Department of Psychology

The Effect of Auditory White Noise on a Three-Stimulus Oddball Task in Attentive and Inattentive Participants

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Abstract

Recent findings have shown that listening to white noise can improve memory in people with ADHD or low levels of attention. The current study explored whether white noise can improve performance on a test of sustained attention. Participants (*N*=19) were divided into an attentive (*N*=10) and inattentive group (*N*=9) based on the inattention sub-section of the ASRS (Adult Self-Report ADHD Scale). Participants completed four blocks of a Three-Stimulus Oddball task. Participants completed the task under four conditions: in silence, while listening to continuous white noise, listening to a tone and listening to short bursts of white noise. It was found that the inattentive group performed worse in all four conditions compared to the attentive group by making more errors and having a higher variability in response times. There was no positive effect of listening to white noise or the tone for either group. The results of the study did not lend support towards the hypothesis that inattentive participants benefit from white noise on a test of sustained attention. It was suggested that future research should replicate the current experiment using more participants, more noise manipulations and by increasing motivation through including continuous feedback. It was also suggested that white noise should be tested in conjunction with working memory tasks and test of inhibition and interference handling since impairments in these processes are also implicated in the ADHD symptom profile.

Key Words: ADHD, sustained attention, white noise, Oddball task**,** response variability, post-error slowing, distractibility

Introduction

Attention Deficit/Hyperactivity Disorder (ADHD) is a common childhood and adult disorder which has been heatedly debated and received a great deal of focus in media. ADHD affects many aspects of cognition and it is not known what causes the disorder. The most commonly used treatment for ADHD is methylphenidate drugs but recent findings suggest that other non-pharmaceutical therapies could also be effective. In a series of studies conducted by Söderlund and colleagues (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010) it has been found that listening to white noise improves performance on memory tasks in people with ADHD or low levels of attention. However, it has not yet been tested whether white noise also improves other cognitive processes such as sustained attention.

Attention

Attention is essential to most aspects of life. In order to learn new things, we need to selectively focus on the relevant information while ignoring irrelevant and distracting elements. We can be distracted by external elements, for example, other conversations around us, but we can also be distracted by internal processes such as when random thoughts cross our minds. Being able to successfully sustain and regulate attention is of great importance for performance at school or at work (Trautmann & Zepf, 2012). Most people experience some difficulties with staying focused during long lectures or meetings, but for a person with an ADHD diagnosis difficulties with attention can severely affect school or work performance and create problems with social relationships. Children with ADHD may, for example, have problems making friends because of difficulties with impulse control or inappropriate behaviour during play. In adults with ADHD, social difficulties may appear because of problems with, for example, listening and following instructions or being forgetful and missing meetings with friends.

ADHD background

It is estimated that ADHD affects around 5% of children in Swedish primary schools (Sjölander, 2012). According to the *Diagnostic and Statistical Manual of Mental Disorders* (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000), there are three subtypes of ADHD; the predominately inattentive one, the predominantly hyperactive/impulsive one and the combined type (inattentive and hyperactive/impulsive). Typical behaviours consistent with ADHD include: difficulties with organization, problems paying attention to details, excessive talking and fidgeting and difficulties remaining seated. ADHD is often thought of as a childhood disorder but it has been found that for many people, the symptoms of ADHD continue into adulthood (Biederman et al. 2000). Symptoms of hyperactivity and impulsiveness have been found to be most common in childhood and then decline later in life whereas inattentive symptoms tend to persist into adulthood (Biederman et al. 2000) There are, however, some problems with the ADHD diagnosis in that people with the diagnosis often show different symptoms and manifestations of the disorder which vary greatly in amplitude, and it has therefore been suggested that ADHD should be viewed as a heterogeneous condition and with a spectrum of severity (Wåhlstedt, Thorell & Bohlin, 2009).

Causes of ADHD

It is not yet known what causes ADHD. Research has found that the disorder is often seen in conjunction with other developmental disorders such as Autism spectrum disorder and several risk factors that correlate with the development of ADHD have been identified (Thapar et al. 2013). These risk factors include: low birth weight, a family history of ADHD and exposure to adversities or toxins such as lead, in early childhood (Thapar et al. 2013). However, no single risk factor can *alone* be used to predict or explain ADHD and none of the factors have been shown to *cause* ADHD (Thapar et al. 2013).

Several theories have been proposed to explain and pinpoint the origin of the neuropsychological deficits seen in ADHD. Among the most influential of these is the cognitive energetic model (CEM) of ADHD put forwards by Sergeant and colleagues (Sergeant et al. 2000, Sergeant et al. 2005). The CEM suggests that ADHD associated deficits are seen at three levels of processing. The first level concerns basic, low levels of processing and here it is suggested that people with ADHD have difficulties with motor organization. The second level is referred to as the energetic pools level and includes arousal, activation and effort. The authors of the model (Sergeant et al. 2000) state that ADHD associated deficits are mainly seen in activation and effort. Finally, the third, and highest, level consists of the executive functions system and deficits in this system become evident in sustained attention and behavioural inhibition (Sergeant et al. 2000). The CEM is quite complex but simply put; it suggests that the main deficits in ADHD stem from not being able to properly adjust one's energetic state in response to task demands. Other authors (Geburek et al. 2012) suggest that most of the symptoms of ADHD stem from problems with monitoring behaviour and errors. It has been argued that people with ADHD are able to successfully monitor behaviour and identify problems but there is inefficiency in implementing top-down behavioural adjustments to improve behaviour.

Treatment of ADHD

ADHD is often treated with an amphetamine mix or a methylphenidate drug that either has an immediate or an extended release period (Castle et al. 2007). In the Nordic countries, methylphenidate is the most commonly used ADHD drug and the prevalence of drug treatment vary between countries. A study found that when looking at a random sample of 1,000 children, from the general population of Sweden between 7-15 years of age, close to 10 children were being treated with an ADHD drug in 2007. In Iceland, ADHD drug treatment was found to be more common with 47 out of 1,000 children in the same age group being treated with an ADHD drug in 2007. (Zoëga et al 2011). In other words, it was not 47 out of 1,000 children with ADHD that were taking the drugs, but 47 out of *all children.* This difference in drug prevalence between countries might reflect different views in the current debate on ADHD. There seems to be a general concern, among laymen and health professionals, that ADHD is over-diagnosed and that too many people are being treated with an ADHD drug (Zoëga et al. 2011). Some of these concerns probably stem from the unknown, potentially negative long-term effects of amphetamine and methylphenidate treatment (Zoëga et al. 2011). Given these concerns, there seems to be a need for developing effective, non-pharmacological therapies for ADHD. These therapies could be of great help to people with an ADHD diagnosis as well as to those who experience difficulties with attention and hyperactivity but who do not qualify for a diagnosis.

Noise as a therapy

Auditory White Noise

One such non-pharmaceutical intervention that has been found to alleviate some of the symptoms of ADHD is listening to white noise while performing a cognitive task (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010). White auditory noise is a random signal that covers all frequencies. Since the signal is random, auditory white noise is not perceived as any tone and therefore sounds similar to the hum of a vacuum cleaner. Since white noise also covers a large spectrum range, it is very effective at blocking out other sounds.

Previous studies on white noise "therapy" for ADHD

The first study to highlight the potential therapeutic application of white noise for people with attention difficulties was conducted by Söderlund, Sikström and Smart (2007). The authors investigated the effect of background white noise on memory performance in children with ADHD and children without ADHD. The children were read lists of verb-noun sentences in the presence or absence of white, background noise and were asked to recall as many sentences as possible. During the presentation of half of the sentences, participants were given the object of the sentences and were asked to perform the verb action (eg. *roll the ball*) and the other half of the sentences were just read and asked to be remembered. Acting out the sentences was meant to yield a better memory performance compared to just listening to the sentences. It was found that the ADHD group performed better with noise compared to without noise when the sentences were acted out but the noise did not affect the ADHD group's performance when the sentences were just listened to. The control group, in comparison, performed worse with noise in the "listen only condition" but noise did not affect performance in the act out condition (Söderlund, Sikström & Smart, 2007). The finding that children with ADHD can improve their performance on a memory task by listening to white noise has important therapeutic implications. However, the study had a few issues that limit the generalization of these results. Firstly, there was no significant difference between the performance of children with ADHD and control children when the memory tasks were carried out without noise. In other words, children with ADHD were not impaired on this task compared to children without ADHD. Noise would be a more beneficial treatment if it was found to improve performance on tasks which children with ADHD struggle with compared to their peers. It would also have been useful if the authors would have included another type of background sound as a control condition since it cannot be known whether it is white noise *specifically* that improved performance or whether any type of sound would have had an effect.

The second study which found positive effects of white noise was conducted by Söderlund, Marklund and Lacerda (2009). In this study, the authors tested a non-clinical population of adults and first examined performance on a dichotic listening task with white noise presented at four different levels ranging from silent to 78dB. Participants had to recall syllables that were presented to one or both ears. Participants were divided into a high and low performing group, *post hoc* based on their recall performance. It was found that both high and low performing participants recalled more syllables when noise was present and louder noise levels were more effective (Söderlund, Marklund & Lacerda, 2009). In the second part of the study, adults, again without ADHD, were tested on a visuo-spatial working memory task where red dots were presented in a particular pattern on a grid either together with white noise or in silence. Participants had to recall the order that the dots appeared and were, again split into a high and low achieving group based on their performance. It was found that noise increased the low achieving group's performance but deteriorated the high achieving group's performance. The findings of the study (Söderlund et al. 2009) showed that white noise does affect performance on both two types of memory tests and importantly it showed that the effects can be cross-modal, in other words that noise can affect visual as well as auditory tasks. However, the method of dividing participants into low and high achieving groups *post hoc* based on performance is not ideal for being able to make inferences about the effect of noise on people with attention difficulties.

In 2010, Söderlund and colleagues conducted a third study on the benefits of noise. This time the authors investigated children without an ADHD diagnosis and separated them into a high and low attentive group based on the teacher's rating of the child's attention level (Söderlund et al. 2010). The children performed a memory test where they had to recall lists of verb-noun sentences. Again it was found that white noise improved the performance of the low attentive group but deteriorated the performance of the high attentive group, to such an extent that there were no longer any differences in performance between the two groups. However, using teacher ratings as a method of identifying children who might benefit from white noise therapy is perhaps not a reliable strategy.

How white noise improves performance

So how did listening to white noise improve performance? One simple explanation is that the addition of noise counteracted boredom on the task which promoted better performance (Söderlund et al. 2010). However, Söderlund and colleagues (2010) have instead proposed that inattentive people benefit from auditory white noise because adding external noise balances their system, allowing for optimal cognitive performance. The authors (Söderlund et al. 2010) suggest that people with ADHD, or inattentive people, have low levels of tonic dopamine in the nervous system. Tonic, or background, dopamine firing is thought to regulate phasic dopamine neuron firing. Phasic dopamine firing occurs when neurons fire in response to a detected stimulus. When tonic levels of dopamine are low, it causes neurons to be more reactive and the system to be more instable. In other words, when there is a low level of background firing, neurons are more likely to fire in response to stimuli. This, in turn is thought to cause problems with cognitive functioning and especially sustaining attention (Söderlund et al. 2010). By adding external noise (auditory white noise) the authors claim that tonic, or background neuronal firing is increased which then stabilizes the highly reactive phasic firing, thereby stabilizing the whole dopamine system. This theory is referred to as the moderate brain arousal model (MBA) of white noise.

Reasons for continuing white noise research

From these three studies (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010) it is clear that white noise does, to some extent, affect performance on memory tasks for people with and without ADHD. White noise is interesting as a potential therapy for ADHD and attention problems because of (a) the immediacy of the effect, (b) the likely lack of side effects, (c) the ease with which the therapy can be applied and (d) the fact that everyone can test the therapy without a doctor's approval.

There are however, several potential issues and unclear aspects with using white noise as a therapy that warrants further investigation. First of all, the previous studies which have looked at white noise (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010) have all used similar memory tasks where white noise has only been played during the encoding stage. It is therefore unclear whether white noise improves memory and recall or whether the improvement is due to higher vigilance and attentiveness at the encoding stage. In other words, the participant may recall more items because they were more alert and could therefore encode more information. This would be interesting to find out so that white noise can be applied during tasks and processes where it will be most beneficial. This could be studied by using a task that tests attention and vigilance rather than memory. Secondly, it is unknown whether it is white noise specifically or sounds in general that improve performance. It would therefore be useful to test at least one other type of sounds to see if the same improvements are seen.

Filling in the gaps

This study addressed some of the remaining questions about white noise associated performance improvements by using a different cognitive task, more control conditions to auditory white noise and a different method of dividing participants into high and low attentive groups, compared to previous studies (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010). Specifically, this study used an Oddball task to assess sustained attention, it compared the effects of presenting white noise continuously or in short bursts to the effects of presenting another type of sound, and finally, it divided participants into an attentive and inattentive group based on scores on a questionnaire assessing inattentive ADHD symptoms.

Sustained attention and the Oddball task

Given that previous research on white noise has mainly used memory paradigms, it is first of all important to test if other processes, such as sustained attention, are also affected by noise. Sustained attention is taxed when a person has to keep a look out for, and detect a rare and unpredictable signal for a prolonged period of time (Sarter, Givens & Bruno, 2001). Tests of sustained attention are characterized by subjects showing a decrease in vigilance and performance over time. It is relevant to test if sustained attention is improved by white noise because it is a basic process that underlies and determines how successful higher processes that involve attention are, such as learning and memory (Sarter, Givens & Bruno, 2001). If white noise is found to improve sustained attention and not just memory, then white noise could be applied to a wider area of tasks that require attention such as reading and attending lectures.

Sustained attention can be tested using an Oddball task. In this study, a novelty Oddball, or a three-stimulus Oddball task was used. The Oddball task requires the subject to detect a rare target image among frequent, standard images while ignoring a third, task irrelevant type of stimuli. More specifically, in this study participants were required to press one button in response to a blue square that was frequently displayed and press another button when a yellow circle appeared. The yellow circle was presented rarely and required participants to switch from the common response option. The third stimulus consisted of photographs of different objects and participants were required to not make a response to these. These novel photographs were presented rarely and were used to make the task harder by distracting the participants and requiring them to inhibit a response. The Oddball is a relatively easy task but the difficulty with the task is that it is very repetitive and quite boring; therefore it requires effort in order to maintain focus on the task.

The Oddball task was also chosen for this study since it is commonly used within the neuroimaging literature. The effect of white noise on attention would be interesting to study using event related potentials (ERP) and the novelty Oddball tasks. There are established ERP attention components associated with this task that could be investigated to elucidate specifically which attention process is affected by white noise. However, in order to be able to carry out this kind of ERP study, it first needs to be established whether subjects show improvements on the Oddball task when listening to white noise. If successful, the current study could serve as a behavioural pilot for a future ERP white noise study.

ADHD associated cognitive impairments

Previous studies have indicated that participants with ADHD are impaired on the Oddball task and other tests of attention (Rubia et al. 2007). Specifically, subjects with ADHD show increased response variability. In other words, these subjects do not necessarily make more errors but the individual's reaction times vary more which is thought to reflect lapses of attention or difficulties sustaining a high level of alertness (Rubia et al. 2007). Some believe that this increased intra-subject variability is a hallmark of the ADHD symptom profile (Buzy et al. 2009). Variability is often used as a measure of sustained attention (Stern & Shalev, 2013) and this study therefore analysed mean reaction times as well as standard deviations of reaction times. This measurement was both used to find baseline performance differences between attentive and inattentive participants and to find a possible modulating effect of listening to white noise.

In this study, the Oddball task was also used to obtain measures of post-error slowing and novelty distraction. Post-error slowing (PES) is a phenomenon found in numerous cognitive tasks where participants show an increased response time after having made an error. This is thought to reflect the participant being more cautious of making another error (Dutilh et al. 2012). Since people with ADHD are thought to have difficulties with performance monitoring and adjusting behaviour to meet performance requirements (Geburek et al. 2012), there are reasons to suspect that inattentive participants show a different pattern of post-error response times compared to attentive participants.

The novel photographs used in the Oddball task were used to attempt to distract the participants. By measuring reaction time to trials following a novel picture, differences in distractibility between attentive and inattentive participants could be revealed. By comparing PES and novelty distraction between attentive and inattentive participants with and without white noise, more specific conclusions about which area of cognition is improved by white noise could potentially be made.

Types of noise

The second issue concerning white noise associated cognitive improvements that needed to be addressed was if white noise affects performance more than another type of sound. The sound used in this study was a 440 Hz sinus wave (A tone). This condition was important to include since the previous studies (Söderlund et al. 2007, Söderlund et al. 2009 & Söderlund et al. 2010) have only used silence or white noise at different volumes as control conditions. Including a second type of sound would also allow it to be established whether white noise *specifically* improves performance or if any additional sound has a similar effect.

This study also investigated whether white noise needs to be played continuously in order to have an effect or whether playing white noise in short bursts during the attention task would be equally, less, or more effective. This condition was included as a control condition because previous studies have not investigated the difference between continuous and interspersed noise presentation. This condition would allow conclusions to be made about whether or not participants adapt to white noise. If participants perform better on the Oddball task while listening to short bursts of white noise compared to continuous noise presentation, participants may have adapted to the continuous noise which would cause the noise to no longer be effective. The short bursts of noise could perhaps be more beneficial because participants' vigilance and alertness would be increased. If the opposite results were found, with continuous presentation being most effective then perhaps the effect of white noise on performance needs to be "built up". The differences in effect between continuous and interspersed noise presentation was important to establish in order to maximize the potential benefit of white noise therapy.

Identifying inattentive participants

The last issue that was addressed by the current study was if the ASRS (Adult ADHD Self-report scale) questionnaire could be used to predict if a person would benefit from white noise on a sustained attention task. In other words, the ASRS was used to separate participants into a high and low attentive group in order to attempt to replicate previous findings of low attentive participants benefiting from listening to noise and high attentive participants being hindered by noise (Söderlund et al. 2009 & Söderlund et al. 2010). The ASRS measures the number and the severity of inattentive, hyperactive and impulsive symptoms of adult ADHD. Previous studies have used formal ADHD diagnoses (Söderlund et al. 2007), median splits based on performance (Söderlund et al. 2009) and teacher ratings of attentiveness (Söderlund et al. 2010) to separate high and low attentive groups. In this study a different method was chosen partly because of the difficulty in recruiting participants with an ADHD diagnosis and also because it was believed that the ASRS questionnaire would perhaps be a more accurate method of assessing attention and concentration problems than looking at reaction times or using teacher assessments. If the ASRS turned out to be an effective strategy of determining if a person would benefit from noise therapy, then the questionnaire could potentially be used as a screener to identify candidates for the therapy.

Aims of the study

(1) Test if white noise improves performance on a test of sustained attention

The main aim of the study was to investigate if white noise, which has previously only been tested on memory tasks, could improve performance on the Oddball task which tests sustained attention. The main reason for addressing this question was to be able to specify if white noise improves attention or memory *specifically.*

(2) Test if white noise is more effective than another type of sound

The second aim of the study was to test, and compare a different type of sound to white noise. The sound chosen for study was a 440 Hz sinus wave, commonly known as an A tone. The reason for adding this control condition was to investigate if it is white noise specifically that has an effect on performance or whether any additional external sound leads to improved performance in inattentive participants.

(3) Test if white noise needs to be played continuously to have an effect

The third aim of the study was to test whether listening to white noise continuously throughout the task would improve performance more than listening to interspersed bursts of white noise. The reason for comparing these two conditions was to elucidate whether participants adapt to continuous white noise or whether the positive effect is most pronounced with longer presentation periods.

(4) Test if the ASRS questionnaire can identify who will benefit from noise

The last aim of the study was to investigate whether the ASRS (Adult Self-Report ADHD Scale) could be used to identify participants whose performance would be improved by listening to white noise. The ASRS was used to split participants into an inattentive and an attentive group in order to attempt and replicate the previous finding that inattentive participants benefit from white noise and attentive participants are hindered by white noise.

Hypotheses

It was predicted that:

(1) Participants with high scores on the ASRS (inattentive group) would perform worse, overall, on the Oddball task compared to the attentive group. This was predicted because previous studies have found that people with ADHD are impaired on this type of task (Rubia et al. 2007). Specifically, the inattentive group would show impairments on some, or all, of the following measurements: (a) overall reaction times, (b) number of errors, (c) variability in responding and (d) post-error slowing and novelty distractibility.

(2) Inattentive participants would perform better when the task was carried out while listening to noise compared to silence. In line with previous research (Söderlund et al. 2007, 2009 & 2010), playing white noise continuously should yield the best performance for the inattentive group since it adds the most amount of external noise. Playing a tone should also improve performance to some extent since it also adds some noise to the dopamine system. The tone is, however, not as good as white noise at blocking out environmental sounds, therefore the performance will not be as good in this condition as in the continuous noise condition. The hypothesis regarding the burst white noise condition is less certain and more of an exploratory nature since there is no previous research on this topic. However, it was tentatively predicted that the burst condition would improve performance for the inattentive group since some noise was added to the system and the unpredictability of the bursts might serve to keep the participant more alert. Although, it could also be the case that the noise bursts distract the participant.

(3) Attentive participants, with low scores on the ASRS, were predicted to show optimal performance in the silent condition since these participants are not thought to benefit from more external noise being added to their system. Their performance was predicted to deteriorate in all three noise conditions and this would be evident in some or all of these measurements: (a) overall reaction times, (b) number of errors, (c) variability in responding and (d) post-error slowing and novelty distractibility.

Method

Participants

Twenty participants originally took part in the experiment. However, one participant was excluded from analysis due to having misunderstood the instructions of the task. This left 19 participants (10 females) between the ages of 22 to 34 (*M*=26.5*, SD*=3.44*)*, recruited from a student population using a social media network and advertisements distributed on and around the university campus. Participants were not offered any compensation for participating in the study.

Design

This study used a mixed between and within subjects, 2x4 design. Attentiveness level (attentive or inattentive), measured on the ASRS questionnaire was the between subjects factor and noise condition (silent control, continuous white noise, continuous A-tone and burst white noise) was the within-subjects factor.

Materials

ASRS questionnaire

Prior to testing, participants were asked to complete an online questionnaire consisting of nine questions assessing the participant's attentiveness level. The questions were taken from the ASRS (Adult ADHD Self-Report Scale) which is available and validated in both English and Swedish. The participants could therefore choose to complete the questionnaire in Swedish or English. The ASRS is a symptom check-list for adult ADHD developed in conjunction with the World Health Organization, consisting of 18 items; half of them assessed hyperactive and impulsive symptoms, and half inattentive symptoms. This study focused on the effect of white noise on *attention*, therefore only the items assessing inattentiveness were used. A score of 17 or above placed participants in the inattentive group and lower scoring participants were assigned to the attentive group. This cut-off score is specified in the scoring of the ASRS and a score of 17 or above means that the person is likely or highly likely to have ADHD.

Attention task

The study used a three-stimuli-Oddball task, also known as a novelty Oddball task. This paradigm entails detecting and responding to frequently and infrequently presented stimuli while ignoring a third, task irrelevant and distracting stimuli. This type of task is relevant for assessing performance in people with attention difficulties, since it involves being able to sustain attention on a dull task for a prolonged period of time, and being able to ignore irrelevant information, and reorienting attention back to the task after seeing irrelevant and distracting information. Problems with these skills are consistent with ADHD symptoms and some of the items of the ASRS screen for these symptoms.

Specifically for this experiment, the Oddball task consisted of three types of stimuli: (a) a standard stimuli which was a blue square, presented on 80% of trials, (b) a target stimuli which was a yellow circle, presented on 10% of trials, and (c) a novel stimuli which were easily identifiable pictures, presented on 10% of trials, with each picture only being presented once. More specifically, the novel stimuli were obtained through Google Images Search, and depicted various household items, animals, instruments and nature scenes. The pictures were picked on the basis that they were likely to be commonly known. The task was programmed in E-Prime 2, and participants were required to press one button in response to the blue square, and another in response to the yellow circle. Finally, participants were instructed to not respond when any other image appeared.

The Oddball task was divided into four blocks with one block per noise condition, and all participants completed all of the four blocks. The order of the blocks was counterbalanced between subjects. Each block consisted of 250 trials (200 standards, 25 targets and 25 novels) and the images were presented for 500ms, followed by a response interval of 1200ms before the next trial started. Any responses made after this 1700ms period were considered as errors of omission. The trials were dispersed in a pseudo-random order so that target and novel trials were not presented consecutively, but were separated by at least two standard trials. This was done in order for the task to meet the requirements for a potential future ERP study. The inter-stimulus interval had a random duration between 800 and 1200ms. This duration was random in order to increase the difficulty of the task. Each block took around 11 minutes to complete, and participants were given a short break between each block. The experiment was presented on a 21 inch CRT monitor. This monitor was chosen because of the higher refresh rate of CRT monitors compared to other types of screens, which allowed a better accuracy of stimulus presentation.

Noise Conditions

Four conditions were used in this study. First, a control condition was used where participants completed one block of the Oddball task in silence, wearing headphones. In the second condition, a block was completed while white noise was played through the headphones continuously throughout the block. This condition was referred to as the continuous white noise condition. In the third condition, the tone condition, a block of the task was completed while a sinus tone of 440hz, commonly known as an A tone, was played through the headphones. In the last condition, the burst condition, white noise was played in bursts of 2200ms. The burst of white noise was started 500ms before the presentation of the image stimulus, and continued to play during the image presentation and during the response interval. The burst of white noise was played on half of the standard, target and novel trials, and the bursts were spread out through the entire block.

All of the sounds were played at 78dB. This is the level which has previously been found to affect performance (Söderlund et al. 2009 & 2010). The sound level was calibrated using a hand-held digital sound level meter held up against a pair of headphones. The headphones used were Koss Porta Pro On-Ear. Open-back headphones were used instead of closed headphones in order to avoid the potential issue of the sound bouncing inside the headphone which would lead the volume reading to be less accurate. The sounds were generated through the application Audacity. All sounds were generated and used as 16-bit, 44100Hz uncompressed WAVE-files.

Dependent Variables

Two main variables were measured in this experiment: accuracy (number of errors) and reaction time for responses (RT). There were three types of possible errors: (a) commission errors where participants pressed the wrong button, (b) omission errors where participants neglected to make a response where one was required and (c) novelty errors where participants made a response when a novel stimulus (photograph) was presented. RT's were also used to calculate values for novelty slowing and post-error slowing. For novelty slowing, RT's to trials after novel pictures had been presented were isolated and compared to all remaining trials with correct responses. For the post-error slowing analysis, the same logic was used and correct responses following error trials were identified and compared to all remaining correct responses. Intra-subject variability in RT was also calculated. This was done by dividing each participant's standard deviation (*SD*) of their mean RT by their mean RT (*SD/M*). The *SD* was divided by the subject's mean in order to obtain a value for the variability that was independent of how fast the participant responded in general. This method of calculating a variability measure has been successfully used in previous research (Epstein et al. 2011a).

Procedure

Testing started with the participant arriving to the lab at the Psychology institution at Lund University having already completed the ASRS questionnaire online. The participant was first given an informed consent sheet which included brief information about the nature and procedure of the experiment and was asked to sign if they consented to participate. The participant was then seated in a quiet room in front of a monitor where instructions were displayed. The instructions informed the participant of the length of the experiment, the number of breaks and which buttons to press on a response box when the blue square or the yellow circle appeared. The participant was also instructed to ignore novel trials and the sounds that would be playing. It was also emphasized that the task should be completed as fast and as accurately as possible. The participant's number determined in which order the four noise conditions were presented. The conditions were counterbalanced so that there were four possible orders in which the conditions could appear. The counterbalancing of conditions was designed so that each condition appeared in the four possible positions once. After the task had been completed, the participant was further informed of the purpose and hypotheses of the experiment if they wished to know more. The session, including information, breaks and debriefing, took around 60 minutes.

Results

Attentiveness level

The mean score of the ASRS questionnaire was 16.32, *SD*=3.888. The scores ranged from 11 to 24. Based on a cut-off score of 17, this meant that the attentive group consisted of 9 participants (mean score= 12.89, *SD*=1.62) and the inattentive group of 10 participants (*M*=19.4, *SD*=2.37). The attentive group consisted of 5 females and 4 males, and the inattentive group of 4 females and 5 males.

Errors

A mixed ANOVA with attentiveness group (attentive and inattentive) as the between subjects factor and noise condition (silent, white noise, tone and burst white noise) and total errors made as the dependent variable, was carried out to test if the inattentive group made more errors than the attentive group.

There was a significant main effect of attentiveness group, $F(1,17) = 8.64, p = 0.009,$ with the inattentive group making twice as many errors (*M*=10.4, *SD*=1.23) as the attentive group (*M*=5.08, *SD*=1.31), when averaged across the four conditions (see figure 1).

There was no significant main effect of condition, $F(3,17) = 1.21$, *ns,* indicating that there was no difference in the number of errors made in the four noise conditions.

There was no significant interaction effect between noise conditions and attentiveness group, $F(3,17) = 2.05$, *ns,* indicating that the two groups did not differ in how many errors were made in the four conditions (see figure 1).

Type of errors

It was then explored if the type of errors made differed between conditions and participants. There were three types of possible errors: commission errors where participants pressed the wrong button (i.e. pressed the button corresponding to the square when a circle was presented and vice versa), omission errors where no response was made where one was required and novelty errors where participants incorrectly made a response when a novel, distracting picture was presented.

A 4x3x2 mixed ANOVA was carried out with condition (four levels) and error type (three levels) as the within subjects factors and group (attentive and inattentive) as the between subjects factor. The number of errors made was the dependent variable.

Again, the ANOVA showed a significant main effect of group, *F(1,17) = 73.26, p < .001* with the inattentive group making more errors in total.

There was no significant main effect of condition, *F(3,51) = 1.21, ns,* no significant interaction between condition and group, *F(5,51) 2.05, ns,* no significant interaction between error type and group, *F(2,34) = .486, ns*, and no significant interaction between condition, error type and group, *F(6,102) = .677, ns.*

There was a non-significant trend towards a main effect of error type, *F(2,17) = 2.98, p = .064*, with participants making more omission errors (*M*=3.53, *SE*=.564) compared to novelty errors (*M*=1.89, *SE*=.367).

There was a significant interaction between noise condition and error type, F(6,17) = 7.46, p < .001. By graphically examining the data (see figure 1), it could be seen that both groups made more omission errors in the burst condition (*M*=5.25, *SE*=1.07) compared to the three other conditions (Silent *M*=2.61 *SE*=.545, Noise *M*=3.22 *SE*=.660 and Tone *M*=3.04 *SE*=.604).

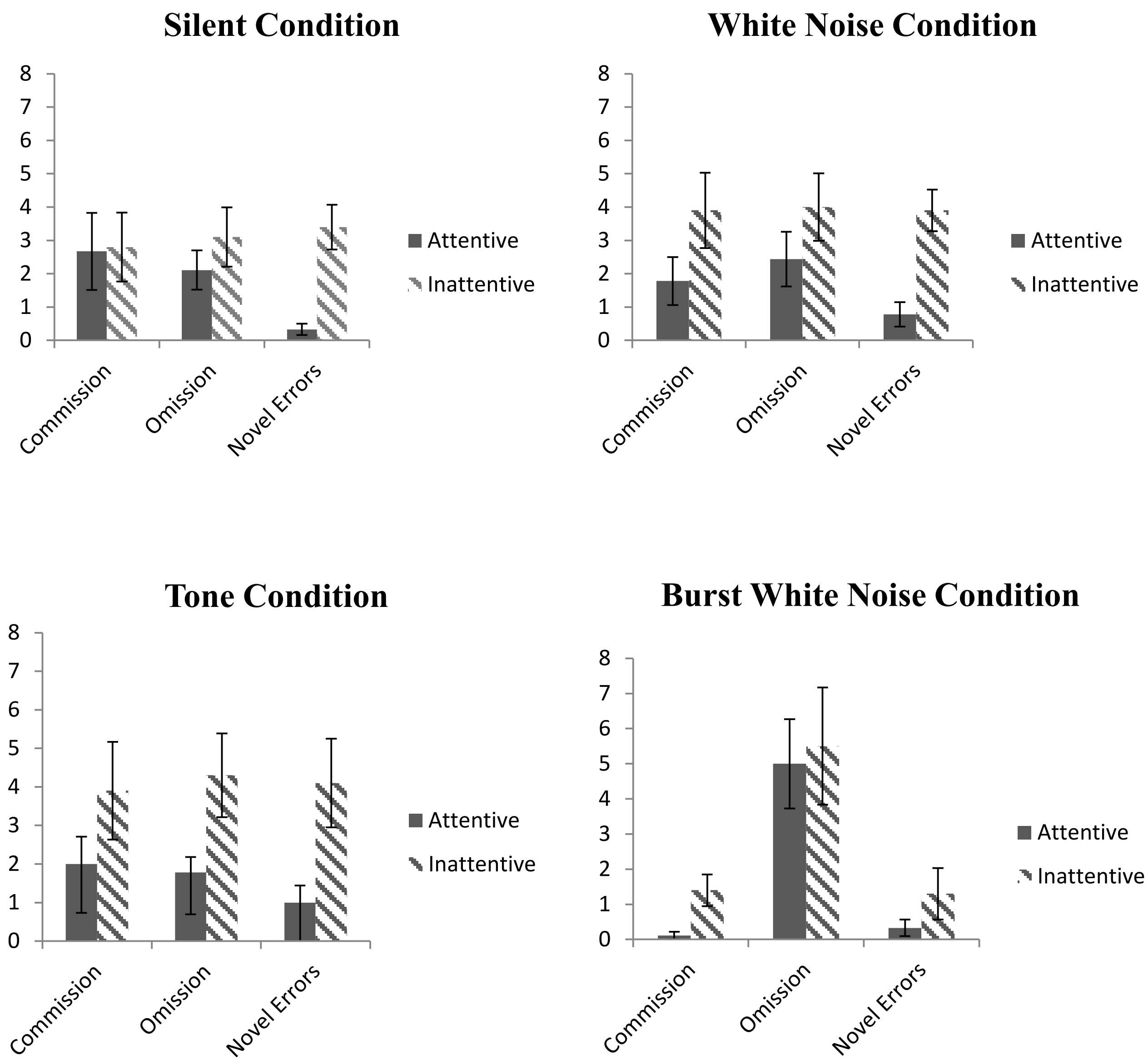

Figure 1. Mean number of errors made per type and per condition for the attentive and inattentive group. The graphs depict the number of the three types of errors made (commission, omission and novel errors) in the four noise conditions (silent, white noise, tone and burst white noise) by the two groups. Errors made by the attentive group are shown in solid grey and the inattentive group's errors are shown in diagonal stripes. Two significant effects can be seen in graph: a main effect of group with inattentive participants making more errors in general compared to attentive participants and an interaction effect between noise condition and error type with more errors of omission made in the burst white noise condition.

Reaction times

A mixed ANOVA with attentiveness group (attentive and inattentive) as the between subjects factor, noise condition (four levels, silent, noise, tone and burst) as the within subjects factor and mean reaction time is milliseconds as the dependent variable was performed.

The ANOVA showed that there was no significant main effect of attentiveness group, $F(1,17) = .068$, *ns,* indicating that, in general, the inattentive group were not slower than the attentive group on the Oddball task.

There was a significant main effect of condition, $F(3,17) = 22.8$, $p < .001$, showing that without considering group classification, reaction times varied significantly between the four noise conditions. Pairwise comparisons revealed that reaction times on the burst block were significantly slower than on the three remaining conditions (Burst *M*=369ms, *SE*=13.9, Silent control *M*=315ms, *SE*=11.3, White noise *M*=314ms *SE*=14.3 and Tone *M*=317ms *SE*=10.1).

There was no significant interaction between condition and group for reaction times, $F(3,17) = .293$, *ns,* indicating that the two groups' reaction times did not show different patterns for the different conditions.

The burst block was further explored by looking at the mean RT for trials presented with white noise and trials presented without noise within the block. A mixed ANOVA was carried out with attentiveness group as the between subjects factor, noise (noise and no noise) as the within subjects factor and reaction time to trials in the burst block as the dependent variable. A significant main effect of noise was found, $F(1,17) = 50.2$, $p < .001$ but there was no significant main effect of group, $F(1,17) = .013$, *ns,* nor was there an interaction effect between noise level and group, $F(1,17)= 1.98$, *ns.* Pairwise comparisons revealed that participants were quicker at responding to trials presented with noise (*M*=340ms, *SE*=12.7) compared to trials presented without noise (*M*=389ms, *SE*=16.2) but this difference was true regardless of the attentiveness of the participant.

When including only the RT trials presented with white noise from the burst block in an ANOVA to with mean RT in the other three noise conditions, RT to trials in the burst block were still significantly slower than RT in all other conditions. There was a significant main effect of condition, $F(3,17) = 4.89$, $p = .004$, but no main effect of group, $F(1,17) = .020$, *ns,* nor a significant interaction between group and condition, $F(3,17) = .759$, *ns*.

Performance variability

Next the variability in responding was explored. Previous research has indicated that a high variability in performance is a hallmark of the ADHD profile. In line with previous research (Buzy et al. 2009) a measure of performance variability was obtained by taking each subject's standard deviation of their reaction times and dividing this by the subject's mean reaction time (SD/M). Dividing by the mean was done in order to obtain a value that was independent of the subject’s speed of responding so that only the *variability* in responding would be measured.

A mixed ANOVA was carried out with attentiveness group as the between subjects factor, noise condition, four levels, as the within subjects factor and *SD/M* as the dependent variable.

A significant main effect of group was found, $F(1,17) = 9.61, p = .006,$ with the inattentive group having a significantly larger performance variability (M=.324, SE=.020) compared to the attentive group (M=.236, SE=.021). This effect can be seen in figure 2.

There was no significant main effect of condition, $F(3,17) = .284$, *ns,* and no significant interaction effect between group and condition, $F(3,17) = .815$, *ns.* This showed that performance variability was not different across the four noise conditions nor did the groups differ in how the performance variability changed across conditions.

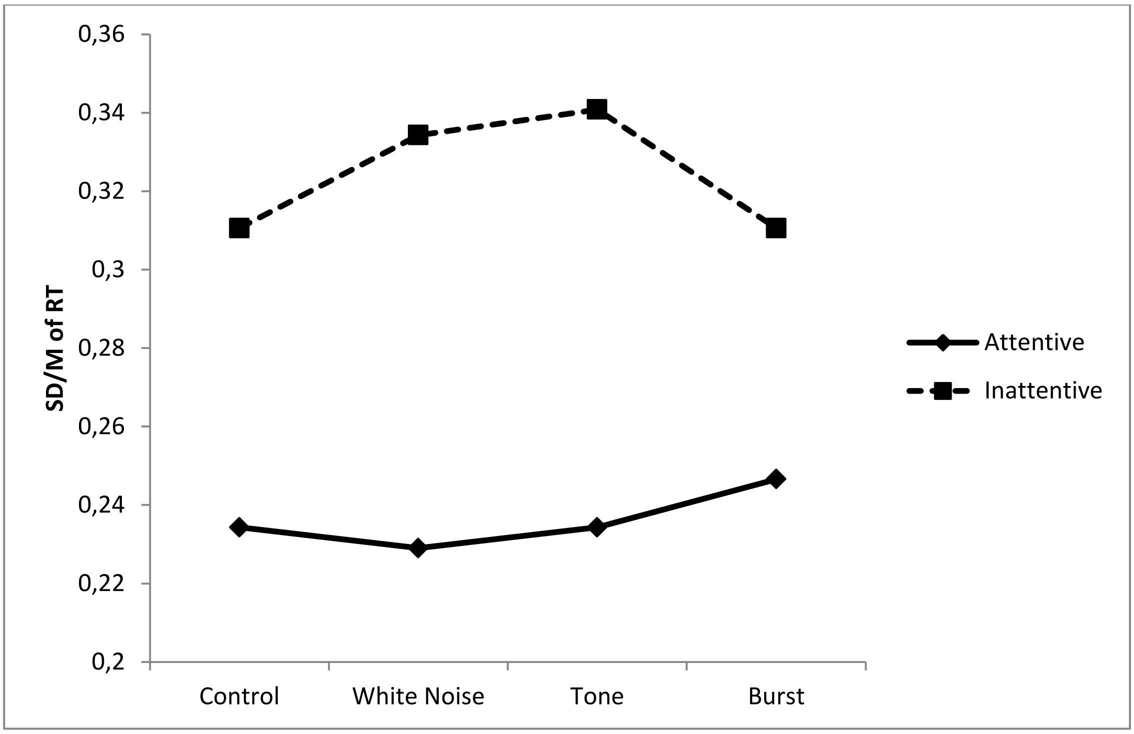

Figure 2. Response variability for each condition for attentive and inattentive groups. The graph shows that the inattentive group had significantly higher response variability across conditions.

Novelty slowing/ distractibility

Next it was investigated whether participants were slower at reacting to trials that followed novel, distracting pictures. If participants did slow down after novel trials it could be taken as a sign of the participant being distracted. Trials following novel pictures (Novel+1) were identified and a mean RT for these trials was calculated for each block and for every participant. These mean RTs were then compared to the mean RT of all other remaining correct trials (OT) in each block.

A mixed ANOVA with condition (four levels) and trial type (two levels, Novel+1 and OT) as within subject factors and group (attentive and inattentive) as between subjects factor was conducted. Reaction time in milliseconds was the dependent variable. There was a main effect of condition with the RT on the burst block being significantly slower compared to other conditions, $F(3,51) = 18.75, p < 0.001$.

There was no significant main effect of trial type, *F(1,17) = .102, ns,* showing that participants *did not* slow down after novel trials. There was also no significant interaction effects between trial type and group, *F(1,17) = .126, ns,* and condition and trial type, *F(3,17) = 1.96, ns,* or between condition, trial type and group, *F(3,17) = .450, ns.* These results showed that there was no post-novel trial slowing for either of the groups and this remained the case for all four noise conditions.

Post-error slowing

Next it was investigated whether participants slowed down after making an error. This is a previously known phenomenon called post-error slowing. Post-error slowing was analysed using the same logic as the analysis of post-novel trial slowing. Trials following errors (Error+1) where correct responses had been made were identified and a mean for these trials was calculated for each block for every participants. The same procedure was then done for all other trials (OT) with correct responses. If the mean RT for trials following errors was slower than the mean RT for remaining trials then post-error slowing can be determined.

A mixed ANOVA with condition (four levels) and trial type (Error+1 and OT) as within subject factors and group (attentive and inattentive) as the between subject factor was carried out. The dependent variable was reaction time in milliseconds.

Again, a significant main effect of condition was found, *F(3,42) = 11.94, p < .001,* with both groups responding slower in the Burst condition. There was no significant main effect of trial type, *F(1,17) = .001, ns,* indicating that overall, there was no evidence of any post-error slowing. There was also no significant effect of group, *F(1,14) = .004, ns.* There was, however, a significant interaction between condition, trial type and group, *F(3,17) = 3.57, p = .002.* By graphically examining the profile plots (see figure 3), it was found that the attentive group showed an *opposite* post-error slowing trend in the white noise condition and the burst white noise condition. In other words, in these two conditions the attentive group was *faster* on trials preceded by errors compared to all other trials. The inattentive group, on the other hand, showed the biggest difference in RT in the burst white noise condition with post-error trials being responded to slower than the other remaining trials. The inattentive group also showed some PES in the silent control condition, but in the white noise and tone conditions there was a slight opposite effect. These results can be seen in figure 3.

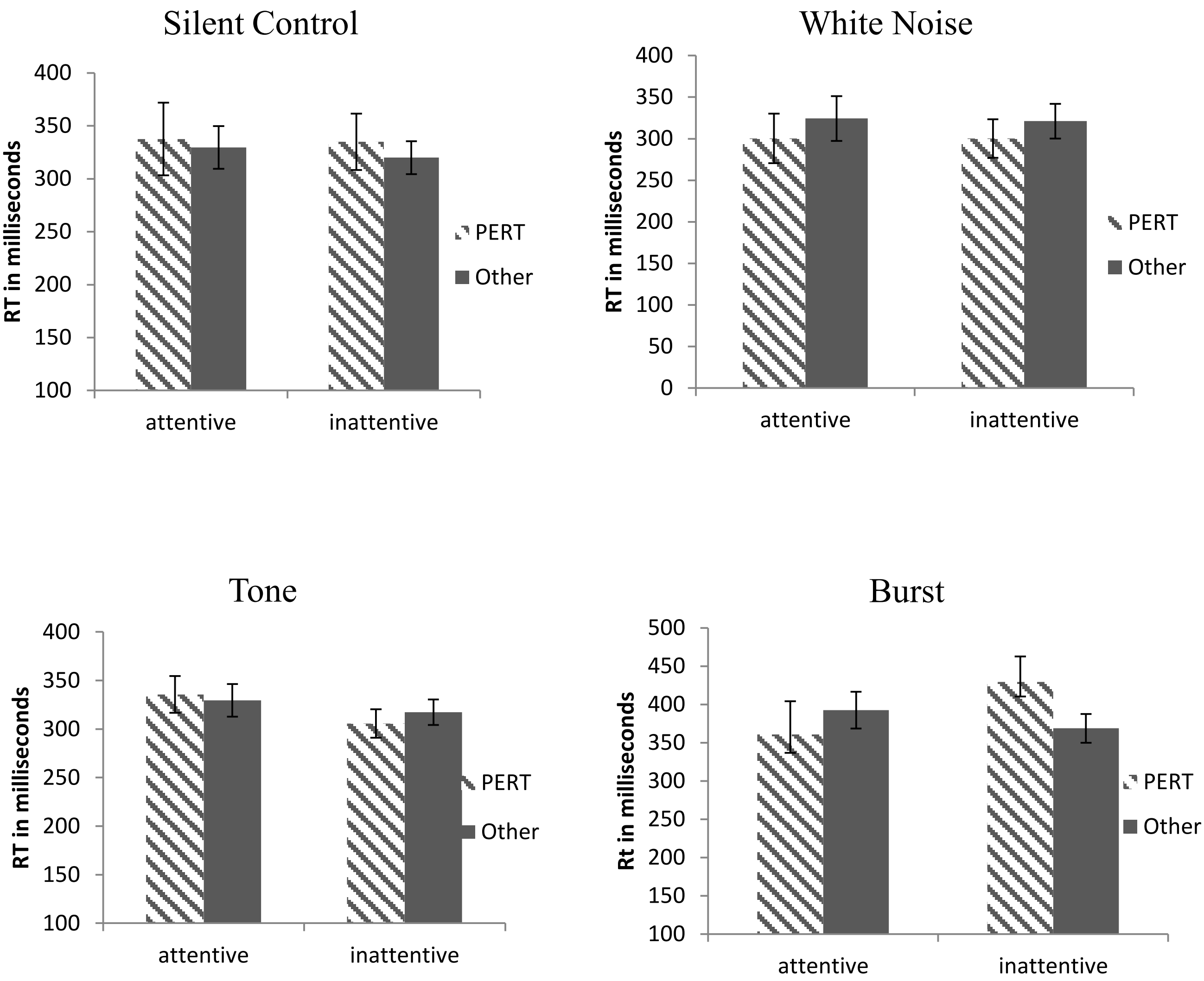

Figure 3. Post-error Reaction Times. The graph depicts the post-error reaction times (PERT) shown in diagonal stripes and the RT for all remaining trials (shown in solid grey) for the attentive and inattentive group, for all four conditions. In order for post-error slowing to be evident, the striped bar should be significantly larger than the solid grey bar. It can be seen that the attentive group showed an *opposite PES* effect in the white noise and burst condition and no significant difference between post error trials and other trials in the silent and tone conditions. The inattentive group showed some PES in the silent and burst conditions. Please note that the Burst condition graph has a different y-axis scale since the RT were generally slower in this condition.

Discussion

This study aimed to investigate the effect of white noise on sustained attention. Participants were divided into an attentive and an inattentive group based on their scores on the Adult ADHD Self-report Scale (ASRS) and performed an Oddball task. As was predicted, participants in the inattentive group showed impairments in sustained attention compared to the attentive group. The inattentive group made significantly more errors and showed larger variability in their reaction times, which is thought to reflect short lapses of attention (Kofler et al. 2013). Reaction times did not, however, vary between the groups, showing that the inattentive group was generally *not slower* than the attentive group. This finding is not very surprising since previous studies have found that people with ADHD are not on average slower than controls on most cognitive tasks, but instead show a larger variability in their speed of responding (Kofler et al. 2013). It can therefore be concluded that the ASRS was successful at identifying participants who struggle with sustained attention and that the group identified as inattentive showed the same impairments as people with ADHD.

White noise effect

The main aim of this study was to see if the performance enhancing effect of white noise that has previously been found on memory tasks (Söderlund et al. 2010) could be replicated on a sustained attention task. However, contrary to what was predicted, the inattentive group *did not benefit* from white noise. It was found that both groups' performance did not differ between the silent control condition, the continuous white noise condition and the tone condition. The only noise effect that was found was that both groups were *slower* on the burst white noise condition and made more omission errors in this block. Within the burst condition, both groups were faster at responding to the trials presented with white noise compared to the trials presented in silence. However, when the noise trials within the burst condition were compared to the other blocks, the burst noise trials were still responded to significantly slower. It was therefore perhaps not the white noise *per se* that gave faster reaction times to the noise trials compared to the silent trials in the burst condition, but instead there might have been an effect of cued versus non-cued trials. It was therefore concluded that the results of this study did *not* support the main hypothesis; performance on the Oddball task was not improved by listening to white noise for inattentive or attentive participants.

Distraction from novel pictures

The Oddball task used in this study required participants to respond to two types of stimuli, a square and a circle, and ignore irrelevant photographs of objects, animals and nature scenes, that were interspersed throughout the trials. The purpose of these task irrelevant photographs was to distract the participants and thereby make the task more difficult. In order to try and measure how distracted the participant was by the photographs, the RT to trials following novel photographs were analysed. However, there was no evidence of the participants in either group slowing down after novel trials. It is perhaps not very surprising that no significant effects were found using this distractibility measurement since the measurement does not seem to have been used before. How much the participants were distracted by novel pictures may instead be better measured using EEG and event related potentials (ERPs). In this type of study, distraction can be revealed by looking at what is known as the P3A, or novelty P3 component. This component is a peak in the EEG around 300ms after stimulus presentation and is shown in response to novel, or surprising items appearing. The size of the P3A component is thought to reflect how much attention is given to the novel item, or in other words how distracted the person was by the item (Gow et al. 2012). It can therefore not be conclusively stated that the inattentive participants in this study were not more distracted than the attentive participants, since the measure used to assess distractibility was probably flawed. Instead, an ERP study could reveal more about this area.

Post-error slowing

Post-error slowing (PES) is a well-established phenomenon and is commonly explained by an increase in response caution after an error which gives a longer response time (Dutilh et al. 2012). It has been suggested that one of the reasons why people with ADHD show impaired performance on cognitive tasks, is that they have a deficiency in their performance and error monitoring (van Meel et al. 2007). In this study, post-error slowing was measured by comparing RT on trials following errors to RT on all remaining trials within a block. The results of this analysis were very mixed. There was no *overall* trend of post-error slowing in either group. There was some evidence of post-error slowing in the inattentive group but only in the burst white noise condition. The attentive group, on the other hand, showed an *opposite* effect in the burst and continuous white noise condition, in where they appeared to respond *faster* to trials following errors.

The results of the post-error slowing analysis are unexpected since it was predicted that the attentive group would clearly show post-error slowing and the inattentive group would perhaps show a smaller slowing, or none at all. However, there appears to be a large variation in the data set regarding post-error slowing. By looking closer at individual participants' RT time, it could be seen that some participants showed post-error slowing trends and some showed strong opposite effects and these trends did not seem to be dependent upon attentiveness level.

This lack of significant results begs the question, why did the attentive participants not slow down after errors on the Oddball task? There does not seem to be any literature on post-error slowing in Oddball tasks, therefore it is hard to find a definite answer to the question. However, a probable explanation for the lack of post-error slowing is that the interval between trials was too long. Previous research on other types of cognitive tasks (Danielmeier & Ullsperger, 2011) found that PES was most pronounced when trials were separated by short intervals and that PES disappeared when the interval was longer than 750ms. In the current experiment, the inter-stimulus interval was random between 800 and 1200ms which might explain why no PES was seen. Again, this is another area where an ERP study would shed more light on the underlying processes. By examining the error-related negativity (ERN), a negative peak in the event-related potential around 50ms after an error has been made (Hajcak & Foti, 2008), more might be revealed about the difference in error processing between attentive and inattentive participants and the possible effect of white noise.

Lack of white noise effect

The biggest question to address regarding the results of the current study is; why didn't white noise improve performance? There are two main directions of explanations available: either the noise manipulation was not successful in this study and the method of the previous studies (Söderlund et al. 2007, 2009 & 2010) was not correctly replicated, or white noise actually has no effect on sustained attention.

In regards to the first option, the method of the current study did vary in a few ways from previous white noise research. First of all, in the continuous white noise condition, noise was played continuously for around 11 minutes. In Söderlund and colleagues (2010) study on verbal recall, white noise was only played during the presentation of a list of word pairs, which took 1 minute and 40 seconds. After the presentation, free recall, without noise followed. This means that the current study presented noise in much longer intervals compared to previous studies (Söderlund et al. 2010). Therefore, one alternative explanation is that noise does not improve performance if it is played in too long sessions.

Secondly, the method of the current study might have differed from previous studies in regards to how the noise volume was measured. In this study a hand-held decibel meter was used. However, to properly measure volume from headphones, the computer used to play the sound and the headphones need to be calibrated using advanced equipment. It is unclear how the previous studies measured their volume; therefore the exact decibel used might have differed. Although it does seem unlikely that a subtle volume difference would completely ameliorate the noise effect.

Lastly, the current study's method differed to that of previous research (Söderlund et al. 2007, 2009 & 2010) in another potentially important way; in the current study the participant sat alone in a room and made their responses directly on the computer, whereas in previous studies, the participants were required to verbally state their response to the experimenter. This could perhaps be part of the reason why a positive effect of noise was not found. It could be that white noise only has a positive effect if the participant is already quite motivated to perform well. The participants in the previous studies (Söderlund et al. 2007, 2009 & 2010) may have had a higher baseline arousal level compared to participants in the current study. The current experiment could have been too boring and the participants' arousal and motivation level would therefore have been too low for white noise to be able to have an effect. Arousal and especially motivation could be increased on the Oddball task, either by having the experimenter present in the testing room or by adding a continuous feedback component about speed and accuracy to the task.

The second option available to explain why a positive effect of white noise was not seen is that white noise does not have an effect on sustained attention. Based on the results at hand it might be the case that white noise affects memory and verbal recall, specifically, and not attention. Therefore, in the previous white noise studies (Söderlund et al. 2007, 2009 & 2010) it would appear that the inattentive and ADHD participants might have performed better when exposed to noise, not because they were able to concentrate more on the task and therefore encode more information, but because their *memory* was improved. According to this reasoning, white noise works by affecting higher processes and not the more basic process of sustaining attention.

The Moderate Brain Arousal Model

This is slightly surprising given Söderlund et al.'s (2010) proposed explanation of how white noise affects performance. The MBA (Moderate Brain Arousal model) states that inattentiveness in people with ADHD stems from low levels of noise, or tonic firing, in the dopamine system. White noise is thought to add to the internal noise level, making the entire system less volatile. Since difficulties sustaining attention is closely linked with inattentiveness, based on the MBA model of white noise, it would be expected that inattentive participants would improve on a test of sustained attention with white noise. In other words, an improvement would be expected since, in theory, the cause of the inattention, low dopamine levels, is being remedied, so therefore one of the main symptoms of inattention should be alleviated. Perhaps white noise does not function in the way that Söderlund and colleagues (2010) suggest.

The proposed MBA account of white noise associated performance improvements makes some assumptions that are hard, if not impossible test. First of all, the assumption that people with ADHD, or more generally, inattentive people, have low levels of dopamine is based on the fact that stimulant medication, which affects the dopamine system of the brain, alleviates symptoms in people with ADHD (Glaser and Gerhardt, 2012). It is not possible to measure the level of dopamine neuron firing in humans without using invasive methods; therefore it is hard to verify that the dopamine system is malfunctioning in ADHD or that this is what *causes* the symptoms. In a disorder as heterogeneous as ADHD, with symptoms varying in type and severity, it seems unlikely that there is one sole cause. Other neurotransmitters, besides dopamine, have been found to be involved in ADHD, especially norepinephrine (Glaser & Gerhardt, 2012). Therefore, the picture is most likely not as clear as the MBA model's account of white noise suggests, with low levels of tonic dopamine resulting in symptoms of inattention.

The second assumption of the MBA model's account of white noise that is potentially problematic is that white noise actually affects the dopamine system of the brain. The model does not specify whether white noise *directly* or *indirectly* adds to the “internal noise” or tonic dopamine neuron firing, but regardless of this, it is not easily possible to test if this assumption holds true. Again, this is because of the lack of non-invasive methods available for assessing tonic neuron firing. The model also does not state *how* external auditory noise adds to internal noise levels and it is not explained why positive effects of white noise are only seen at louder noise levels. According to the model, should white noise not add to the internal noise at all amplitudes, as long as the sound is perceived?

Regardless of the accuracy of the MBA model's account of how white noise improves performance, according to the results of the current study it could be the case that white noise only improves memory and not attention. If this is true, what implications does this then have for the possibility of using white noise as a therapy for ADHD?

Since the ability to sustain attention underlies a great deal of other processes such as reading, listening to instructions and memorizing, white noise therapy would obviously have been a successful therapy if it was able to help sustain attention. So far, white noise has only been found to improve recall on memory tasks. However, poor memory is not a main symptom of ADHD and therefore, if memory is the only process improved by white noise then the therapy might not make a big difference in scholastic performance, work performance or social relationships for people with ADHD or ADHD symptoms. Sustained attention is, however, a process that *is* impaired in ADHD and in people with ADHD consistent symptoms, as the results of the current study show. More effort should perhaps instead be put into finding non-pharmaceutical therapies for improving sustained attention.

Limitations

The current study contained some limitations that should be addressed if the experiment was to be repeated. First of all, it was attempted to replicate the previous study on white noise (Söderlund et al. 2010) by playing white noise at the same volume (78dB). However, none of the previous studies specified their exact method of measuring volume. In order to measure volume accurately from headphones, advanced equipment is needed. This type of equipment is difficult to obtain which is why this study used a regular decibel meter instead. This method may have resulted in an inaccurate decibel reading and the white noise may not have been played at exactly 78dB. This limitation did probably not affect the results of the current study greatly, but is still important to address.

The second issue with the current study regards the burst white noise condition. In this block, white noise was played 500ms before the picture was presented and continued to play throughout the picture presentation. Half of the trials were presented with noise, and half without. Due to various technical limitations, there was some lag in the sound and picture presentation. This resulted in the pictures being presented for a longer period of time on some trials. Some of the participants interpreted this lag as if their response to the picture had not been registered and therefore pressed the corresponding button twice. This limitation may have affected the results on the burst block by creating slower response times. However, this limitation is not crucial for the results since it does not affect the main manipulation of the study which was continuous noise versus no noise.

The third limitation that should be addressed in a replication of this experiment is the low number of participants used in the study. It would be valuable to continue testing more participants to see if an increase in power would reveal a positive white noise effect. It would also be useful to test a wider range of participants by for example, including children and teenagers and participants with higher scores on the ASRS questionnaire and more ADHD symptoms.

Future research

Future research on white noise effects should first of all address the limitations of the current study and repeat the experiment using more participants with a wider age range and more ADHD symptoms. It should also be tested whether presenting white noise at different volumes and at varying lengths results in a performance enhancing effect. The participants' motivation and arousal levels should also be manipulated by, for example, using feedback and higher event rates on the Oddball task. Other tests that tax sustained attention, besides the Oddball task, could also be used to attempt and find a white noise effect.

If these manipulations still do not result in evidence towards white noise affecting attention then research should instead focus on exploring if other processes besides verbal recall, episodic memory and attention are improved by listening to white noise. The most interesting area to investigate would be the effect of white noise on working memory. Working memory is one of the key components that is impaired in ADHD and deficits in working memory affects many other abilities such as problem solving, planning and executing steps to obtain a goal (Klingberg et al. 2005).This type of research could, for example, use an N-back working memory task to test if white noise improves performance. In the N-back task, participants are shown different pictures and have to identify when a picture that was shown two presentations ago is repeated. People with ADHD have been shown to be impaired on the N-back task by having a larger response variability and lower accuracy compared to controls (Epstein et al. 2011b). This makes the N-back task ideal for testing white noise effects. There are also several working memory training schemes available for people with ADHD that have shown positive effects on symptoms of inattention and hyperactivity (Klingberg et al. 2005). If white noise is found to have an effect on working memory, it would be very interesting to test the computer training programs for working memory together with white noise. Perhaps this could increase the effect of the working memory training.

Other cognitive processes that should be tested for effects of white noise are interference handling and inhibition because these processes have also been found to be impaired in ADHD (Epstein et al. 2011). Specific tasks that could be used include: the flanker task (interference), the stop-signal task (inhibition) and go/no-go tasks (inhibition). These three types of tasks are also possible to use in an ERP study which, if conducted, would shed more light on the effects of white noise on cognition.

In regards to future directives for improving sustained attention in inattentive people or people with ADHD, training schemes like those used to improve working memory (Klingberg et al. 2005) could be explored. Sustained attention may not be improved only through repeated practice since the tasks are very boring and training adherence could be hard to achieve, therefore, strategies for increasing *motivation* to sustain attention should be found and evaluated. This could potentially be done through using reward schemes, specifically tailored to an individual.

Conclusion

In conclusion, this study was unsuccessful at replicating a positive white noise effect for inattentive participants on an Oddball task. It was found that inattentive participants were impaired, compared to attentive participants, on the Oddball task but that these impairments were not reduced by listening to white noise. However, it is suggested that a positive effect of white noise on the Oddball task could be seen if baseline arousal levels and motivation to perform at a high level are increased. It is also suggested that the experiment should be repeated with a higher number and a wider range of participants and using varying volumes and lengths of noise presentation before it can be concluded that white noise does not affect sustained attention. It is proposed that future research on white noise therapy for people with ADHD should also focus on investigating noise effects on working memory tasks, inhibition tasks and interference tasks. More attempts should also be made in order to find more alternative non-pharmaceutical therapies to improve sustained attention in inattentive people and people with ADHD since this ability underlies a great deal of other important, higher level processes.

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