Exploring the Powers of Mindfulness-Based Training on Enhanced Executive Function and Improved Response Accuracy

By

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Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Humans are flooded with a large number of visual stimuli at any waking moment, and to act efficiently, we filter information based on how relevant it is to us and avoid stimuli that may be considered distracting. Research has demonstrated that those who meditate have improved executive functioning compared to controls, however observing the mechanisms behind these improvements, needs further exploration. Visual event-related potentials (ERPs) can be used to assess visual selective attention. Specifically, in response to lateralized attended stimuli the N2pc (posterior contralateral) is associated with top-down attentional selection and the distractor positivity (Pd) with lateralized distractor suppression. Through using these visual ERPs, we were able to explore the mechanisms behind improved visual attention that we see in experienced meditators specifically the lateralization of target selection and suppression.

We hypothesized that those who have been meditating consistently can draw their attention more efficiently towards a target, represented by a larger N2pc, and suppressing distractors, represented by a larger Pd. Additionally, we hypothesized that the meditators would respond more accurately than controls and would have a reduction in interference post-error indicated by a larger error-related negativity (ERN).

Electroencephalography (EEG) was collected from 28 participants (15 control, 13 meditators; 19-31 years). Meditators had to be meditating for at least the past year with an average of 45 minutes spent in meditation each week. ERPs were measured using EEG to investigate cognitive processing using a modified flanker task where two sets of three-letter arrays were arranged vertically on either side of a white fixation cross, one green array, the other red. Participants were instructed to indicate whether the middle letter of the attended array (red/green) was a consonant or a vowel via keypad. Participants were instructed to attend to either array across 10 blocks (5 attend-green; 5 attend-red) with 100 trials presented per block for a total of 1000 trials. N2pc and Pd were extracted from correct trials only via subtracting contralateral-ipsilateral electrodes (P3/4 and P7/8) relative to the attended target or distractor for the N2pc and Pd, respectively. ERPs were quantified via mean wave amplitude over a time window of 200-300ms (N2pc) and 300-400ms (Pd) after stimulus onset. ERN was extracted by subtracting correct from incorrect trials and taking the peak negative amplitude within 0-150ms after response onset at the Cz site. Response time (latency) was recorded, and accuracy was measured via correct vs error trials (excluding missed trials).

Results showed that on average meditators had larger N2pc and Pd components, however, the two-way mixed ANOVAs for the N2pc and Pd did not reveal a significant difference between meditators and a control group regarding the size of the N2pc or Pd component, however the there is a strong possibility of a type II error regarding the N2pc. The effect size for the N2pc indicated practical significance and we may have been underpowered in detecting this significance due to a small sample size. On average meditators were more accurate, however we failed to detect a statistical improvement between the two groups, similarly to the N2pc, the effect sizes regarding accuracy suggest practical significance and that the current lack of statistical significance may be misleading. However, we did find a significant effect of colour in both accuracy and latency revealing that regardless of group, participants were more accurate and had a faster response on attend-green trials. Although ERP data reveal no significance regarding the effect of colour, there was a trend present where in meditators the Pd amplitude was larger in attend-green versus attend-red trials. Suggesting that this effect of colour on accuracy and latency is due to distractor suppression, not target selection. Additionally, there was a main effect of time for both the N2pc and Pd components, participants experienced attentional fatigue in the form a reduced activity directed towards suppressing distractors and attending to targets in the form of a smaller Pd and N2pc, respectively. Overall, on average those who had been meditating for at least a year experienced larger N2pc and Pd components compared to a control, however a statistical significance was not reached as a result of being underpowered in conducting these tests.

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1.0 Introduction

Humans are bombarded with a large amount of visual information at any waking moment, and to act efficiently, we filter information based on how relevant it is to us and avoid stimuli that may be considered distracting to enable our attention to focus on information that is related to our goal. However, there are stimuli in our visual field that are not related to our immediate goal but beg for our attention through salience-driven control. A fast-moving object, a large flash of light, tend to pull our attention and we cannot help but give them the attention that is begged for. Being able to focus effectively is a key aspect of one’s lifestyle, such as being able to achieve certain tasks throughout the day and make essential quick decisions. Having strong attentional capabilities is essential.

Meditation is deeply rooted in the mindfulness-based practices of Buddhism. The nature of meditation requires the person to actively focus their attention on the body or specific thoughts through the use of breathing techniques and at beginner stages the use of a guided session. Through various studies using imaging techniques it is well established that meditation should not be considered rest but a trainable skill, much like sports, that depends on consistent practice and engaging attentional capabilities for one to improve and become proficient in the skill of meditation (Ives-Deliperi et al., 2011; Short et al., 2010; Lazar et al., 2005). Much like training for sport, meditation trains us for the outside world, helping us prepare for environments that may be anxiety or stress-inducing or for whatever challenges may present.

As an intervention, meditation has produced a plethora of positive outcomes, such as a reduction in stress and anxious tendencies along with improved attention and cognitive abilities. Engaging in meditation practice has enhanced executive functioning through an improved attentional reorienting control and an improved response accuracy rate when compared to a control group (Tsai et al., 2018; Temper & Inzlicht, 2013). One area that we do not yet have a fully comprehensive understanding of is how this improved attentional control is achieved. Using electroencephalography (EEG), we can observe certain event-related potentials (ERPs) that reflect some mechanisms that may be responsible for these differences. Focusing on two components, N2 posterior contralateral (N2pc) and distractor positivity (Pd) which represent attentional target localization and distractor suppression, respectively. This will allow us to observe how the relationship between these two mechanisms occur in a visual search task. Additionally, by observing these components, we can gain insight into how well meditators can direct their attention towards the target and avoid the surrounding distracting stimuli. We will also be observing the Error-Related Negativity (ERN) to contribute to the growing body of research in the field, which demonstrates that those who engage in extensive meditation training are better at handling a conflict in the desired and actual response.

2.0 Literature Review

2.1 Mindfulness-based practices

Integrating mindfulness-based practices has gained popularity in the last decade with an abundance of yoga studios and meditation centers popping up across Western societies. However, there is a deep history of mindfulness behind the popular physical and mental health benefits. Mindfulness-based practices, specifically meditation, has a strong foothold in the art of Buddhist practices and some Eastern religions. One of the most critical concepts that bring together mindfulness-based practices is the act of being completely present at the moment. This includes being intentional with the rate of one's breathing, completely focusing on the body, and avoiding rumination of irrelevant thoughts and feelings (Kabat-Zinn, 2003). It is no secret that meditation can reduce stress, and improve our attentional capabilities (Basso et al., 2019), but outside of these improved mental health aspects, the pool is relatively untapped.

The primary cognitive response when trying to meditate is to direct your attention towards salient thoughts and feelings regardless of the goal, however, during meditation practice, there is a strong focus on controlling that attention. It requires efficient executive functioning to override that allocation of attention towards the primary response of attending to the salient stimuli along with purposefully focusing on remaining in a meditative state. One effective activity to do during meditation to refine that attention is to engage in a body scan, actively thinking about the body and its position in space along with what muscles are relaxed, and which ones are contracted. This is typically done in a toe to head fashion, by taking the time to focus on the body, allowing the meditator to focus their attention and stay engaged in that meditative state (Ortner et al., 2007).

2.1.1 Meditation history

Meditation will be the main mindfulness-based practice discussed in this thesis. There is a wealth of easily accessible guided meditation sessions through video-based streaming platforms and apps, showing that even though it has ancient roots, meditation has adapted to fit our modern-day needs. Meditation is typically a technique designed to help people relax, it does this by addressing different aspects of one's problems. However, in the next section, we will observe this to not always be true. Training the mind to observe and focus on the physical, psychological, and spiritual parts of oneself, has gained considerable traction over the years (Marlatt & Kristeller, 1999). Meditation as an intervention can be used for a diverse population of issues, such as, assisting psychological distress and preventing a relapse into a depressive state (Teasedale et al., 1995). However, as the years have gone on, we have seen that these interventions can assist with many problems outside of feelings of anxiety and depression. A mindfulness-based intervention has been demonstrated to be associated with reduced physical inactivity in adults (Strowger et al., 2018), and suggesting that meditation used in a specific way can open the door to assisting a large population struggling with various issues or illnesses.

2.1.2 Types of meditation and their intentions

The practice of meditation is commonly understood to bring a state of relaxation or peace. However, this is not entirely true for all styles of meditation. The type of meditation greatly depends on the intentions that are being set by the meditator. Essentially, what the meditator hopes to achieve from engaging in the practice. Lumma and colleagues (2015) explored the relationships between different kinds of meditation practice, heart rate (HR), and high-frequency heart rate variability (HF-HRV), along with their subjective rating of effort and likability towards the kinds of meditation. The three types of meditation used in this study were:

loving-kindness, breathing, and observational. These types of meditation differ based on what the focus is. A loving-kindness style is used in an affirmation way, this can be providing positive affirmations to oneself or towards others. A breathing-styled meditation is simply focusing on solely breathing, the rate, and the depth of the breaths, some will use cues to change breathing style. Finally, an observational style is observing the body as a whole, focusing on one part of the body noticing the muscles and how the body exists in space. Not only were all types different from each other in the results, but the loving-kindness, and the observation meditation, both had a significantly higher HR and effort level than the breathing-focused meditation. Interestingly, all styles had an increase in HR and likability and a decrease in HF-HRV and effort compared to when at rest. However, the magnitude of these changes varied per style. This research demonstrates that certain styles of meditation, observational for example, require greater cognitive efforts and physiological arousal than a simple breathing meditation (Lumma et al., 2015).

2.1.3 Meditation versus rest

Practicing meditation is commonly misinterpreted as simply rest. Researchers have used fMRI to explore the idea that meditation is a learnable skill that requires dedicated practice, just like any other cognitive-based task. One study conducted by Ives-Deliperi and colleagues (2011) used fMRI to observe areas of cortical activity during a state of meditation compared to a control task. Their study used participants that were extensively experienced in meditation (minimum 4 years of practice) and had participants complete the mindfulness-based stress reduction (MBSR) intervention before the experiment. Their findings showed a decrease in activity along the midline cortical structures, including the left ventral anterior cingulate cortex, bilateral anterior insula, bilateral precuneus, and right medial prefrontal cortex, and an increase in activity was exhibited in the right posterior cingulate cortex when compared to a control task of categorizing random numbers (Ives-Deliperi et al., 2011). These findings give light to more of the neurological differences between a period of rest and meditation, indicating that these two are not the same. Providing support to debunk the misconception that meditation is simply resting. Since this study did not utilize a control group, we do not know to what extent the changes may occur in someone without meditation practice or with/without the MBSR intervention.

2.1.3.1 Default Mode Network (DMN)

There is a network of cortical regions that form what is known as the Default Mode Network (DMN), discovered to be associated with the act of mind-wandering or when the brain is considered to be “at rest”. Mason and colleagues (2007) observed areas of activation during mind-wondering via fMRI, they constituted that mind-wandering is a psychological standard that appears when the individual is unoccupied, for example, the DMN becomes active when a task no longer requires any conscious supervision to be performed.

The DMN is composed of a midline core (posterior cingulate cortex/precuneus and anterior medial prefrontal), a dorsal medial prefrontal cortex subsystem (lateral temporal cortex, temporoparietal junction, and temporal pole), a medial temporal lobe subsystem (posterior inferior parietal lobule, parahippocampal complex, hippocampal formation, retrosplenial cortex, and ventral medial prefrontal cortex) (Andrews-Hanna et al., 2010)

Using the DMN has provided researchers with quantifiable insight into what happens to our brains when we meditate and reinforced the idea that meditation is not comparable to rest. Within the last decade, research has demonstrated that meditators produce reduced activity in the DMN compared to non-meditators during an active task, indicating that meditators are more focused on the task at hand rather than engaging in mind wondering (Garrison et al., 2015). Additionally, research has provided us with evidence as to what cognitively is happening during meditation, Pagnoni (2012) found that there was reduced activity in the DMN during meditation practice, and in Brewer et al. (2011) specifically in meditators there was a reduction in the posterior cingulate cortex and the precuneus during a meditation vs rest relative to controls. In the same study, they found that the regions that were reduced in meditators during a period of meditation included the middle temporal gyrus, anterior cingulate cortex, fusiform gyrus, and precuneus, areas related to the DMN.

2.1.4 Cortical changes and meditation experience

Although meditation can be considered restful, it can also be a challenging cognitive activity. Lazar, and colleagues (2005) observed via MRI increased cortical thickening in those with extensive meditation experience compared to a control group. The cortical thickening was localized to the prefrontal cortex and the right anterior insula, which is not a surprise since these areas are highly associated with the allocation of attention and sensory processing (Lazar et al., 2005). Additionally, findings suggested that those who are long-term meditators showed resistance to age-related cortical decline, with 50-year-old participants with long-term meditation experience, having the same cortical thickness in Brodmann areas 9 and 10 as a healthy 25-year-old.

The Lazar et al (2005) findings were also supported by a similar study conducted by Engen and colleagues (2018). Understanding that these attentional and sensory processing-related structures thicken over a period with extensive mindfulness practice, compared to those who do not engage in meditation practice. This thickening of these areas is a result of neuroplasticity, demonstrating that there may be some related link between the increased cortical thickness and meditation. However, these studies utilized a group of long-term meditators, and in Lazar et al (2005), although their controls were matched through, age, sex, race, and years of education, there was no control of physical activity, diet, or any other lifestyle choices. Since we know that on average those who meditate are on average more physically active (Strowger et al., 2018), we cannot draw concrete conclusions that there is a correlation between the cortical thickness, and one's meditation experience. A more appropriate approach would be to utilize an meditation intervention and observe pre and post against a matched control. Holzel and colleagues (2011) utilized the intervention approach and took meditation naïve participants and put them through the 8-week Mindfulness-Based Stress Reduction (MBSR) program. Their results showed an increase in grey matter in variety of areas related to memory processing, emotional regulation and learning such as the posterior cingulate cortex, temporo-parietal junction, and the cerebellum compared to a control group. Although this method resulted in a strengthened correlation between the meditation experience and the cortical thickness, Holzel and colleagues still failed to further isolate the source of the causality. Since looking at physical activity for example, they did not control for how one's physical activity changed throughout the intervention. Although the MBSR is intensive and restrictive, there is a possibility that one's physical activity levels increased. In order to combat this and localize any changes in the cortices to meditation intervention, steps need to be observed in assessing ones physical activity pre and post intervention, along with any other lifestyle attributed that may influence these cortical areas observed in studies like Holzel and colleages (2011) or Lazar and colleagues (2005).

Gard and colleagues (2014) observed age-related changes under the influence of meditation and yoga. Fluid intelligence decreases with age, their findings showed that those of middle age who practiced either yoga or meditation had a slower decline in fluid intelligence than a control group. They also developed findings that show meditation was positively correlated with resilience and global network efficiency. These findings provide further evidence that incorporating meditation into one's daily routine can greatly benefit mental fitness by slowing down or even preventing age-related cognitive decline.

Further support through recent fMRI imaging research strengthens the concept that meditation is a trainable skill. Short and colleagues (2010) focused their attention on the anterior cingulate cortex (ACC) and the dorsal lateral prefrontal cortex (DLPFC) for meditators. Results showed that during a state of meditation, these areas are significantly more active compared to a control task or identifying the colour of geometric shapes, and in addition, they concluded that the extent of one's meditation experience is also an influencing factor. Long-term meditators had significantly more active ACC and DLPFC compared to short-term meditators (Short et al., 2010).

2.1.5 Performance accuracy and meditation

Tsai et al (2018) observed the performance accuracy of meditators and a control group. They observed the effects of a meditation intervention (day one) and 30 min rest (day two) on performance accuracy on a rapid serial visual presentation (RSVP) task. The order of meditation and rest was balanced. Across both groups, there was a significant improvement in accuracy of post-meditation intervention compared to both pre-test and post-rest suggesting that just a small bout of meditation before a task can significantly improve performance, instead of just taking a period of rest (Tsai et al., 2018).

2.3 N2 posterior contralateral

In order to observe lateralization of attention towards a target this study utilized the N2 posterior contralateral (N2pc) ERP component, sometimes referred to as the posterior contralateral negativity (PCN), allows for observation of attentional allocation or reorienting between target and distractor stimuli. The N2pc is recorded from the lateral occipital scalp location at around 200-300ms upon onset of the task being displayed (Hickey et al., 2009; Jannati et al., 2013, Bacigalupo & Luck., 2015). This ERP gets its name from its location, occurring at the EEG electrode site contralateral to the target stimulus in the visual field, where there is a large negative deflection at the N2 location occurring 200-300 ms after the stimulus onset. The N2pc is quantified by subtracting the ipsilateral from contralateral electrodes isolating the lateralization of attention towards the target (Hickey et al., 2009). Early research had suggested that the N2pc is representative of the suppression of a salient distractor stimulus along with focusing attention onto a target in the lateral visual field driven by top-down mechanisms since it was elicited when both target and distractors were present (Luck & Hillyard., 1994b). This suppression of a distractor is conducted through the inhibition of the input to neurons responsible for the target stimuli (Luck et al., 1997). These assumptions were supported by Luck and Hillyard (1994b) through their various experiments that explored under what conditions the N2pc could be elicited. The N2pc failed to be elicited when there was no distractor present supporting the idea that the conflict and fight for attention between the target and distracter are what produces the ERP, possibly through the active suppression of the distractor (Luck & Hillyard., 1994b). However, others argue that the component is representative of the process related to the direction of attention towards the target, rather than the suppression of the distractor. Eimer's (1996) work surrounding the mechanisms of the N2pc used a target presented in one visual hemifield with all distractors presented in the opposite hemifield. Eimer conducted 3 different experiments, altering the number of present distractors, showing that N2pc effects were comparable to those throughout the experiments suggesting that the N2pc primarily reflects the selection of target stimuli. Their findings went against the interpretations from Luck & Hillyard (1994b) conflicting with the idea that the N2pc specifically indicated distractor suppression.

Even with this clash of evidence, researchers have agreed that the N2pc represents the functioning of visual-spatial attention by the differential managing of stimuli in one visual field in relation to the opposite visual field (Jolicœur et al., 2008).

2.3.1 Ambiguity resolution theory

Proposed in 1997, Luck and colleagues established an attention theory that combined the competing hypotheses of Desimone and Duncan (1995), which states that the primary goal of attention is to form resolution between competing neural representations, and Treisman's *feature integration theory* (Treisman and Gelade, 1980) which observes that attention is required to avoid features from different objects from combining. The ambiguity resolution theory suggests that the output of a neuron becomes ambiguous when numerous stimuli are present in the receptive field of a neuron because it is not apparent which of the stimuli contains the traits that are characterized by the neuron (Luck., 2012). Luck and colleagues (1997) represent the role of attention by allowing the person to solve the ambiguity of stimuli by driving the focus to one stimulus and allowing for all the neural activity to reflect that attenuated stimulus rather than trying to gather visual information about all stimuli in the visual field. It is through this resolution of ambiguity towards a stimulus that the N2pc component reflects (Luck., 2012). This theory was still in support of the early research suggesting that the N2pc is modulated through the suppression of the task-irrelevant stimuli. As previously stated, other researchers propose the idea that the N2pc could be indicative of the modulation of the relationship between the target and distractor rather than just a representation of suppression, posing the idea that the N2pc may reflect multiple mechanisms (Hickey et al., 2009).

2.3.2 Eliciting the N2pc

The N2pc occurs in a posterior location and establishes a distribution with the greatest component occurring in the PO7/PO8 electrodes relative to the target localization (Hopf et al., 2000). The primary generation for the N2pc has been localized to the inferior occipitotemporal cortex, however, involves a circuit that includes both parietal and occipitotemporal locations observed via magnetoencephalographic (MEG) recordings (Hopf et al., 2000). Depending on the scale of the competition between the target and the distractor, the N2pc occurs at multiple stages along the ventral processing pathway. When the stimuli present large-scale competition, the primary activity site for the N2pc is located in the late anterior region of the ventral stream (lateral occipital complex), the inverse is as expected with the small-scale competition N2pc being primarily localized in the posterior intermediate region (area V4) of the ventral stream confirmed by fMRI results (Hopf et al., 2006). The N2pc component is not a well isolated and defined ERP and due to the anatomical nature of the V4 area, stimuli that occur in the lower visual field are likely to engage the dorsolateral sites that are closer to the scalp, leading to a greater component of the N2pc. The same can be observed in the opposite; stimuli in the upper visual field will activate the sites of the ventral surface of the occipital lobe, resulting in a more diminished ERP component (Luck., 2012).

The N2pc is typically calculated by subtracting the average waveform of the ipsilateral electrode from the target stimuli, from the contralateral electrode (Tsai et al., 2018). This difference between the two electrodes is considered the *contralateral-minus-ipsilateral* difference which enables the experimenter to single out the N2pc component from the wealth of brain activity (Papaioannou & Luck, 2020).

In the early stages of exploring the N2pc, Eimer (1996) ran 3 different experiments to explore the conditions under which the N2pc could be elicited and where the component size varied. Experiment 1 established that the size of the N2pc under a form discrimination task is significantly larger when compared to a colour-based discrimination task. Experiment 1 also suggested that the N2pc can be elicited when there are few distracting stimuli presented with the target stimulus. Experiment 2 further explored what the N2pc component represents; by eliminating some of the distracting stimuli to only have one distracting stimulus and one target, they were able to elicit an N2pc component, much like in experiment 1. Eimer’s findings suggest that the component may be more representative of attentional selection towards target stimuli, rather than the inhibition of the distractor indicating that it is directed by top-down processing. He strengthened this in a third and final experiment, where the stimuli are word strings and priming the participant with what the target stimuli is, removing the salience component of the distractor. The N2pc was successfully obtained in this scenario where the target and distractor had to be defined via their semantic properties (Eimer, 1996). These results indicate that selective attention is driven by top-down processing directing attention towards a stimulus that shares features with the target that the participant had been primed with before the task.

Looking at the theories of Luck and Eimer surrounding the N2pc, it is suggested that the component should not alter with physical differences between the target and distractor stimuli. Interestingly, Hickey et al., (2006) demonstrated that an N2pc can be selected from a highly salient distractor following a target-elicited component. The experiments suggested from these results that the difference in colour between a target and distractor component is capable to elicit the N2pc component. This method of stimulus physical disparities is used in the current study, utilizing the difference in colour of the stimuli to identify a target and distractor.

2.3.3 Physical disparities driving N2pc component

As of 2011, Zhao and colleagues recognized that there is not yet a clear, distinct picture as to what attentional processes drive the N2pc response and investigated the physical disparities in attributes of both the target and distractor stimuli. They assessed this by modifying the level of disparity between a target and a distractor through varying levels of the stimulus colour. They also explored the difficulty regarding visual discrimination, as explored in Eimer's (1996) study regarding the N2pc and visual discrimination tasks previously described. Eimer's study only observed N2pc sensitivity between two kinds of search tasks, form, and colour discrimination, suggesting that this sensitivity was due to differences in attentional processing for each task. To explore the role of discriminative difficulty of the task itself, Zhao et al., (2011) used homogenous stimuli. Using two form visual search tasks (easy and hard), their results showed no variation in the composition of the N2pc component between the levels of the discriminative difficulty, leading Zhao and colleagues to conclude that the difficulty does not seem to be a critical factor in the N2pc component (Zhao et al., 2011).

Regarding the theories presented by Luck and Eimer, the task difficulty regarding stimulus discrimination is driven by varying processes required for the task, and this would alter the component of the N2pc depending on the level of difficulty. During a visual task, attention is drawn towards the target that the participant had been primed with prior to the experiment using top-down processing: the more challenging the task (the more form similarities that are shared between the target and distractor), the more attention is required to be allocated towards the target, which would elicit a larger N2pc component in response. The results from Zhao et al (2011) do not match this, however, since their results showed no significant difference in component regarding the difference in discrimination difficulties. It is clear that this is an area of eliciting the N2pc that will require further research to reach a definitive answer, and based on the current information, it alludes to there not being one concrete answer for how stimuli discrimination difficulties influence the N2pc component.

2.3.4 The distractor-elicited N2pc

Since the N2pc is not driven by entirely top-down processing, salience can also drive this attention towards visual stimuli. Hickey et al. (2006) observed under what conditions the distractor-elicited N2pc can be produced: under the idea that the target-elicited N2pc cannot be elicited when the target is along the vertical midline of the visual field, they observed an N2pc component when the distractor was placed in the lateral field. These results support the salient-driven hypothesis, and that attention is driven toward the more salient stimuli. Hickey and colleagues also notably observed that when a target and distractor stimulus occur in opposite lateral visual hemifields, there are both target and distractor-elicited N2pc components that occur contralaterally to their respective stimuli. These findings suggest that participants orient their attention towards the more salient, however task-irrelevant, distractor prior to their orientation to the target stimuli. These findings support the theories that the salience of a stimulus plays a critical role in the driving of attention and that this process is not entirely focused on task-relevancy (Hickey et al., 2006).

2.3.5 N2pc and visual crowding

In 2015 Bacigalupo and Luck showed that selective attention plays a role in crowding in the visual field by observing the differences in component size in the N2pc. Their findings found that attention efficiency begins to decrease when the distance between the target and the flanker becomes too small. The roles of working memory and attention during a target flanker task have a strong foothold in the effect of crowding since working memory is called in when bottom-up processing fails and requires assistance to drive attention towards the target (Bacigalupo & Luck., 2015). The target-flanker visual search task that was used in this study will be used for this thesis and the flankers will be placed at the optimal distance from the target as outlined in their results.

2.2 Positivity distractor

The question of what drives attention toward visual stimuli has two cohesive hypotheses for this selection: one, the salience of the stimulus, and two, the goals of the participant. One of the main ERPs that will be used as an indicator of this attentional selection is the distractor positivity (Pd). The Pd component is an indicator of efficiency regarding an individual's ability to direct their attention away from a distracting stimulus or flanker via attentional suppression. The Pd shares similarities with the N2pc regarding its localization and measurement, occurring contralateral and posterior to where the distractor occurs within the visual field. It is also quantified in a similar manner by taking the difference of the contralateral minus the ipsilateral electrodes (Hickey et al., 2009).

2.2.1 Salience-driven selection hypothesis

The salience-driven selection hypothesis represents the idea that attention if allowed to wander freely, will be drawn to the most salient stimulus regardless of task relevancy. This particular mechanism is driven by a mainly bottom-up process, meaning that the attentional allocation to stimuli in the visual field is primarily motivated by how well the stimulus can be identified in a visual scene due to its salient characteristics (Itti & Koch, 2001).

Sawaki and Luck (2010) proposed a *signal suppression hypothesis* for the allocation of attention in the visual field. Attention is driven primarily through bottom-up processing where salient stimuli generate a signal that they refer to as an "attend-to-me" signal, regardless of the stimuli's relevance to the task. Attention is drawn to these stimuli depending on the salience of the signal itself, not only by itself but also in conjunction with other stimuli. High contrast between two stimuli can increase its salience (Sawaki & Luck, 2010; Bretherton et al., 2020).

2.2.2 Goal-driven selection hypothesis

This selection method mainly uses top-down processing, unlike attentional allocation towards salient-driven stimuli. For this to be directed, the participant should be primed prior to the task by instructing them to identify a specific object/stimulus in the visual field before they begin the task. This mechanism employs top-down processing when starting the task, utilizing the frontal lobes and their connections to the primary visual cortex (Itti & Koch, 2001).

Wolfe and colleagues (1994) explored the use of colour in stimuli and alterations in the delivery of instructions. Using colour to describe a stimulus can be an efficient method in visual search, however, there must be an adequate difference between the target colour and the distractors (Nagy & Sanchez, 1990). Wolfe et al (1994) established that goal-specific attention cannot be effectively guided towards a stimulus that is of more than one colour (e.g., a red and green target), instead, the attention can be guided to a target stimulus of one whole colour (e.g., an entirely red target) (Wolfe et al., 1994).

Jumping back to Sawaki and Luck's (2010) theory on the *signal suppression hypothesis,* this hypothesis is altered when you introduce the *contingent voluntary orienting hypothesis,* which states that the take over of attention by a salient stimulus is reliant on the task-dependant attentional control mechanisms that determine what kinds of stimulus components will capture attention. The "attend-to-me" signal from a salient stimulus can be suppressed by the priority signal of the task-relevant target stimulus. This allows for the salient-driven mechanism to be overridden by the goal-driven mechanisms, represented by the Pd (Sawaki & Luck, 2010; Bretherton et al., 2020)

2.2.3 Distractor positivity in extensive meditation practices

The exploration of the mechanisms of the improved attentional capabilities has been a fresh study interest. Throughout meditation practice, one typically controls their attention to focus on breathing or the body and avoid rumination. Since the prior fMRI research concludes that mindfulness is a trainable skill, this indicates that there should be an improvement in the mechanisms of focusing attention on specific target stimuli. A recent study conducted by Tsai et al (2018) explored this idea with electroencephalography evidence. Their findings demonstrated that during an RSVP task, those with extensive meditative practice experienced a larger Pd component than the control group, suggesting their actions were more effective at suppressing the distractor stimulus when compared to the control group for target-like distractors (Tsai et al., 2018). This suggests that those with extensive mindfulness practice are able to effectively identify characteristics that do not fully match the target requirements and suppress these distracting stimuli better than the control group.

2.4 Error-related negativity

Detecting when a conscious error on a choice reaction-time (RT) task has been made is represented by an ERP called the error-related negativity (ERN). Gehring and colleagues (1993) reported the presence of the ERN onset shortly after the commission of the error in a choice reaction time (RT) task and provided supporting evidence that the ERN is associated with accuracy monitoring. This sharp negative deflection after the response onset only occurred on error trials and the deflection was greatly reduced on correct trials (Gehring et al., 1993)

The participant must be aware of the error they had just made and know the correct response in order for the ERN to be elicited. Regarding ERN amplitude size, there are various conditions play, for example, the task must emphasize accuracy over speed in order to generate a larger ERN. This was established by Gehring et al. (1993), using three compensatory conditions, one focusing on speed, one on the accuracy, and the third being a neutral condition. Using a simple choice RT task, they demonstrated that the ERN was significantly larger in amplitude for the accuracy compensatory condition when compared to both the speed and the neutral conditions, supporting the view that the ERN is correlated with the degree to which accuracy is essential to the participant.

There has been debate regarding what the ERN represents. Some argue that it reflects the recognition of an error (Gehring et al., 1993), whereas some more recent research suggests that it reflects the detection of conflict between the desired outcome versus the actual outcome when an error is made (Carter et al., 1998). Even with conflict in ideas, it is more accepted today that the

ERN represents the acknowledgement that an error had occurred. With this being said, we have not yet ruled out the possibility that the ERN may reflect multiple mechanisms, much like other ERPs.

Regarding the size of the amplitude and what this may indicate, research suggests that the larger the ERN peak amplitude, the more of a controlled response strategy which is related to a greater accuracy rate (Herrmann et al., 2004; Pailing et al., 2002).

2.4.1 ERN localization

Research has demonstrated that upon commission of an error, the caudal region of the anterior cingulate cortex (ACC) becomes activated immediately following the incorrect response (Van Veen & Carter, 2002; Kiehl et al., 2000), suggesting that this area is the generator of error response mechanism.

A study conducted by Herrmann and colleagues in 2004 set out to fine-tune the location of the ERN generation since the specific location of the ERPs origin was still unknown. Results of Herrmann et al (2004) showed that the ERN has been localized to achieve an increased electrical activity in the medial and middle frontal gyrus (BA 6) and the gyrus postcentralis (BA 7) along with the caudal area of the ACC. BA 6 is also known as the supplementary motor area (SMA), which is supportive of prior work conducted by Luu and colleagues (2003), suggesting that the ERN may be generated in a combination with the SMA and ACC since they are in close proximity to each other (Herrmann et al., 2004).

2.4.2 Error processing and meditation

Exploring how the ERN is manifested in those with extensive meditation training quickly gained the attention of researchers. Using various choice-based tasks, such as the Stroop task, researchers have seen a significant increase in ERN amplitude in those with this extensive mindfulness-based training, along with fewer errors made overall (Temper & Inzlicht, 2013). Extensive mindfulness-based practice could result in enhanced executive functioning and could account for increased performance monitoring. A study conducted by Temper & Inzlicht (2013) further explored what aspect of meditation is used to drive this increase in the ERN, and ultimately enhanced executive functioning. They observed two components: emotional acceptance, and mindful awareness between both the control and experienced group through a standardized questionnaire. Emotional acceptance, that is the act of recognizing emotions non-judgmentally and actively avoiding rumination to focus attention, is heavily practiced during meditation and trying to stay in a state of mindfulness. Results demonstrated that those who exhibited greater emotional acceptance had an increased ERN amplitude, but there were no significant results regarding ERN amplitude when it came to observing the impact of mindful awareness. They concluded that the increased emotional acceptance was one of the driving forces behind the increased ERN (Temper & Inzlicht, 2013).

As discussed, there is a wealth of meditation styles out there that have varying physiological requirements, and depending on the style of meditation, this can have an influence on your error processing mechanism and how you respond to certain tasks. Saunders et al (2016), used two different meditation interventions, thought-focused and present-moment feelings focused, to observe the changes in error processing mechanisms. Those who focused on their feelings performed slower, but more accurately compared to those who had engaged in thought-focused meditation.

With the research seen in the last decade, some have struggled to elicit a significant difference in ERN with solely a meditation intervention compared to a control (Eichel & Stahl, 2020), however, those that have experience-based inclusion criteria (Temper & Inzlicht, 2013) have shown a significant difference in the ERN amplitude compared to a control. This could suggest that are long-term consolidation effects are present.

This is the motivation for this thesis to exclusively use meditators who have experienced meditation for at least one whole year in hopes to achieve a similar result regarding the magnitude of the ERN size between experienced meditators and a control group as seen in prior studies with similar inclusion criteria.

2.4.3 ERN and meditation styles

Looking at meditation as an intervention, Saunders, and colleagues (2016) explored changes in the ERN after different styles of meditation. ERN amplitude increased when participants had undergone a meditation intervention that focused on one's feelings and being present in the moment, contrasting with a thought-focused meditation which had no significant changes in ERN magnitude (Saunders et al., 2016). Although participants did not differ in their dispositional/trait mindfulness, Saunders and colleagues (2016) failed to report their background on meditation/mindfulness to give a more well-rounded image of their experience. There was no indication if these participants were novices or had prior experience, just their scored on the Philadelphia Mindfulness Scale. Additionally, there was a lack of a control group used, just the two groups for each style of mindfulness, the addition of a control group undergoing a control task (i.e., reading) would have strengthened the results supporting that there is an overall correlation between ERN amplitude size and meditation style, providing that we see no difference in ERN size pre and post control task.

2.4.4 Neurobiological and functional mechanisms related to error processing

Studies observing the ERN and other ERPs typically utilize neurologically healthy individuals, in the case of the ERN we exclude those with anxiety/depression/obsessive-compulsive related disorders due to a significantly larger ERN amplitudes, compared to a neurologically healthy control group (De Bruijn et al., 2004). This section will break down the mechanisms be why we see this inflation of the ERN and one of the related brain areas.

The rostral cingulate zone (RCZ) is involved in monitoring upon error commission including the response towards the errors and the response conflict that is represented by the ERN amplitude. These changes in prediction when an error is made are induced by the phasic alterations in the activity of the mesofrontal/mesolimbic dopamine systems. This increase or decrease represents the continuous events and whether they are considered better or worse, respectively, from that predicted outcome (Schultz, 2002). These signals are ultimately directed towards the RCZ which then generates the ERN. The ERN has been heavily linked to being influenced by the slight change in dopaminergic neurotransmission. This was demonstrated by using amphetamine, to increase the release of dopamine, which led to a significantly larger ERN amplitude compared to a placebo. These results indicate a role of dopaminergic involvement in action monitoring, and also contribute to the understanding that those with neurological disorders that have dopaminergic involvement have a larger ERN (De Bruijn et al., 2004). This reasoning is why those with any anxiety or depression-related neurological illnesses will be excluded from the current study. On the opposite side, De Bruijn and colleagues (2004) also observed the neurobiological function of lorazepam in reducing ERN size. Lorazepam (benzodiazepine category) is commonly used as a meditation to treat anxiety-related disorders and works as a positive allosteric modulator of fast inhibitory neurotransmission through GABA via the $GABA_A$

receptor complex. Lorazepam administration can indirectly inhibit the ACC functioning through these GABAergic pathways that innervate the ACC directly.

3.0 Study Title: *Exploring the Powers of Mindfulness-Based Training on Enhancing Executive Function and Response Accuracy*

3.1 Rationale

The exploration of the benefits through the use of mindfulness-based training, specifically meditation, has become a popular topic of research, with results demonstrating benefits that are not just isolated to mental health improvement as once was previously thought. The implementation of a meditation-based intervention into one's lifestyle has seen improvements such as a reduction in physical inactivity in adults and reduced fall rates in individuals receiving treatment for multiple sclerosis (MS) (Mills & Allen, 2000). Yet we do not have a fully comprehensive understanding of how these improvements occur. Looking at the changes in cortical structure, it is clear that those who have extensive meditation practice are experiencing improvements related to attention and executive functioning through the increased arborization of the frontal cortex and other attentional-related areas. One of the main goals of this study is to observe these improvements in their functional context and quantify the enhanced attentional capabilities of extensive meditation practice.

One outcome of extensive meditation practice is the enhanced executive functioning seen through an improved ability for effective attentional selection through improvements in accuracy in certain tasks. This suggests that the implementation of meditation-based practices into one's lifestyle may improve their ability to focus, and this can be significantly beneficial for individuals that struggle with attentional deficit disorders. However, we need to first fully understand how the mechanism works. Many studies currently use a meditation-based intervention in combination with selecting participants that are experts in their meditation field. In this study, we will be removing the intervention and focusing on one's long-term experience with meditation.

We have an understanding that those who have engaged in dedicated mindfulness practice for an extended period (> 1 year) have an enhanced executive control demonstrated by ERNs of significantly greater amplitudes indicating an increased reduction in interference upon error commission (Temper & Inzlicht, 2013). During these tasks, the meditators also significantly had a greater task accuracy response. The idea that those with extensive mindfulness practice typically have enhanced executive functioning is well established within research, however, alterations in the ability to allocate attention effectively towards a target and away from a distractor stimulus requires further exploration.

By exploring the components, N2 posterior contralateral (N2pc), and the distractor positivity (Pd) during a modified-flanker task, we will gain a better insight into the potential consolidated mechanisms of this improved executive functioning. The N2pc component will provide direction on how well the participants are able to direct their attention towards the target and the suppression of cortical activity geared towards the distracting stimuli. The Pd however, will give us insight into the inverse functioning; how well meditators are able to suppress the attention towards flankers or distracting stimuli.

In this study, the ERN will also be elicited to contribute to and strengthen current research that has observed error processing in meditation experts.

3.2 Objectives & hypotheses

1. Determine the enhanced attentional allocation through improved attentional direction towards task-relevant stimuli and suppression of distracting elements between meditation experts and a control group. This observation was made through comparing the components of the ERPs N2pc and Pd.

Hypothesis: I hypothesize that those in the meditation group will demonstrate improved attentional allocation towards a lateralized visual target represented by a larger N2pc compared to a control group. Additionally, I expect to see a greater ability to suppress the distractor stimuli, represented by a larger Pd component compared to a control group.

2. Observe reduction in interference post-error in experienced meditators compared to control group.

Hypothesis: Consistent with previous literature, I hypothesis that meditation experts will experience reduction in interference post-error through decreased conflict of expected versus actual outcomes compared to the control group, indicated by a significantly greater ERN amplitude.

3. Determine the effect of attentional fatigue in meditators compared to control group

Hypothesis: I hypothesise that both groups will decrease in both the N2pc and Pd components due to the attentional fatigue effects of the tasks. However, the meditation group will decrease at a significantly slower rate that the control due to the practice effects of purposefully sustaining their attention for long periods of time through meditation practice.

3.3 Methods

3.3.1 Subjects

Overall, 28 neurologically normal, healthy adults were recruited for this study, aged between 19-31. Participants in the meditator group were required to have been meditating for the prior year, averaging at least 45 minutes of meditation per week. For this study there was no limitation to meditation styles, since we do not currently have the information from research to create distinct boundaries within the different styles of meditation of isolate groups of a sufficient size. 13 meditators were collected, one was excluded due to a miscommunication in the criteria, the meditator had misinterpreted the for and did not qualify for either group after clarification. Age ranged from 19-31 with a mean age of 24. The average length that participants had been participating in meditation was 2.46 (SD: 1.88)years with an average of 40 minutes in length per meditation session. Participants in the control group (n=15) had no more than an introduction to mindfulness, for example, participating in a short, guided meditation.

Anyone with a current diagnosis of generalized anxiety disorder (GAD), depression, and/or obsessive-compulsive disorder (OCD) were excluded from the study to avoid variability in ERN amplitude due to neurological conditions.

3.3.2 Experiment design

This study consisted of one session, approximately 1.5 hours in duration. Individuals were recruited for the study through word of mouth and posters placed in the buildings around University of Waterloo’s campus. Upon recruitment, individuals were emailed either the meditation screening form (Appendix A) or control (Appendix B) for their desired group along with the information letter and consent form (Appendix C). They were given the option to electronically fill out the forms or they were able to fill them on upon their arrival into the lab. The requirements for the screening form were described via email and if they met those requirements they were invited to come into the lab. On the day of the experiment, prior to the individual entering into the lab, the participant was asked to change into a medical grade face mask. The experimenter then verbally went through the information letter to refresh the participant on what the study consists of, they then signed the consent form and completed the screening questionnaire if it was not done prior.

Following the signing of the consent form and the completion of the screening questionnaire, the participant was seated to prepare for the electroencephalography (EEG) cap. Preparation was complete once each electrode has an impedance of <5kΩ.

3.3.2.1 Behavioural Task

Participants were comfortably seated at a distance of 70 cm away from a screen. The stimuli appeared on the screen consisting of a black background and a continuously visible white fixation cross in the centre of the screen (Figures 1a, 1b). Each stimulus was comprised of two vertical arrays of 3 letters (uppercase Geneva font) with one array located on each side of the fixation cross, centered at 8.83^{o} from the vertical median. One array coloured red and the other green, and the sides that they occurred on varied randomly throughout the trials. The letters that appeared on each trial were selected randomly without replacement from a set of five vowels (A, E, I, O, and U) and five consonants (N, F, L, G, and J). The middle letter in the array was placed on the horizontally on either side of the fixation cross and participants were verbally primed in task instructions to understand that the middle letter of the attended coloured array is the target. Letters acting as flankers were directly above and below the target and placed at 3.13^{o} from the horizontal midline to avoid the effect of "crowding" and to effectively elicit the N2pc component as outlined in Bacigalupo & Luck (2015) stimuli were placed 15 cm from the fixation cross on either side. Speed and accuracy were equally expressed to the participant. At each block, the participant was instructed to attend to either the red or green array and to indicate whether the middle letter of that coloured array was a vowel or a consonant. Participants indicated this choice using their dominant hand pressing a button representing vowel or consonant on a key pad once the stimuli had appeared. The stimulus duration was 200ms, after the stimulus disappears participants had 1600ms to make a response. Each participant performed 10 blocks of 100 trials for a total of 1000 trials, 5 attend-red and 5 attend-green blocks, presented in alternating order beginning with attend-green.

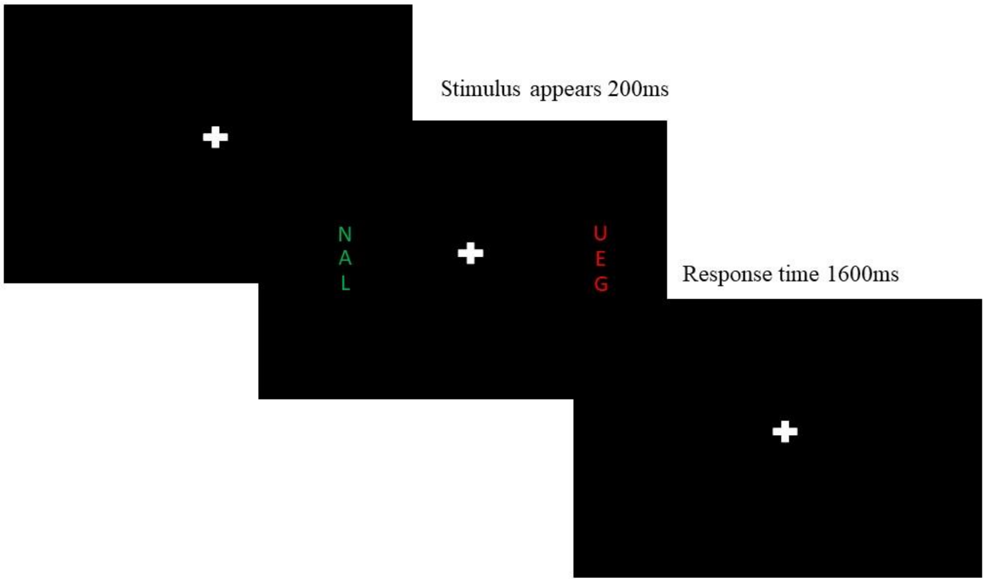

Figure 1a. Stimulus timing and set up for one trial of the study where the participant begins with a white centre fixation cross, then two sets of lateralized 3 letter arrays arranged vertically appear for 200 ms, participants then have 1600 ms to indicate their answer with their dominant hand on a key pad.

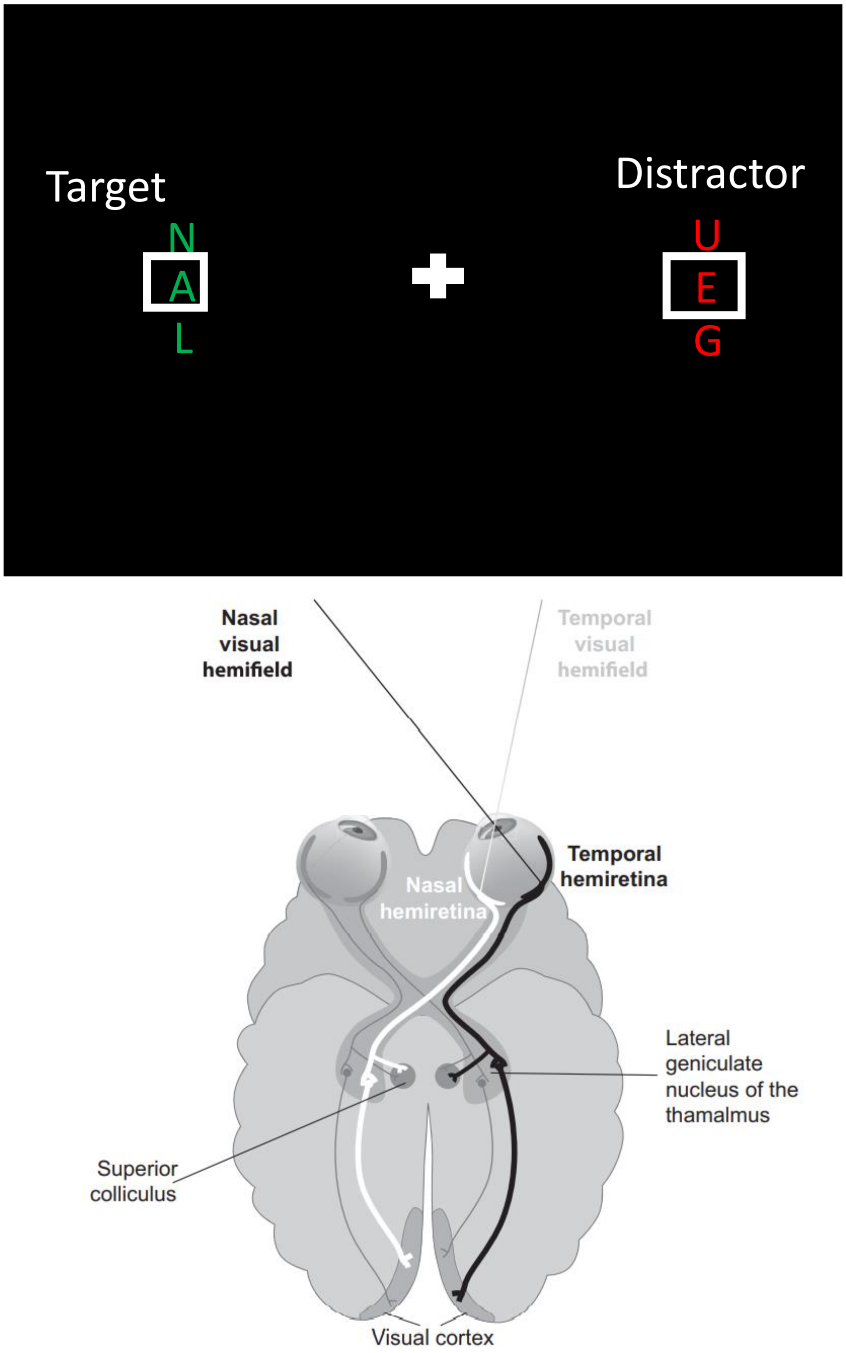

Figure 1b: Screen presented in front of participant for the visual search task, participants are instructed to attend to either the green or red letter and report whether the letter in the middle is a vowel or a constant. The unattended middle letter (red in this example) is considered the distractor, the middle letter of the attended middle letter (green) is primed to be the target. The diagram of the visual pathway displays the route that the target/distractor takes to be contralateral to where it appears in the visual field (figure from Huber-Huber et al., 2015)

3.3.2.2 Data acquisition

EEG was collected during the block trials using a 32-channel cap (Quik-cap, Compumedics Neuroscan, NC, USA) according to the 10-20 system, EEG was collected from 24 electrodes (FP1, FP2, Fz, FCz, F3, F4, FC3, FC4, O1, O2, Oz, P4, P3, P8, P7, Pz, C3, C4, CP4, CP3, CPz, Cz, TP7, TP8). Data was amplified, filtered (DC-200Hz, 6dB octave roll-off) and digitized at 500Hz (SynAmps2, Scan 4.5, Compumedics Neuroscan, Charlotte, NC, USA) N2pc and Pd were recorded from P3/P4 and P7/P8, and the ERN was localized from electrode Cz. N2pc and Pd were both quantified by taking the mean average over a time window of 200-300 ms and 300-400 ms respectively of the difference wave of contralateral-ipsilateral relative to the target/distractor location. The subtraction of the two hemispheres isolates the activity that is directly related to the lateralization of attention towards the visual targets. Electrodes on each hemisphere were average to create an average waveform (P3 and P7 waveforms were averaged together, and respectively P4 and P8 were averaged together). Electrodes were referenced to linked mastoids, with all channel impedances less than 5 kΩ.

EEG data analysis was conducted through MATLAB and is as follows:

1. Raw continuous EEG data is filtered using Basic FIR at 0.01 Hz high pass and 50 Hz low pass.
2. Independent component analysis (ICA) was conducted on data for ERN only analysis for blink removal
3. Event list is created through ERPLAB
4. Function BINLISTER (ERPLAB) is used to assign bin-based epochs to the data. N2pc and Pd are epoched for 800 ms to the stimulus onset -200-600 ms. ERN epoched to the response onset -200-600 ms.

5. Artifact and blink rejection conducted though a peak-to-peak moving window excluding any epochs containing > 100 μV (N2pc and Pd only)
6. Average ERPs were created
7. ERP filtering using IIR Butterworth at 30Hz lowpass
8. Bins were assigned to create two new bins, "left target" and "right target" to identify the epochs where the target appeared in the right vs left visual field
9. New channels were created by averaging the electrodes on the hemisphere and subtracting the contralateral-ipsilateral relative to the target location for N2pc and for the distractor location for the Pd

In addition to the electrophysiological data, behavioural data was also collected during the task. Participant's response time and accuracy rates were obtained via a customized LabView program (National Instruments, Austin, Texas, USA), which recorded the timing of participants response upon onset of the stimuli and the latency. Additionally, the program sent event codes to the continuous EEG file indicating the stimuli appearance and the response of the participant.

Behavioural analysis was conducted using the event codes for stimulus onset and the participants response key. Stimulus codes were matched to the response code to see correct versus incorrect trials. Task response latency was observed by looking at the time difference between the stimulus onset and the task response event code. Both methods were performed in Microsoft Excel and statistical analysis for behavioural and ERP data was conducted in RStudio.

3.3.3 Statistical analysis

To address the study objectives stated in section 3.2 Objectives & hypothesis, the following analysis were performed:

1. A) The N2pc and Pd were generated by pooling the blocks of each colour (attend-red and attend-green) together to form two values of each ERP for every participant. Each component observed the between effect of group (meditators and control) and the within effect of colour (attend-green and attend-red) through a two-way mixed measures analysis of variance (ANOVA). All ANOVAs were tested for homogeneity of variance and normality via Levene's Test and Shapiro-Wilk test respectively.

B) Comparison of peak amplitudes of the ERN at the Cz and electrodes between the meditation and control group indicated whether the meditation group are more efficient at handing conflict between an expected outcome and the actual out come indicated by the ERN. ERN was generated through pooling of the blocks and measured by subtracting the correct trials from the error trials.

C) Observing the potential role of attentional fatigue on the N2pc and Pd components. A linear mixed model using group (meditator, control) and time (blocks 1,2,3,4,5,6,7,8,9,10) as categorical factors was calculated. Pairwise comparisons were used to breakdown any main effects and interactions with an applied Bonferroni correction

2. Accuracy rates were collapsed across the attended blocks looking at the effect of colour using a two-way mixed measures ANOVA observing the effects of colour (attend-green, attend-red) and group (meditators, control).

3. Reaction times (Latency) was collapsed across attended blocks looking at the effect of colour using a two-way mixed measures ANOVA observing the effects of colour (attend-green, attend-red) and group (meditators, control)).

4. Exploratory analysis was additionally performed regarding the accuracy and latency in relationship with years of meditation experience, as well as how long an average meditation session is. This was observed through observing a Person Product Correlation for both relationships with accuracy and latency with meditation experience and average meditation session length.

4.0 Results

4.1 Part A: N2pc and Pd

Three participants in the control did not yield a N2pc and/or a Pd component and were dropped from analysis. N2pc results showed to on average be larger in the meditator group (Table 1) (Figures 2a, 2b, 3a). Similar results were present in the Pd where the component was on average larger in the meditator group which is aligned with the main hypotheses of this study (Table 1) (Figures 2a, 2b, 5a).

In the N2pc, the two-way mixed measures ANOVA found no statistical main effect of group, meditators and control regarding the size of the N2pc component ($F(1,22)=1.83$, $p=0.19$ (partial $eta^2=0.072$), however the effect size suggests the presence of practical significance between the two groups and that we may have been underpowered in detecting this change. Additionally, we did not find a main effect of colour ($F(1,22)=0.66$, $p=0.42$, partial $eta^2=0.002$), and there was no interaction between group and colour ($F(1,22)=0.72$, $p=0.40$, partial $eta^2=0.022$) (Figure 3b).

A two-way mixed measures ANOVA revealed no significant difference between the control and meditators regarding the size of the Pd component ($F(1,22)=0.259$, $p=0.62$, partial $eta^2=0.011$). There was no statistical main effect of colour in the Pd component, ($F(1,22)=3.418$, $p=0.078$, partial $eta^2=0.003$), additionally, no statistical interaction between group and colour ($F(1,22)=3.53$, $p=0.073$, partial $eta^2=0.003$) however there is a present trend where in the meditator group, the Pd amplitude is smaller on attend-red trails compared to attend-green (Figure 5b).

	Mean (µV)	**Standard Deviation (µV)**	**Standard Error**	**Effect size (Cohen's d)**
Controls N2pc	-2.67	1.93	0.56	0.552
Meditator N2pc	-4.13	3.19	0.92	
Control Pd	6.40	6.68	1.93	0.208
Meditator Pd	7.61	4.81	1.39	

Table 1. Mean amplitude (µV), standard deviation (µV), standard error, and effect sizes of both groups (control and meditator)

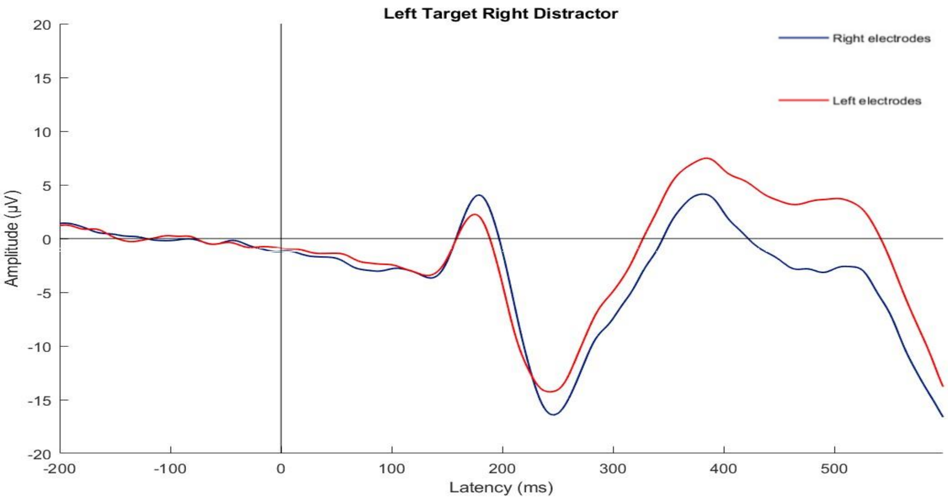

Figure 2a. Grand average wave form for control group showing the averaged right electrodes (P4/P8) and left electrodes (P3/P7). Left target and right distractor.

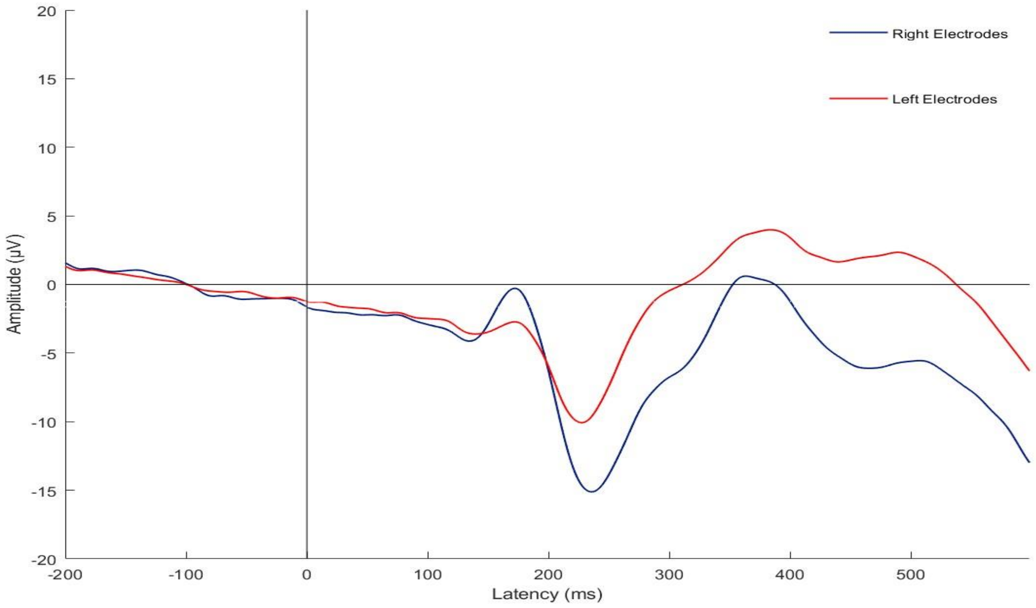

Figure 2b. Grand average wave form for meditator group showing the averaged right electrodes (P4/P8) and left electrodes (P3/P7). Left target and right distractor.

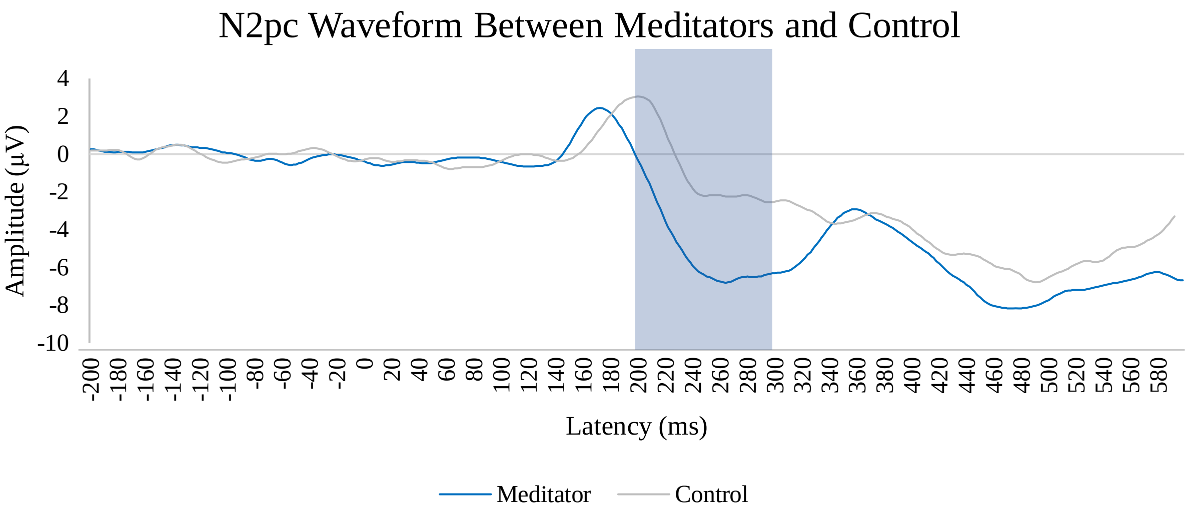

Figure 3a. Grand average control and meditator groups for N2pc wave form for a target in the left visual field measured across 200-300 ms after stimulus onset. Contralateral electrodes (P4/P8) minus ipsilateral electrodes (P3/P7).

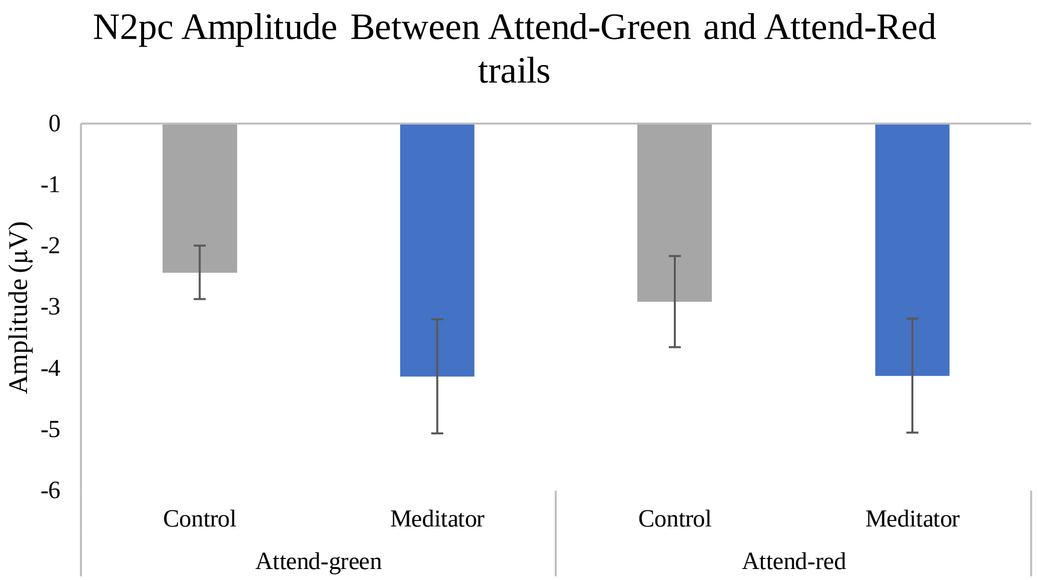

Figure 3b. N2pc average amplitude of both groups (control, meditator) across the attend-green and attend-red trials. Standard error represented in bars.

A linear mixed model looking at the effects of group (control, meditator) and time (blocks 1,2,3,4,5,6,7,8,9,10) on the N2pc component revealed no main effect of group (*F*(1,22)=1.34, *p*=0.26, partial eta^2=0.06), a main effect of time where on average the N2pc amplitude of participants decreased as the study progressed (*F*(9,198)=2.23, *p*=0.022, partial eta^2=0.09) and no interaction of time and group (*F*(9,198)=0.94, *p*=0.49, partial eta^2=0.04) (Figure 4a). Linear mixed model was also run on the Pd component observing the effect of group and time. Similarly, we no main effect of group (*F*(1,22)=0.23, *p*=0.64, partial eta^2=0.01), a main effect of time where the average Pd amplitude decreased as the study progressed (*F*(9,198)=4.1, *p*=4.1x10$^{-5,}$ partial eta^2=0.16), and no interaction of time and group (*F*(9, 198)=0.51, *p*=0.86, partial eta^2=0.02) (Figure 4b). Pairwise comparisons revealed significant difference in Pd amplitude between block 1 and blocks 7 (*p*=0.048), 8 (*p*=0.027), and 10 (*p*=0.0018), block 2 and block 10 (*p*=0.035), block 3 and block 10 (*p*=0.13).

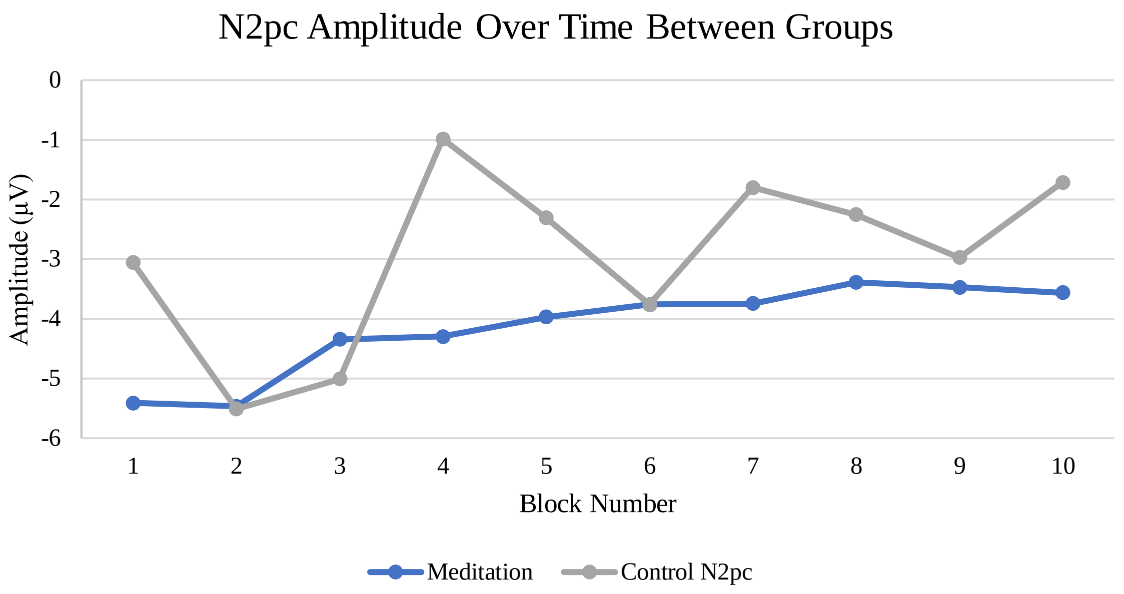

Figure 4a. Amplitude (µV) of N2pc over time of both meditator and control groups

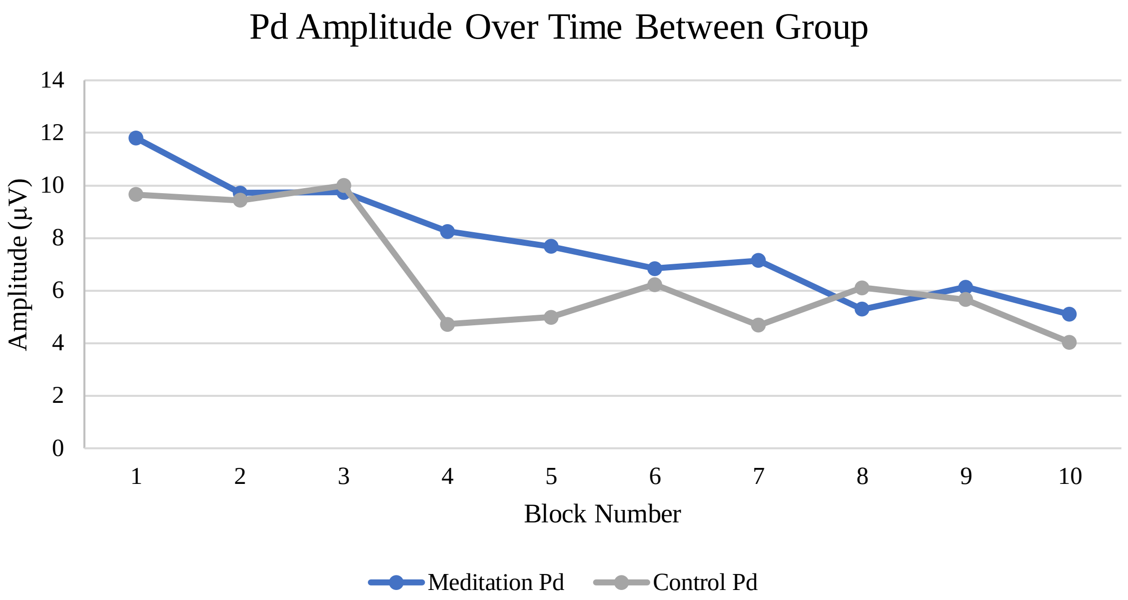

Figure 4b. Distractor positivity (Pd) average amplitude over time of Meditator and Control groups

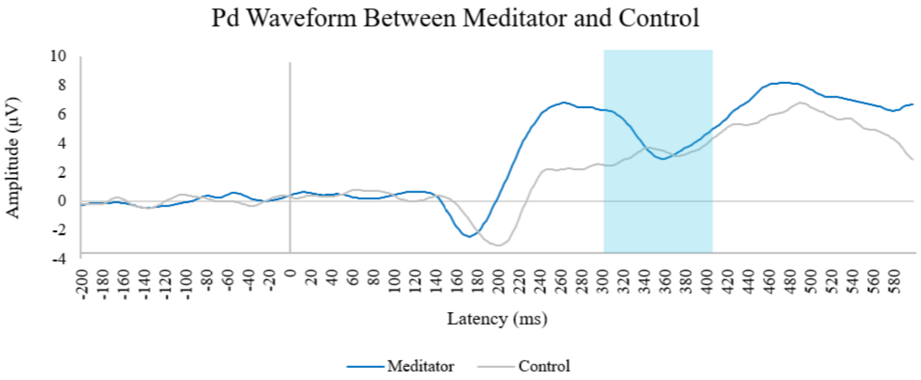

Figure 5a. Grand average control and meditator groups for positivity distractor (Pd) component wave form for a distractor in the right visual field measured across 300-400 ms after stimulus onset. Contralateral electrodes (P3/P7) minus ipsilateral electrodes (P4/P8).

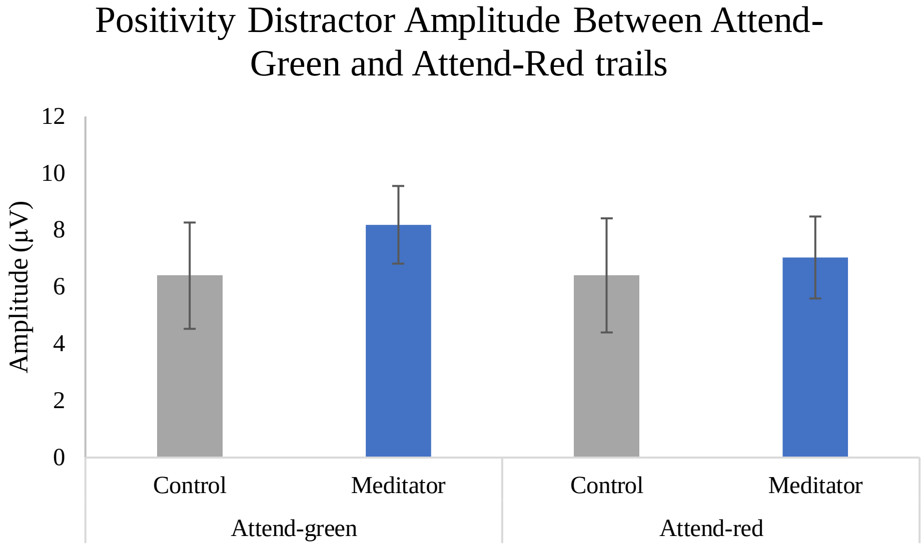

Figure 5b. Positivity distractor average amplitude of both groups (control, meditator) across the attend-green and attend-red trials. Standard error represented in bars.

4.2 Part B: Error-Related Negativity

The results from the present study revealed the presence of a more negative error vs correct waveform in half of the control group (n=7) and was primarily found in the Cz electrode (Figure 6). No ERN waveform was found in the meditation group; therefore, no statistical analysis measures will be taken.

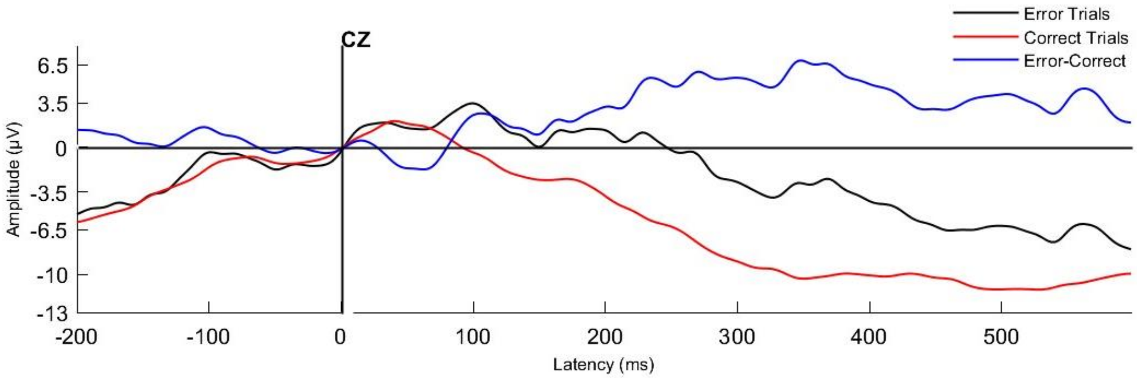

Figure 6. Waveform of the error-related negativity (ERN) for control group (n=7) with the presence of the ERN occurring in the around 50 ms after response onset in the Cz electrode

4.3 Part C: Behavioural results

Behavioural data from the 12 participants in the meditation group compared to the 15 participants in the control group showed that on average the meditator group were more accurate but performed slower than the control (Table 2). During the study, attended colour alternated meaning that blocks 1, 3, 5, 7, 9 are attend-green, blocks 2, 4, 6, 8, 10 are attend-red. Results regarding accuracy from a two-way mixed measures ANOVA demonstrate, no main effect between the groups ($F(1,25)=1.52$, $p=0.53$, partial eta$^2=0.013$), however, a main effect of colour was present showing that on average participants had a significantly worse task-accuracy when attending to red targets ($F(1,25)=182.99$, $p<0.05$, partial eta$^2=0.56$). No interaction between group and colour ($F(1,25)=1.57$, $p=0.22$, partial eta$^2=0.011$) (Figure 7).

	Mean	**Standard Deviation**	**Standard error**	**Effect size (Cohen's d)**
Controls Accuracy	88.77 %	3.81 %	1.099	0.122
Meditator Accuracy	89.17 %	3.63 %	0.94	
Control Latency	355.97 ms	72.10 ms	20.81	0.109
Meditator Latency	362.64 ms	48.52 ms	12.53	

Table 2. Mean, standard deviation, standard error, and effect sizes of both groups (control and meditator) for accuracy (%), latency (ms).

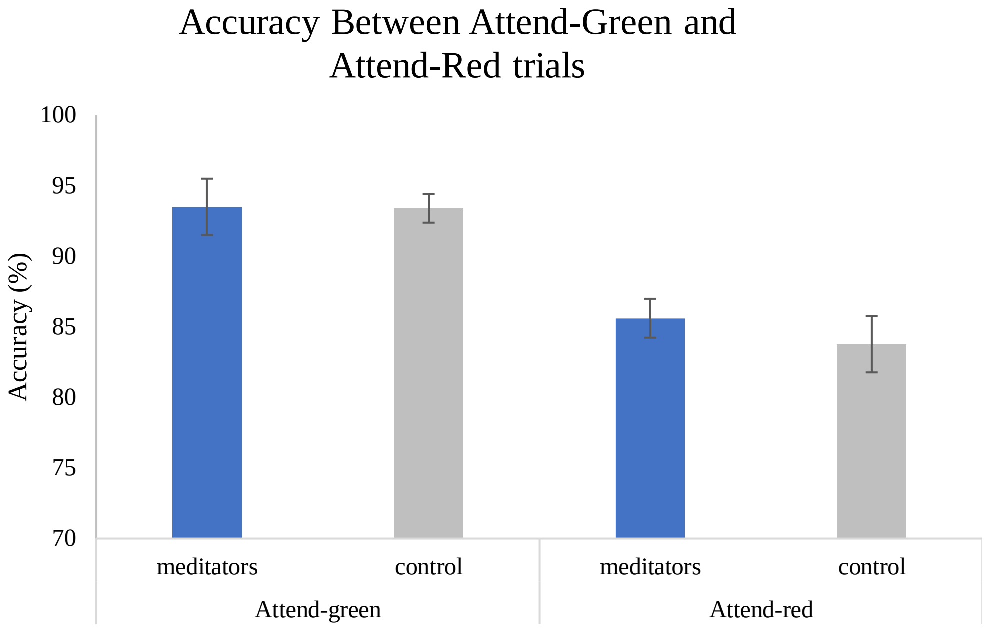

Figure 7. Task accuracy average of both groups (meditation and control) between the attend-green and attend-red blocks. Standard error represented in bars.

A two-way mixed measures ANOVA looking at latency revealed no significant differences between the two groups regarding latency (*F*(1,25)=0.202, *p*=0.66, partial eta^2=0.008) however showed a significant main effect in colour (Table 2) (*F*(1,25)=49.84, *p*<0.05, partial eta^2=0.01),. There was no significant interaction of group and colour (*F*(1,25)=3.11, *p*=0.09, partial eta^2=0.00065) (Figure 8). Multiple regression results show that the addition of the factor of group has no significant change when predicting latency or accuracy (*F*(24,2)=0.328, *p*=0.72, R^2=0.027) (Figure 9a, 9b).

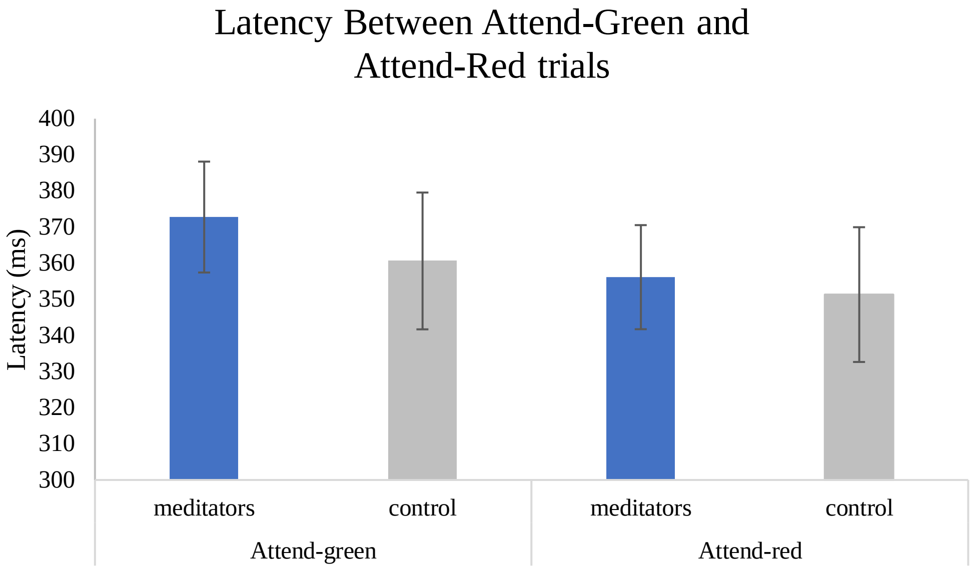

Figure 8. Task response latency (ms) over blocks showing both groups, meditation and control, block numbers 1, 3, 5, 7, and 9 are attend green, blocks 2, 4, 6, 8, and 10 are attend red. Standard error represented in bars.

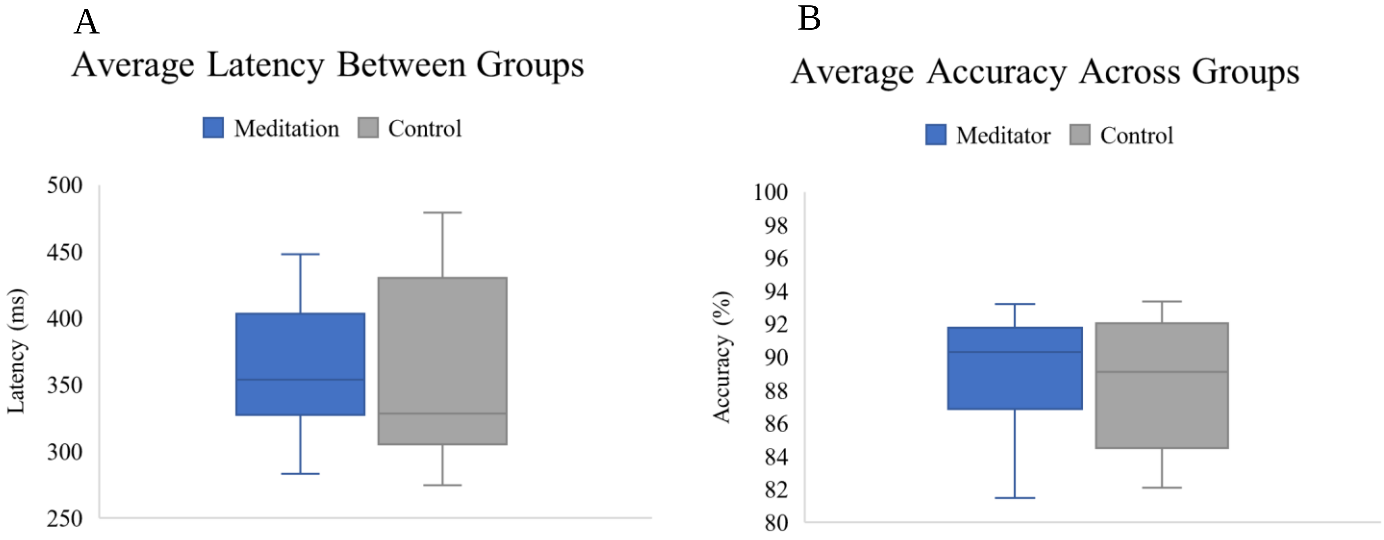

Figure 9a. Box blot of average latency (A) and accuracy (B) between meditators and controls.

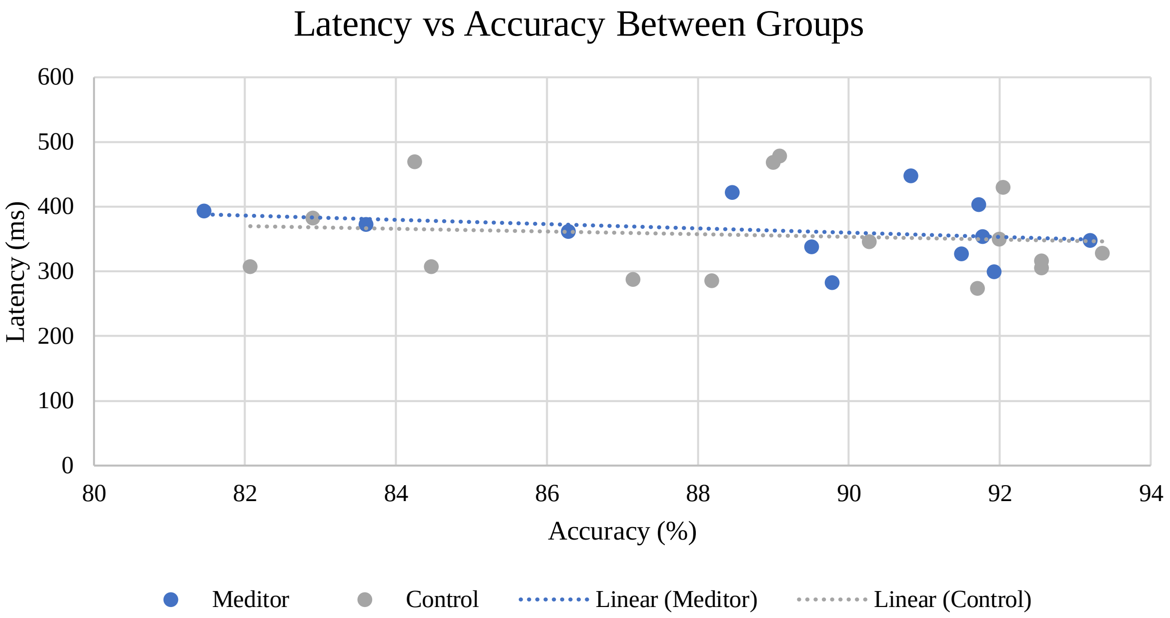

Figure 9b. scatter plot of relationship between task accuracy and latency between the two groups.

4.4 Part D Exploratory Behavioural Results

Exploring the relationship between Accuracy with how long someone who has been meditating (Figure 10a) and with the average length of a meditation session (Figure 10b). Running a Pearson Correlation, we found a weak positive correlation (*df*=10, *p*=0.202, r=0.40) looking at the relationship between years of meditation experience. Observing Accuracy with average meditation session length, there was a very weak positive correlation (*df*=10, *p*=0.71 r=0.12).

The relationship with latency was also explored. A Pearson Correlation revealed no relationship when looking at the years of meditation with latency (*df*=10, *p*=0.96, r= -0.015) (Figure 11a). In addition, there was also no relationship between the average length of a meditation session and latency (*df*=10, *p*=0.83, r= -0.072) (Figure 11b).

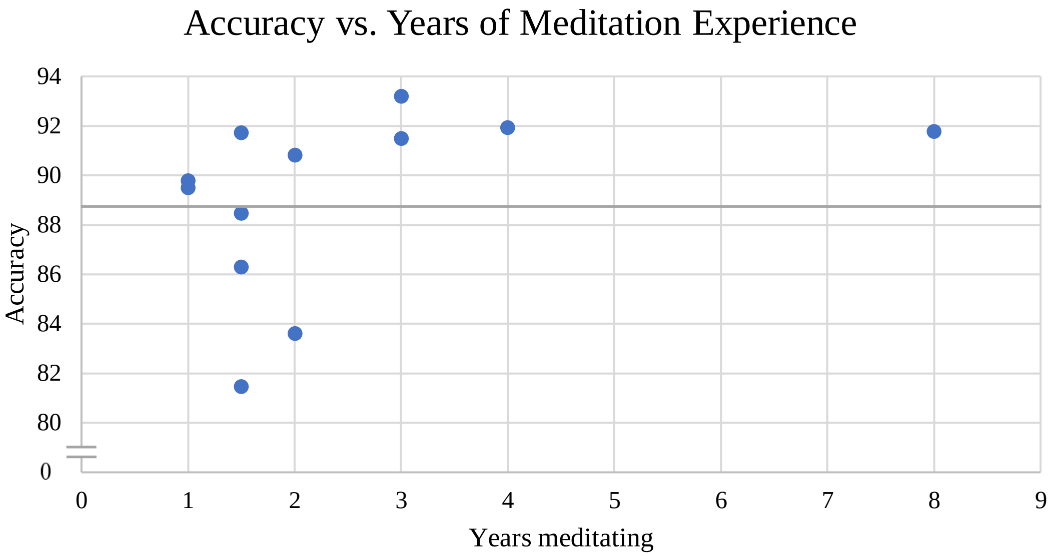

Figure 10a. Scatter plot of meditation group displaying the relationship between the number of years they have spent meditating and their mean accuracy percentage. Control average accuracy shown in the grey line (88.7 %).

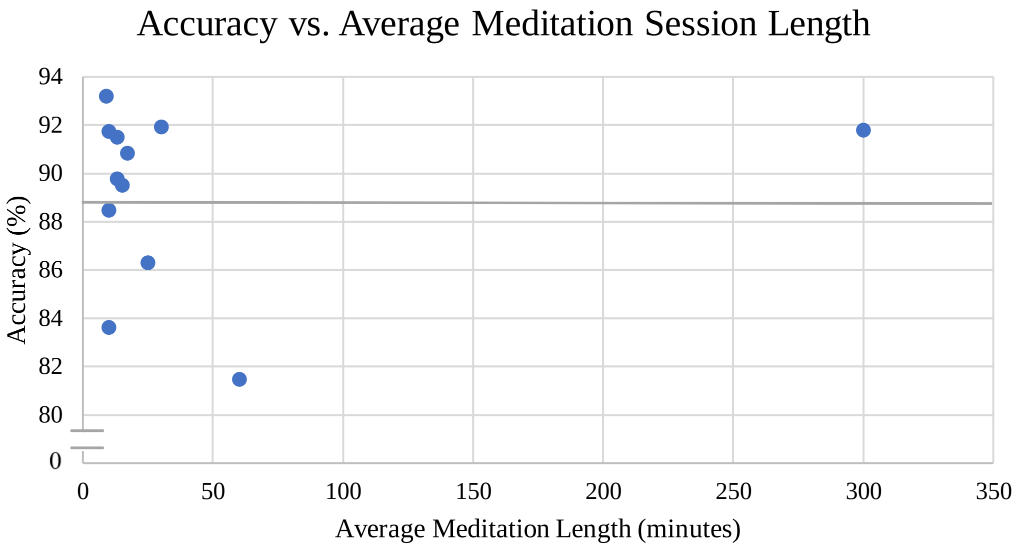

Figure 10b. scatter plot of meditation group showing the relationship between the average length of their meditation sessions and their mean accuracy performance on the task Control average accuracy shown in the grey line (88.7 %).

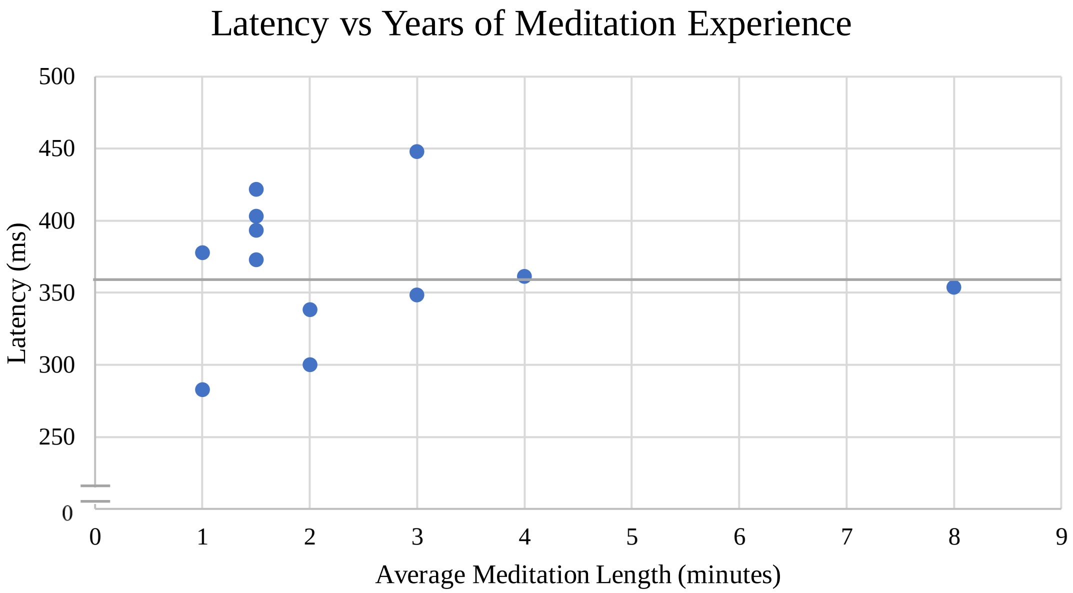

Figure 11a. scatter plot of meditation group showing the relationship between the average length of their meditation sessions and their average latency on the task. Control average latency shown in the grey line (355 ms).

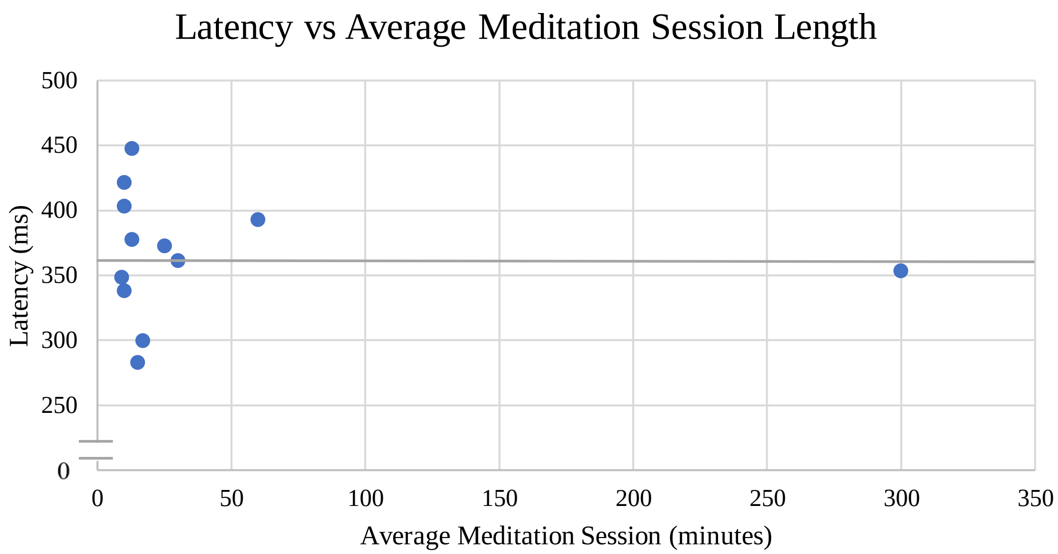

Figure 11b. Scatterplot of meditation group displaying the relationship between the number of years they have spent meditating and their average latency during the task. Control average latency shown in the grey line (355 ms).

Accuracy and latency were also explored by obserivng the effect of time using a linear mixed model. Since we see a main effect of colour present in both accuracy and latency, both analyses were conducted for each colour (attend-green blocks and attend-red blocks) (Figures 12, 13). Results of the attend-green accuracy revealed no main effect of group ($F(1,25)=0.0042$, $p=0.95$, partial eta^2=0.00017), however, a main effect of time was presents where the average accuracy of participants decreased over the course of the study ($F(4,100)=13.86$, $p=4.98\text{x}10^{-9}$, partial eta^2=0.36), and no interaction of group and time ($F(4,100)=1.59$, $p=0.18$, partial eta^2=0.06). Pairwise comparisons revealed significant difference in block 1 compared with blocks 3, 5, 7, and 9. In the attend-red blocks there was no main effect of group ($F(1,25)=1.24$, $p=0.27$, partial eta^2=0.05), no significant main effect of time ($F(4,100)=0.99$, $p=0.41$, partial eta^2=0.04), and no interaction of group and time $F(4,100)=0.23$, $p=0.92$, partial eta^2=0.0093).

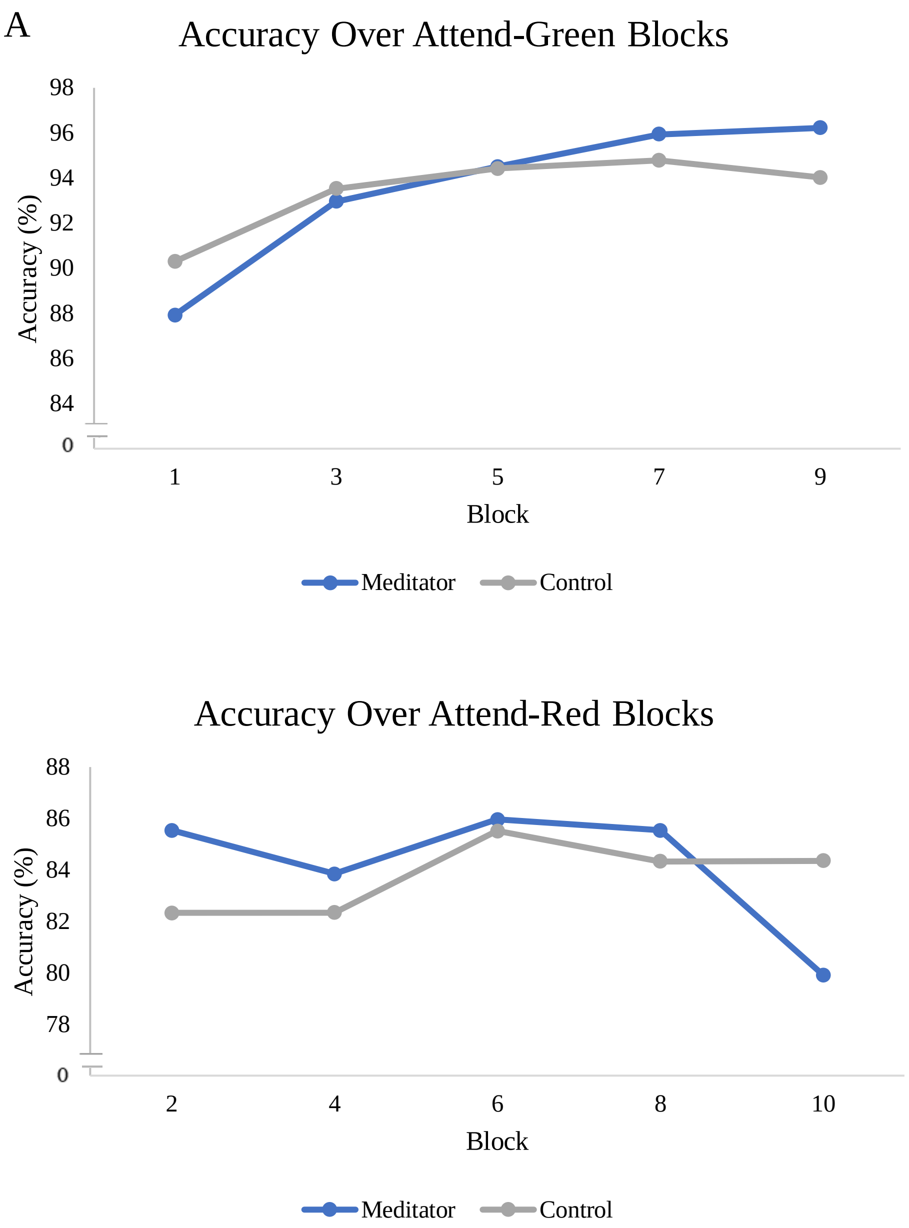

Figure 12. Meditator and control accuracy (%) over Attend-green (A) and attend-red (B) blocks

Results from the linear mixed for task response latency in the attend-green trials showed no main effect of group ($F(4,25)=0.33$, $p=0.57$, partial eta^2=0.01), a main effect of time where on average task-response times decreased as the study progressed ($F(4,100)=25.45$, $p=1.49\text{x}10^{14}$, partial eta^2=0.5), and no interaction of group and colour ($F(4,100)=1.32$, $p=0.27$, partial eta^2=0.05) (Figure 13). The pairwise comparison reveled a significant difference between block 1 and blocks 3, 5, 7, 9, and between block 3 and 9. The attend-red blocks also revealed no main effect of group ($F(1,25)=0.096$, $p=0.76$, partial eta^2=0.00038), a significant main effect of time ($F(4,100)=5.11$, $p=0.00087$, partial eta^2=0.17), and no interaction ($F(4,100)=0.38$, $p=0.82$, partial eta^2=0.02). Pairwise comparisons revealed a significant difference between block 2 and block 10, and between block 4 and block 10.

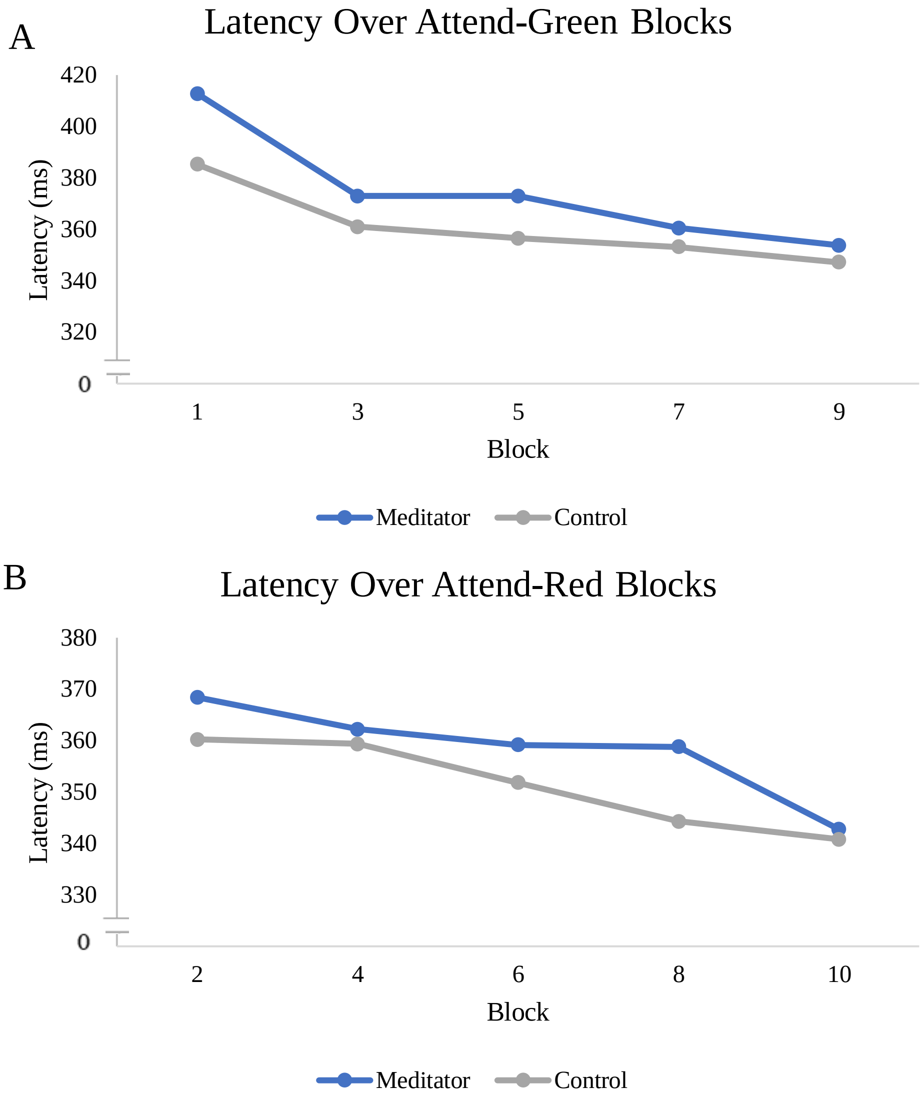

Figure 13. Meditator and control task response latency (ms) over Attend-green (A) and attend-red (B) blocks

5.0 Discussion

In this experiment, we aimed to find what role top-down and bottom-up processing played in the improved attentional awareness as seen in those who regularly practice meditation. Additionally, we aimed to observe any behavioural (task accuracy and latency) changes between meditators and a control group

The main findings are as follows:

- The direction of mean N2pc and Pd components align with hypotheses (Table 1) however, no statistically significant differences were found looking at the components between groups (control and meditator). However, for the N2pc, the magnitude of the effect size indicates that there is practical significance between the two groups and that we were underpowered in detecting this change.
- On average meditators showed to have better task accuracy than the control group. However, we were underpowered in detecting a statistical improvement in accuracy for meditators due to a small sample size.
- Presence of equal attentional fatigue experienced through a decrease in size in both N2pc and Pd components was seen across both groups.
- Colour showed to play a significant role in response accuracy and task response latency for both groups with green-attend trials having significantly higher accuracy and longer latency than red-attend trials in both groups.
- The was a weak positive relationship between years spent meditating and accuracy on the task, suggesting that the more experience one has with meditation, the greater their accuracy.

- There is no relationship between task response latency and meditation experience and/or average meditation session length.

5.1 Electrophysiological Results (N2pc &Pd)

The main hypotheses for the current study were to see if top-down and bottom-up attentional processing was influenced by whether one had been meditating for at least one year. We chose to observe mechanisms of visual stimulus attentional direction and suppression. These were in the form of the N2 Posterior Contralateral (N2pc), which indicates the top-down mechanisms of drawing attention towards a stimulus that one has been primed to recognize as a target, and through the Distractor Positivity (Pd) which provides a measure of visual stimulus suppression.

5.1.1 Group differences in ERPs

The main hypotheses for this study surrounded the differences between meditators and a control group when looking at visual processing ERPs (N2pc and Pd). We saw no statistical significance in both the N2pc and Pd when it came to the difference in groups in the ANOVA. Although, in both cases, the component was larger in the meditator group statistical significance was not reached. This trend in the N2pc does support the hypothesis that meditators would have better attentional control in the forms of target selection and distractor suppression, however, we did not reach a statistical significance between these group. However, the effect sizes it indicates a practical significance regard the N2pc and that we may have been underpowered in detecting any statistical increases in the meditators regarding the N2pc component and that the current lack of statistical significance may be misleading.

We were likely underpowered in running these tests to achieve statistical significance due to a small sample size. The direction of the average mean is in the alignment with the current study's hypothesis (Table 1). Through running a series of simulations, we are able to observe the sample sizes required to achieve a power of 0.8 in a two-way ANOVA. For the N2pc, we need to see 50 participants overall (partial eta^2=0.08) to observe a significant difference between meditators and control. Regarding the Pd, there was a trend present that the Pd is larger on attend-green trials compared to the attend-red for the meditator group. A sample size of 31 overall (partial eta^2=0.12) is required to observe a significant interaction of colour and group at a power of 0.8. Suggesting that there is a strong possibility of a type II error in the present study regarding the Pd and the effect of attended colour and that this may be due to sampling error.

5.1.2 Colour changes driving ERPs

The N2pc and Pd components were broken down by a two-way mixed measured ANOVA to observe the effect of attended colours on the size of the components. The was no main effect of attended colour in either component, however, there was a trend in the Pd that a larger amplitude occurred when they were attending to the green target (suppressing red distractors) (Figure 5c). This trend of colour in the Pd results tells us that the mechanism of distractor suppression might be influenced by the colours red and green, and not the focusing on the target itself. Since there was no trend or significant main effect of colour observed in the N2pc (Figure 3c), likely the act of focusing the attention on the target is not influenced by the difference in target colours, at least in this case, the colours red and green. Involving more coloured stimuli will help confirm if this remains true. The increased activation in the area, represented by a larger Pd indicates that individuals are able to suppress red distractors (attend to green targets) more efficiently than green distractors (attend to red targets).

This difference in colour may be down to certain cognitive psychological influences, one's current predispositions to the colours red and green. Regarding the N2pc, prior research agrees with the current findings that the N2pc amplitude does not differ across red versus green targets (Fortier-Gauthier et al., 2013). However, Fortier-Gauthier and colleagues did observe the Pd and claimed that they did not detect the Pd in trials with green distractors, which is not the case in the present study, although the Pd is smaller when suppressing green distractors, it is present. The reason why this difference exists is unknown but could be down to differences in the visual task used, Fortier-Gauthier and colleagues utilized a visual cue to identify the target prior to the task, whereas in the current study, participants were verbally cued on how visually the target will appear (attend red versus green). These differences in task design between the current study and Fortier-Gauthier at al., potentially could altering one's ability to suppress the distractor if they have already been visually cued. Additionally, there was no difference in form of the stimuli in Fortier-Gauthier et al (2013), unlike the current study which may have made their task less challenging in suppressing the distracting elements.

5.1.3 ERPs versus Time

The current study consisted of 10 blocks of 100 trials for 1000 trials total, each block lasted for around 4 minutes, resulting in 40 minutes of meaningful attention that was required of the participants to effectively complete the task. The participants were allowed a short break in the middle of the study if desired. We wanted to explore the rate of attentional fatigue between the two groups regarding both the N2pc and the Pd. We predicted that both groups would experience a decline in the size of the component as the blocks progressed, but we also predicted seeing an interaction between the two groups. Since during meditation, you are actively training your attention to focus on a goal, we expected this would translate over into seeing a slower decline in attentional fatigue in the meditators. Results of the linear mixed model showed a significant main effect of time in both the N2pc and Pd components, however no effect of group or any interaction of group and time. This reveals that regardless of if one had been meditating for more than a year, they will equally experience attentional fatigue in the form of a reduced activity directed towards suppressing distractors and attending to targets in the form of smaller Pd and N2pc components, respectively (Figures 4a, 4b).

Typically, meditation does not utilize visual stimuli, with the exception of some new trends in the field (virtual reality (VR)), therefore this may be why we do not see that meditators have reduced attentional fatigue when it comes to a visual attention tasks.

5.2 Behavioural Analysis

Secondary hypotheses surrounded the changes in behavioural results in comparison with meditators and control. We have seen from prior studies that meditators tend to perform more accurately on tasks (Tsai et al., 2018) and the implementation of a meditation intervention also improves one’s accuracy (Basso et al., 2019). We were expecting to observe similar results in the current study regarding accuracy. Studies looking at speed (latency) found meditators to perform faster than a control group (van Vugt & Jha., 2011), however, this is not the case for the current study.

5.2.1 Effect of colour on Accuracy & Latency

Both accuracy and latency presented an obvious pattern that there was a difference in attended colour across both of the two groups (Figures 7, 8). Performing a two-way mixed measures ANOVA using colour and groups as factors we were able to confirm suspicions that an effect of colour was present in accuracy suggesting that participants in both groups equally got more incorrect trials on attend-red blocks compared to attend-green blocks. These findings regarding accuracy were consistent across all participants where every participant experienced a decreased average accuracy on the attend-red blocks compared to attend green (Figure 14). This was an interesting finding since there were no reported colour differences in Bacigalupo & Luck (2015) which this task was designed.

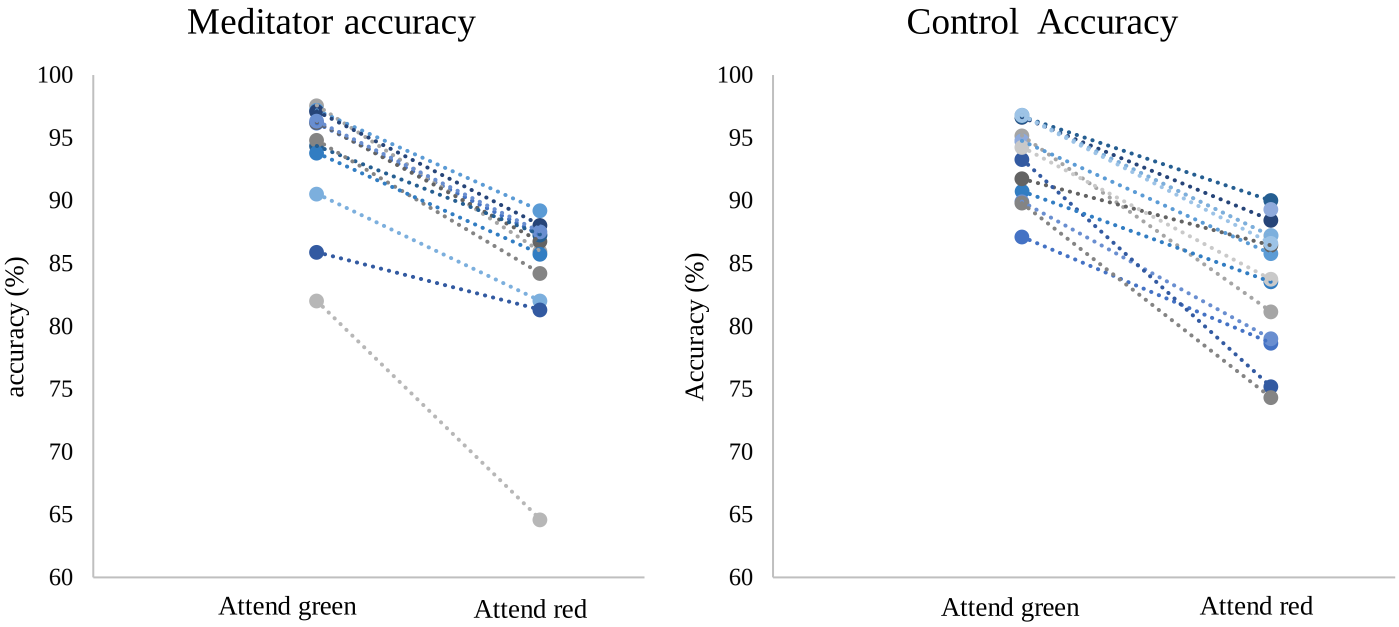

Figure 14. Average task-response accuracy of all attend-green and attend-red trials of individual participants showing the consistent decrease in average accuracy in attending red versus attending green across both groups.

Since there was an effect of colour found in accuracy, we ran a two-way mixed ANOVA on latency to see if this effect of colour was persistent. Looking at latency we see that both groups were on average 13 ms slower on attend-green than on attend-red. Although participants were equally stressed accuracy and speed, there is an obvious influence of colour that can alter one's performance. The ANOVA confirmed suspicions showing the main effects of attended colour in latency, indicating that regardless of if one has meditated for at least one year, they have faster responses on attend-red trials. The latency results of this study were unexpected. We cannot determine causality in this study; however, we could speculate that depending on the attended colour, one may prioritize accuracy and speed differently.

As mentioned in the ERP section, there is the possibility that there is cognitive psychological reasoning behind the red vs green environments and what kind of feelings they may evoke, resulting in changes in how our intentions manifest.

Gaspelin & Luck (2017) suggest that if individuals have been repeatedly exposed to a colour that has never been the target they may learn to suppress items in that colour. In common day-to-day life, we relate the colour green to mean "go" and red to mean "stop" (traffic lights) or with enter and exit signs being commonly green and red, respectively. These kinds of predispositions to the colours used in the task may have influenced the behavioural data, translated into the current study, when attending to red, participants are faster but less accurate, and when attending to green, they are slower, but more accurate. Briki and Hue (2016) observed the affective judgement of colours red, green, and blue. Red was strongly associated with dominance and arousal, whereas green showed only a minor association with arousal and was more pleasurable than red. Additionally, in other research, seeing a red stimulus had led to a hindered cognitive performance (Elliott et al., 2007) which may relate to the decrease in accuracy that we see in the current study. Another study showed that cycling in a red environment for 7 minutes demonstrated a decreased distance travelled when compared to cycling in a green environment (Briki et al., 2015). These kinds of findings support that accuracy may be hindered but do not quite provide answers when it comes to the decreased latency in attend-red trials.

5.2.2 Group differences in Accuracy & Latency

Improved accuracy had been interpreted differently across various studies. Fox and colleagues (2012) saw improved introspective accuracy in the form of a two-point discrimination task between experienced meditators and novices. Additionally, they found a positive relationship between one's experience with meditation and introspective accuracy, a similar relationship that we see in this current study observing accuracy and meditation experience (Figure 10a). In this positive relationship between accuracy and meditation experience, after about 2 years of meditation practice, we see accuracy results > 90% which is higher than the average accuracy of the control group. There is one participant that draws out the relationship between accuracy and years of meditation experience, if this participant is removed, this strengthens the positive relationship to reveal a Pearson Correlation coefficient of $r=0.44$. Further research looking exclusively at accuracy and years of meditation experience would be needed to confirm where the threshold is for the consolidation of the mechanisms behind improved accuracy to occur.

As previously mentioned, Tsai and colleagues (2018) found an improved task-response accuracy after a period of meditation was used as an intervention on both a meditator group and control, whereas in this study we observed meditation experience as a criterion for participants rather than implementing a period of controlled meditation. Accuracy can be observed in several methods. Hodgins and Adair (2010) used various visually stimulating tasks to observe the differences in attention in those who regularly meditate. Their findings indicated improved visual concentration in identifying rapidly moving stimuli, providing support for the current study since similar mechanisms are used in the task suggesting improvements could translate over to the modified-flanker task used in the current study. When observing the means of accuracy between groups, the meditation group has a higher average than the control group (Table 2), which from previous studies was expected, however, statistical significance was not reached. Looking at the effect size for the accuracy between the groups, we may have been underpowered in achieving the results that had been obtained in prior studies regarding the increased accuracy rates.

The same simulations ran for the ERPs, were also run for behavioural analysis to observe at what sample size is required to see a significant main effect of group. A sample size of 56 (power=23.02, partial eta=0.07) would be required to see a significant increase in meditators regarding latency of task response and a sample size of 96 (partial eta=0.04) to see a significant increase in meditators for task accuracy at a power of 0.8. As discussed prior, those who meditate have been shown to exhibit improved accuracy in many facets, however, we did not see this in the current study, which is likely due to a high sampling error and being underpowered in performing the ANOVA.

Regarding task response latency, prior research has shown that response time is significantly faster after undergoing a mindfulness training intervention (van Vugt & Jha., 2011), in the present study this is not the case, since we see meditators have a slightly longer task response latency than controls (Table 2). Possibly because the faster reaction time could be short-lived when meditation is used as an intervention.

Regarding the relationship between latency and meditation experience (Figure 11a) and average meditation session (Figure 11b), unlike accuracy, we do not see any correlation suggesting that meditation history cannot be used as a predictor for latency.

Multiple regression results of using the factor of group to predict one’s accuracy and latency showed to have no statistical significance (Figures 9a, 9b). Regardless of if one meditates or not, participants were able to equally focus on both accuracy and speed during the task.

Behavioural results were also observed over time using a linear mixed model. However, they were separated based on attended colour since there was found to be a significant difference between attend-green and attend-red in early statistical analysis. Accuracy revealed a significant main effect of time only in attend-green trials (Figure 12). Time (block number) was used as a categorical factor because of the variability in attend-red accuracy across blocks. Why time only had a significant effect on attend-green trials and not attend-red, is not clear and would require further investigation. Latency, however, exhibited a main effect of time across both the attend-green and attend-red blocks (Figure 13). These results show that attentional fatigue resulting from a visually stimulating task does decrease accuracy, but only on attend-green blocks, and latency on both attend-green and attend-red.

5.3 ERN

The ERN was only elicited in 7 of the control participants, and none of the meditator group. This was largely due to program design; we know from prior research that the ERN represents error awareness and is only elicited when the participant is aware that they had made an error (Gehring et al., 1993). With the present task, it was a quick response time, and participants were not revealed their accuracy rating throughout the task, and as a result, it is likely that participants were not focused enough on their accuracy for individual answers since there was no feedback. The task had been initially designed to elicit the N2pc, not the ERN, however, we did not know for certain that an ERN would not occur using this modified-flanker task. A potential factor regarding the lack of ERN presence may be a result of equally expressing accuracy and latency to the participant, since we know from Gehring and colleagues (1993) series of experiments, that the ERN is most effectively elicited when accuracy is prioritized. However, in this study, we wanted to observe the response time of meditators in an unbiased way. In the future, if the ERN is to be looked at it would have to be through a separate task away from the N2pc/Pd task. Much like we saw in Temper & Inzlicht (2013) we know that those who practice meditation long-term (> 1 year) produce larger ERN amplitudes than a control group using a Stroop task.

5.4 Limitations and Future Directions

We did not see the statistically significant improved accuracy in meditators in this study that has been noted in other studies that use meditation as an intervention. One possibility is that this may be because these effects of improved accuracy may be short-lived after a meditation intervention. To observe this in a future study, experienced meditators and control could be assessed in a test, retest fashion, one where they perform a fast-response modified-flanker task upon arriving at the lab after not meditating for a certain period and then retested on the same task following a meditation intervention.

Another possibility may be due to the requirements of the study. For the meditator group, participants needed to have a minimum of 45 minutes of meditation a week on average, and although the large majority exceed that practice, it may not have been conservative enough to see the changes in accuracy, latency, and ERP components. Today, we do not have an ideal “amount” of meditation one should be doing regarding both length of time per session and frequency. However, studies that have used meditation as an intervention based on physiological observations have used a wide variety, commonly between 5-20min of daily meditation implemented (Lin & Mai., 2018; Crosswel et al., 2019). However, outside of a short-term intervention, it was unrealistic to expect participants to practice every day for at least a year, so a weekly range was more realistic and accessible for recruitment.

Participants had self-reported their experience, which could have resulted in biases and exaggeration when it comes to them reporting their experience with meditation. These possible inaccuracies in one’s meditation experience could provide a reason as to why we do not see any statistically significant differences between the groups regarding behavioural data as well as ERP data. Participants in the mediation group may have exaggerated their experience with meditation in order to meet the requirements or vice versa whereas members of the control group may have played down their experiences with meditation in order to fit into the control.

Since it is well understood that meditation does have long-term cortical effects and increased arborization in areas related to attentional processing, the requirements for meditation practice for this study may need to be altered to see these effects represented in ERPs. Lazar (2005) observed cortical thickness in long-term meditators, seeing that years of meditation practice were correlated with the cortical thickness of the inferior occipitotemporal visual cortex, which is the same area where the N2pc and Pd components can occur. Research to observe this relationship in an electrophysiological sense could consist of groups of meditators separated by their meditation experience (potentially through years of consistent experience) and observe any relationship between their experience and the size of the N2pc and Pd, being compared to a control group. Through this study design, we should be able to see at what point along one’s experience with meditation we see potential consolidated effects regarding improved attention displayed in ERP.

As mentioned in the influence of time versus ERPs, we did not see any statistical differences in the way attentional fatigue affects the two groups. This is most likely due to the fact the meditators do not typically use visual stimuli in their meditation process. In the current study, we did have one participant that engaged in virtual reality-styled meditation. RelaWorld is a new meditation system that is designed with neuroadaptive virtual reality technologies. The electroencephalography-driven equipment allows users to quantify their own meditation experience. This system involves numerous styles of meditation, but one in particular is the focused attention type, where the user focuses their attention on a highlighted object in the water of the virtual display (Kosunen et al., 2016). Practice in this style of attentive meditation may translate the best to the task in the current study, with one being able to focus their attention on the visual field rather than on internal systems as we see with traditional meditation styles. Further research could explore this by utilizing a VR as a meditation intervention over a couple of weeks and observing the rate of attention fatigue in visual attention-related ERPs before and after the intervention.

5.5 Conclusion

In summary, the current study did not achieve significant differences in the behavioural data regarding the group of the participants (meditator or control), however, participants exhibited a strong influence of colour over both accuracy and latency regardless of their group. Participants perform significantly more accurately and slower on attend-green (suppress-red) trials compared to attend-red (suppress-green). The cause of this requires further research, however, could be a result of psychological predispositions, since we commonly associate green with “go” and red with “stop”. Additionally, researchers have found that there is a decrease in motor performance associated with red environments, which could explain the decrease in accuracy in attend-red trials. However, this does not explain the slower response time.

Regarding the N2pc and Pd, no statistical significance was found regarding the effect of colour, however, the trend seen in the Pd could explain that the difference in behavioural is a result of attentional suppression mechanisms. Research looking at colour disparities in the N2pc and Pd is in its infancy and requires further observation to produce concrete results. Although we did find that on average meditators we more accurate and produce larger N2pc amplitudes compared to a control group, we did fail to find a statistical increase in these areas. However, it is likely that we were underpowered due to a small sample size and that the current lack of significance is misleading in the current study.

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Appendices

APPENDIX A

University of Waterloo

MEDITATION SCREENING FORM – MEDITATION EXPERT GROUP

Below is a questionnaire used to exclude participants considered not suitable for the meditation expert group as well as evaluate their experience with meditation practices. This information, as well as your identity, will be kept confidential in all future publications.

PLEASE COMPLETE THE FORM BELOW

Participant Code:______________________________ **Age: __________________**

Please PRINT your answers for the following:

What kind of meditation do you typically practice the most?

What other kinds of meditation do you practice?

When were you first introduced meditation?

How long have you been routinely practicing meditation?

How many times a week do you typically practice meditation?

How long is a typical meditation session?

On average, do you collectively meditate more than 45 minutes a week, every week for the last year?

____

Are there any other mindfulness-based practices that you participate in (e.g., yoga, Tai Chi, etc.)? Please specify.

____

If yes, how often a week do you practice? How long is each practice?

____

For the following questions please CIRCLE YES or NO:

Have you engaged in acute physical activity in the past 24 hour prior to entering the lab?

YES NO

Have you ever engaged in any kind of music therapy?

YES NO

Have you ever been diagnosed with an anxiety related disorder (e.g., Generalized Anxiety Disorder)?

YES NO

Have you ever been diagnosed with a depression related disorder (e.g., Severe Depression, Bipolar Disorder)?

YES NO

Have you ever been diagnosed with Obsessive-Compulsive Disorder (OCD)?

YES NO

Do you have an allergy to rubbing alcohol?

YES NO

Have you used psychotropic medications in the past two weeks?

YES NO

APPENDIX B

University of Waterloo

MEDITATION SCREENING FORM – CONTROL GROUP

Below is a questionnaire used to exclude participants considered not suitable for the meditation expert group as well as evaluate their experience with meditation practices. This information, as well as your identity, will be kept confidential in all future publications.

PLEASE COMPLETE THE FORM BELOW

Participant Code:______________________________ **Age: __________________**

For the following questions please CIRCLE YES or NO:

Have you ever engaged in meditation practice beyond an introductory level?

YES NO

Have you ever engaged in any other mindfulness-based practices beyond an introductory level (e.g., Yoga)?

YES NO

Have you engaged in acute physical activity in the past 24 hour prior to entering the lab?

YES NO

Have you ever engaged in any kind of music therapy?

YES NO

Have you ever been diagnosed with an anxiety related disorder (e.g., Generalized Anxiety Disorder)?

YES NO

Have you ever been diagnosed with a depression related disorder (e.g., Severe Depression, Bipolar Disorder)?

YES NO

Have you ever been diagnosed with Obsessive-Compulsive Disorder (OCD)?

YES NO

Do you have an allergy to rubbing alcohol?

YES NO

Have you used psychotropic medications in the past two weeks?

YES NO

I hereby declare that all information given on this Control Group screening form is true and complete in every respect.

______________________________ ______________________

Signature of Participant Date

APPENDIX C

EXPLORING THE POWERS OF MINDFULNESS-BASED TRAINING ON ENHANCING EXECUTIVE FUNCTIONING AND RESPONSE ACCURACY

INFORMATION LETTER

Principle Investigator: W. Richard Staines

Co-Investigator: Sophie Chambers

Institution: Department of Kinesiology, Faculty of Applied Health Sciences, University of Waterloo

Objectives: The exploration of the benefits through the use of mindfulness-based training, specifically meditation, has been become a popular topic of research, with results demonstrating benefits that are not just isolated to mental health improvement as once was previously thought. The implementation of meditation into one's lifestyle has seen improvements in individuals' lives, such as a reduction in physical inactivity in adults and reduced fall rates in individual's post-stroke. Yet we do not have a fully comprehensive understanding of how or why these cognitive changes occur. One outcome of extensive mindfulness practice is the enhanced executive functioning seen through and improved ability for effective attentional allocation and improvement in accuracy in certain tasks. Suggesting that the implementation of mindfulness-based practices into one's lifestyle may improve their ability to focus, this can be significantly beneficial for individuals that struggle with attentional deficit disorders. However, we need to first fully understand how the mechanism works.

We have an understanding that those who have engaged in dedicated mindfulness practice for an extended period of time (> 1 year) have an enhanced executive control demonstrated by error-related negativity ERNs of significantly greater amplitudes indicating a decrease in post-error slowing (PES) upon error commission, during these tasks, the experts also significantly had a greater task accuracy response. The idea that those with extensive mindfulness practice typically have an enhanced executive functioning is well established within research, however, alterations in the ability to allocate attention effectively towards a target and away from a distractor stimulus requires further exploration.

Procedure: For this study there will be two different groups; experimental (meditation experts) and a control (those with little to no meditation experience). This experiment will use electroencephalography (EEG), a non-invasive technique which measures electrical brain activity. In order to record EEG, an elasticised cap containing 32 surface electrodes will be used. Prior to putting on the cap, a gentle skin abrasive will be applied to the mastoids (bony protrusion behind the ears) to remove dead skin and oily residue. This will be followed by rubbing alcohol to clean off any remaining gel residue. Mastoid electrodes will then be attached to the cleaned area and the EEG cap will be put on. A conductive gel will be injected into each of the electrodes to allow for electrical signals from the brain to conduct from the scalp to the electrode.

Participants will be comfortably seated at a distance of 70 cm away from a screen using a chin rest. The stimuli will appear on the screen and will consist of a black background and a continuously visible white fixation cross in the centre of the screen. Each stimulus is comprised of two vertical arrays of 3 letters (uppercase Geneva font) with one array located on each side of the fixation cross, centered at 8.8° from the vertical median. One array will be coloured red and the other green, the sides that they occur on will vary randomly through the trials. The letter that will appear on each trial will be selected randomly without replacement from a set of five vowels (A, E, I, O, and U) and five consonants (N, F, L, G, and J). The center letter in the array will be placed on the horizontal median and is considered the target stimuli, flanker letters are directly above and below the target and will be place at 3.13° from the horizontal median.

Speed and accuracy will be equally encouraged to the participant. At each trail block the participant is instructed to attend to either the red of green array and to indicate whether the middle letter of that coloured array was a vowel or a consonant. Participants will indicate this choice using their dominant hand on a key pad. The stimulus duration will be for 200msec. Each participant will perform 10 blocks of 100 trials, there will be 5 attend-red and 5 attend-green blocks, presented in alternating order

This study will take approximately 2 hours to complete and consists of a single EEG session. Upon completion, you will be provided with a sink, shampoo/conditioner, and a towel to rinse out any electrode gel from your hair and scalp.

Confidentiality and Security of Data: All personal information that is gathered during the study will remain strictly confidential, and at no time will your name be associated with any of the information. All paper data will be stored in a locked filing cabinet where only the researchers will have access to it. There is potential for data to be present within written work or presentations, but such data will be grouped, and no personal identifiers will be present. Information, including electronic data and data sheets, will be password-protected (electronic data) and secured in a locked room in the Department of Kinesiology at UW (AHS 2698) to prevent unauthorised access. The de-identified data will be stored for at least 7 years.

Benefits: This study will not provide any direct benefit to you, but the information it provides will lead to better understanding of normal physiological brain processes. This may, in turn, aid in developing therapeutic techniques for recovery after brain injury and may lead to greater understanding of sensorimotor-related brain pathologies.

Risks: Use of EEG poses minimal risk; it involves surface electrodes that do not come into contact with the skin. Contact is made between the skin and the recording electrodes with conductive gel. In rare instances, it is possible that your skin may be sensitive to the conductive gels or rubbing alcohol used for surface recordings. In such cases, a skin rash is possible. You may feel discomfort from the EEG cap or electrode preparation, especially if these techniques are new to you. In order to minimise these risks, you will be informed at the beginning of the session and reminded throughout the duration of the session that you are permitted to take short breaks between blocks. Also, after finishing each block, the experimenter will ask you whether you feel comfortable proceeding before continuing.

Exclusion Criteria: In order to participate in this study, you must be between 18-40 years of age. Prospective participants may not be being treated (and have no history of being treated) for any anxiety or depression related mental illnesses. In addition, you must have no known allergy to rubbing alcohol. You must have strong English in order to follow and respond to task instructions.

Participation in the Experiment: Participation in this study is completely voluntary and you may decide not to partake in this research, not to answer individual questions, or not to participate in certain procedures. Withdrawal from the study may occur at any time without reprisal by informing the experimenter that you would like the experiment to stop. Any data obtained may be used as described above, unless you request to withdraw your data. You can request your data be removed from the study up until 07/22 as it is not possible to withdraw your data once papers and publications have been submitted. In appreciation for your time, you will receive $25 for the session. You are able to withdraw at any moment during the study, however the payment will be adjusted, $10 /hour will be allotted for the amount completed of the study. Please note that the amount received is taxable. It is your responsibility to report this amount for income tax purposes. You are free to withdraw from the study at any time, however payment in the form of remuneration will not be received if they study is not completed.

Contact Information: If you have any questions about the study at any time, please contact either Sophie Chambers (co-investigator) at sa2chamb@uwaterloo.ca or Professor Staines at 519-888-4567 ext. 37756.

Concerns About Your Participation: I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #43394). However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact the Office of Research Ethics at 519-888-4567 ext. 36005 or reb@uwaterloo.ca

1. CONSENT FORM

I agree to take part in a research study being conducted by Dr. Staines and his research team in the Department of Kinesiology, University of Waterloo.

I have made this decision based on the information I have read in the Information Letter. All the procedures, and any risks and benefits have been explained to me. I have had the opportunity to ask any questions and to receive any additional details I wanted about the study. If I have questions later about the study, I can ask one of the researchers.

Richard Staines, Kinesiology, 519-888-45637 ext. 37756

I understand that I may withdraw from the study at any time without penalty by telling the researcher.

This project has been reviewed by and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. If you have any comments or concerns resulting from your participation in this study, you may contact the Office of Research Ethics at 519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca

Placing your signature below indicates that you have read the entire consent form. By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

Signature of Participant _____________________ Print name ___________________

I would like to receive feedback on the outcome of the study follow its completion (please check one):

____ YES ____ NO
If yes, please provide your email: ____

Signature of investigator __________________ Print name _____________________

Date ___________________________