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Effects of Mindfulness Meditation on Selective, Sustained Attention, Brain Neural Oscillations, and Short-term Memory

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EFFECTS OF MINDFULNESS MEDITATION ON SELECTIVE, SUSTAINED ATTENTION, BRAIN NEURAL OSCILLATIONS, AND SHORT-TERM MEMORY

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Abstract

The following extended literature review and research proposal study started initially as a complete research proposal but, due to the challenges COVID-19 has brought, it has become a stand-alone piece of work without data collection. The goal is to synthesize a broad range of literature and previous research on mindfulness meditation and its effects on attention, memory, and brain activity and thus, offering a new perspective and a proposed research path on this subject.

This proposed research study, besides previous studies, indicates that mindfulness meditation is expected to improve and enhance selective and sustained attention, which results in better attentional performance and shows potential brain activity changes, especially in gamma frequency and a significant enhancement of short-term memory capacity. The specific mechanism and process through which mindfulness affects attention, brain activity, and short-term memory capacity have yet to be identified and understood. This study contributes to our understanding of mindfulness meditation's effects on the whole brain activity by focusing on how it can enhance our short-term memory, improve our sustained and selective attention, and how it affects brain activity when it comes to cortical processing. There remains much to be done to fully grasp and comprehend how we can utilize mindfulness meditation to enrich and maintain cognition in young adulthood and beyond.

Keywords: mindfulness, meditation, brain, attention, cognition

Dedication/Appreciation

This thesis would not have been possible without the guidance and encouragement of my faculty mentors Dr. Cary Savage and Dr. Jacquelyn Omelian. Through this whole process, they provided insightful feedback, and they would never fail to give encouraging words when I needed them the most. More than anything, thank you, Dr. Savage and Omelian, for the patience and flexibility during these uncertain pandemic times that brought many challenges.

To the UNL Psychology department, my advisors Tamy Burnett and Christina Fielder, my mom and dad that support me from another country, my brother and my friends and mentors, thank you, and I appreciate all of your incredible support!

To all the women and Latinxs in STEM,

It all begins with an idea. No matter what it is, work and develop it. Aspire to leave your footprint in the world so you can inspire others to do the same.

Introduction

Meditation is an ancient practice as it was originally practiced in ancient cultures such as Buddhism (Kirmayer, 2015). Regardless of its traditional roots, practitioners have adapted it into a more secular, evidence-based meditation form. Generally, some of the improvements in cognition from meditation overall have been observed in a wide variety of cognitive functions such as memory, attention, verbal fluency, and overall cognitive flexibility (Marciniak et al., 2014). The effects of meditation work through mechanisms that are likely multifaceted and might influence different brain regions via diverse pathways. (Jindal et al., 2013).

Further, there is a myriad of different types of meditation, and the one this study focuses on is mindfulness meditation. In simple terms, meditation is a practice, and through this, one can develop different qualities one can focus on developing, including mindfulness; mindfulness involves focusing one’s attention on experiences associated with the present. Mindfulness meditation has been used as a lens for observation, research, and intervention; this is seen in therapies such as Mindfulness-Based Stress Reduction (MBSR) and Therapy and Mindfulness-Based Cognitive Therapy (MBCT). Changes in neuronal excitability and the proliferation of neurotrophic growth factors are multiple things that change as a result of practicing mindful meditation (Loprinzi & Frith, 2018). Mindfulness meditation has proven to be a powerful tool as it has shown the potential to help improve cognitive abilities. In light of these, we are interested in studying whether mindfulness meditation is something worth implementing in our daily lives. More importantly, it is worth exploring in college students a specific group that might benefit substantially from improved cognitive function, specifically attention.

In one study, researchers compared Hatha Yoga's effects to mindfulness meditation effects on working memory in adolescents. The results suggested that mindfulness meditation was more effective in improving working memory than Hatha Yoga (Quach et al., 2016). This indicates that the type of practice also plays a role in the effects of assimilating meditation and mindfulness. Mindful meditation was selected as the primary variable in this present study because students might be more prone to utilizing mindful meditation as an efficient attention enhancing tool than other forms of meditation. This is assumed as guided mindful meditations are now widely available in technological devices like phones, tablets, and laptops. Students will be able to utilize them more easily than other types of meditation. In another study, the effects of meditation on African American college students' academic performance were assessed. The study addressed the impact of mindfulness meditation on academic performance during a full semester, and the research found that the semester GPAs of the meditation group were significantly higher than the nonmeditation group (Hall, 1999). Similarly, the overall cumulative GPAs of both groups were also higher in the meditation group. This information is important to consider in broader implications such as educational systems on all levels as it might be beneficial for students and their academic performance.

As for mindfulness meditation’s specific effects on attention, a study in 2009 evaluated mindfulness meditation practice and levels of mindfulness on attentional performance. This study hypothesized that mindfulness meditation practice was positively related to increased attentional performance and better cognitive flexibility. Interestingly, they found that mindfulness meditation is positively correlated with processing speed, reasonable attentional and inhibitory control, good coordination of speed, and performance accuracy (Moore & Malinowski, 2009). The authors suggested that mindfulness meditation develops mindfulness quality, which would be an effective therapeutic measure and thus, this might prove to be a new method to improve cognitive abilities. The current study will focus specifically on the effects of mindfulness meditation training on attention. Considering the previous studies, it is essential to study further mindful meditation and its impact on selective, sustained attention and visual scanning speed in college students. Visual scanning is part of our visual processing; this is how we can focus on certain things and stay organized when performing tasks (Dundon et al., 2015). As for selective and sustained attention, both are pivotal for our cognition. Selective attention is the process in which we can focus on a specific object in the environment for a certain interval of time and allows us to filter out unimportant stimulus (Hanania & Smith, 2010). On the other hand, sustained attention maintains response persistence, enabling continuous effort and focusing over extended periods (Ko et al., 2017). In light of the types of attention being studied, college students are a key population to focus on; it is important to start implementing this tool that improves overall attentional cognition during the early adult year.

Furthermore, little is known about the neural processes by which meditation works, and there is a need for more thorough research when it comes to the underlying neurobiology and structural changes. Generally, long-term anatomical changes have been evaluated with structural magnetic resonance (MR) imaging, which provides accurate spatial resolution. There is evidence that meditation can lead to structural changes in the brain, like the increased cortical thickness of the insula, the prefrontal cortex, and the anterior cingulate cortex (ACC) (Lazar et al., 2005; Santarnecchi et al., 2014; Engen et al., 2017). Nonetheless, the temporal resolution for such observable changes in brain regions is constrained. In contrast, imaging modalities such as magnetoencephalography (MEG) and electroencephalography (EEG) provide an outstanding temporal resolution that can pick up on short-term oscillatory changes during meditation while surrendering spatial resolution.

Certain EEG studies have stated changes in spectral band frequencies during meditation. For instance, a 2009 study where researchers analyzed EEG changes during nondirective meditation found a significant increase in theta power in the meditation condition when averaged across all brain regions (Lagopoulos et al., 2009). Nondirective meditation uses methods where practitioners do not actively pursue a particular experience or state of mind (Xu et al., 2014). The human theta rhythm is an oscillatory pattern described by oscillations in the 3.5–7 Hz range (Lee et al., 2018). In humans, increased cortical theta oscillations have been pronounced during a variety of learning tasks. Tasks such as recognition (Hsieh et al., 2011), virtual spatial navigation tasks (Watrous et al., 2011), and recall (Sederberg et al., 2003) were associated with increased theta oscillations.

Additionally, it was found that theta waves were significantly greater in the frontal and temporal–central regions as contrasted to the posterior region. Further, there was also a significant increase in alpha power in the meditation condition compared to the rest condition; it was found that alpha waves were significantly greater in the posterior region as compared to the frontal region (Lagopoulos et al., 2009). More in-depth, theta oscillations during wakefulness occur in frontal midline regions, such as the prefrontal cortex (Asada et al., 1999) and anterior cingulate cortex (ACC; Onton et al., 2005). This frontal midline theta (Fm theta) activity appears to be linked with concentrative attentional engagement, and there is also evidence for increased alpha power and synchrony in frontal, parietal, and occipital regions during meditation (Travis, 2001; Cahn et al., 2013). Although there has been comprehensive research on theta and alpha waves, their mechanisms are still not completely understood, and there is not a lot of updated research to argue otherwise.

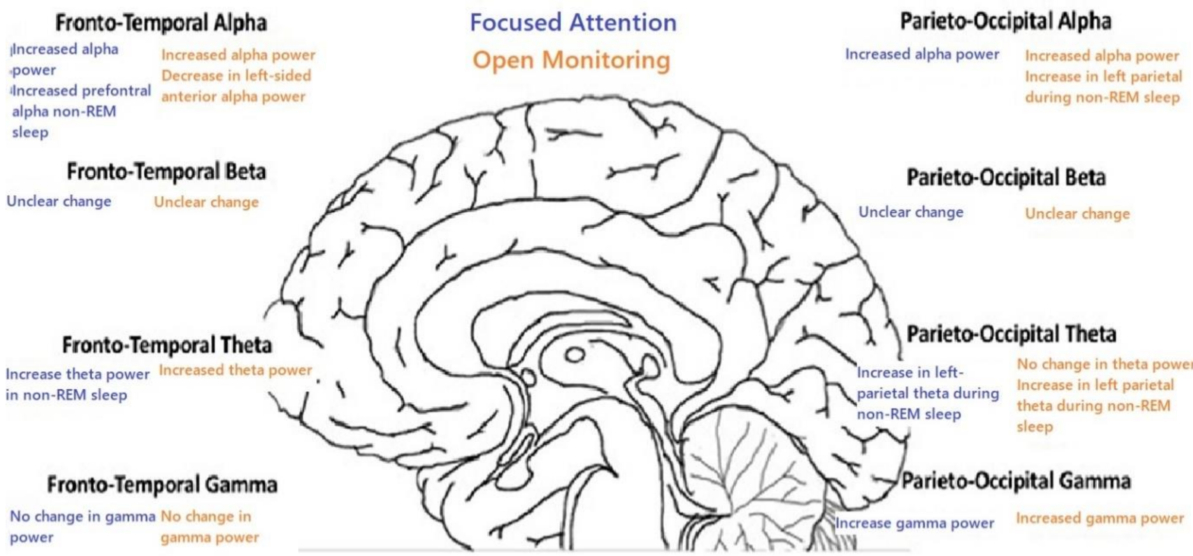

Figure 1. EEG oscillation contrasts between focused attention and open monitoring meditation practices (Lee et al., 2018).

According to more complete and recent studies, gamma power is positively correlated with participant's meditation experience. This study will focus on how mindfulness meditation practice is correlated to changes in the EEG gamma frequency range that are ordinary to a variety of meditation practices (Braboszcz et al., 2017). Gamma brainwaves are the highest frequency brain waves as they oscillate approximately between 30 to 100 Hz. Synchronized gamma oscillatory activity happens throughout the cortex, and they are thought to be associated with peak levels in concentration and cognitive functioning (Bartos et al., 2007). Additionally, gamma and theta work together to recruit neurons that stimulate local cell column activity (Lisman et al., 2013). According to Braboszcz et al., 2017, meditation might be able to enhance gamma wave production. As a result, this research study will focus upon the EEG reading in gamma frequency more than alpha or theta power readings as there is more to research on this particular brain wave and its behavior when it comes to mindfulness meditation. Generally, understanding how meditation regulates these neural oscillations, specifically EEG gamma frequency, may help explain the relationship between neural oscillations and cognitive processes.

Moreover, attention is a critical cognitive processing skill, and it is intertwined with another vital mental skill: memory. Past research has argued that attention and working memory are both keys to learning new information as memory has a limited capacity. Thus attention determines what will be encoded, and as a result, one cannot operate without the other (Oberauer, 2019). Working memory is a very diverse and versatile system, linking short-term memory and attention (Cowan, 2016). A study in 1996 examined the regions of activation in the brain connected to working memory tasks, and the researchers attempted to recognize the specific areas in the brain in charge of the executive function of working memory. They found foci of activation in the anterior cingulate gyrus (Salmon et al., 1996). This finding was further supported by Holzel et al. (2011), as they also found strong activation of the ACC when participants were undergoing working memory tasks. Considering the findings, 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.

While studies appear to have shown a relationship between mindfulness meditation and improved working memory, the length of the mindfulness meditation intervention involved has been varying, alternating from one to eight weeks; thus, measuring working memory can become inconsistent across studies. Shorter intervention periods are generally preferred to longer ones due to their ease, accessibility, and convenience (Bergen-Cico et al., 2013). According to the study by Youngs et al. (2020), a single, short mindfulness meditation intervention can improve performance on a short-term memory task. In this study, participants were asked to perform a face memory task. Once completed the task, participants were randomly allocated to one of three groups, audiobook (11 men and 19 women) and meditation (12 men and 18 women). These groups listened to an 8-minute audio recording with instructions to follow along as best as possible and notify the researcher when it finished. The meditation group was given a breathing exercise, while those in the audiobook group listened to a neutral recording. The results showed that those who listened to an audiobook or filled their time however they wanted failed to show an improvement. The authors argued that mindfulness meditation could improve (relevant) short-term memory capacity by freeing up cognitive resources to work on the task at hand (Youngs et al., 2020).

Overall, the proposed study will assess if mindful meditation can improve and enhance cognitive aspects such as selective and sustained attention and short-term memory, and how it affects brain oscillations in UNL college students. Additionally, the difference in time duration of mindful meditation will also be measured in this study, as the time duration of meditation has shown in the presented literature review to be key and an important role in how the effectiveness of this mindful practice.

Methodology

Participants

This study will include 80 total participants, who will be divided into either a 3,5 or 10-minute meditation or a no meditation control group. Participants will be male and female college students ranging from 19-23 years old recruited through UNL's SONA research participant program.

Mindful meditation

The Headspace (Headspace, Inc.) phone application will be used as the guide for mindful meditation. The app consists of different meditations with different time durations. The subjects will be played on the 'Basics' playlist, which is meant for beginners. This meditation has a 3-time duration: 3 min, 5 min, and 10 min. They are given by the same mindfulness coach and consist of the same content. This application was chosen for this experiment as its popularity has risen; many people are now using it due to its easy availability and well-explained meditation sessions. Considering this generation's knowledge and handiness with technology, this would be an interesting and practical way to introduce mindfulness meditation to college students as something they can use in their daily lives.

Measuring Selective and sustained attention and visual scanning

The D2 test is an internally consistent and valid measure of visual scanning accuracy and overall speed (Bates, M. E., Lemay E. P Jr. 2004). The D2 test measures processing speed, rule compliance, and quality of performance in response to the discrimination of similar visual stimuli. It allows estimation of attention and concentration performance. It consists of 14 lines, each comprised of 47 characters, for a total of 658 items (see Figure 1). The subject must scan each line and cross out all the “d’s” with two dashes. The participant is allowed 20 seconds per line.

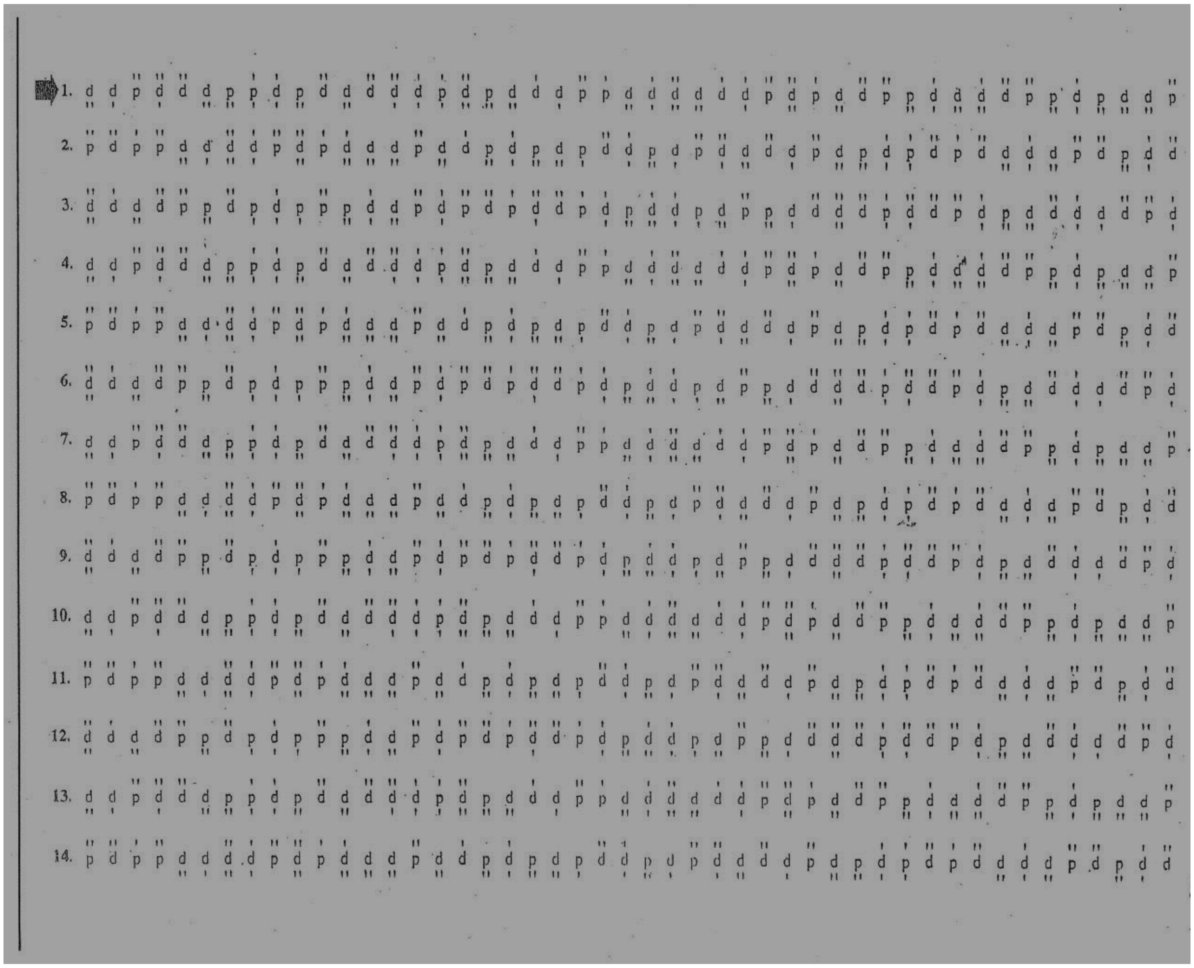

Figure 2. D2 test. Cognitive test that measures selective and sustained attention, as well as visual scanning function.

When analyzing the D2 test results, we calculate the number of total items (targets + distractors) processed: it is the rate noted R. Next, it is necessary to calculate the number of errors noted F; here, we take into account the number of omissions (forgotten targets) denoted F1 but also the number of additions (surrounded distractors) denoted F2.

$$F = F1 + F2$$

Then calculate the error percentage: F% = (F1 + F2) x 100 / R

Measuring brain oscillations

This study will be following Braboszcz, C., Cahn, B. R., Levy, J., Fernandez, M., and Delorme, A., 2017 protocol to measure brain oscillations. Briefly, there will be the use of external electrodes; the right and left mastoid electrodes will be recorded as well as a vertical and horizontal electrooculogram (EOG) by placing two periocular electrodes above and below the left eye and then two electrodes at both the left and right outer canthi. We will make sure the participants are seating in a comfortable position where they can also hold still. As mentioned in Braboszcz et al., 2017, the experimental room will be soundproof, and to confirm the good quality of EEG signal, participants will be asked to wash their hair before joining the recording session and, for non-scalp electrodes, their skin will be carefully cleaned using an alcohol solution.

Measuring short-term memory

Short-term memory will be measured with a face memory task presented on a desktop computer adapted from previous work by Youngs et al., 2020. Following the protocol from the mentioned 2020 study, on each trial, a single facial photograph will be initially displayed onscreen, which the participant will be instructed to select with the mouse. Next, this face and a second face will be seen onscreen, and the participant will have to choose the new face. If the correct response is selected, the process will continue, and each time a new face will be introduced until a maximum of 30 face images are displayed. Trials will terminate when an incorrect response is given, and the number of correct responses will be recorded. Additionally, after every response, the new display of faces will be randomized concerning spatial position onscreen, which means that the participants will not use location information to make their decisions.

Procedure

Each student participant will be directed to a research room in the CB3 lab and will read and sign a consent form, with the investigator present to answer any questions. Then, we will take the participant's general information: major, age, year, handedness, and general level of stress they are feeling at that moment. We will allow the participants 3 minutes to relax and freshen up by allowing them to go to the restroom, drink water or simply sit down for the time given (if they are feeling very or moderately stressed, this will allow for better data baseline). Once the resting time and all of the forms are filled, we will explain an overview of the experiment. We will explain the D2 test and the face memory task, and then give notice and explain the meditation audio that will play later on. The participant will have electrodes placed, and the electrodes will be set for the experiment's entirety. Next, they will be instructed to take the two tasks in a private room with the lead researcher present. Right after both tests, we will ask them to listen to the audio, which will play the mindful meditation recording from the Headspace application. Participants will listen to the 3, 5, or 10-minute meditation (each participant will only participate in one condition) and then retake the D2 and face memory task test after the meditation is done. There will be 1-minute rest in between tests/tasks. The control group will only be given a three-minute rest and the 1-minute rest in between tasks, and then continue again to the second round of the attention and memory tasks. Overall, we plan to re-test all groups with D2 and the face memory task a second time, following meditation or rest. During the whole experiment, they will be sitting down as comfortably as possible, and in case of feeling sleepy or lethargic, they are allowed to get up and stretch in the resting times given briefly. The experiment's time duration will vary with each participant, depending on survey and consent form time lapse and what time modality the subject is randomly assigned.

Statistical Analysis

A mixed-model ANOVA will be done, which requires a minimum of two categorical independent variables, and at least one of these variables has to vary between-units, and at least one of them has to vary within-units. Since there are four groups, each will be tested twice. We hypothesize that all the meditation groups in 3, 5, and 10-minute conditions will have a significant change between the first and second tests (D2 test and face-memory task). As well, there will be no significant main effect for none and meditation group (Group x Condition interaction) as they are randomly assigned, and groups are changing differentially between the first and second tests. After establishing a significant interaction, we will do a post-hoc test (i.e., Dunn’s Multiple Comparison Test) in order to test the simple effects.

As for the brain oscillations, following a similar analysis in the Braboszcz et al. (2017) study, EEG data will be first referenced to the right mastoid and downsampled from around 1024 Hz to 256 Hz. There will be a rejection of low-frequency segments to remove signals related to subjects’ head and body movements. Rejection of high-frequency activity will help reject data portions of muscular activity. The data will be checked visually for any potential remaining artifacts. Analysis of variance (ANOVA) will also be used to assess the EEG spectral power's significance across groups and conditions using mixed-design ANOVA when comparing between and within-subjects’ variables in the same model. As suggested in the 2017 study, for a more adequate localization of the effects over electrodes, post-hoc tests were performed within EEG.

Hypothesized results

When individuals are in a mindful state, their attention to external phenomena is so broad and diverse that they adjust to a relatively large number of stimuli, materials, and cues in their surrounding environment (Dane, 2011). In light of this and previous studies, when it comes to selective and sustained attention, we predict that the participants will do significantly better in the D2 test after the meditation than without it. The control group will not have a significant difference in attentional improvement. Additionally, participants in the 10-min group are expected to do relatively better than those in the 3-min and 5-min group. Consistent with previous research, all the groups that practice mindfulness will show increased cognitive performance; in this case, shown in selective and sustained attention. Interestingly, the aspect of different time intervals (3, 5, and 10 min) will be a new observation and may suggest if we should focus further research on how long a meditation should take to use it to its full potential to improve cognitive abilities.

As for the brain oscillations, we predict that there will be significant gamma frequency changes in the before and after meditation in EEG readings when undergoing the instructed tasks. According to previous findings, this mindfulness meditation practice will most likely correlate with changes in the EEG gamma frequency range common in meditation practices (Braboszcz et al., 2017). We predict that the meditation group will show higher gamma amplitude than control subjects; in other words, the median gamma power in the three meditators groups (3, 5, and 10min) could be higher than the gamma power in most of the control subjects. In addition, all participants are expected to have around the same EEG gamma power before a meditation period or rest period; the gamma frequency is expected to show changes for the meditation groups, mostly only during and after the meditation. When the participants are taking the test the second time, due to the change in tasks, there will probably be an increased gamma wave oscillation and power. Gamma is modulated by sensory input and internal mechanisms such as attention and working memory (Jia et al., 2011), and so, due to the nature of the D2 test and the face memory task, there will be an observable prominent gamma rhythm that indicates a signature of engaged networks.

Finally, short-term memory is expected to be enhanced in all the meditator groups but not in the control group. More specifically, we predict that there will be a significant improvement in visual short-term memory for the 10-minute group, more than the 5 min or 3 min group, building upon earlier research showing that 10-minute mindfulness meditation sessions have led to reduce significantly psychological stress enhance attentional control (Norris et al., 2018). As for the control group, a predicted result will be that, due to having two cognitive tasks that might lead to fatigue, the participants might worsen the second round of tasks. The overall anticipated trend will be an increase in short-term memory capacity as the meditation session's time duration is greater, and the control group might experience a decline in short-term memory capacity.

Discussion

This research aims to explore the effects of mindful meditation on selective and sustained attention, as well as changes in brain gamma wave oscillations and short-term memory capacity in UNL college students. As for attention, the practice of mindfulness is expected to improve and enhance selective and sustained attention, which results in better attentional performance. Time is expected to play a role in how much improvement the participants will have; a longer duration of mindfulness will likely have a greater positive effect on sustained attention, and the participants will do significantly better on the D2 test than shorter time period or no meditation groups. Results differing from these expectations would suggest that other factors are important to consider when applying meditation to students, and it might depend on significant levels of stress during the day.

Mindfulness meditation is also anticipated to affect brain activity, mainly gamma frequency. The median gamma power in the three meditators groups (3, 5, and 10min) is expected to be higher than the gamma power in most control subjects. One possible explanation for this case is that gamma coordination has shown to have spiking activity, which in part is central to cortical processing (Jia et al., 2011), and because of the type of cognitive tasks that the participants are undertaking, they will likely use cortical areas that will yield in elevated gamma power. As the overall effects of meditation on gamma power, high-frequency activity is expected to be associated with meditation. Although gamma power could have a potential role in meditation, it is still less clear whether it may just simple by-product of network activity or has a substantial significant functional role.

Lastly, in addition to previous research, this study indicates that mindfulness meditation will enhance short-term memory capacity. A possible increase in performance on the face memory task due to mindfulness meditation extends previous research indicating that this type of meditation practice can improve a variety of elements in our short-term memory (Lykins et al., 2012). A possible explanation as to why mindfulness meditation might improve short-term capacity is that there is some part of short-term memory that is busy and inhibited by task-irrelevant information in the course of task performance. Mindfulness meditation could then potentially improve relevant short-term memory capacity by minimizing this information, which might allow focused cognitive resources to be put to use on the task at hand. Nevertheless, it is essential also to acknowledge that the specific mechanism and process through which mindfulness affects short-term memory capacity has yet to be identified and understood. In light of this, this study is contributing to our understanding of mindfulness meditation's effects on whole-brain activity by shedding light on how it can enhance our short-term memory, improve our sustained and selective attention, and how it affects brain activity when it comes to cortical processing.

All in all, the mechanism of how meditation affects our cognition and physiology is still yet to be unraveled and studied. There remains much to be done to fully understand how we can use mindfulness meditation to improve and maintain cognition in young adulthood and beyond. It really could be the key to also implementing it as a daily practice in the education system, so students are able to learn and process information in a better way.

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