MINDFULNESS AND MEMORY: EFFECTS OF MINDFULNESS MEDITATION ON MULTIPLE WORKING MEMORY SENSORY MODALITIES

By

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Abstract

The work of Mrazek et. al (2013) and Quach et. al (2016) demonstrated that WM performance and capacity could be improved through a consistent mindfulness practice. Taken together with the work of Holzel et. al (2001) and Gray and Braver (2002), who demonstrated the activation of the anterior cingulate cortex (ACC) during mindfulness meditation and working memory tasks, respectively, a link between working memory and mindfulness meditation is established. However, no one has explored how mindfulness meditation impacts the WM processing of different sensory inputs. This research analyses the potential impact of a two-week Mindfulness Meditation intervention on multiple working memory (WM) sensory modalities (i.e. auditory, identity, and visuo-spatial). The results of this study do not support claims of enhanced cognitive performance or improved health measures. The experimental and control groups in this study did not differ in any meaningful way in overall working memory, working memory subsystems, or their physiological measures. So, we posit that the two-week Mindfulness Meditation course, which differed from previous research, was not an effective intervention to elicit major change in cognitive performance, or improved health measures.

Mindfulness and Memory: Effects of Mindfulness Meditation on multiple Working Memory Modalities

Mindfulness Meditation is an ancient practice originating in Theravada Buddhism. However, its adoption as evidence-based therapy like Mindfulness Based Stress Reduction (MBSR) Therapy and Mindfulness Based Cognitive Therapy (MBCT) has generated a distinctly secular form of mindfulness meditation. Kabat Zinn (2014) describes mindfulness as paying attention, on purpose, non-judgmentally, in the present moment. As such, his MBSR Therapy adopts three pillars of mindfulness: attention, intention, and attitude (Shapiro, Shauna L., et al., 2006). These concepts are interwoven and work together to grow one's mindfulness practice, and a consistent practice can lead a variety of beneficial psychological changes.

Previous research by Mrazek et. al established a psychological link between consistent mindfulness practice and improved working memory performance. Additionally, strong activation of the anterior cingulate cortex (ACC) during both meditation and working memory tasks provide a biological link between Mindfulness mediation and working memory. Taken together these findings demonstrate that Mindfulness meditation can impact the working memory performance based on material processed by each informational buffer (sensory modality). The improved focus resulting from consistent mindfulness meditation can benefit individuals' working memory through the activation of ACC, allowing individuals to better regulate sensory information to improve executive working memory function and capacity for all informational buffers. This study will test the effectiveness of a short-term mindfulness practice (two weeks) on the different sensory subsystems that integrate into working memory. The first goal of this experiment is to recreate the results of Mrazek et. al and demonstrate that mindfulness meditation can improve working memory performance. The second goal of this experiment is to see how effective a consistent mindfulness practice can be in facilitating working memory performance on all testable sensory modalities. We hypothesize that mindfulness meditation will benefit working memory performance based on material processed by each informational buffer (auditory, visual, and spatial). This is based on the previous research that supports the anterior cingulate cortex (ACC) as a key neurological center for the executive function of working memory. As such, the ACC plays a large role in diminishing conflicting, unnecessary signals from reaching the cortex, allowing a human to focus on an object. Based on this research, and the research that supports the positive impact of meditation on the ACC, we believe performance based on sensory subsystems will benefit equally.

Literature Review

Jon Kabat-Zinn, the founder of Mindfulness Based Stress Reduction Therapy (MBSR) and the Director of the Stress Reduction Clinic and Mindfulness in Medicine, Health Care, and Society at the University of Massachusetts, was one of the pioneers who brought mindfulness to science. Mindfulness originates in ancient Buddhist practices and is considered a core practice of the Buddhist eight-fold path to enlightenment, or right mindfulness. It is a state achieved through consistent practice with a variety of different ways to practice it such as breathing meditations, walking/sitting meditations, eating meditations, and thought-labeling meditations. The practice of mindfulness can be carried out through a variety of exercises, both formal and informal, that focus attention on the body, thoughts, experiences, emotions, and sensations. Formal mindfulness practices require time to be set apart specifically for meditation, and informal mindfulness practices occur outside of meditation as an individual goes about their day. Kabat-Zinn (2001) defines it as “paying attention in a particular way: on purpose, in the present moment, nonjudgmentally” (p. 22). Mindfulness is deliberately practiced to create “an appreciation for the present moment and the cultivation of an intimate relationship with it through a continual attending to it with care and discernment" (Kabat-Zinn, 2001, p. 23). While this definition may seem vague, it hints at a neurological mechanism for mindfulness.

As this practice has been adopted by and integrated into western culture and science, mindfulness has lost much of its religious background, separating it from its roots. However, clinicians and scientists have been able to utilize this new form of meditation to explore the potential benefits of mindfulness. Samuelson, Carmody, Kabat-Zinn and Brat (2007) conducted a study in a Massachusetts prison, where they trained the inmates in an eight-week MBSR course and measured its impact on their emotional state. They found that the prisoners taking part in this course felt decreased anxiety and aggression along with increased confidence. Following on the success of Kabat-Zinn's MBSR therapy, studies were conducted exploring the impact of mindfulness meditation on individuals suffering from chronic depression and found that the rate of incidence and relapse into depressive episodes was significantly reduced by consistent meditation practice (Teasdale et. al, 2000). Additionally, mindfulness practice has been linked to an increase in individual self-control. In a study conducted by Friese, Messner, and Schaffner (2012), they found that meditation allowed their participants to counteract the effects of self-control depletion following an emotional suppression task to enable these participants to perform on par with those that were never asked to suppress their emotions. Meditation allowed these individuals to restore self-control lost as a result of the experimenter's emotional suppression task. This occurred following just one session of meditation in between the tasks.

Meditation, when practiced long term, has also been shown to cause significant physiological changes in the brain. Lazar et al. (2005) demonstrated that experienced meditators have significantly increased their cortical thickness in areas controlling "somatosensory, auditory, visual, and interoceptive processing" (p. 4). This increase in plasticity for the region allows for increased functioning in these perceptive areas due to regular focused attention. Lazar et. al (2005) proposed that this change in the somatosensory neurons could be due to both "directing attention towards behaviorally relevant sensory stimuli within a relaxing setting over repeated practice sessions" (p. 4). The change in neuroplasticity can facilitate greater cognitive and emotional processing. Kirk, Brown, and Downar (2015) studied meditation's ability to alter neural pathways such as the reward processing pathways, which control the bodily responses for reward anticipation and receipt. In experienced meditators, there was less activation in the anterior insula, often associated with "negative arousal," meaning they were less "engaged in reward anticipation" (Kirk, Brown, and Downar, 2015, p. 757). This supports mindfulness meditation as a viable option for drug and alcohol addiction treatment, as well as obsessive compulsive disorder (OCD).

One of the key components of mindfulness meditation consists of attention. Studies conducted on consistent meditators have found the practice allows them to hold their focus for greater lengths of time, and find distractions disrupt their focus less frequently during meditation practice and everyday life (Hölzel et al., 2011, p. 539). Often, the attention is anchored to an object, or sensation. For example, breathing meditations have meditator focus on the sensations of inhaling and exhaling in order to anchor oneself, and if they catch themselves drifting off into thought then they refocus their attention on the breath. In a review conducted by Hölzel et. al (2011), attending to an object while disregarding other thoughts is known as "conflict monitoring, or executive attention" (p. 540). Executive attention is thought to be enabled by the anterior cingulate cortex (ACC), where it detects conflicting information signals and, with the fronto-insular cortex, "is involved in switching between activations of different brain networks, thereby facilitating cognitive control" (Hölzel et. al, 2001, p. 540). Additionally, neuroimaging confirms that meditators experience increased activation of the ACC during a resting state after only five days of focus-based meditation. Additionally, experienced meditators with 2-12 years of experience saw a significant increase in ACC cortical thickness (Hölzel et. al, 2001, p. 540). This neural link between executive attention and focus meditation suggests that elements under cognitive control, sharing a similar connection to the ACC, could be greatly impacted by consistent meditation practice.

Baddeley proposed a multiple components model of working memory. By his definition, working memory is formed by the collection of memory subsystems that are separate, finite, and transient (Baddeley, 1983, p. 311). His multicomponent model proposed a central executive and three sensory subsystems. The central executive function processes and controls the flow of sensory information (Baddeley, 1983). The central executive function and the three sensory subsystems are entirely distinguishable, and the executive function can act independently upon the stored sensory information. This proposed executive function can amplify relevant sensory signals to be used in working memory, allowing an individual to retain important information for a limited amount of time, around 1-15 seconds. The working memory's sensory subsystems "can be stratified into informational buffers based on information type" (Jonides et al., 2008, p. 195). Baddeley conceived of several information types, which are the phonological loop, the storing of verbal and auditory information, and the visuo-spatial sketchpad, which stores visual-spatial and object-based information. Since these informational buffers are stored independently from each other, working memory performance is a function of both the amount of stored information and the effectiveness of the central executive function.

Neuroimaging can provide key clues as to biological origins of this psychological phenomena known as working memory. In a study examining the regions of activation in the brain due to working memory tasks, Salmon et. al (1996) attempted to isolate the regions in the brain responsible for the executive function of working memory. They found foci of activation in the anterior cingulate gyrus (BA 24) (Salmon et. al, 1996, p. 1620). This finding is further supported by the work of D'Esposito et. al (1995), which reported activation of the anterior cingulate gyrus has been implicated in visual working memory tasks. Additionally, Gray and Braver (2002) found strong activation of the ACC was during a working memory task. The activation of the ACC in both working memory tasks and mindfulness meditation hints at a potential link between the executive function of working memory and mindfulness meditation.

Others have explored this link before, Quach et. al (2016) looked at the impact of mindfulness meditation on working memory capacity in adolescents. They had two test groups, one Hatha yoga group (54 participants) and one mindfulness meditation group (65 participants), and a control waitlist group (53 participants). The meditation group received meditation based on MBSR. Each test group met twice weekly for four weeks with a 45-minute intervention for a total of six hours. Also, both groups were encouraged to practice daily for around 15-30 minutes at home. They found a significant increase in working memory performance after four weeks in the meditation group, but not the Hatha Yoga group, or control. As a result, they are quick to identify the "results are consistent with the notion that the practice of meditation – which requires sustained attention while simultaneously redirecting attention back to the current experience – is closely related to the function of working memory" (Quach, Alexander, Jastrowski Mano, 2016, p. 493).

Another study, more similar to the pool of participants taking part in this experiment, studied the impact of mindfulness meditation on the working memory of students studying for the GRE. Mrazek et. al (2013) took forty-eight participants and randomly divided them up into a experimental group, receiving the mindfulness intervention, and a control group, taking a nutrition class. Both groups met eight total times over the course of two weeks for 45 minutes per session. The mindfulness training was also based off MBSR therapy, but they abbreviated the training interval (from eight weeks down to two). Working memory was measured using an operation span task, where "to be-remembered stimuli were alternated with an unrelated processing task" (Mrazek et. al, 2013, p. 777). Mzrazek et. al (2013) found that the mindfulness intervention significantly improved the participant's working memory capacity. Additionally, the mindfulness intervention was shown to increase their GRE score, and decrease their mind-wandering, measured from a self-report and a retrospective thought-sampling probe.

Quach et al. (2016) were able to establish a potential link between a consistent mindfulness meditation practice and improved working memory. Mzrazek et. al (2013) were then able to demonstrate that this improvement in working memory capacity could be found after only two weeks of mindfulness meditation, which is the timeframe used in this study. ACC activation in both working memory tasks and during mindfulness meditation provides a possible insight into the neurologic mechanism of this improvement (Gray and Braver, 2002; Hölzel et. al, 2001). Taken together these findings support the two primary goals of this experiment: one, demonstrate the effectiveness of mindfulness meditation's positive impact on working memory performance; two, explore the impact of mindfulness meditation on specific sensory modalities like audition, visuo-spatial, and identity.

Materials

The consent forms, Mindfulness Attention Awareness Survey (Brown, K. W., & Ryan, R. M., 2003), and Perceived Stress Scale (Cohen, S., Kamarck, T., & Mermelstein, R., 1994) were all collected using Qualtrics software. Both blood pressures and heart rates were collected using an upper arm CVS Health Series 400 Blood Pressure Monitor. Auditory guided meditations were given by Saki F. Santorelli, EdD, MA, a professor of medicine, director of the Stress Reduction Clinic, and executive director of the Center for Mindfulness in Medicine, Health Care, and Society at the University of Massachusetts Medical School, and Florence Meleo-Meyer, MS, MA, the Director of Oasis Institute for Mindfulness-Based Professional Education and Training. The three guided meditations used in this experiment are *Sitting Meditation: Awareness of the Breath*, *Sitting Meditation: Awareness of Breath and Body*, and *Sitting Meditation: Expanding Awareness.* These guided meditations are from his Online Mindfulness Based Stress Reduction Course and are presented through headphone speakers (Avantree Superb Sound Wired On Ear Headphones). The working memory task was run through Visual Basic 6.0 software. The cloud service Google Drive was used for participants to allow continued access to the guided meditations exposed to during the experimental sessions.

A Hewlett Packard Touchsmart computer was used to the display the stimuli and participants responded by clicking one of the two buttons on the monitor. The computer monitor dimensions were 48.26 cm (l) X 30.48 cm (w). Over ear headphones (Avantree Superb Sound Wired On Ear Headphones) were used to present auditory stimuli.

Visual stimuli were presented in 20 possible locations arranged as two concentric circles. Each possible location with the circles was marked with a small white circle in the center of the response location. This visual field map was added to increase performance on location trials. Participant responses were made to press one of two buttons labeled “match” or “no match” located in the center of the screen. The response buttons were visible only after all stimuli in a trial had been presented. Following the participants response, they were provided with three buttons labeled “Location,” “Identity,” and “Auditory”. These served to check the participants understanding pertaining to which of the three distinct trial types they had just encountered. The identity stimuli were distal photographs of black and white snowflakes. The location stimuli were distal photographs of colored kaleidoscopes. Participants were trained to attend to the features of snowflake images, while disregarding the location in which they appear; whereas they were to attend to the location, but not the features, of kaleidoscope images. Auditory stimuli were presented from either side of the headphone speakers, and were trial-unique sounds composed of one of eight, 500 ms duration tones, with three-part frequency modulation. Participants were trained to attend to the sound, but not the location of the speaker from which it was produced.

Procedure

Survey Data Collection

Upon beginning the experiment, participants were instructed to read through an informed consent document presented through Qualtrics software. Next, participants were instructed to complete a 10-question Perceived Stress Scale as outlined by Cohen, Kamarck, & Mermelstein (1994). This information was collected because past studies on mindfulness found that scores in this scale decreased with an increase in Mindfulness Based Stress Reduction practice. Additionally, they completed a Mindfulness Awareness Attention Scale (Brown & Ryan, 2003). This information was collected because they found mindfulness practitioners differentiated themselves on this scale, which they attributed to enhanced self-awareness. Finally, participant's blood pressure and heart rate were recorded. Chen et al. (2013) found a significant decrease in systolic blood pressure and a non-significant decrease in heart rate that results from increased, consistent mindfulness practice. All this information (i.e. Perceived Stress Scale scores, Mindfulness Awareness Attention Scale scores, blood pressure, and heart rate) was collected at the beginning of meeting, resulting in three data collections in total.

Pretraining

Next, participants were given the instructions and pretraining for the working memory task. They were asked to read the following instructions:

> This task requires you to play a game that tests memory. In this game, you will be briefly presented with a location, sound, or image that will serve as your primary target. You goal is to remember your primary target, and then decide whether or not a second target location, sound, or image matches your primary target. Each trial will begin with a white cross at the center of a black screen. Please rest your eyes on the cross until your primary target appears either on the screen, or from the speakers. A short delay will follow the presentation of your primary target.
>
> After the second target appears, two buttons labeled “Match” and “Non-Match” will appear on the screen. If the second target matches your primary target, click the button “Match” using the mouse. If not, click the “Non-Match” button. Please only click one time at the answer choice so that the computer can accurately detect your response. Correct responses will result in a yellow background, and incorrect responses will result in a red background. Then, three boxes will appear labeled “Identity,” “Sound,” and “Location.” Please respond to the box that matches the type of trial that just occurred. Finally, the white cross will appear again to signal a new trial.
>
> Now, there are many ways in which a class of objects could be said to match. In this game, there is a single rule for what constitutes a match for each different set of possible targets. Kaleidoscope image targets must match location, regardless of pattern; sound byte targets must match sound, regardless of the location from which it plays; and Snowflake image targets must match in identity, or pattern, regardless of location.

Participants then performed six trials in the experimenter’s presence that were identical to the trials seen in the test phase. The trials included one match and one non-match from each of the three stimulus types. The participants were given the opportunity to ask clarifying questions regarding the task. When participants stated that they understood the training phase, they were guided through a PowerPoint presentation on all three trial types, what changes they should be attending to, and what changes to ignore (e.g. in location trials they should attend to the locations of the three kaleidoscope images and ignore the pattern they display). Participants were then allowed to ask remaining questions. The experimenter then started the program and left the room until it finished.

Working Memory Test

Testing consisted of 144 trials, with 48 trials of each stimulus type presented in a pseudo-randomized order such that no trial type was presented more than three times consecutively, and an equal number of match and non-match trials were presented. Each trial consisted of the presentation of two stimuli for 500 ms, separated by a blank interval that varied in length. On location and identity trials the blank interval lasted 200 ms, while auditory trials were increased to 600 ms. These changes were made to increase the performance of participants in location and identity trials and decrease performance on auditory trials. The match and no match response buttons appeared immediately following the presentation of the second stimulus and disappeared after five seconds**.** If a button was pressed, both would immediately disappear. The screen would then fill with a solid color for two seconds to provide feedback to the participant; correct responses resulted in a yellow screen, whereas incorrect responses resulted in a red screen. Following this visual feedback, the “location,” “identity,” and “sound” trial type check buttons would appear and disappeared after ten seconds. A correct response to the trial type buttons would result in their immediate disappearance, whereas an incorrect response would lead to the two incorrect trial types disappearing prompting the participant to click the correct trial type. The Trials were separated by a two-second intertrial interval during which a white cross was displayed at the center of the screen. During Identity trials the sample and target stimuli were always presented in different locations. On match trials, the sample snowflake matched the target snowflake in appearance exactly, and the correct response was to the “match” button. On non-match trials, the sample snowflake was distinctly different in appearance, and the correct response was to the "non-match" button. In Spatial trials the sample and target stimuli were different, albeit similar, images. In the sample, three different kaleidoscope images were presented in rapid succession, 500 ms apart, in different locations across the visual map, and then one more kaleidoscope image would appear as the target stimuli. On match trials, the target image would be in one of the three previous sample locations, and the correct response was to the "match" button. On non-match trials, the target image would not be in one of the three previous locations, and the correct response was to the "non-match" button. In Audible trials the sample and target stimuli were presented from different headphone speakers. On match trials, the target auditory stimuli would match the sample exactly in tone and pitch. On non-match trials, the target auditory stimuli would differ from sample in either tone, or pitch. These differences in spatial or object existed to facilitate a participant's attendance to only the relevant dimension.

Meditation Training

There were two groups taking part in the experiment. The control group was subjected to two weeks of learning about mindfulness meditation training and its benefits through reading academic journals. However, they were specifically instructed to not meditate at any point during the two-week duration of the experiment. The experimental group was trained in mindfulness-based stress reduction therapy once a week for two weeks and asked to practice daily. Both groups underwent an initial baseline working memory test and a comparison test following two weeks of meditation training.

The meditation training for the experimental group consisted of a two-week curriculum based on the well documented Mindfulness Based Stress Reduction Therapy program, developed by Jon Kabat Zinn. We trained and tested participants nine at a time and asked them to track their meditation progress using a meditation journal. Participants recorded their daily meditation experience by identifying the type of meditation they underwent, the duration, and a few words about their experience that day. The control group read two academic articles (one each week) discussing what mindfulness meditation is and the benefits of mindfulness meditation such as decreased stress anxiety, and increased self-control (willpower). These sessions were conducted in the same room as the working memory test for both groups. Session 1 lasted two hours for both groups and an hour for both groups in Session 2 and Session 3.

Session 1.

Following the conclusion of the working memory task, the control group read the article/workbook called “Mindfulness Based Stress Reduction” which functions as an academic approach to teaching mindfulness meditation. To assess the participants level of involvement with the article they were asked to fill out a simple reading comprehension worksheet asking them to list some potential benefits of mindfulness meditation. The instructor answered any questions they had but will explicitly tell them to not meditate for the duration of the experiment. This part is key and was made explicitly clear.

Following the conclusion of the working memory task, participants in the experimental group were taught about the origins of Mindfulness in Buddhist and Hindu religion and its evolution into evidence-based therapies like Mindfulness Based Cognitive Therapy and Mindfulness Based Stress Reduction Therapy. Then, they learned about the benefits of a consistent mindfulness practice like decreased stress, anxiety, depression, and anger (Samuelson, Carmody, Kabat-Zinn, & Bratt, 2007). Next, participants were guided through a week one overview including meditations and basic mindfulness concepts. Next, they are taught how to position themselves properly before meditation in a seated position. They are instructed to keep an upright posture with both feet firmly planted on the ground and their hands either folded on their lap or placed in front of them in a relaxed manner. Finally, the experimenter directs them to begin playing an audio only guided meditation by Dr. Saki F. Santorelli titled *Sitting Meditation: Awareness of the Breath* that runs for 15 minutes. Following the meditation, they are given a week 1 objectives worksheet that outlines what they learned and their assignments outside of the classroom. For homework, these participants were asked to practice the breathing meditation, either in silence or with the guided meditation, daily. Then, they are asked to track their daily meditation activity using a meditation journal.

Session 2.

In week two, the control group read a practice review regarding the evidence-based benefits of mindfulness-based therapies, including MBSR. This article is by Davis & Hayes (2011) and it explores the clinical relevance of mindfulness meditation in psychotherapy and in general health both physical and mental. To assess the participants level of involvement with the article they were asked to fill out a simple reading comprehension worksheet asking them to list some potential benefits of mindfulness meditation. They were again reminded that they cannot meditate for the duration of the experiment.

In week two, the test group was trained to expand their field of awareness through various cognitive techniques incorporated into the regular practices they already learned. Participants were introduced to two new concepts: expanding their field of awareness to the rest of their body and expanding their field of awareness to their own thoughts. These concepts are important for the growth of body awareness and emotion regulation (Hölzel, Britta K., et al., 2011). The first audio-only guided meditation is by Florence Meleo Meyer titled *Sitting*

Meditation: Expanding Awareness that played for 20 minutes. For the breathing meditation, Participants began the meditation similar to their week one training, but now they were asked to 'label' their thoughts to institute the growth of emotion regulation. Participants were directed to attune to their thoughts. In doing so, the participant was instructed to draw attention to their thoughts and simply observe them until they dissipate. Then, they underwent a sitting body scan Dr. Saki Santorelli titled *Sitting Meditation: Awareness of Breath and Body,* which played for 20 minutes. In this meditation, participants were asked to use this expanded field of awareness to attune to their whole body. Finally, participants are asked to practice the *Sitting Meditation: Awareness of Breath and Body* two times outside of the experiment, either in silence or with the guided meditation, and the *Sitting Meditation: Expanding Awareness* five times outside of class, either in silence or with the guided meditation. They were asked to track their daily meditation activity using their meditation journal.

Session 3.

Following the abbreviated two-week MBSR training both control and test groups were brought in to do a follow up comparison working memory test. Both pretraining and training were carried out in the same manner as before. Finally, a subjective ratings and intervention efficacy test was administered to the participants following the conclusion of the working memory task in which the experimental group was asked to rate their experience with the meditation on a scale of 1-10. With 1 indicating they felt the meditations were not effective at all, and 10 indicating the meditation were maximally effective (Chen, Yu, et al., 2013). The control group is asked how much they felt they learned about mindfulness meditation from the articles.

Results

The participant pool was comprised of 58 participants (27 experimental and 31 control) that completed the full 2 weeks of the experiment. This was out of an original 90 participants that started the 1st session of the experiment, making for a 64.4% overall retention rate (participants that came to all three sessions). The age of participants ranged from 18-27 with the vast majority of participants ranging from ages 18-22. All participants were students at Texas Christian University.

Blood Pressure, Heart Rate, and Surveys

Systolic blood pressure (SBP) trended down in the experimental group from a peak of 117 mm Hg ($SD = 12.88$) in Session 1 to 115 mm Hg in Session 3, whereas, in the control group average SBP peaked at 114 mm Hg in Session 2 and went down to 110 mm HG in Session 3 (see Fig. 1). An analysis of variance conducted on SBP with group (experimental and control) as a between-subjects factor and session (1, 2, and 3) as a within-subjects factor revealed a significant Group by Session interaction, $F(2, 112) = 4.04$, $p = 0.02$, but no main effects, Fs < 1.08, ps > 0.33. A Tukey's Honestly Significant Differences (HSD) post-hoc test was conducted on the interaction but revealed no comparisons reached significance, ps > 0.14. Mean arterial pressure (MAP) is often used to measure the average pressure on the arterial walls of an individual and was measured using the participants blood pressure. While not measured by Chen et al. (2013), MAP accounts for resistance, flow, and pressure within the arteries, and is an accurate measurement of the average arterial pressure throughout the body at any given time. Both groups trended down as across the three sessions with the experimental group decreasing from 88 mm Hg to 83 mm Hg and the control group decreasing from 85 mm Hg to 84 mm Hg (Fig. 2). However, there was no significant main effects, Fs < 2.86, ps > 0.06, between these two groups.

Heart Rate (HR) leveled out in the experimental group but showed an increase, when compared across groups, over each session in the control group with 74 BPM in Session 1, 79 BPM in Session 2, and 78 BPM in Session 3 (Fig. 3). Statistics were not run on HR. The experimental group potentially could show more resistance to excitatory physiological stimuli, like completing a working memory task, than the experimental. These results could potentially support the findings of Chen et al. (2013) with a larger participant pool, and a longer meditation period. However, it appears that the 2-week mindfulness intervention utilized in this study was not sufficient enough to elicit any significant physiological in the experimental participants over the control.

Answers on the Perceived Stress Scale (PSS) were scored as outlined by Cohen, Kamarck, & Mermelstein (1994), and summed together. Average PSS scores for the experimental group decreased over the three sessions from 19.45 in Session 1 to 18.72 in Session 3 (Fig. 5). The control's PSS scores stagnated with an average of 19.37 in Session 1 and 19.66 in Session 2 (Fig. 5). Both groups saw a dip in their PSS scores in Session 2 as the control fell to 17.31 and the experimental fell to 16.62 (Fig. 5). As a result, both groups experienced a significant change, $F(1, 56) = 14.46$, $p < 0.01$, over time but there were no other significant main effects, $Fs < 0.85$, $ps > 0.43$. Next, the Mindfulness Attention Awareness Scale (MAAS) was scored according to the parameters set by Brown & Ryan (2003) and averaged for each participant. This means that a score of 0 correlates to less mindfulness and a score near 6 correlates to greater mindfulness. The control group's MAAS scores slightly increased over each session from 3.72 (Session 1) to 3.77 (Session 3), and the experimental group's scores were nearly identical in Session 1 and 3, around 3.78, but saw a spike in Session 2 of 3.86 (Fig. 4). These slight changes in MAAS scores were non-significant when compared between groups and across interactions, Fs < 0.19, ps > 0.81. It was hypothesized that the SBP, MAP, and PSS scores would all decrease as the MAAS scores increased for participants in the experimental group, more so than in the control group. Taken together these results indicate that the two-week mindfulness intervention was not sufficient to alter the subjective reporting of the experimental group over the control. The decrease in MAP and PSS scores both indicate that the mindfulness intervention could be effective given a longer meditation intervention with a larger participant pool, but the lack of a significant decrease in SBP, or rise in MAAS scores, mean the reverse could be true as well.

Working Memory

The overall performance between the first test session and the second test session did yield a significant difference between the groups (Fig. 6). A repeated measures analysis of variance (ANOVA) yielded interesting results as the experimental group that received the mindfulness meditation performed significantly worse, $F(1, 56) = 11.11$, $p < 0.01$, than the control group overall. It also revealed a significant effect over time, $F(1,56) = 22.58$, $p < 0.01$, for both groups from test session 1 to test session 2. This was to be expected considering they would be more practiced with the task the second time around. When the test sessions were separated out there was still a difference in performance on the working memory task between groups with the experimental group performing worse in both Test Session 1 and significantly worse in Test Session 2, $F(1,56) = 11.11$, $p < 0.01$ (Fig. 7). A Tukey HSD Post-Hoc analysis of Trial Type by group interaction, encompassing all three trial types (auditory, location, and spatial), revealed that participants in the experimental group were performing significantly lower in exclusively the auditory task, $p = 0.01$, but the comparison between experimental and control groups in identity and location trials did not reach significance, ps > 0.87 (Fig. 7). Another

Tukey HSD Post-Hoc analysis of the Trial Type by Group by Time demonstrated similar results with the auditory trial type reaching significant group difference in both Test Session 1 (p = 0.01) and Test Session 2 ($p < 0.01$), but the between group difference in both Test Session 1 and Test Session 2 for identity and location did not reach levels of significance ($p > 0.10$) (Fig. 7, Table 1). Which is notable because the experimental group was not exposed to the mindfulness intervention until after their first working memory task was complete. This reveals that there may be some difference in the auditory capabilities between groups. By the second session both groups performed at the same level in both location (95.0%) and identity (87.5% for experimental and 89.7% for control) trial types (Fig. 7). The fact that the location trial performance seemed to level out around 95% suggests a possible ceiling effect, meaning that specific trial was now too easy for the participants and they had very little room to improve.

When comparing performance between groups on match and nonmatch trials over both test sessions, both groups performs better on match trials indicating a potential bias. After the first test session, the difference between percentage correct on match and nonmatch trials for the experimental group is 7.7% and for the control it is 6.0% (Fig. 8). This indicates that the experimental group is slightly more biased to respond to the match button than the control group. After the second test session, both groups are hovering around a difference of 5.4% with the control group still performing better overall (Fig. 8). Comparing this bias across trial types, both groups reduce their bias in audible trials, but the percent difference between test sessions for the control group is 15.0% and the experimental is only 3.0% (Fig. 9). This trend towards reducing their bias is interrupted in Identity trials where the control group sees a slight increase in the difference between performance on match and nonmatch trials, while the experimental group continues to reduce the difference (Fig. 9). On location trials the experimental group shows a nonmatch tendency during both sessions, but in the second test session the nonmatch bias is less pronounced (Fig. 9). The experimental group has a slight nonmatch bias in the first session, but this data is probably due to the ceiling effect mentioned earlier because both groups are performing very well on location trials in both test sessions. However, there was no analysis was compiled to measure differences in bias between groups, so no inferences can be made as to the significance of these results. These results are inconclusive as to whether meditation can alter an individual's tendency to select bias.

Discussion

This study had three primary goals. We attempted to replicate findings of improved working memory performance and decreased SBP following regular meditation practice. Additionally, the working memory task used in the experiment allowed for the analysis of benefits of meditation to one or more separate domains of working memory. The data from this experiment does not support claims of enhanced cognitive performance or improved health measures. The experimental and control groups in this study did not differ in any meaningful way in overall working memory, working memory subsystems, or their physiological measures. In fact, the only reliable difference between groups occurred before the manipulation was even introduced and persisted across sessions. The control group outperformed the experimental group in terms of percent correct on location and identity trial types, but especially the auditory trials (Fig. 7). There were many differences in the current procedure from previously published work, which likely explain the different outcomes.

Quach et. al (2016), who demonstrated working memory capacity and performance could be enhanced by meditation. Quach et al. (2016) had participants meet twice a week for 4 weeks with each meditation session lasting 45 minutes at a time for a total of 6 hours of meditation. Mrazek et al. (2013) utilized a two-week meditation intervention, but they had participants meet with the researchers eight separate times for 45-minute meditation sessions, making for 6 total hours of meditation over two weeks. The 2-week meditation intervention of this experiment required participants to meet once a week and they were instructed to complete 105-120 minutes of independent meditation per week for a total of 3.5-4 hours of total meditation. The success of the Quach et al. and Mrazek et al. studies may have been due to a stronger meditation intervention that was effective with longer, in-person meditation sessions, or an MBSR course lasting 4 weeks.

With respect to analyzing which sensory subsystems connected to working memory could experience the greatest growth in their performance following a mindfulness meditation intervention. Unfortunately, being unable to elevate working memory performance with meditation rendered this second goal mute. The only finding of an effect on one subsystem, was that mindfulness meditation hindered improvement of auditory working memory (Fig. 8, Table 1). The ACC has been shown to aid processing of sensory information for visual and auditory working memory tasks (Klingberg and Roland, 1997). Also, it has been elucidated that the ACC is integral in guiding shifts in attention from one stimulus to another (Bush, Luu, and Posner, 2000). Mindfulness meditation's ability to elicit ACC activation should be enough to improve, or at least stabilize, working memory performance to the point that the experimental group is expected to have equal, or greater, performance across all three sensory modalities when compared to the control group. The significant decrease in auditory performance in the experimental group combined with relatively similar performance and increases in both identity and spatial trials suggests that our meditation intervention was insufficient (or activated a different pathway) to activate the ACC neural pathway. This conclusion is supported by the lack of significance between groups found in the SBP, MAP, MAAS, PSS, and HR, further suggestions the ineffectiveness of the two-week mindfulness meditation intervention used in this study. It is also very likely that there is something outside of the meditation intervention that impacted the auditory working memory performance of the experimental group.

One possible explanation for the overall poor performance in auditory tasks, when compared to identity and location could be the Colavita Effect (Fig. 7). The Colavita effect asserts that humans have a natural visual dominance over other sensory modalities (e.g. auditory) and contends that “humans have a strong tendency to actively (i.e., endogenously) attend to visual events as a means of compensating for the poor alerting properties of the visual system” (Sinnet, Spence, and Soto-Faraco, 2007, p. 673). This sort of visual dominance could explain the participants poor auditory performance, because they are presented with essentially two visual working memory tasks and one auditory task. Posner and Nissen (1974) posit that switching between these modalities has a cost associated with it, and the cost of switching from visual to auditory modalities has a larger cost associated with it. Thus, auditory performance suffers as a result of this switch. This concept could explain the overall poor performance in the auditory working memory tasks as participants were often tasked with switching from a more visual modality to an exclusively auditory modality. However, this does not explain why the experimental group failed to improve as much as the control group.

Prior to this study, the impact of mindfulness meditation on MAP had not been explored. The downward trend in MAP over two weeks of mindfulness meditation could warrant further study. For others researching meditation, tracking MAP could be a good way to establish the effectiveness of their meditation. For example, MAP has been used for years to track the blood pressure and effect of treatment for hypertensive and patients experiencing septic shock

(Magder, 2014). Using MAP, the results predict the potential for mindfulness meditation to reduce MAP, which could be applied to hypertensive patients.

Finally, the impact of Mindfulness Meditation in reducing bias was not of expressed interest in this study. However, the mechanisms that allow for the possibility of improved working memory performance from consistent mindfulness meditation practice also have the potential to reduce bias. The ACC is not only implicated in higher cognitive functions like working memory, but also has been implicated in selective attention mediation. This describes one's ability to exert intentional control over attention to focus on a stimulus (Kock, Vels, and Vorlander, 2011). By activating the ACC, meditation has the potential to boost selective attention. This increased selective attention should allow an individual to more accurately discern changes in stimuli, thus decreasing any response bias to simply select "match" on each trial. Unfortunately, the results of this experiment are inconclusive with regards to meditation's ability to alter selective attention, or natural biases.

Future studies should examine a wider participant pool that may be more motivated to partake as the retention rate over two weeks for the whole experiment was 66%. This could also be due to the large commitment of the study. Also, future studies should look at expanding the meditation course to 4 weeks, because it takes time to truly practice meditation before the changes in attention and awareness can take hold. Other researchers like Kirk, Brown, and Downar (2015) and Quach et. al (2016) have utilized a 4-week MBSR course with positive results.

In conclusion, the impact of mindfulness meditation on specific working memory sensory modalities was unable to be evaluated due to an ineffective mindfulness meditation intervention. The lack of significance between groups in HR, MAP, SBP, MAAS scores, and PSS scores indicated the ineffectiveness of the mindfulness meditation. Additionally, there was a significant difference between groups before the intervention could even be introduced, which indicates that there was a variable that was unaccounted for when testing each group. Finally, the most significant finding in this study is that a two-week mindfulness meditation intervention with at least 220 minutes of meditation, not in-person, is not enough to bring about a physiological, subjective, or working memory performance change.

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Appendix

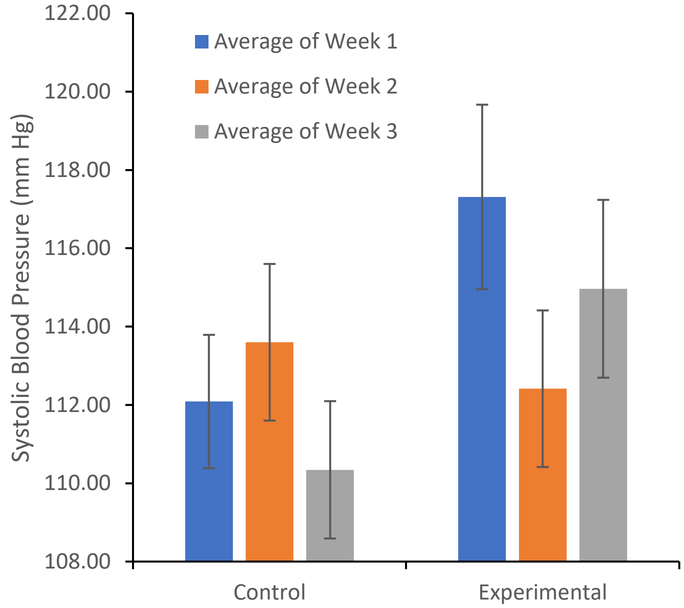

Figure 1: Average SBP Across Groups. Measure of average systolic blood pressure (SBP) in both experimental and control groups in 3 different sessions over 2 weeks with one week between each session. Using a repeated measures ANOVA, there was a significant difference found across Time (Session 1,2,3) and Group (Control, Experimental) interaction, $F(2, 112) = 4.04$, $p = 0.02$. There was no other significant main effect, $Fs < 1.08$, $ps > 0.33$.

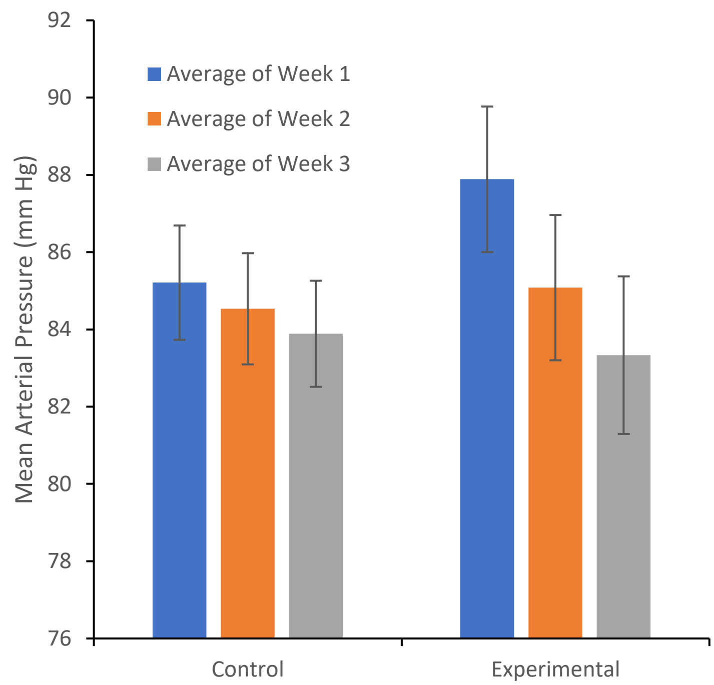

Figure 2: Average MAP Across Groups. Measurement of average mean arterial pressure (MAP) in both experimental and control groups in 3 different sessions over 2 weeks with one week between each session. Using a repeated measures ANOVA, there was no main effect found across groups or time, Fs < 2.86, ps > 0.06.

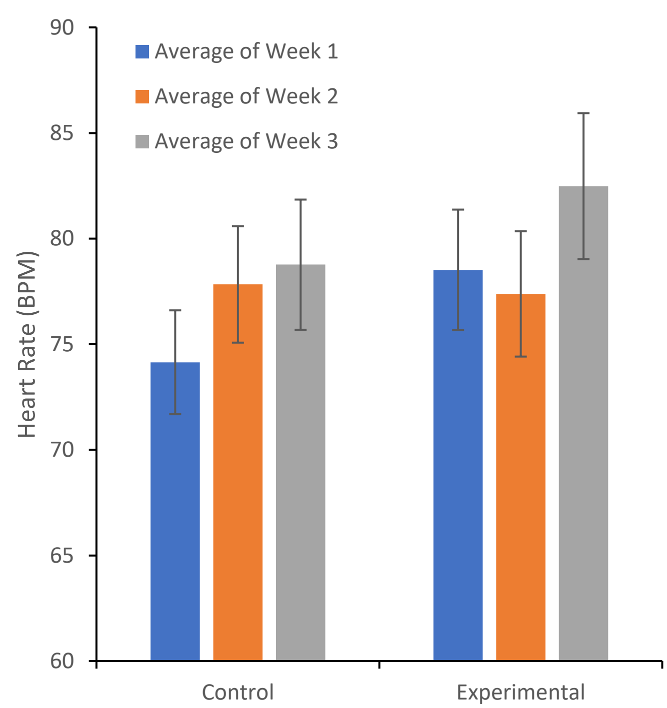

Figure 3: Average HR Across Groups. Measurement of average heart rate (HR) in both experimental and control groups in 3 different sessions over 2 weeks with one week between each session. No analysis was performed for this data set.

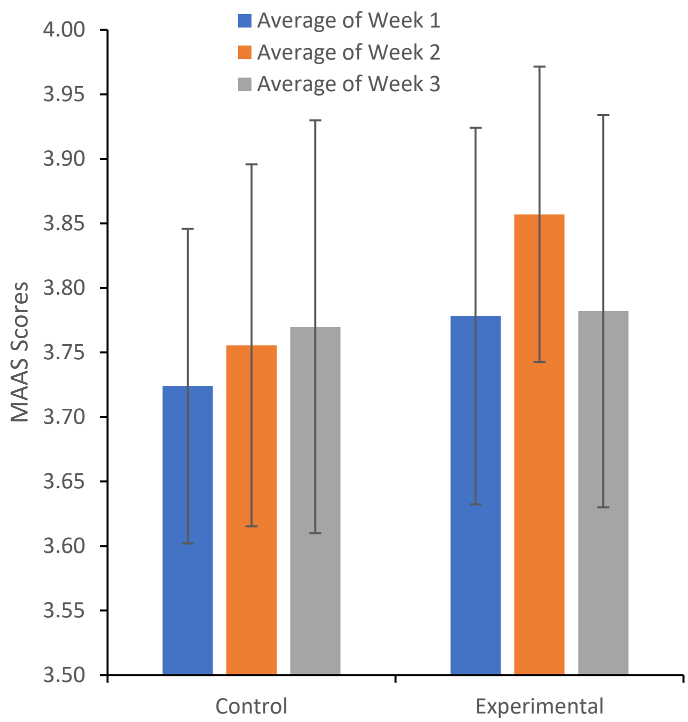

Figure 4: Average MAAS Scores Across Groups. Measurement of average Mindfulness Attention Awareness Survey (MAAS) scores in both experimental and control groups in 3 different sessions over 2 weeks with one week between each session. Using a repeated measures ANOVA, there was no main effect, or effect by interaction found, Fs < 0.19, ps > 0.81.

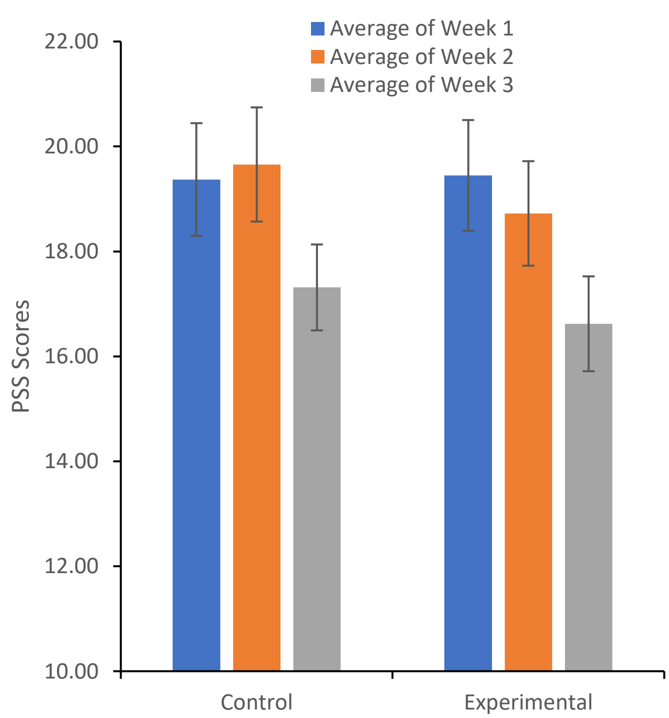

Figure 5: Average PSS Scores Across Groups. Measurement of average Percieved Stress Scale (PSS) scores in both experimental and control groups in 3 different sessions over 2 weeks with one week between each session. Using a repeated measures

ANOVA, there was no significance found across groups, by interaction, Fs < 0.85, ps > 0.43. However, there was significance found across time (Session 1,2,3) for both groups, F(1, 56) = 14.46, p < 0.01.

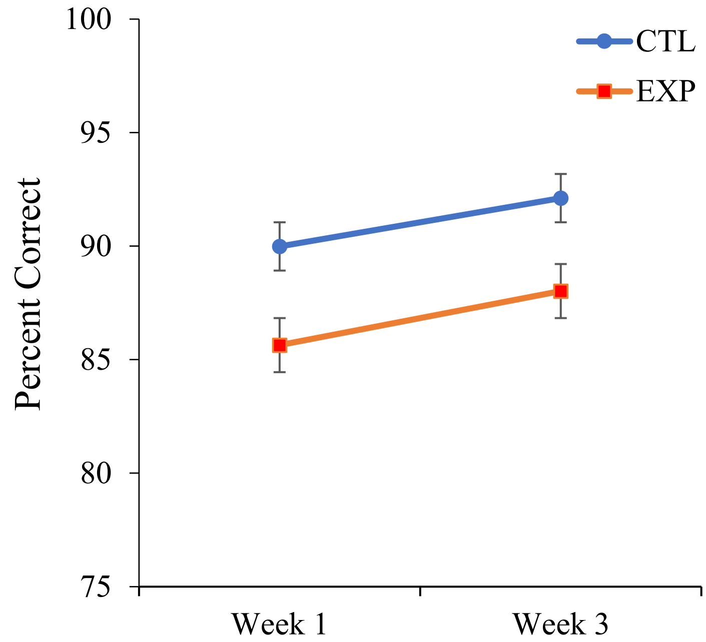

Figure 6: Overall Performance Across Groups. Overall performance on the working memory task in control (CTL) and experimental (EXP) groups from Test 1 to Test 2 with 2 weeks between test sessions. Using a repeated measures ANOVA, there was significance between groups (Control and Experimental), F(1, 56) = 11.11, p < 0.01. Also, there is a significant effect across time, F(1,56) = 22.58, p < 0.01.

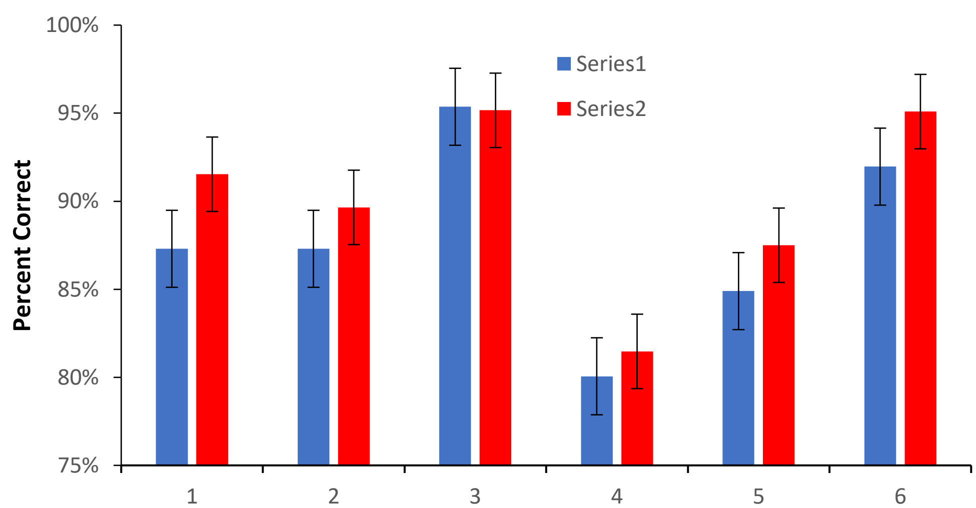

Figure 7: Percent Correct Across All Sensory Modality Trial Types. Percent correct on the working memory task across all three trial types (audible, identity, and location) in both experimental and control groups for both test sessions taken two weeks apart. Series 1 is Test session 1, and Series 2 is Test session 2. Using a repeated measure ANOVA, there was a significant difference found across groups, F(1,56) = 11.11, p < 0.01, a significant main effect of Trial Type, F(2,112) = 23.68, p < 0.01, a main effect of time, F(1,56) = 22.58, an effect by Trial Type and Group interaction, F(2,112) = 4.19, p = 0.02, and an effect by Trial Type, Group, and Time interaction, F(2,112) = 4.95, p = 0.01.

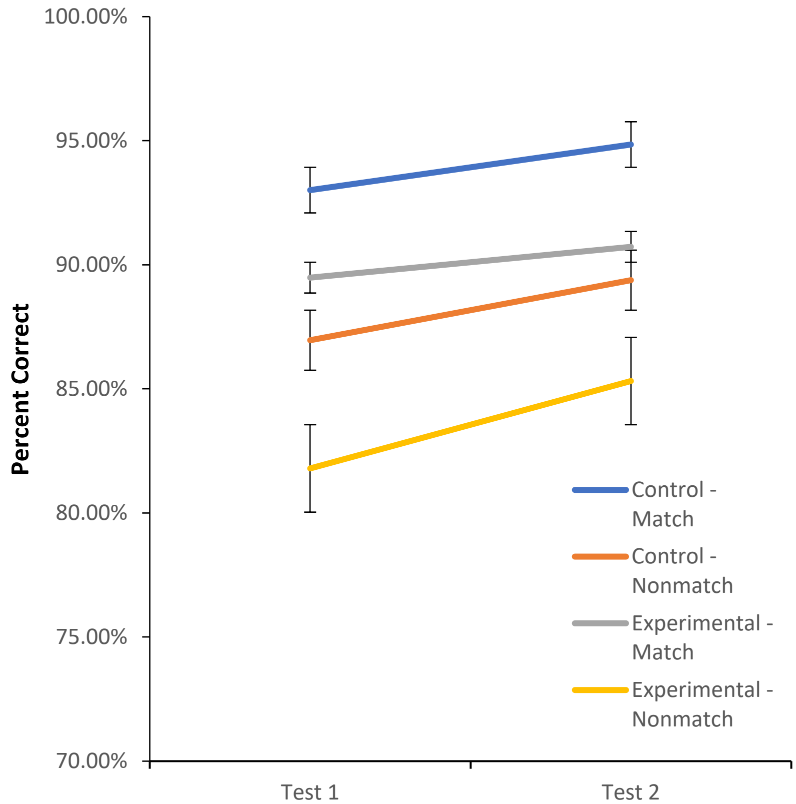

Figure 8: Percent Correct on Match and Non-Match Trials. Percent correct on the working memory task in match and non-match trials for both test sessions taken two weeks apart. No analysis was performed on this data set.

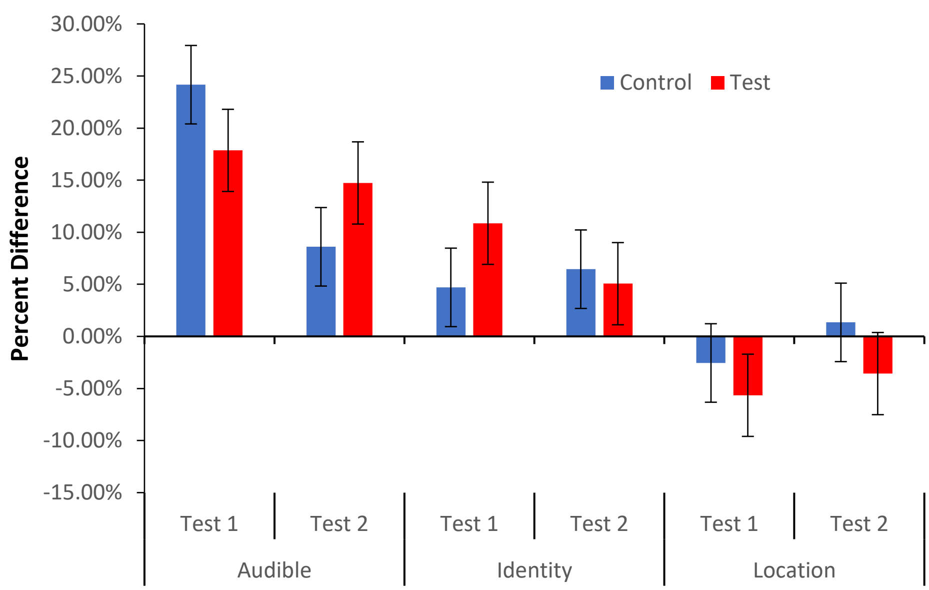

Figure 9: Percent Difference between Match and Nonmatch trials. Percent difference in performance on Match and Nonmatch across all trial types for both test sessions taken two weeks apart. No analysis was performed on this data set.

	B/T Group Difference During Test 1	B/w Group Difference During Test 2
Audible	$p = 0.014$	$p = 0.00040$
Identity	$p = 0.19$	$p = 0.24$
Location	$p = 0.096$	$p = 0.82$

Table 1: Analysis of Trial Type by Group by Time interaction. Results from a Tukey's HSD Post Hoc analysis of group differences between the experimental and control groups across each trial type separated by test sessions. Analyzing the Trial Type by Group by Time interaction illustrated in Figure 7. Each test session occurred two weeks apart from each other. Significant p values are highlighted in red.