prior to behavioral and subjective measures of mind-wandering when compared to “on-task” periods. This study supports the idea that external attention decreases when people engage in mind-wandering and indicates that the P300 is a valid and reliable tool to use in investigating neural correlates of mind-wandering.

Another study provides additional evidence for decoupling, using ERP methodology to monitor attention (Barron et al., 2011). In this study, the researchers had participants complete a sustained attention task on the computer while EEG was recorded. The task consisted of three stimuli: a red circle, a green square, and a blue square. The red circle was the target and was presented 13% of the time, the green square was the frequent stimulus and was presented 74% of the time and the blue square was the novel stimulus was presented 13% of the time. The participants were instructed to respond only to the target stimulus and to do nothing when the other two were presented. The blue square had a much larger area than both the green square and red circle, which were of similar sizes because, as the novel stimulus, the blue square was meant to be distracting. At the end of the sustained attention task, the participant filled out a retrospective question asking how much they thought that they were mind-wandering during the task. The ERP results of this study support the perceptual decoupling hypothesis. Peaks for the target and the novel stimuli decreased when a participant was engaged in mind-wandering,
indicating that overall awareness to the outside world is decreased. If instead the person was just more distractible while mind-wandering they would still have had a large peak in response to the novel stimulus. In sum, results support perceptual decoupling rather than distractibility characterization of mind-wandering.

Two components of the ERP P300 are important to discuss because while one is activated by the target, the other is activated by the distractor (Barron et al., 2011). These two main subcomponents of the ERP P300 are called the P3a and the P3b, and each component is indicative of different aspects of attention and shows up more strongly in a different area of the scalp. The P3a shows up more strongly as a peak on frontal locations of the scalp and is indicative of a novel stimulus being detected, meaning this peak occurs when the person sees something that they were not expecting (Luck & Kappenman, 2012). The P3b is stronger in posterior locations of the scalp and occurs when someone sees something they are looking for (e.g. the target stimulus in the Barron task) (Luck & Kappenman, 2012). In prior findings, both the P3a and P3b decreased when mind-wandering occurred (Barron et al., 2011). This means that both the attention given to novel (unexpected) stimuli and attention given to target (which is expected and task relevant) stimuli decreased. This supports the decoupling hypothesis because both types of externally directed attention decreased, meaning during mind-wandering overall external attention decreases and is directed inward.

In sum, several studies using P300 ERP as a measure of attention have found that the P300 is reduced when mind-wandering occurs. This supports the perceptual decoupling hypothesis: that mind-wandering decreases awareness to external stimuli. The distractibility hypothesis states that during mind-wandering, the mind is getting distracted more easily, but contrary to this hypothesis, neural responses to external distractors are reduced during mind-
wandering. Instead, empirical evidence to date supports the perceptual decoupling theory, in which attention to all external information is reduced. These findings raise the question of whether interventions that enhance attention to the external world can reduce mind-wandering.

**Mindfulness and Attention**

Along with the increase in mind-wandering research comes research on methods to reduce mind-wandering. Specifically, mindfulness may play a role in reducing mind-wandering. Mindfulness is the process of bringing one’s attention to the present moment and withholding judgment. Mindfulness involves being open and accepting of what is occurring around you (Anderson, Lau, Segal, & Bishop, 2007). Mindfulness can be practiced in many forms, such as mindfulness meditation, mindfulness-based stress reduction, and mindful breathing. These are all examples of how people have used mindfulness in beneficial ways. Mindfulness has become more popular in recent years and it is important to look into its possible effects on the mind to see if it has any lasting effects on the way the brain reacts to stimuli and situations. Mindfulness has been shown to affect attention because one of the main focuses of practicing mindfulness is practicing attention and awareness of the present experience. This means that in practicing mindfulness people are practicing directing their attention in certain ways. This may affect mind-wandering because mind-wandering involves changes in attention. When attention is directed inwards when mind-wandering occurs. The present research aims to examine whether mindfulness affects the cognitive process of mind-wandering.

Overall, studies have found that mindfulness is an intervention that shows promise in reducing mind-wandering. The question of the mechanism behind how mindfulness reduces mind-wandering remains unanswered. One possibility is that mindfulness decreases mind-
wandering by simply reversing mind-wandering’s effects on attention. Because mind-wandering likely involves decoupling, it could be the case that mindfulness involves re-engagement with the external world in general, which would be the opposite of decoupling. Another possibility is that the effects on attention are not the direct opposite of mind-wandering, but still have an impact on and reduce mind-wandering.

Mindfulness has two major aspects, attention monitoring and acceptance training, and both are critical in reducing mind-wandering (Rahl, Lindsay, Pacilio, Brown, & Creswell, 2017). Attention monitoring is when attention is concentrated on a stimulus and meta-awareness, an understanding of the current state of mind, is used to maintain attention on the stimulus (Rahl, et al., 2017). Acceptance training is the practice of acceptance and regulation of negative emotion that in turn should boost cognitive performance. One study separated their sample into three groups: one group had just the attentional aspect of mindfulness training of mindfulness, another group had both attentional training and acceptance training, and a control group had training that was not about mindfulness (Rahl et al., 2017). In a 3-day mindfulness training program the attentional training and acceptance group received instruction in both attentional training and acceptance, while the attentional training only group received training and instruction about attentional monitoring instruction only. The sample was split in this way because mind-wandering is clearly related to attentional training and they knew that attentional training would be an integral piece of reducing mind-wandering; however, it was unclear if mind-wandering was affected by the part of mind-wandering that teaches acceptance and non-judgment. The group that had both the attentional and acceptance training reported reduced mind-wandering while the group that only had the attentional aspect of mindfulness training did not report reduced mind-wandering. These results imply that acceptance training is a critical aspect of
mindfulness that contributes to reduced mind-wandering. Future studies must make sure to include both acceptance training and attention training in attempting to manipulate frequency of mind-wandering.

Waiter and Dubois (2016) also found that focus could be increased through mindfulness. One group performed a brief mindfulness exercise while a second group performed an arithmetic exercise and a third group performed an attention monitoring exercise. In this study, the ten-minute mindfulness activity led to improved accuracy on a Stroop task when compared with the arithmetic exercise, but not when compared with the attention monitoring exercise. These results suggest that the attentional monitoring aspect of mindfulness is what affects performance on the task. This is interesting because other research has demonstrated that having both the attention monitoring exercise and acceptance training are important in reducing mind-wandering (Rahl et al., 2017). Although the Waiter and Dubois (2016) study did not assess mind-wandering, one might infer from these results that attention payed to the Stroop task was increased by both the attentional task and the mindfulness task, which would mean there was less mind-wandering. If that is true, then logically this study suggests that mind-wandering can be decreased by solely attention monitoring.

Different types of mindfulness manipulations have been shown to influence attentional control in different ways. In one study, a group of participants took an 8-week mindfulness-based stress reduction (MBSR) course (Anderson et al., 2007). The courses were taught by certified mindfulness-based stress reduction therapists. In the group that took the MBSR course attentional control did not improve; however, object detection did improve. In this study they did pre-testing and post testing so they were able to see the effect or lack of effect that the MBSR course or control condition had on participants. Attentional control was measured using a
sustained attention task in which participants were supposed to press a key when they saw the letter k. A noise was played in the background to increase the difficulty of the task. Object detection was tested by showing participants the name of an object then showing them a complex drawn image on the screen. The image remained on the screen until participants indicated by pressing a key whether or not the object was in the drawing. They tested object detection in order to measure non-directed attention, as opposed to more focused directed attention as was tested in the sustained attention task.

This is interesting because it suggests that mindfulness increases all aspects of attention and therefore could be considered to be the opposite of mind-wandering. In this case, instead of increasing control in only certain specific important areas, attention to the external world in general was increased after the mindfulness manipulation. Performance on the sustained attention task did not improve because participants were paying attention to all information coming in, not just relevant information. This supports the idea that mindfulness is the direct opposite of mind-wandering. If perceptual decoupling happens as a result of mindfulness then, this article is arguing that “re-coupling” occurs as a result of practicing mindfulness.

Similarly, in a different study mindfulness and mind-wandering are presented as opposites from each other (Mrazek, Smallwood, & Schooler, 2012a). Again, mindfulness is described as increasing overall attention to the world in general, while in line with the decoupling hypothesis mind-wandering is supposed to decrease attention to the external world overall. In this study, one group of participants listened to an eight-minute mindful breathing exercise, one group passively relaxed, and one group read. The group that performed the mindful breathing exercise had improved performance on the sustained attention task compared to the other two groups. This may have occurred because mindfulness increases focus and reduced TUTs by bringing attention
to a simple stimulus, such as breath. This is similar to the way that the results of Anderson et al were interpreted, in which mindfulness practices resulted in a general increase of attention to the external world.

As previously mentioned, mind-wandering often results in impaired performance on tasks and mindfulness combats mind-wandering in that it is associated with increases in focus. A study examined the effects of mindfulness training in graduate record examinations (GRE) test scores (Mrazek, Franklin, Tarchin, Phillips, Baird, & Schooler, 2013). Participants were randomly selected to attend either a two-week long mindfulness training course or a two-week long nutrition class. After the course was completed participants who participated in the mindfulness training scored significantly higher on the GRE than those who took the nutrition class. Additionally, people who took the mindfulness class engaged in less mind-wandering.

There are two possible interpretations of these findings. The first is that the results may be due to mindfulness practices affecting awareness to all external stimuli. Because people were less likely to engage in mind-wandering they were able to focus better on the test. Another possible explanation for the results is that mindfulness did not just increase awareness in general, but instead increased awareness of important stimuli. Maybe in addition to being able to defend better against TUTs, people were also able to be focused only on the GRE as opposed to other distractors in the room, which would further explain the higher GRE scores for the mindfulness group. This would mean that instead of being simply the opposite of mind-wandering, mindfulness is more specific. If mindfulness increased awareness to just the GRE that would mean that mindfulness increases awareness to important stimuli and not all external stimuli, and therefore is not acting in reverse of perceptual decoupling. If mindfulness were the opposite of
mind-wandering it would increase awareness of the external world in general, rather than specifically enhancing attention to relevant information.

The explanation that mindfulness increased focus on the GRE in particular instead of on external stimuli in general is a better explanation for the results of the Mrazek et al. (2013) study. If people had increased awareness of the external world in general they may not have performed better, because external stimuli that were not related to the test may have also been salient and therefore distracting. Conversely, if only task-relevant stimuli are focused on due to mindfulness practices, this would explain why people were able to better focus on the task and not be distracted by other external stimuli.

While there is evidence that mindfulness reduces mind-wandering, there are still key issues unresolved about the exact mechanism, namely 1) what aspect of mindfulness affects mind-wandering, and 2) whether mindfulness simply reverses the decoupling of mind-wandering or has a more specific effect. While some studies argued that both the acceptance and attentional aspects of mindfulness were required to decrease mind-wandering (Rahl et al., 2017), other studies found that only the attentional aspect of mindfulness was required to reduce mind-wandering (Waiter & Dubois, 2016). It may be that if one is able to better accept their emotions and avoid judgment, they attend better to the present moment. In this way, both acceptance and attentional training would be important to reduce mind-wandering, because the acceptance affects attention. In the present research, the mindfulness task involves both acceptance and attention aspects. Another discrepancy in the literature is that some studies argues that mindfulness and mind-wandering are direct opposite of each other (Mrazek et al., 2012a), while other studies argued that mindfulness changed attention in a more specific way than just overall greater attention to external stimuli (Anderson et al., 2007; Mrazek et al., 2013). While there is
evidence supporting both of the hypotheses, there are more studies that found results supporting
the idea that mindfulness is more specific and therefore, while it remains something that reduces
mind-wandering, mindfulness is not the direct opposite of mind-wandering.

**Rationale for Present Study**

The purpose of the present study is to examine how mindfulness training affects the neural
measures of attention that have been previously shown to be reduced by mind-wandering.
Through using an ERP task that dissociates measures of general perceptual awareness from
attentional selectivity, we can test whether mindfulness is simply the opposite of mind-
wandering and causes increased awareness of the external world in general, or if mindfulness
produces selectively focused attention on relevant stimuli. As previously discussed, mind-
wandering has been associated with perceptual decoupling, and although mindfulness is known
to reduce self-reports of mind-wandering, it is not yet clear whether it does so by “recoupling” in
general, which in effect would “reverse” and be directly in opposition to the effects of mind-
wandering, or through enchaining attention to task-relevant information only.

While some evidence suggests that mind-wandering leads to perceptual decoupling,
other evidence has been used to support other theories, such as the idea that mindfulness and
mind-wandering are opposites. Although there is general agreement that mindfulness leads to a
reduction in mind-wandering, how this process occurs is still relatively uncertain. Understanding
the processes behind mind-wandering and why it occurs is important because it has important
implications for attention overall. People often have trouble focusing on important tasks, and if
mind-wandering can be controlled that is an important first step in discovering how to remedy
attentional deficits. Using ERP P300 as a tool to monitor attention is an important resource
because having the ability to visualize internal processes of the mind and see what networks are active can lead to a deeper understanding of what is occurring during mind-wandering and potentially a deeper understanding of why it occurs.

Although it is known that mind-wandering reduces attention to external events, how mindfulness affects attention to external events is less clear. To address this question as well as to better understand the neural processes behind mind-wandering and mindfulness, this study will manipulate mindful breathing and examine its on both self-report measures of mind-wandering and neural indices of attention (ERP P300) to both distractors and task-relevant information in a sustained attention task.

The review of literature and an analysis of the findings and results has led to three main hypotheses. Hypothesis 1 is that the mindfulness task preceding the computer task will cause participants to engage in less mind-wandering throughout the task. This hypothesis is supported by the literature reviewed that related mindfulness with attention (Water & Dubois, 2016; Anderson et al., 2007; Mrazek et. al., 2013). Mind-wandering causes reduction in attention, and mindfulness increases aspects of attention, therefore adding a mindfulness manipulation before someone completes a task should cause increases in attention and decreases in mind-wandering. This hypothesis is stating overall that we expect to replicate previous findings on the effects of mindfulness of mind-wandering.

Secondly, we expect that mind-wandering will decrease the ERP response to both task-relevant and distracting stimuli. This is also a replication hypothesis and is in line with the perceptual decoupling hypothesis (Barron et al., 2011). Both the novel stimulus and the target stimulus should show a reduced peak during mind-wandering because in perceptual decoupling, attention to the external world decreases because it is decoupled with the mind and attention gets
directed to the internal mind. In periods of time that the participant identifies as mind-wandering through response to experience-sampling probe, we expect to find reduced P3a and P3b responses to distractors and task-relevant stimuli, compared to periods when participant self-reports being “on-task”.

Our third and final hypothesis is that mindfulness will not increase attention to the external world in general, but instead will increase attention specifically to task relevant information therefore increasing focus. This hypothesis is novel, as little prior research has combined mindfulness, ERP, and mind-wandering. While there is some self-report data supporting the idea that mindfulness is more effective at increasing attentional focus to task relevant information (Anderson et al., 2007; Mrazek et al., 2013), there is also research that argues mind-wandering and mindfulness are opposites (Mrazek et al., 2012a). We expect to find that mindfulness affects selective attention by increasing focus on task-relevant information. If this hypothesis is true, we expect that for ERP responses, mindfulness will increase the P3b response to the target, but not the P3a response to this distractor. The increased peak for only the target shows that task-relevant information is acquiring more attention. The P3a response for the distractor stimulus should remain the same because this is not task relevant information and does not require a response.

Testing these hypotheses will help us to better understand the processes behind mind-wandering, how it occurs, and how mindfulness attenuates its affects. Providing a deeper understanding of how both mind-wandering and mindfulness can be used to affect frequency of mind-wandering is relevant in clinical situations. Clinically it can be used to deal with deficits in attention. It is important to understand how to increase and sustain focus during important task such as in educational setting or driving a car.
Method

Participants

The sample was recruited from the undergraduate population at Haverford College. Participants were 18 years or older and most did not have significant prior experience in mindfulness meditation. Prior experience was determined by self-report in which participants were asked to rate the amount of experience they had with mindfulness using a 7-point Likert-type scale; 1 being "none" and 7 being "a lot of experience". Participants who choose a 5 or below were included in the present study. There were 24 participants: 16 female, 7 male, and 1 other/prefer not to say.

Overview of Procedure

The EEG cap was applied and participants were randomly assigned to listen to either the mindfulness recording or the ethical foundation and awareness recordings. After the recording was listened to, participants were instructed to complete the sustained attention task on the computer.

Each participant was tested on a single occasion. After the testing session, the participant completed a mindfulness questionnaire and a mind-wandering questionnaire in order to have baseline level of trait individual differences in mindfulness and mind-wandering that each person has or engages in. This initial information was exploratory to see if individual differences in initial mindfulness have any effect on the efficacy/effects of the mindfulness manipulation.

Mindfulness Manipulation

Mindfulness was manipulated on a between-subjects basis. One group listened to a recording clip of 14 minutes and 23 seconds by John Kabat-Zinn, a key proponent of
mindfulness, in which he leads the participant in a mindful breathing exercise. The other group listened to two Kabat-Zinn clips of 6 minutes and 39 seconds and 7 minutes and 42 seconds. The first clip talks about the importance of having an ethical foundation and in the second clip talks about the importance of awareness. While the two clips used by group 2 contain concepts that may be related to mindfulness, they are not actually mindfulness exercises, so they should not have the same effect as explicit instruction in mindfulness. Two clips were used for group 2 because this makes it so that the amount of time spent listening to clips is about the same.

Additionally, this study used clips in which the voice speaking is the same, so the only variable changing was the content of the recordings. These clips are empirically validated as they were used in prior studies (Larson, Steffen, & Primosch, 2013; Bing-Canar, Pizzuto, & Compton, 2016).

**Sustained Attention Task**

This experiment used a variation of the sustained attention task from an earlier study (Barron et al., 2011). There were three possible stimuli: a target stimulus, which the participant is supposed to respond to, a distractor stimulus, and a frequent stimulus, neither of which the participant is supposed to respond to. Participants used a key on the keyboard to respond to the target stimulus. The target stimulus was a red circle of which appeared in 13% of trials, the frequent stimulus was a green square which appeared in 74% of trials, and the distractor stimulus was a blue square with a larger area, which appeared in the remaining 13% of trials. The testing phase consisted of 10 blocks of 100 trials each. Stimuli appeared on screen for 200ms followed by an inter-stimulus interval of 1000ms.

In addition to asking participants about mind-wandering retrospectively, we inserted probes into the trial. The probe caught method was used because it allows us to make within-
subjects comparisons. We were able to compare brain activity on mind-wandering versus on-task episodes within each individual. This was useful because we manipulated mindfulness between subjects. By using the probe-caught method for mind-wandering, we had a better chance of being able to assess mind-wandering within a person, regardless of which mindfulness manipulation group they were in. Probes appeared at unpredictable intervals and asked participants if they were mind-wandering or on task. Participants selected an answer and continued with the task. We used 3 probes per block, which resulted in 30 probes total. Using this number of probes helped to ensure that we received enough reports of mind-wandering in order to test the hypotheses.

**EEG Recording Method**

In the EEG recording a Quik-Caps fabric cap with silver/ silver chloride electrodes was used. The study recorded from the Fz, F3, F4, Pz, P3, P4, Cz, C3, and C4 sites. Analysis focused on the Fz, Pz, and Cz sites, which is where the P300 is most pronounced. The data was collected using mastoid reference. A NuAmps amplifier controlled by the Scan software was used. We used a sampling rate of 1000 Hz and the filter setting of 0.5-40 Hz. Four electrodes placed around the eyes were used to record blinking and eye movements.

Off-line, data were re-referenced to the average of the two mastoids and subjected to manual artifact rejection of gross artifacts (e.g. movement, electrode malfunction) and Neuroscan’s blink reduction algorithm to minimize the effects of blink voltages on other scalp channels. Epochs of EEG data surrounding each event marker (stimulus onset) were extracted, from 200 ms before stimulus onset to 600 ms after, and subjected to baseline correction based on the pre-stimulus interval. Epochs were then averaged separately for each trial type (targets, frequents, distractors) to create ERP waveforms, and the P300 peak amplitude (defined as
maximum amplitude between 300 and 450 ms post-stimulus) was extracted for each participant, trial type, and electrode site. For additional analyses described in the results section, epochs were averaged separately for trials that occurred 10 trials prior to a probe screen to which the participant responded either “mind-wandering” or “on task,” such that P300 amplitudes could be examined separately for these two types of self-reported mental experience.

**Self-Report Measures**

After participants completed the task they were assessed on trait levels on mind-wandering and mindfulness. This assessment occurred after the task because this way it is less likely that their task and EEG data were contaminated by any effects of self-reflection due to the questionnaires they completed. After the task participants also completed a single item measure of mind-wandering where they were asked the question “What percentage of the time during the task do you think your mind was wandering?” and they answered on a sliding scale from 0 to 100.

Mind-wandering was assessed using the 5-item Mind-Wandering Questionnaire (MWQ; Mrazek, Phillips, Franklin, Broadway & Schooler, 2013). This questionnaire is intended to evaluate dispositional tendencies towards TUTs. Participants responded to phrases such as “I have difficulty maintaining focus on simple or repetitive work” and “I do things without paying full attention” using a 6-point Likert scale with options from “almost never” to “almost always.” We included this scale because it is possible that people’s disposition toward mind-wandering could affect how the mindfulness manipulation influences their amount of mind-wandering. People who are disposed to mind-wander more often may not be as influenced by the mindfulness manipulation, or they could be more influenced by it. This questionnaire is included for exploratory purposes.
Trait mindfulness was assessed using the 15-item Five Facet Mindfulness Questionnaire (FFMQ; Baer et al., 2008). This assesses dispositional amounts of mindfulness. Participants responded to statements such as “I notice the smells and aromas of things” and “I perceive my feelings and emotions without having to react to them” using a 5-point Likert-type scale with options from almost always to almost never (Baer, Smith, Hopkins, Krietemeyer, & Toney, 2006). This was included because dispositional mindfulness may affect the way that the mindfulness manipulation affects mindfulness. Maybe people who are already predisposed to be mindful will not be as affected by the mindfulness breathing exercise, because they are already very mindful. This questionnaire is also included for exploratory purposes.

**Results**

**Survey**

The group that underwent the mindfulness manipulation was compared with the control group on how much mind-wandering was reported in the post-test survey using an independent samples T-test. We predicted that there would be less mind-wandering in the mindfulness group, than in the control group based on literature review of what previous studies had found. The percent of time that participants retrospectively reported mind-wandering was slightly higher for control ($M = 74.8\%, SD = 27.6$), compared to mindfulness ($M = 62.3\%, SD = 15.4$), but the difference was not significant ($t(22) = -1.37, p = .185$). This matches our prediction; however, we expected the difference to be greater and to yield statistically significant results. Due to unforeseen circumstances, the number of participants in the experiment was lower than expected, which may have impacted the ability to get statistically significant figures to report.

For the mind-wandering questionnaire (MWQ) part of the survey, we compared the answers from the mindfulness group to that of the control group using an independent samples T-test. We found that the
MWQ score for the mindfulness group ($M=20.08, SD=3.029$), was slightly lower than that of the control group ($M=22.08, SD=6.360$), but the difference was not significant ($t(22) = -0.984, p = .336$). We did not expect to find any group difference in trait measure of mind-wandering because participants were randomly assigned to mindfulness vs. control groups, so this result matched our predictions.

Likewise, using an independent samples T-test we compared the mindfulness group with the control group on their scores for each of the five facets on the FFMQ-15. There were no group differences on any of the FFMQ subscales ($p$s > .09). See Table 1 for more information. Again, this is what was predicted, because random assignment should not yield group differences in trait measures.

**E-prime data**

First, we compared the mindfulness group to the control group on the number of probes (out of 30) to which they responded “mind-wandering” (rather than “on-task”), using an independent samples T-test. We expected to find less mind-wandering in the mindfulness group due to the fact that the mindfulness exercise was predicted to decrease mind-wandering. As predicted there was significantly less mind-wandering in the mindful group ($M=13.50, SD=7.17$) than for the control group ($M=19.92, SD=7.48; t(22) = -2.15, p = .043$).

Next we compared the Mindfulness and control groups on the number of targets they correctly detected and responded to. The prediction was that there would not be very much difference because the task was designed to be easy in order to induce mind-wandering. The percent of targets detected for the mindfulness manipulation group ($M=0.97, SD=0.06$) was not significantly different than that of the control group ($M=0.96, SD=0.10; t(22) = 0.753, p = .459$), indicating that both groups showed very high levels of target detection, as expected.

We compared the mindfulness group with the control group on how long it took them to respond to the target using an independent measures T-test. We predicted that the reaction time
might be slightly faster in the mindfulness group due to the increased focus we expected that the mindfulness group would have. The reaction time for the mindfulness group ($M = 194 \text{ ms}, SD = 42.9$) was slightly lower (faster) than the reaction time for the control group ($M = 230 \text{ ms}, SD = 63.0$), but this difference was not statistically significant ($t(22) = -1.682, p = .17$).

Next, we wanted to see if the responses that participants gave to the probes, which asked if they were mind-wandering or not, correlated with the percentage of time participants estimated that they were mind-wandering throughout the task on the retrospective questionnaire. We expected that these two measures of mind-wandering would correlate. As predicted, there was a highly significant correlation for count of mind-wandering responses to probes with retrospective self-report of mind-wandering from survey ($r = .842, p < .001$). This strong relationship cross-validates the experience sampling and retrospective measures of self-reported mind-wandering.

**ERP data**

**Figures 1a-c** show the ERP waveforms for the three stimulus types at the three electrode sites of interest. Upon visual inspection, the waveforms appear to show P300 peaks to targets in the 300-400 ms range, as expected.

In our first analysis of P300 amplitudes, we sought to find out whether typical P300 effects of target frequency would be present and whether they would differ between the mindful and control groups. To do so we used a 3 x 3 x 2 factorial ANOVA in which the independent variables were stimulus type (distractor, frequent, target), site (Fz, Cz, Pz), and condition (mindfulness group, control group). The dependent variable in this ANOVA was the P300 amplitude. We found that there was a main effect of stimulus type ($F(2, 42) = 39.604, p < .001$). The means for the distractor ($M = 2.48 \mu\text{V}, SEM = 0.47$), the frequent ($M = 0.88 \mu\text{V}, SEM = $
0.43), and the target ($M = 5.96 \mu V, SEM = .067$) all differed from each other (Bonferroni post-hoc test, $p_s > .001$). This is the pattern that we predicted: the biggest P300 peak to the target, which was both rare and task-relevant; intermediate response to the distractor, which was rare, but not task relevant, and smallest response to the frequents, which were frequent and not task relevant. See peaks in Figures 1a-c. No other effects in this ANOVA were statistically significant ($p_s > .137$). It is important to mention that the fact that there was a nonsignificant interaction effect between stimulus type and condition indicates that there was no effect of being in the mindfulness or control group on the P300 response to different stimulus type, which does not match our prediction. Additionally, the interaction effect between stimulus type and interaction site indicated that the peaks to the distractor versus target did not occur in different areas of the brain. This suggests that counter to predictions, there was not a clear differentiation between the P3a and P3b reaction.

We wanted to compare EEG responses to stimuli in the period before the experience sampling probe for responses indicating that the participant was mind-wandering versus responses that the participant was on-task. This allows us to test the hypothesis that mind-wandering will decrease ERP response to all three stimuli in the task. In order to do so, data was extracted from 10 trials before each probe, and then categorized as either mind-wandering or on task, depending on the participant’s response to the probe. ERPs were created for each of the six resulting trial types (distractor, frequent, and target for mind-wandering and on-task episodes) and extracted P300 amplitudes. Some subjects ($N=21$) were missing data because they did not have enough of either mind-wandering or on task responses, or because a rare distractor or target did not happen to appear within that particular ten trial windows before the probe.
In this analysis, we sought to determine whether the P300 amplitudes differed for stimuli occurring during mind-wandering versus on-task episodes within a participant. A 3 x 2 x 3 ANOVA as performed on P300 amplitudes, with factors stimulus type (distractor, frequent or target), probe response (mind-wandering or on task), and electrode site (Fz, Cz, Pz). The interaction between stimulus type and probe response was not significant, failing to support the hypothesis that mind-wandering reduces P300 response to all three stimuli. As in the prior analysis there was a significant main effect of stimulus time ($F(2, 42) = 39.604, p < .001$).

Comparison of means with the Bonferroni post-hoc test revealed that the frequent ($M = 1.209, SEM = .420$) was significantly different from both the target ($M = 6.609, SEM = 1.302$) and distractor ($M = 5.292, SEM = 1.150; p > 0.003$); however, the target and distractor responses were not significantly different.

Next, for exploratory purposes, we examined whether the P300 effects were correlated with individual differences in mind-wandering or trait mindfulness on a between-subjects basis. To do so we calculated the difference between the target P300 and frequent P300 amplitude and correlated those differences with the trait mindfulness and mind-wandering variables. We correlated the P300 difference score (target-frequent) with percent time mind-wandering, the MWQ, each of the five FFMQ facets, mind-wandering responses to the probe, and response time to the target. We found that the P300 effect negatively correlates with the observations facet of the FFMQ ($r = -0.611, p = .002$). This means that someone who had higher P300 peaks to the target (vs. frequent stimulus) was less likely to be observant. Additionally, we found that the P300 effect positively correlates with the nonjudgmental facet of the FFMQ ($r = 0.442, p = .035$) and the P300 effect negatively correlated reaction time to target ($r = -.463, p = .026$). These
results mean that people who are nonjudgmental are more likely to have higher P300 peaks and that people with faster reaction times to the target are more likely to have higher P300 peaks.

We also then calculated the difference of the P300 amplitude to the target versus distractor (to quantify the ability to distinguish task-relevant versus rare irrelevant stimuli) and correlated those difference scores with percent of time mind-wandering, MWQ scores, FFMQ facet scores, mind-wandering responses to probe and response time to target. The only significant finding was that the P300 target-distractor effect negatively correlated with the observation facet of the FFMQ \((r = -.710, p < .001)\). Theses unpredicted findings will be discussed further in the discussion section.

**Discussion**

The aim of the present study was to examine how a mindful breathing exercise affects the measures of attention that have previously shown to be reduced by mind-wandering. The P300 wave of the ERP was used as a physiological measure of attention. We predicted that the mindfulness task would cause participants to engage in less mind-wandering throughout the computerized attention task and that the P300 ERP response to all three of the stimuli would be reduced while mind-wandering. Overall while those in the mindfulness group reported somewhat reduced mind-wandering, effects of mindfulness and mind-wandering on the P300 responses to stimuli did not emerge as predicted.

Trends in the data are consistent with the expectation that mindfulness reduces mind-wandering. This is seen in the finding that participants in the mindfulness group were significantly less likely to report mind wandering in response to the probes. A similar trend for the retrospective report was found, though it was not significant. Additionally, the survey
estimate of percentage of time mind-wandering is likely accurate because responses were highly correlated with the amount of times participants responded that they were mind-wandering/ not mind-wandering. The mindfulness group showed slightly faster reaction times, thought this was not significant. Although this result was not statistically significantly, it lends support to the hypothesis that mindfulness decreases mind-wandering because if the mindfulness group was more focused (e.g. paying more attention and mind-wandering less) then we would expect that the mindfulness group would have faster responses when compared with the control group. Although it is important not to overinterpret results that are not significant, there is a pattern in the finding that are consistent with less mind-wandering in the mindfulness group.

Previous research found that listening to a brief recording designed to elicit mindfulness led to reduced mind-wandering in a task done directly after the recording (Mrazek, Smallwood, & Schooler, 2012a). The present study was similar in that a recording was played for participants who were then asked to complete a task. The current study found evidence that the mindfulness recording led to reduced levels of mind-wandering. The results of the present study agreed with the results of this the 2012 study. Additionally, if more participants it is possible that insignificant findings that are in line with predictions may be significant.

The second hypothesis in the study was that mind wandering would decrease the ERP response to all stimuli in the task. As previously mentioned, this would support the perceptual decoupling hypothesis, because the person would be focusing their mental energy on internal thoughts instead of on external stimuli, such as the task. We did not obtain data to support this hypothesis. There were no significant differences between the P300 peaks when participants were mind-wandering directly before a probe, compared to when they reported being on task. This hypothesis was not supported by any of the data we obtained.
A previous ERP study contradicts the data obtained in this study and instead supports the decoupling hypothesis. In this previous study ERP measures were taken during periods of mind-wandering, P300 peaks were reduced during behavioral and subjective periods of mind-wandering when compared to on-task periods (Smallwood, et al., 2008). This supports the perceptual decoupling hypothesis, and provides support to the idea that P300 peaks should be reduced during mind-wandering periods. The P300 measures in our study did not show a decrease in amplitude during mind-wandering periods, when compared to on task periods. That means that this study does not agree with the earlier study that showed that it was decreased and does not support the perceptual decoupling hypothesis.

The third hypothesis was that mindfulness will increase attention to task-relevant information, and not to all external stimuli. This would mean that mindfulness increases focus. The ERP data did not support this hypothesis because there were not significant differences between the mindfulness group and the control group P300 responses to the stimuli. The study did not find a main effect of mindfulness, which would have implied increases attention to external stimuli, nor did it find an interaction effect between mindfulness and stimulus type, which would be predicted by the hypothesis that mindfulness enhances focus to task-relevant information. Rather, mindfulness appeared to have no impact on P300 responses, despite the fact that those in the mindfulness group did report less mind-wandering in response to the probes.

A prior study was able to test for the third hypothesis using the differences between P3a and P3b peaks for different stimulus types (Barron et al., 2011). The study found that ERP peaks were decreased by mind-wandering. The difference between the P3a and P3b peaks is discussed. The researchers found the P3a peak was stronger on the frontal locations of the scalp distractor and was unexpected stimulus appeared (e.g. the distractor). The p3b peak was stronger
in the parietal regions of the scalp and was elicited when a participant sees something they are looking for (e.g. the target). Based on the previous research we expected stinger peaks at the frontal location (Fz) for the distractor and stronger P300 peaks at the other regions (Cz, Pz). In our study, there was no clear pattern in which the distractor elicited a stronger response from the frontal region, or the target elicited a stronger response in the Cz and Pz sites. Rather, the P300 response was significantly stronger to the target (vs. the distractor and frequent) across all three scalp sites. Therefore, conversely to the prior study, our data does not show any differentiation between the P3a and P3b peaks. Predictions that mindfulness would affect attention specifically to the target (and not the distractor) were based in the assumption that the target and distractor effects could be spatially separated into the P3a and P3b. Without this overall effect in the dataset as a whole, we did not have the precondition for examining the effects of mindfulness on P3a versus P3b.

In addition to the primary hypotheses we also did an exploratory analysis to see if FFMQ and MWQ scores related to the P300. Surprisingly, two different facets of the FFMW correlated with P300, but in opposite directions. The P300 effect correlates negatively with the observation facet of the FFMQ and positively with the nonjudgmental facet of the FFMQ. This means that for those that scored high on the nonjudgmental facet, had better differentiation between the P300 response to the target and frequent stimuli, and that those who scored higher on observation had less differentiation between the target and frequent stimuli. As this was an exploratory analysis it is not known why these effects occur, and the results seem counterintuitive so it is difficult to determine plausible explanations. One possibility that explains the correlation between the observation facet of the FFMQ and P300 effect is that people who are more observant notice the frequent more than someone who was less observant.
This increase in noticing of the frequent would cause their ERP wave for the frequent to be closer to what it is got the target, explaining the negative correlation between observation and P300 effect. Because these were exploratory analysis and the findings were counterintuitive, future studies are needed to determine whether these correlations are reliable.

**Strengths and Limitations**

This study also had several strengths in design and procedure. In terms of design the study was examining something novel that has not been looked at in this way before. This study examined mindfulness, mind-wandering and ERP waves in conjunction. While many previous studies have looked at two these factors together, they have not attempted to look at all three in conjunction.

In addition to the fact that this study in unique, parts of the data support the claim that the measures used were valid. Firstly, there was a strong positive correlation between the percentage of time that people estimated they were mind-wandering retrospectively on the survey and the amount of times that they indicated that they were mind-wandering to the experience-sampling probes that occurred intermittently during the task. This suggests that people were accurately estimating/ answering the probes because the two kinds of answers matched across participants. Another strength that is exemplified through the data is as previously mentioned in the results section the P300 significantly differed in responses to the target, frequent, and distractor. This suggests that the task being used was successful in eliciting the peaks that we expected to find. It also supports the fact that the EEG was being carried out correctly and on the correct sites on the head for the ERP P300.

This study had several limitations, some of which may have contributed to the fact we did not find what we expected, and some of the data we collected did not match what previous similar research had found. The first clear limitation is that there was a small sample size (N=24)
of participants. Having a smaller sample size reduces the probability that the statistical analyses will yield significant results. The fact that mindfulness was manipulated between subject, meant that group comparisons involved group sizes of N=12 each, which is likely to yield inadequate statistical power. Even for the within-subjects’ comparisons of P300 responses during mind-wandering versus on-task episodes, the dataset was limited because some participants did not have enough trials meeting the criterion and this had to be excluded. The sample size was so small because due to the COVID-19 pandemic data collection had to be stopped unexpectedly, and while we were initially planning to have about 40 participants that had to be changed due to the circumstances.

Another possible limiting factor is that participants looked over at the computer that recorded that ERP data they would have been able to see the researcher entering if they were in the mindfulness or control condition. Some of the participants may have seen this, and although they were unaware of the hypothesis, this may have affected their view of the recording they listened to and how they responded. If someone knows they are the control they might be predisposed to know that they are not ‘supposed’ to feel mindful, and vice versa for the mindfulness condition. This could produce significant effects in self-reported mind wandering if the mindfulness group thinks that they are not supposed to mind-wander.

A third confounding factor was that while initially we had planned to limit the sample to people who had none or minimal exposure to mindfulness, out of the people who volunteered for the study many indicated intermediate levels of exposure to mindfulness. In order to get data from as many people as possible given the time constraints, people who indicated that they had medium levels of experience to mindfulness and meditation were still accepted into the study. People who are more practiced at mindfulness may be better at getting into a mindfulness
mindset as they have done it before. This may have affected the results because group
differences might have been unintentionally minimized because even the “control” participants
had some mindfulness experience. Thus, this issue could account for why we did not see as
strong differences between the mindfulness and control group as we expected.

Another limitation is that some participants mind wandered for almost the entire task,
while others indicated very low levels on mind-wandering throughout the task. This made it hard
to look at the differences in an individual between when they were mind-wandering and not
mind-wandering, because you cannot compare them accurately if the reports are skewed in one
direction by a large amount. Additionally, ten trials were chosen to be the number of trials
extracting the P300 from before the probe arbitrarily. This may have been too few trials,
especially since not all sets of ten trials included a target or distractor. The intention was to
capture a window of time that did not go back too far before the probe, since it is unknown how
far back in time the subjective experience indicated by the probe response would go. In other
words, because the temporal duration of mind-wandering can vary (and is not controlled by the
researchers), researchers have to make arbitrary assumption about the state of mind going back
in time prior to the probe response. This is what was done in this study. A different number of
trials may have yielded ERP results that were closer to what was predicted or were different in
some other way. This could be examined by additional analyses of this same dataset.

Future Directions

Conducting studies similar to the present could be valuable because this study combines
mindfulness and self-report of mind-wandering with the physiological measurements that EEG
provides. This study should be repeated with more people, because as previously discussed, it is
likely that the small sample size contributed to the lack of significant results to some degree. It is also important to replicate the study because having data that connects the reduced rate of mind-wandering due to mindfulness with physiological results could help to explain why and in what ways mindfulness helps with focus. It could even lead to important clinical applications of mindfulness for people who have attention disorders or issues.

It could also be interesting to examine how mindfulness affects mind-wandering and why it is that mindfulness has the potential to increase focus. How is it that mindfulness is able to do so? What causes mind-wandering? I think it could be interesting to do this using imaging techniques such as EEG and fMRI. An example of a possible study using EEG would be a study testing the perceptual decoupling theory. A researcher could have a participant complete a task designed to elicit mind-wandering and then use EEG to observe activity in the brain. If the area of the brain that was active when the participant was fully engaged in a task, was less active when they are mind-wandering that would support the perceptual decoupling theory of mind-wandering. A possibility for studying mind wandering using fMRI is to look at the BOLD signals that occur when a participant is mind wandering versus not mind wandering. The high spatial resolution of the fMRI imaging is useful for highlighting what areas of the brain may be implicated in mind-wandering. Using fMRI, one could test whether the DMN is responsible for mind-wandering. Much is unknow about the processes involved in mindfulness and looking at the perceptual decoupling theory using EEG and the involvement of the DMN through fMRI are just some of the possibilities for future directions on mind-wandering research.

Additionally, I would be interested in seeing research that relates much of what is discussed in this article to the real world, outside of the lab. Studies should be done outside of the lab in a more natural environment to see if results are generalizable and applicable to real world
situations. The lab is different from the real world, because in lab situations a participant usually has one task or main focus point. Outside the lab this is often not the case. There are more distractions and cases in which mind wandering is likely, and understanding how this happens in the real world is important in terms of discovering possible clinical applications of mindfulness and its ability to reduce mind wandering. One example of this is the study in which they found that performance on the GRE was increased after mindfulness training (Mrazek, et al., 2013). The findings of this study; that a short mindful breathing can reduce mind-wandering, could be useful to apply outside of the lab. For example, studies could be done in classrooms, where one class does mindful breathing and then students take a test or perform an activity. Then the ability of the students to focus and the scores on the tests could be compared with a control group. If the students who were in the mindfulness group performed and focused better, that would be evidence that mindfulness can be beneficial and can be used to reduce mind-wandering in a classroom setting. As was mentioned previously, mind-wandering can have detrimental effects in situations like driving a car and classroom performance (Smallwood & Schooler, 2015). Because mind-wandering can be detrimental in many situations, it is imperative to find ways to reduce it. Presently, mindfulness seems to be a likely pathway through which reduction of mind-wandering can occur. The possible benefits of application of mindfulness techniques in reducing mind-wandering could be broad reaching and beneficial to people in both a clinical setting and in everyday life.

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<td>10.41</td>
</tr>
</tbody>
</table>

**Table 1.** Mean and standard deviation for the mindfulness and control groups on each subscale of the FFMQ.
| Control SD | 2.30 | 2.71 | 1.68 | 3.77 | 2.07 |

**Figure 1a.** Average ERP waveform at Fz site for frequent, distractor, and target stimuli, for all participants
Figure 1b. Average ERP waveform at Pz site for frequent, distractor, and target stimuli, for all participants
Figure 1c. Average ERP waveform at Cz site for frequent, distractor, and target stimuli, for all participants.
References


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