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The Effects of White Noise Exposure on Cognition: An Examination of the Impacts of White Noise Presentation on Recall and Cognitive Load

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THE EFFECTS OF WHITE NOISE EXPOSURE ON COGNITION: AN EXAMINATION OF THE IMPACTS OF WHITE NOISE PRESENTATION ON RECALL AND COGNITIVE LOAD

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I dedicate this thesis to my parents, Leslie and David Witty. Thank you, mom for being an ever-present source of inspiration, support, and encouragement to me. Thank you, dad for always motivating me to push forward no matter the circumstances over the years. I also dedicate this thesis to my dog, Lucy for her companionship and company throughout the entire writing process.

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White noise has historically been utilized as a tool for offsetting or masking sounds that may be perceived as disruptive, most commonly during the sleeping process. More recently, literature has begun to explore the possibility of using white noise as a tool to suppress these potentially distracting sounds within the area of cognitive processing. Present literature suggests that white noise may be a useful tool for masking noises like these in order to improve cognitive performance, especially for those individuals who may possess inattentive symptoms. However, this research has largely been conducted using tasks that involve working memory or visual processing and often only featuring participants with inattentive symptoms. More research is needed to determine the effects of white noise on intentional cognitive processing in more realistic, academic scenarios that measure recall of information.

This study tested the effects of white noise presentation on recall and cognitive load. Specifically, this study determined whether studying with white noise resulted in increased performance on a reading recall test compared to studying with ambient sound (whatever sounds were naturally occurring in the environment of the participant), whether performance level differences in the white noise and ambient sound conditions were related to inattentive symptoms, and whether perceived differences in cognitive load levels were related to white noise exposure.

Introduction

Complex cognitive tasks include demands such as effortful perception, attention, reasoning, and decision making. A wide variety of factors influence our performance on cognitive tasks, including many internal variables and environmental factors. Internal variables such as mood, stress level, and self-efficacy have all been shown to impact cognitive performance (Scrimin et al., 2014; Seeman et al., 1996). In a study examining the relationship between sleep levels and cognitive performance, Wilckens et al. (2018) demonstrated that higher levels of sleep quality were associated with higher levels of working memory, task switching, recall, and verbal ability and fluency. Environmental factors including drug ingestion, caffeine consumption, room temperature, and lighting levels have all been shown to affect cognitive performance as well (Weiss & Laties, 1962; Xiong et al., 2018). Another major environmental factor that can influence cognition and will be the main variable discussed in this paper, is sound (Söderlund & Sikström, 2008).

Interestingly, the impact of sound on cognitive performance varies widely depending on the type of sound and characteristics of the participants. One example of this can be found when examining the orienting response, an automatic shift in attention upon presentation of a novel stimulus (Sokolov, 1963). In relation to sound, this theory suggests that responses to sound vary depending on how unexpected as well as how loud a noise may be. Graham and Clifton (1966) found that escalating heart rates were associated with stimuli that may be described as unpleasant or sudden, whereas more calming stimuli that occur when a situation entails focus and attention were associated with de-escalating heart rates (Graham & Clifton, 1966). Knez and Hygge (2002) showed that achievement on cognitive tasks was negatively impacted when participants were exposed to irrelevant speech (i.e., spoken conversation unrelated to the cognitive tasks within the study). Similarly, Anderson et al. (2010) found music to have a negative effect on reading comprehension in junior high school students when they completed the reading comprehension subtest of the Gates-MacGinitie Reading Tests while listening to comprising *Billboard Magazine's* (2006) top hit singles; however, other research has suggested that listening to certain types of music can actually enhance cognitive performance as Shellenberg et al. (2007) found after playing an up-tempo Mozart piece for children before they completed a subtest on an IQ test. Thus, different types of sound may impact performance on complex cognitive tasks differently. Complex cognitive tasks are defined as "complex tasks [that] require a greater effort and/ or attention, such as multiple/dual tasks (e.g., complex motor coordination, working memory tasks)" (Bradley and Higenbottam, 2003, as cited by Taylor et al., 2016, p. 2).

One type of sound that is still in need of additional research to determine its impact on cognitive performance is white noise. Most commonly seen by the public in the form of a "white noise machine," the company "The Sharper Image" markets their white noise machines to "block out background sounds to reduce your stress and help you fall asleep or concentrate in a busy, noisy office" (White Noise Machine, n.d.). This claim suggests that white noise can be used as a tool to inhibit potentially distracting background noises so that individuals are able to sleep or focus better. This idea then leads to the possibility that white noise could have the potential to be used as a tool by many to particularly improve concentration and cognitive performance through the repression of attention-diverting stimuli.

What is White Noise?

White noise can be described as a sound with equal intensity expanding over a broad frequency range (Kuo, 2018). Characteristically, white noise is a constant, static sound that mimics traditional background noises similar to that of a box fan, sound machine, or air conditioner. White noise is most commonly used as a tool for masking noise-related distractions or disruptions. For example, decades of research have found that white noise can be beneficial for sleep induction and maintenance. White noise may be useful in helping restless infants fall asleep (Spencer et al., 1990) and increases the noise-level tolerance for sleeping subjects exposed to ICU noise (Stanchina et al., 2004). Similarly, Farokhnezhad (2016) found that white noise increased and maintained sleep in one hospital's coronary care unit. These results suggest that white noise can serve as a tool to off-set or "dull" peak noises that may be considered distracting or disrupting to the sleeping process.

The previously described experiments are based on the concept of stochastic resonance. Stochastic resonance is "the statistical phenomenon in which stimuli presented under a detection threshold can be detected in the presence of noise" (Sikström & Söderlund, 2007, p. 1047). In other words, when stimuli are presented at a noise level that is below our stochastic resonance threshold, a criterion that can be modified by the presence of a broadband sound such as white noise, we tend to not notice those noises. As highlighted above, Stanchina et al. (2004) found that white noise acted as a tool that increased the noise-level tolerance for sleeping infants, therefore modifying the infants' threshold for distracting or disruptive noises.

Research suggests the benefits of white noise with sleep patterns; however, we question its effects on cognitive functioning while one is awake. According to Söderlund & Sikström (2008), we learn best when our brains are in a moderate state of arousal. Could the addition of white noise encourage brain arousal and benefit individuals during times of intentional cognitive processing during learning?

White Noise and Cognition

Lately, more research is emerging that is exploring the possibility of utilizing white noise as a tool to improve concentration and cognitive performance in addition to using it as an aid to promote sleep. This recent investigative shift is supported by a theory known as the moderate brain arousal model (MBA) model (Helps et al., 2014). This model posits that moderate levels of neural noise (i.e., adequate levels of dopamine production over time) are required for well-functioning signal transmission within the brain. When an individual has appropriate levels of neural noise per the MBA model, they process stimuli in the form of external/environmental noises more effectively (Helps et al., 2014). As Othman et al. (2019) explains, when an external noise is presented at a low level (i.e., too quiet/soft to an individual), it lacks the energy needed to enhance sensory system identification of information (Faisal et al., 2008); but when noise is presented at a high level (i.e., too loud/harsh to an individual), it can mask the targeted signal for which the participant may be listening (Kujala et al., 2009). Therefore, for the effective identification of external stimuli to take place, it largely depends on the level and type of noise, as well as the threshold to noise that an individual has based on their internal neural noise levels (static frequency versus variable frequency, high volume levels versus low volume levels, etc.).

Another factor that can impact cognitive performance is cognitive load. Cognitive load is best described as a complex structure that signifies the levels of mental effort that an individual experiences while focusing on a specific task (Paas & van Merriënboer, 1994a). Cognitive load, in relation to learning and understanding new concepts and information, can be either useful or harmful depending on the form that it takes (Pass et al., 2003a). Pass et al. (2003a) explains the three different categories of cognitive load. The first category, intrinsic cognitive load, is directly related to the "element interactivity" because "demands on working memory capacity imposed by element interactivity are intrinsic to the material being learned" (Pass et al., 2003a, p. 1). Levels of intrinsic cognitive load are likely to vary depending on the nature of the content and/or materials that an individual is using during the learning process (Pass et al., 2003a). The next category, germane cognitive load, is generally viewed as positive and typically occurs when individuals encounter information and instruction useful to schema construction and automation. Germane cognitive load is understood to aid in the learning experience as it is often useful in effective schema construction during the learning process. The final category, extraneous cognitive load, however, can be harmful to the learning process. Extraneous cognitive load often occurs in situations that feature distracting environments or ineffective/confusing directions and often impedes the learning process as it is likely to yield ineffective schema construction.

Keeping the stochastic resonance phenomenon and the MBA model in mind, perhaps there is potential for white noise to impact perceived levels of cognitive load. Because distracting environments (e.g., disruptive noises) can be linked back to producing extraneous cognitive load and disrupting the learning process, perhaps white noise could be utilized as a tool to eliminate this source of extraneous cognitive load by working to increase the stochastic resonance threshold of an individual and therefore eliminating potentially distracting noises from the learning environment.

White Noise and Inattentive Symptoms

Effective encoding and cognitive processing may also depend on certain characteristics of the individual learner, particularly the possession of inattentive symptoms (Sikström & Söderlund, 2007). Individuals with inattentive symptoms are highly sensitive to environmental stimulation, and therefore, their threshold to noise may be lower per the stochastic resonance phenomenon (Sikström & Söderlund, 2007). This sensitivity would make those with inattentive symptoms more susceptible to unanticipated distracting noises in a learning environment such as irrelevant speech from surrounding peers, cell phone pings, pencil tapping, etc. (Sikström & Söderlund, 2007). Keeping the MBA model in mind (i.e., that moderate levels of neural noise are still useful for efficient brain signal-transmission), white noise may be a beneficial tool for learners struggling with inattentive symptoms by repressing outside distractive or disruptive noises through the use of constant, static sound. According to Söderlund & Sikström (2008), the MBA model predicts that children with inattentive symptomology necessitate higher noise levels for optimum cognitive performance compared to their typically developing peers. White noise could act as a tool to increase the stochastic resonance threshold in individuals with inattentive symptoms by working as a tool to inhibit irrelevant background noise, therefore making them less susceptible to potentially distracting sounds.

In a study of school-age participants with and without ADHD diagnoses (inattentive type, hyperactive type, and/ or combined type) performing visual tasks in white noise and silent conditions, the performance of children with ADHD improved when white noise was added (Baijot et al., 2016). In fact, when children with ADHD were exposed to white noise during the task, their performance leveled out to be equal to that of typically developing children (Baijot et al., 2016). However, the performance of those children without ADHD diagnoses did not improve upon the addition of white noise, suggesting that the addition of white noise may be beneficial for some, but not all children (Baijot et al., 2016). Söderlund et al. (2010) exposed children with and without inattentive symptoms to white noise and silent conditions during an episodic verbal free recall test. Inattentive children's episodic recall performance increased when they studied words in a white noise condition, as opposed to in silence, while the performance of those children without inattentive symptoms was worsened in the white noise condition (Söderlund et al., 2010). These results again suggest that the addition of white noise during a complex cognitive task may only positively affect some children, but not all. Another study by Sikström et al. (2010) found that self-rated attentiveness levels were directly related to reaction time on a Go/No-Go task, with performance improving for those with inattentive symptoms when provided with external stimulation in the form of white noise exposure.

White noise exposure has been shown to lead to significant performance improvements on span board and word recall tasks for children who struggle with inattentive symptoms, suggesting white noise as a potential intervention option that is both low-cost as well as easy for teachers, administrators, and parents to access for children who struggle with these inattentive symptoms in an academic setting (Söderlund, et al., 2016). In an examination of the performance of students with ADHD (obtaining a *T*-score of 70+ one at least one of the primary ADHD indices from the Conners 3-P) on reading and writing tasks by Batho et al. (2015), white noise exposure improved reading time and writing fluency. Thus, white noise may be a useful tool in decreasing the susceptibility of those with inattentive symptoms to potentially disruptive sounds and increasing the amount of neural noise in these individuals needed to promote maximum cognitive performance. These conclusions further emphasize the need for continued research on the effects of white noise on cognition as it is important to understand how the presence of inattentive symptoms may impact an individual's response to white noise exposure in an academic setting.

Limitations in Existing Literature and Directions for Future Research

Research on using white noise as a tool for individuals who do not struggle with inattentive symptoms is much less common and in need of further investigation. Sikström & Söderlund (2007) argue that the presence of white noise may not be helpful for typically-functioning adults as they possess the optimal neural noise level according to the MBA model. Helps et al. (2014) found that white noise improved the performance of sub-attentive children (those children who fell in the bottom 20% on an attention scale completed by their teachers) during executive functioning tasks, while it worsened the performance of super-attentive children (those children who fell in the top 20% on an attention scale completed by their teachers). To revisit the MBA model and the stochastic response phenomenon, the performance of super-attentive children in the white noise condition may have worsened because the addition of white noise induced too much arousal, which resulted in poorer functioning signal transmission. However, Helps et al. (2014) also found that white noise did not affect the performance of those students identified as normal-attentive (those children who fell in the mid-range on an attention scale completed by their teachers), suggesting that in a mixed-abilities classroom containing both children with and without inattentive symptoms, white noise still may be a useful studying tool for some, but not necessarily all children.

Othman et al. (2019) sought to address the lack of research on white noise being used as a tool to facilitate cognitive performance in typically functioning adults. Their study featured twenty typically functioning adults who completed an auditory word-based backward recall task during various levels of white noise. The auditory working memory (AWM) performance of typically-functioning adults was significantly enhanced during an auditory word-based recall task. Angwin et al. (2017) demonstrated that white noise exposure led to superior lexical acquisition (i.e., "how to obtain, with computational methods, information about the lexical units of a language from texts in this language" (Lemnitzer & Kunze, 2005, p. 3) when typically-developing young adults completed a visually-based new-word learning task. Similarly, Manan et al. (2012) found that typically-developing young adults accurately recalled more words in the presence of white noise than in silence when completing a word-based recall task.

Although the previously described research is exciting in the sense that it suggests white noise may be a useful tool for both individuals with inattentive symptoms as well as those who are typically-developing/functioning, conclusive evidence on white noise's usefulness remains unknown. The literature supports white noise as a useful tool to improve sleep; however, we know much less about its effects when presented during complex cognitive tasks. As others such as Batho et al. (2015) and Othman et al. (2019) have noted, there is very little existing literature on this particular topic. It is possible that white noise could serve as a tool to help individuals concentrate. However, due to the lack of existing research and the potential of white noise as a tool to improve concentration, further research is needed to clarify white noise's impact on cognitive performance.

The present study aimed to expand the body of research that examines white noise as a tool to improve complex cognition. Although current research heavily relies on white noise's effects during structured cognitive tasks that involve working memory or visual processing, this study examined the application of white noise as a study tool in a more realistic, academic scenario that measures recall of information. As such, this study utilized ambient noise as its control condition rather than silence due to the fact that ambient noise more accurately reflects the sounds naturally occurring in an academic environment more so than complete silence. Next, because existing literature on this topic also largely tends to focus only on individuals with inattentive symptoms, this study featured participants with and without inattentive symptomology, to determine the relationship between inattentiveness and recall performance.

The research questions for the present study were as follows:

1. Do participants perform better on a recall test after reading in the presence of white noise than after reading in the presence of ambient sound?
2. Is there an interaction of inattentiveness and condition, i.e., participants with more inattentive symptoms demonstrate larger performance differences between

white noise and ambient sound conditions, compared to participants with lower levels of self-reported inattentive symptoms?

3. Are levels of perceived cognitive load lower when participants read in presence of white noise than when they read in the presence of ambient sound?

The hypotheses were as follows:

1. Overall participant performance on a recall test will be stronger when participants read in the presence of white noise than when participants read in the presence of ambient sound.
2. Participants with higher levels of self-reported inattentive symptoms will perform significantly better on a recall test after reading in the presence of white noise than after reading in the presence of ambient sound, and this difference will be greater than among participants with lower levels of self-reported inattentive symptoms.
3. Perceived cognitive load will be lower when participants read in the presence of white noise than when they read in the presence of ambient sound.

Method

Participants

Participants consisted of undergraduate psychology students ages 18 and over (N = 30) recruited via an online research participation system that rewards study participation with class credit.

Materials

Science Texts

Participants read two science texts previously utilized with college students by Karpicke and Blunt (2011) during each condition. Each text is approximately 260 words in length and was sourced from the reading comprehension section of a test-prep book for the Test of English as a Foreign Language (TOEFL; Rogers, 2001 as cited by Karpicke & Blunt, 2011). Participants were assigned both texts in random order and read one text in an ambient sound condition and one text in the white noise exposure condition (the order of conditions was also randomly assigned). Seven minutes were allotted for the participant to read each text (Bae et al., 2019). Participants were not able to click forward from the passage until the full seven minutes had passed. Once the participant's seven minutes were up for each passage, they were instructed to click forward immediately to the next screen.

NASA Task Load Index (NASA-TLX)

The NASA Task Load Index (NASA-TLX) was used as the measure of cognitive load. The NASA-TLX assesses the following six domains to determine the amount of mental effort being designated toward a particular task: mental demand, physical demand, temporal demand, performance, effort, and frustration. The NASA-TLX measures each of these domains on scales of 0-100 with 5-point increments to assess the mental effort exerted during a specific task. Hart (2006) surveyed 550 studies in which this index was utilized and found it to be simple to use as well as a reliable tool for detecting experimental manipulations with a test/retest correlation of .83 (Hart & Staveland, 1988).

Filler Task

A video filler task was administered to participants upon completion of each passage and the NASA-TLX in both conditions. The task consisted of participants watching a brief nature video and answering a single multiple-choice question about the content of the video once it finished verifying attention to the content. The purpose of this task was to increase the amount of time between reading the passage and completing the recall test. The task also served as a preventative tool to decrease the likelihood that the participant may be rehearsing information from the passages mentally before the recall test was administered.

Recall Test

Each text was also accompanied by a brief recall test (11 multiple choice and 4 short answer/inference questions) to assess how accurately participants were able to recall information from the texts. These recall tests were administered after completion of the video filler task and NASA-TLX survey for each respective passage. Both recall tests were composed of 15 questions each (with possible scores ranging from 0-15) featuring a mix of multiple choice and open-ended/inference items, making for a total of 30 questions overall assessing recall from the content of each of the science texts. 11 multiple choice items were used as this particular format of question is widely used in the university setting. However, because multiple choice questions pose the risk of a participant accurately guessing an answer when they may not truly know the answer to the question being posed, 4 open-ended inferential questions were also used to assess participants' ability to apply information learned from the reading passages. Each of the questions on the test were sourced from the same, widely referenced Karpicke and Blunt (2011) study. An additional quality check question was added to each of the two reading recall tests to check for attention to the test (i.e., "Please select 'strongly agree'"). Cronbach's alpha was used to determine the internal consistency of the two recall tests. Reliability ranged from .70-.74, indicating moderate reliability. Each question was scored as a "1" for correct and a "zero" for incorrect. The participant's total score from both multiple choice and inference questions on each represents their overall recall performance in each condition.

Adult ADHD Self-Report Scale (ARS)

Part A of the Adult ADHD Self-Report Scale (ARS) was used to measure participants' inattentive symptoms. The Part A is a nine-question subset of questions from the full ARS that specifically measures inattentive symptoms only (Part B accounts for hyperactive/ impulsive symptomology) used to identify potential ADHD cases. Adler et al. (2006) found that the internal consistency of the scale was high for rater administered and patient-administered versions (Cronbach's alpha 0.88, 0.89, respectively).

Headphones

Participants were required to wear their own headphones or earbuds during the white noise condition reading passage portion of this study.

Audio Files

One audio file was utilized for the purposes of this study. The audio file utilized played white noise at the level of approximately 75 dB. The white noise audio file played through the participant's headphones when they began reading the science text in the white noise condition and stopped when after the allotted seven minutes for their study session had ended.

Demographics Survey

A demographics survey was administered at the end of the study for data collection purposes on the participants of this study. Gender, age, GPA, ACT score, and race were surveyed as well as if the participant had any existing diagnoses including but not limited to specific learning disorder or ADHD. At the end of the demographics survey, two additional quality-check questions were asked. The first question asked the participant if they played the designated audio file the entire duration that they were instructed to do so. The second question asked the participant if they participated in the study in full seriousness and did not simply click through the measures without reading them. These questions included disclosure statements that their responses would not affect their research participation credits.

Procedure

The study was administered virtually via Zoom videoconferencing software as a result of the COVID-19 pandemic. This study was structured in the form of a within-subjects design. All participants were exposed to the control condition (ambient sound) as well as the experimental condition (white noise). Ensuring all participants have exposure to both control and experimental conditions allowed each participant to create their own "baseline" measurement within the control condition.

After providing informed consent, participants were randomly assigned their order of conditions by the experimenter (white noise followed by ambient sound, or ambient noise followed by white noise). Participants were then assigned two science texts from Karpicke & Blunt (2011) in random order. Each participant completed two seven-minute study periods over two different narrative science texts (one study session within each condition). Participants read the first text in one of the two randomly assigned conditions (white noise or control). Participants read the second text in the opposite condition that they were assigned to for the first text (white noise or control). Participants completed the white noise exposure condition with headphones on and with white noise playing through the headphones at a level of 75 dB. The participants were allotted seven minutes to read and study one of the randomly assigned science texts in each condition. Participants were instructed to utilize the entire seven minutes to study each passage and told that they will be asked some questions about the passages later on.

Immediately following the seven-minute study session for each reading passage, participants completed the NASA-TLX. Following completion of the NASA-TLX after reading each text in their respective conditions, participants then watched a brief nature video as a filler task to prevent rehearsal of the information from the previous passage. Participants were asked a single question after each of these filler task videos to check for attention to the content of the video. Upon completion of all of the previously listed tasks in both the ambient sound and white noise exposure conditions (in randomly assigned order), participants then completed the two recall tests composed of 15 questions each, making for a total of 30 questions overall assessing recall from the content of both science texts. One additional quality check question was added to each recall test to verify participant attention to the test. Following the completion of all the aforementioned tasks, participants then completed Part A of the Adult ADHD Self-Report Scale (ASRS) to self-rate their inattentiveness. Lastly, participants completed a demographics survey.

Analyses

The original analysis plan included using the SPSS general linear model (GLM) to conduct a multivariate analysis of variance with the independent variable (factor) as condition, the covariate as inattentiveness, and the dependent variables as test performance and cognitive load. However, due to the small sample size, there was not sufficient power for multivariate analyses of variance. Instead, dependent samples t-tests were used to test Hypotheses 1 and 3 below, and correlational analyses were used for Hypothesis 2. The original hypotheses were as follows:

1. Overall participant performance on a recall test was expected to be stronger when participants read in the presence of white noise than when participants read in the presence of ambient sound.
2. Participants with higher levels of self-reported inattentive symptoms were expected to perform significantly better on a recall test after reading in the presence of white noise than after reading in the presence of ambient sound, and this difference should be greater than among participants with lower levels of self-reported inattentive symptoms.
3. Perceived cognitive load was expected to be lower when participants read in the presence of white noise than when they read in the presence of ambient sound.

Results

The mean age of subjects was 19.57 years (*SD* = 1.9). Twenty-three percent identified as male, 73% as female, and 3% as non-binary. Seventy-seven percent were Caucasian/White, 17% were Black/African American, 3% were Asian or Pacific Islander, and 3% did not wish to disclose their race. Fifty-seven percent were freshmen, 23% were sophomores, 10% were juniors, and 10% were seniors in college. The mean ACT score of subjects was 23.44 (*SD* = 3.41). The mean GPA of subjects was 3.11 (*SD* = .55). The mean performance score on recall tasks was 11.45 (*SD* = 2.76) with possible scores ranging from 0-15.

To test the hypothesis that overall participant performance on a recall test would be stronger when participants read in the presence of white noise than in the presence of ambient sound, a dependent samples *t*-test was conducted. On each recall test, the possible scores ranged from 0-15. There was no significant difference in recall performance when participants read in the presence of white noise (*M* = 11.43, *SD* = 2.62) compared to when participants read in the presence of ambient sound (*M* = 11.47, *SD* = 2.93), $t(29) = -.059$, $p = .95$, failing to support Hypothesis 1.

Due to the small sample size (n = 30), it was not possible to test Hypothesis 2 (i.e., that participants with higher levels of self-reported inattentive symptoms would perform significantly better on a recall test after reading in the presence of white noise than in the presence of ambient sound, and this difference will be greater than among participants with lower levels of self-reported inattentive symptoms). However, a Pearson correlation was used to explore potential relationships between participants' inattentiveness scores and performance based on condition (white noise or ambient sound). The mean inattentiveness score of participants based on their self-ratings on the ARS was 19.20 (*SD* = 5.51) (possible scores ranging from 0-36). The correlation between inattentiveness and recall performance in the white noise condition was not significant, $r(29) = -.040$, $p = .84$. Similarly, the correlation between inattentiveness score and recall performance in the ambient sound condition was not significant, $r(29) = .003$, $p = .99$. Thus, although Hypothesis 2 could not be tested, correlational results indicate that there was no relationship between recall performance and inattentiveness level, regardless of condition.

A second dependent samples *t*-test was conducted to test the hypothesis that perceived cognitive load would be lower when participants read in the presence of white noise than when they read in the presence of ambient sound (Hypothesis 3). Contrary to the original hypothesis, participants' self-ratings of cognitive load after reading in the presence of white noise ($M = 7.94$, $SD = 2.46$) were significantly higher than their ratings of cognitive load after reading in the presence of ambient sound ($M = 6.88$, $SD = 2.13$), $t(29) = 2.67$, $p = .012$; $d = .49$. The effect size for this analysis ($d = .49$) was found to be just short of Cohen's (1988) standard for a medium effect ($d = .50$). These results indicate that participants experienced lower levels of perceived cognitive load when exposed to ambient sound as opposed to added white noise.

Discussion

This study examined the impact of white noise presentation on recall and cognitive load. More specifically, this study determined whether studying with white noise resulted in improved performance on a reading recall test compared to studying with ambient sound, whether inattentive symptomology and recall performance were related to one another, and lastly, whether perceived differences in cognitive load levels were affected by white noise exposure. Contrary to the original hypotheses, white noise did not appear to benefit participants in a realistic academic scenario in terms of recall performance or cognitive load. Additionally, inattentiveness was not associated with recall performance in either condition (white noise or ambient sound). Interestingly, white noise exposure appeared to have a detrimental effect on cognitive load levels, with participants rating their perceived levels of cognitive load in the white noise condition significantly higher than in the ambient noise condition.

This possibly harmful impact may be explained by the sounds that participants reported most often hearing while studying: 50.0% said ambient sound was most common during studying, 33.3% indicated music, 13.3% reported silence, and 3.3% reported a combination of white noise and music. Based on these responses, participants may have perceived the addition of white noise to be a type of novel stimulus, and therefore, found its addition to their environment while studying to be distracting. Participants feeling distracted by white noise exposure could account for heightened levels of cognitive load in the white noise exposure condition. Additionally, it may also be valuable to consider that for some participants, neither condition may have been representative of their typical studying environments.

Another possible explanation for these results comes from the moderate brain arousal model (MBA) model. As previously discussed, moderate levels of neural noise are necessary for effective signal transmission within the brain (Helps et al., 2014). Notably, past studies have found that individuals with ADHD symptomology possess lower levels of neural noise, and therefore require additional stimulation in order to process stimuli more effectively (Söderlund & Sikström, 2008). Because only 20.0% of participants reported an existing ADHD diagnosis, he addition of white noise to the environment may have generated too much noise per the MBA model and worked to generate extraneous cognitive load rather than to suppress potentially distracting sounds in their environment as intended. In other words, the addition of white noise to non-ADHD participants/participants with lower inattentiveness scores may have produced heightened levels of noise and acted as a distraction rather than as a tool to facilitate moderate levels of neural noise.

There are several limitations that should be considered along with the results of this study. First, these results should be generalized with caution as this study featured a limited sample size of participants. Due to the small sample size of the study, we were unable to run the originally planned analyses to test Hypothesis 2 (i.e., it was impossible to include covariates that may have been useful to consider due to insufficient power).

Additionally, motivation may have been different for participants in the virtual setting rather than in an actual classroom or other in-person setting. Lastly, although participants were told at the beginning of the study to close any tabs or windows on their computer that were unrelated to the study, it is still possible that participants were susceptible to distractions on their computer (emails, notifications, browsing irrelevant websites, etc.) that would have been controlled for if the study was conducted in an in-person setting. However, conducting the study over a virtual platform presented a unique opportunity to explore the potential of white noise exposure as a virtual intervention as students have been primarily learning virtually for the past year as a result of the COVID-19 pandemic. This may be useful to future research as students continue to learn in online formats.

These results are encouraging for students, teachers, and parents alike in the sense that most students do not appear to necessitate white noise exposure in order to perform well academically. Most students in our sample do not currently use white noise while studying; therefore, it is good news that most students do not appear to be missing out on a tool that could benefit their academic performance. However, white noise may still be a useful intervention for some individuals. More research is needed to determine the efficacy of white noise exposure for students with inattentive symptomology.

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