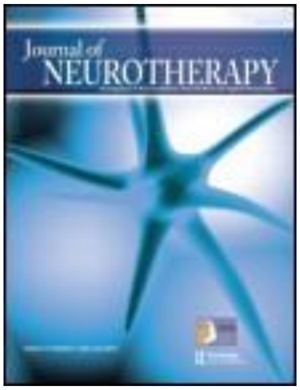

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Working in and with Noise: The Impact of Audio Environment on Attention

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SCIENTIFIC FEATURES

WORKING IN AND WITH NOISE: THE IMPACT OF AUDIO ENVIRONMENT ON ATTENTION

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This study examined the relationship between audio environment and attention. Although background noise has generally been assumed to be distracting, recent research has suggested that the opposite may be true. Attention was assessed in 27 participants using a continuous performance test under three different noise conditions: exposure to ambient noise (the control), pink noise, and a television audio track. Participants' attention was significantly improved in pink noise as compared to the ambient noise, whereas no differences were found between the ambient and television conditions. These findings suggest that not all noise is created equal when it comes to paying attention.

Every student has his or her own preferred environment in which he or she chooses to study or do work. Some flock to the library, whereas others retreat to the privacy and solace of their dorm rooms. Both locations include the primary requirements for the task at hand: desks with chairs, space to read or take notes, and outlets to plug in a laptop to complete assignments. The main difference between these two locations is the environment *around* the student. Some students enjoy the presence of friends or other students around them while they study; others write messages of ''Do Not Disturb'' on their dorm-door whiteboards. Similarly, some students prefer silence in order to work well, whereas others listen to music, talk, or use white or pink noise tracks on their music players.

It is this last factor, the person's preferred ''audio environment,'' on which this article focuses. Intuition would suggest that the quieter an environment is, the easier it will be to work effectively in that environment. However, recent research has shown that the opposite may be true. Shih, Huang, and Chiang (2009) evaluated individuals' concentration on work in environments with and without music. Their results were surprising; although the group that listened to music while taking the test did score the lowest, the group that listened to music just prior to the test actually scored significantly higher than the controls that took the test with no music. Alternatively, Wohlwill, Nasar, DeJoy, and Foruzani (1976) found that *scores* on a performance task were not affected by noise; however, subjects working in the noisy environment reported higher levels of frustration and gave up faster when given an unsolvable task. This suggests that noise can affect task persistence and emotional regulation in challenging situations. Results such as these have encouraged school systems to install classroom sound systems to address what seems to be a downward trend in academic performance by providing the ideal level

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background noise for students (Samuels, 2007).

Other researchers have conducted similar work; however, instead of using music, they are using audio noise of differing frequencies, (e.g., white or pink noise). The terms ''white'' or ''pink'' noise refer to the power density-to-frequency ratio of the noise and are determined by the color of light waves that have a similar frequency profile (i.e., the frequency profile that makes up pink noise is shared by pink light waves; McDonnell & Abbott, 2009). Research has shifted to using this type of noise instead of music, as it lends itself to being easily repeated over time and decreases the amount of complex variables that are introduced by using music that consists of variations of tone, pitch, tempo, and lyrics. This present study adds to this emerging literature by specifically examining the effect of audio environment on a person's performance on an attention task. The following sections address the assessment of attention and the effect that noise may have on attention.

WORKING IN AUDIO NOISE

The idea that noise is distracting to work completion is not usually questioned, but because some people claim to work better while listening to music or watching television, there is a need to find out how much of an effect noise has on task performance in comparison to completing the task in a quiet environment. Wohlwill et al. (1976) showed that scores on a performance task were not affected by noise; however, the subjects who worked on the performance task in the noisy environment had higher levels of frustration and gave up earlier when given an unsolvable task. This showed that although there may not be impairment to performance due to a noisy environment, it is clear that noise can affect human behavior in challenging situations. These results raise questions about how attention interacts with audio stimuli. The following sections address how attention is assessed and how noise may have a positive effect on attention.

Assessing Attention

Attention is defined as the element of cognitive functioning in which mental focus is maintained on a specific issue, object, or activity. The ability to accurately assess someone's ability to pay attention is very useful in the world of psychology. With more and more children being diagnosed with attention disorders based solely on symptoms, it is beneficial for the field to develop more objective ways of evaluating them. Different objective measures of attention have been developed and are considered variations on a continuous performance test (CPT). Many different versions of CPTs have been developed, some specifically for use in identifying attention deficit hyperactivity disorder (e.g., Llorente et al., 2008) and others for more general use (e.g., Homack & Riccio, 2006).

The main differences in versions of the CPT are centered around the original intention of the test designers, for example, whether they intended their CPT to be used to help diagnose a clinical population, such as the Tests of Variables of Attention (Llorente et al., 2008), or to be used in a wider range of applications including clinical diagnosis as well as research, such as the Conner's CPT (Homack & Riccio, 2006). CPTs come in many different forms. However, the basic form of the CPT remains fundamentally constant. During a generic CPT, the subject will be seated in front of a computer screen and given access to the computer mouse, or some other type of clicker device. The subject is instructed that the computer screen will display a series of letters, one at a time. The subject is instructed to click the mouse or other device every time a new letter is shown, except when that letter is an *X*. Once the test begins, the computer keeps track of the subject's reaction times as well as the different types of errors made by the subject.

There are two basic types of errors that are tracked during a CPT. The first is called an error of omission. An error of omission is when a subject fails to submit a click response when he or she should have during the test; for example, not clicking when the subject is presented the letter *A* would constitute an error of omission. The second type of error that is tracked in a CPT is an error of commission. An error of commission is when the subject submits a click response when he or she should not have; for example, submitting a click response when the subject is presented with the letter *X* would constitute an error of commission.

All of the data collected by the CPT are used to gain a picture of the quality of the subject's ability to pay attention. When compared to a score normed for age and gender, the test is also able to identify specific types of deficits in attention (i.e., impulsivity) and decision making based on this data. This information may be valuable when trying to evaluate a subject to see if he or she should be diagnosed with attention deficit hyperactivity disorder (ADHD), and the results can give clinicians clues as to which type of medications may work best for that patient (Homack & Riccio, 2006).

Ballard (2001) looked at some of the differences between the available versions of the CPT. They showed that although several versions are more or less susceptible to different types of attention errors, all of the CPTs evaluated were of the same level of reliability in evaluating a subject's general ability to have continuous focused attention (Ballard, 2001). Thus, although some CPTs are better in certain clinical situations, CPTs are an overall accurate measurement of a subject's continuous attention.

Audio Environment's Impact on Attention

Anyone who has tried to listen, focus, or complete work while a building is under construction is well aware of how distracting background noise can be. Previous research on work efficiency suggests that performance tends not to be optimal in a silent environment or in a very noisy environment. Rather, there is an ideal level of background noise that facilitates maximum work efficiency (Ballard, 2001; Shih et al., 2009). Research also suggests that placing those diagnosed with ADHD in an environment with certain levels of background noise decreases some of their symptomology (Swingle, 2008). More important, however, is the finding that this ''ideal'' level may differ among different populations. Söderlund, Silkström, and Smart (2007) compared the cognitive performance of controls with subjects diagnosed with ADHD while exposed to white noise. They found that although the white noise was a hindrance to the controls, it actually increased cognitive performance in the subjects with ADHD.

With respect to attention, Fosnaric and Planinsec (2008) examined attention among 20 male adolescents (*M* age = 13.5 years) while completing a task under many different stressors, such as changes in temperature, lighting, and noise. It was found that audio environment was most related to task performance. On all four of the study variables—errors of commission, errors of omission, correctly answered responses, and correctly omitted responses—subjects performed significantly better when the background noise level was optimized for task completion as opposed to when the noise level was at a maximum or the task was performed in silence. This result further supports the theory that attention may be optimized with a specific amount of audio noise in the environment.

Alternatively, Dosher and Lu (2000) conducted a complex study in which four subjects were trained to first detect and later differentiate between four different audio cues and some additional invalid cues. They then evaluated the subjects' ability to perform identification and differentiation tasks in both quiet and noisy environments (with varying degrees of noise-to-signal ratio). Results suggest that the addition of noise had no significant effect on the subjects' ability to complete the task, regardless of ratio. However, it should be noted that the nonsignificant finding might be attributed to Dosher and Lu's reliance on a dichotomous attention score (success vs. failure) as opposed to a measure such as a CPT that is scored on a continuous scale, allowing for greater range of scores.

In explaining why background noise did not affect performance in their study, Dosher and Lu (2000) reference a neural mechanism called the thalamic filter. Located in the forebrain, the thalamic filter helps to filter out ambient sensory inputs so that a person can focus on the largest and most intense sensory input. This prevents the individual from being completely distracted by even the slightest sound (Huertas, Groff, & Smith, 2005). Dosher and Lu (2000) believed that a similar mechanism is responsible for helping to filter out background noise while we concentrate. These claims have not yet been investigated in human beings; however, many studies have used computer models of human neural networks to demonstrate the plausibility of this theory, and even show that certain sounds could possibly enhance performance. To explain this theoretical background noise filter, they rely on a physics phenomenon called stochastic resonance (Balenzuela, Braun, & Chialvo, 2012; Kawaguchi, Mino, & Durand, 2011).

Stochastic Resonance

In physics, noise is thought of as any random signal in the system that is not the primary signal of focus. In an audio system, the noise is categorized by its frequency, measured in Hertz (Hz) and different frequency ranges are named after colors. The way noise interacts with the primary signal of interest is affected by many different factors, the largest being the type of system (McDonnell & Abbott, 2009). There are two basic types of systems, linear and nonlinear systems (Balenzuela et al., 2012). Linear systems are defined as systems in which signals correlate with each other in first order (e.g., $y = 2x$) and nonlinear systems are simply defined as any system that is not linear in nature (e.g., $y = x^2 + b$). Stochastic resonance (SR) occurs in nonlinear systems (Ward & Kitajo, 2005).

One of the defining characteristics of a linear system is that any noise is detrimental to the transmission of the primary signal of interest. The stochastic resonance theory states that, in a nonlinear system, there is a specific amount and type of noise that can increase the speed and quality of the transmission of the primary signal of interest (Balenzuela et al., 2012). In other words, SR is "the presence of noise in a nonlinear system [that] is better for output signal quality than its absence" (McDonnell & Abbott, 2009, p. 1). Introduced in 1980, SR theory has only recently been applied to the mechanisms of information transfer in the human brain.

The transmission of signals through the human brain is nonlinear in nature (Kawaguchi et al., 2011). In 2010, Mino and Durand showed that stochastic resonance could play a key role in increasing the speed of transmission of neural signals in the hippocampal CA1 region of the brain using a computer model. Further, Kawaguchi et al. (2011) used a computer simulation of a neural network to conclude that there was evidence to support the presence of SR inside a neural system. They found that by adding audio noise to the simulation, the speed of transmission in the hippocampal CA1 region increased; however, they also showed that too much noise started to have the opposite effect. This means that it is possible that there is a specific type and amount of background noise that could increase the rate of the transmission of electrochemical signals from neuron to neuron in the hippocampal CA1 region of the brain. Kawaguchi et al. concluded from their models that SR could account for the background noise having an effect on the speed of the brain's signal processing and transmission. The key is that the type and ratio of background-to-signal noise introduced to the system must be precise and constant to have an SR-like effect on the speed of transmission in the brain.

In a clinical setting, the plausibility of the SR phenomenon affecting human attention and cognition for certain populations has some anecdotal support (Ward & Kitajo, 2005). As previously mentioned, Söderlund et al. (2007) conducted a study in which the cognitive performance of subjects with ADHD was evaluated while they were placed in an environment with white noise (a signal that has equal intensity in all relevant frequencies;

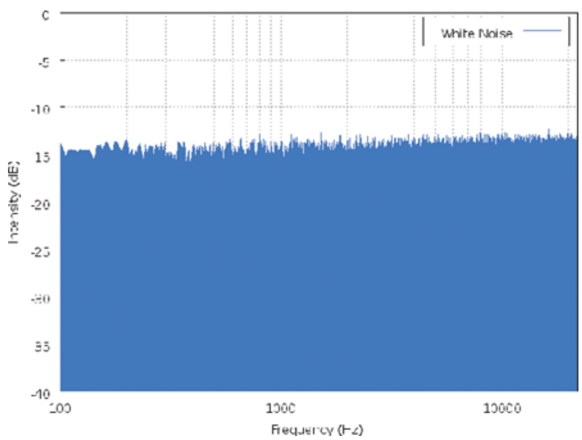

FIGURE 1. White noise frequency profile. (Color figure available online.)

see Figure 1). Subjects were given three tasks to perform: a high memory performance task, a verbal task, and a low memory task. The subjects with ADHD who were tested in the presence of white noise had significantly higher scores than their control counterparts, suggesting that this specific frequency of noise may enhance functioning.

Because SR may affect the way our brains respond to background noise, how does this apply to attention in applied settings? Let us consider a student who is diligently studying in his or her room: the music is on, and the student pores over a textbook highlighting and taking notes on a pad. Is SR at work? The answer is, probably not (Dosher & Lu, 2000). Although some people may claim that music playing in the background helps them pay attention to their work, SR theory does not support this claim. For any benefit to be gained from SR, noise would have to be delivered at a highly specific audio frequency (in relation to the signal of interest). This noise would be similar to the type of background buzz that can be heard on some older speakers.

Unfortunately, there is no research that provides any evidence to support the SR occurring in a living human brain because all research has been limited to computerized neural simulations. Although previous studies have examined the effects of external noise on work efficiency, there has yet to be an in-depth look at noise's effect on attention. If neural stochastic resonance were to be shown in a human study, it would open up a myriad of new possible lines of research in the area of neural acoustics. This could have a major impact in treatment methods for people diagnosed with neuropsychological disorders affecting attention. Although not studying SR directly, the purpose of this study was to explore the effect that different types of background noise have on a person's ability to pay attention. For example, if pink noise frequencies provide an increase in attention scores, then this could provide another piece of supporting evidence for research into the plausibility of a SR-like phenomenon in the human brain.

The Present Study

This pilot study examined the relationship between attention and different types of background noise. This study tested subjects' attention while being exposed to multiple types of external noise, including pink noise, ambient noise, and complex noise produced through exposure to a television audio track. Although there is not any research into the specific effects of pink noise on attention (as measured by a CPT), this frequency profile (Figure 2) is commonly used in products claiming to provide the ideal background noise for studying.

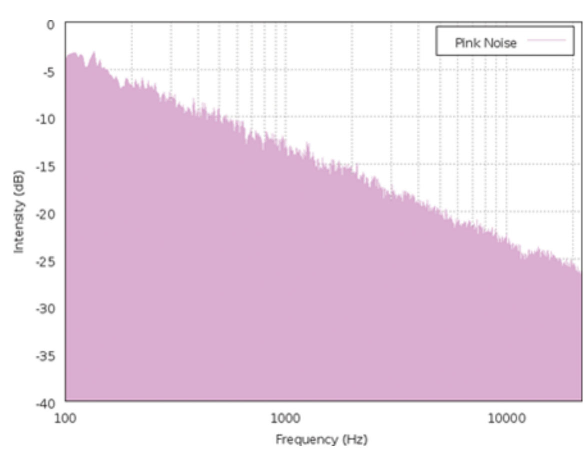

FIGURE 2. Pink noise frequency profile. (Color figure available online.)

RQ1: Does the addition of complex television noise in a subject's audio environment affect his or her attention compared to a control audio environment?

Hypothesis. Based on work by Ward and Kitajo (2005), we hypothesized that exposing a subject to television noise would have a negative effect on the subject's attention.

RQ2: Does the addition of pink noise in a subject's audio environment affect his or her attention compared to a control?

Hypothesis. Although there is a lack of research into the effects of pink noise, we hypothesized that exposing a subject to pink noise would have some effect (either positive or negative) on the subject's attention.

METHOD

Participants

Participants for this study were 27 undergraduate psychology students (male = 14.8%). Subjects were recruited from a university subject pool. Participants ranged from 18 to 53 years of age ($M = 19.5$). Participants could not carry a diagnosis of ADHD or any other disorder involving attention. Based on a power analysis assuming a medium effect size ($f = .25$) and a within-subjects design, using a repeated measures analysis of variance analysis, a subject sample size of 28 participants should yield a power value greater than 0.8.

Measures

Continuous Performance Test. The CPT is a visual paradigm used for the evaluation of attention as well as the response inhibition component of executive control. It represents an effort to incorporate reliable and objective assessment into evaluations for ADHD and other neurological disorders (Ballard, 2001; Homack & Riccio, 2006; Llorente et al., 2008). The test poses no significant risk to the subject beyond what is normally incurred by viewing a computer screen and clicking a button. The CPT used in this study was conducted with Thought Technology equipment. It consists of a game-show-style clicker (Figure 3) that

FIGURE 3. Continuous performance test clicker.

the subject presses in response to a target stimulus (Figure 4) and does not press in response to a nontarget stimulus (Figure 5). During each of the three conditions (ambient noise, pink noise, and TV noise), subjects completed two phases (high and low target ratio) for a total of six phases of testing. The high target ratio phase was defined as a ratio of 3.5:1 targets to nontargets; in the low target ratio phase, that ratio was reversed. Data on the subjects' reaction times, as measured by the delay between when a target stimulus was presented (as recorded by a photo-cell sync; see Figure 6) and when the subjects activated the clicker, as well as errors of omission and commission, were recorded using the Thought

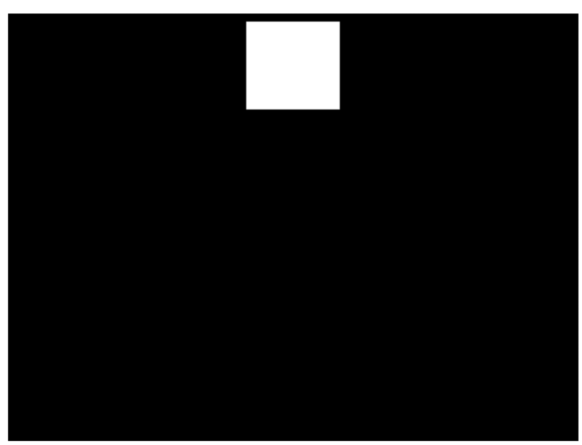

FIGURE 4. Continuous performance test target stimulus.

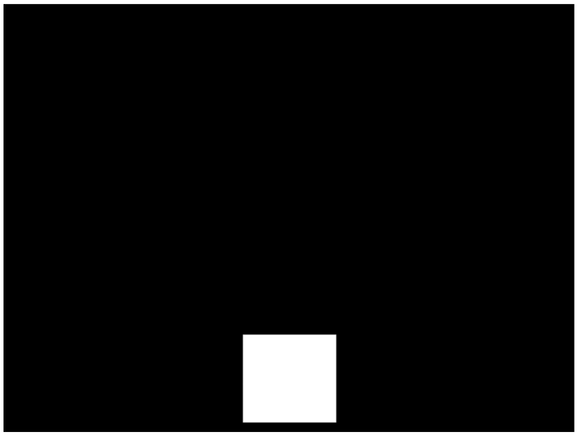

FIGURE 5. Continuous performance test nontarget stimulus.

Technology software. All of the data were saved for later analysis.

Questionnaire. Subjects were asked to answer questions from a brief questionnaire, which included questions about demographic information and the types of audio distractions they usually have in their typical study environment (see Table 1).

Procedure

Subjects, one at a time, were seated in a small room in front of a computer. The room had a speaker in order to produce different audio environments in which the subject was given the CPT. Subjects were asked demographic questions and then were administered the CPT. The three conditions were control (ambient room noise), pink noise, and a prerecorded section of audio from a television sitcom. The order of these tests was randomized for each subject to attempt to control for any learning or fatigue effects during the CPT. The test–retest reliability of CPTs depends highly on the length of the test and the amount of time between each phase of the test (Llorente et al., 2008). Following the CPT, the subjects answered questions about their audio preferences and their perceived performance. Subjects were then provided with a written debriefing.

FIGURE 6. Continuous performance test fiber optic sync.

TABLE 1. Participant's Demographic Information and Study Habit Data

Gender	*M* Age	% who converse while studying	% who have the TV on while studying	% who listen to music while studying
Male[a]	20.25	50.00	75.00	100.00
Female[b]	21.13	47.83	39.13	78.26
Total[c]	21.00	48.10	44.40	81.50

[a] $n = 4$.
[b] $n = 23$.
[c] $N = 27$.

Data Analysis

All of the data were collected and analyzed using a repeated measure analysis of covariance (ANCOVA) to examine relationships between the different noise environments and attention scores. Specifically, we looked at the total percentage of correct target responses (Response %), the total percentage of correct nontarget responses (Inhibit %), and average response time in milliseconds across the three conditions.

RESULTS

Participants' mean scores on the CPT are summarized in Table 2. To examine the hypotheses that attention would be affected by audio environment, an ANCOVA was run using Response % and Inhibit % from all conditions as covariates. The rationale for including the measures of error as covariates was based on their connection to the reaction time scores. It is known that there are inherent

TABLE 2. Descriptive Data for the Continuous Performance Test Variables in Different Conditions and ANCOVA Results

	Descriptive data		ANCOVA results		
	M	*SD*	*f*	*p*	Cohen's *d*
Reaction time (ms)					
Control condition	271.49	33.81			
TV sitcom noise condition	269.89	34.02			
Pink noise condition	270.76	32.66			
Control v. pink noise v. TV sitcom noise			4.32	0.02	0.953
Control v. TV sitcom noise			1.998	0.172	0.602
Control v. pink noise			4.268	0.05	0.879
TV Sitcom noise v. pink noise			0.053	0.82	0.09
% Error of omission					
Control condition	0.97	1.38			
TV sitcom noise condition	1.81	4.07			
Pink noise condition	1.53	3.64			
% Error of commission					
Control condition	3.71	3.82			
TV sitcom noise condition	4.97	5.23			
Pink noise condition	5.06	3.94			

Note. ANCOVA = analysis of covariance.

relationships between a participant's reaction time scores and the amount and type of errors that they produce (Homack & Riccio, 2006; Llorente et al., 2008). For example, a faster reaction time increases the likelihood of errors of commission. Mauchly's test indicated that the assumption of sphericity had been upheld, $\chi^2(2) = .459$, $p = .795$. The results of the three-way ANCOVA show that participants' reaction time was significantly affected by the audio condition they were in: control, pink noise, or TV sitcom noise, $F(2, 40) = 4.32$, $p = .02$, $d = .95$. Two-way ANCOVA post hoc analyses were used to examine significant differences between each of the audio conditions using Reponse % and Inhibit % as covariates. These data indicated that there was a significant difference in participants' reaction times between the control condition and the pink noise condition, $F(1, 22) = 4.27$, $p = .05$, $d = .88$. Specifically, participants' reaction times were significantly faster in the pink noise condition than in the control condition ($M = 270.76$ vs. $M = 271.49$). There was no significant difference in participants' reaction times between the control condition and the TV sitcom noise condition, $F(1, 22) = 2.00$, $p = .17$, $d = .60$, or between the TV sitcom condition and the pink noise condition, $F(1, 22) = 0.053$, $p = .82$, $d = .09$.

DISCUSSION

The researchers examined two specific hypotheses about the effect of audio environment on attention. Contrary to the subject's common studying practices, wherein 44% studied with the television on and 82% studied while listening to music, the researchers hypothesized that the complex sound of a television sitcom would impair attention. In addition, on the basis of previous research and the hypothesized construct of stochastic resonance in the human brain, we hypothesized that attention in the pink noise would differ from attention in the control condition.

Participants' mean reaction times in the three different audio conditions indicate, participants' reaction times were slower in the control ($M = 271.49$) condition than in the pink ($M = 270.76$) and TV sitcom ($M = 269.89$) noise conditions (see Table 2). To evaluate whether these differences were significant, an ANCOVA was run using the different types of errors as covariates in the analysis. The data show a statistically significant difference between subjects' reaction times across the three conditions, $F(2, 40) = 4.32$, $p = .02$, $d = .95$. Post hoc analyses were run to examine where the differences in attention were.

Post hoc analyses found that there was no statistically significant difference between participants' reaction time scores between the control and TV sitcom noise conditions. This result suggests that participants' speed in responding to the visual stimuli presented during the CPT was similar across the TV sitcom audio environment and the ambient control audio environment. This outcome contradicts the researcher's first hypothesis and suggests that the TV sitcom noise did not impair participants' response time in a CPT attention task.

Post hoc analyses of participant's reaction time in the control and pink noise conditions identified a statistically significant difference between participants' reaction time scores across conditions, $F(1, 22) = 4.27$, $p = .05$, $d = .88$. Participants' reaction times were significantly faster in the pink noise condition ($M = 270.76$) as compared to the ambient noise control condition ($M = 271.49$). Thus, contrary to conventional thinking, these findings suggest that complex television noise did not impair attention, while pink noise, or a signal that has combines relevant frequencies with decreasing intensity, decreased reaction times in comparison to the control. These results lend some credence to products marketing pink noise producers as increasing attention.

These findings also lend indirect support to the theory of stochastic resonance, which poses that there is a specific amount and type of background noise that may increase the speed and effectiveness of a nonlinear system (in this case, the neural network in the human brain). Further, because this decrease was present in the pink noise but not the TV sitcom noise condition, the generally accepted theory of stochastic resonance that only a specific type of noise, and not noise in general, may have a beneficial effect on a neural network is supported (Kawaguchi et al., 2011; Söderlund et al., 2007).

Limitations

The primary threat to the internal validity of this study was that participants' scores on the CPT could increase with each attempt due to a learning effect. To try to counteract this learning effect, the study design randomized the order in which the subjects completed the three conditions (ambient noise, TV sitcom, and pink noise). The external validity of this study is limited to a nonclinical population. In future research it is recommended that the sample size and diversity be increased in order to increase the external validity of the results. This study was limited to the use of a university subject pool and as such, all of the participants were college students. This means that although the data are valuable and useful when talking about a college student population, it is difficult to generalize these results to any group outside of that population. Specifically, research with younger, grade school aged children would be of great interest. Similarly, geriatric populations and clinical populations, including those suffering from attention disorders such as ADHD, would be of interest.

It is also recommended that a more difficult CPT be used in order to allow for more sensitivity in the testing differences in attention. Researchers found that the CPT used in this experiment (while effective) was generally easy for participants and that a more challenging test may be more effective in identifying differences in attention. Similarly, formulating a test that more closely mimics the type of attention required to do real-life tasks would be beneficial in that it would be a better gestalt of attention in real-world (practical) applications.

Future Research

In future research into this area, it is suggested that an expanded sample is used. This study was limited to the use of a university subject pool and, as such, all of the participants were college students. This means that although the data are valuable and useful when talking about a college student population, it is difficult to generalize these results to any group outside of that population. Specifically, research with younger, grade school aged children would be of great interest. Similarly, geriatric populations and clinical populations, including those suffering from attention disorders such as ADHD, would be of interest.

It is also suggested to establish a more effective tool to measure attention. Researchers found that the CPT used in this experiment (while effective) was generally easy for participants and that a more challenging test may be more effective in identifying differences in attention. Similarly, formulating a test that more closely mimics the type of attention required to do real-life tasks would be beneficial in that it would be a better gestalt of attention in real-world (practical) applications.

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