Distractor or Noise?
The Influence of Different Sounds on Cognitive Performance in Inattentive and Attentive Children

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1. Introduction

It is a well known and certified fact that noise under most circumstances interfere with cognitive processing of various kinds, e.g. vigilance (e.g. Broadbent, 1951), arithmetic's (Broadbent, 1958), and response speed (Broadbent, 1957). This effect is assumed to be due to the competition of attentional resources between the target and the distracting stimuli. This finding is often replicated and found valid among different tasks and participant populations (Belleville, Rouleau, Van der Linden, & Collette, 2003; Boman, 2004; Klatte, Meis, Sukowski, & Schick, 2007; Rouleau & Belleville, 1996). Most research since Broadbent's days has dealt with the negative effects of noise and different kinds of auditory distraction. In line with this earlier research has demonstrated that inattentive persons, such as children with ADHD (attention deficit /hyperactivity disorder) are even more susceptible to distraction as compared with their attentive peers. This has been shown in numerous of studies (e.g. Corbett & Stanczak, 1999; Geffner, Lucker, & Koch, 1996; Rickman, 2001).

However, in contrast to the main body of evidence, there have been a few reports of contradictory findings. Specifically, it has been shown that under certain circumstances, children with attentional problems, rather than being distracted, actually benefit from environmental noise presented with the concurrent target task. Until recently, this facilitating effect of non-task related environmental auditory stimulation has been limited to the effects of background music on arithmetic task performance by children with ADHD (Abikoff, Courtney, Szeibel, & Koplewicz, 1996; Gerjets, Graw, Heise, Westermann, & Rothenberger, 2002). In addition, road traffic noise was found to improve episodic memory among children from households with low socio-economic status, a group that is likely to be distinguished by attentional problems and academic under-achievement (Matheson et al., 2010; Stansfeld et al., 2005). However, these studies have not provided a satisfactory theoretical account for why noise, under certain circumstances, can be beneficial for cognitive performance.

There are some early studies that provide a theoretical account for noise enhancement. In these studies, hyperactive children improved their performance in demanding attention tasks where noise was introduced by visual stimulation (Zentall, 1986; Zentall & Dwyer, 1989; Zentall, Falkenberg, & Smith, 1985), or auditory stimulation (Zentall & Shaw, 1980). In these experiments the positive effect was attributed to a general increase of arousal, formulated in a theoretical framework named "the optimal stimulation theory" (Zentall & Zentall, 1983). However, this optimal stimulation theory has not been explored or developed further.

The aim with the present chapter is to present a plausible theoretical explanation as to why, when, and how noise can improve executive functions and cognitive performance in various tasks. Our research has recently extended these findings and for the first time will here be suggested a theoretical framework for understanding which conditions are necessary for noise induced cognitive enhancement to occur. We have shown that auditory noise has different effects on the memory performance of children with an ADHD diagnosis compared to normally developed children (Söderlund, Sikstrom, & Smart, 2007). These effects have been replicated, and found valid in further studies comprising sub-clinical, inattentive participants (Söderlund, Marklund, & Lacerda, 2009; Söderlund, Sikström, Loftesnes, & Sonuga-Barke, 2010). In the following section we introduce a model and findings that demonstrate a link between noise stimulation and cognitive performance. This has been named the Moderate Brain Arousal (MBA) model (Sikström & Söderlund, 2007), which suggests a link between attention, dopamine transmission, and external auditory noise (white noise) stimulation.

2. The phenomenon of Stochastic Resonance

Perceptual stochastic resonance (SR) is the counterintuitive phenomenon by which weak sensory signals that cannot be detected because they are presented below the detection threshold, become detectable when additional random (stochastic) noise is added (Moss, Ward, & Sannita, 2004). Signaling in the brain is characterized by noisy inputs and outputs. The crucial task of the central nervous system is to distinguish between the signal, the information-carrying component, and noise that constitute meaningless neural inputs. The paradox is that the brain can actually use noise to differentiate the signal in the targeted stimuli from noise, so noise actually improves or increases the signal-to-noise ratio. The requirement for this phenomenon to occur is the introduction of non-linearity in the response, for example through a threshold function. This is shown in Figure 1, where the noise and the signal interact. The noise adds to the signal and brings the neuron over the activation threshold, and elicits a neural response (action potential), giving the auditory system a representation of the signal (a sinus tone).

SR is well established across a range of settings, and exists in any threshold-based system. The concept of SR was originally introduced to explain climate changes (Benzi, Parisi, Sutera, & Vulpiani, 1982), but has been identified in a number of naturally occurring phenomena, some examples are: in bi-stable optical systems (Gammaitoni, Hänggi, Jung, & Marchesoni, 1998); in mechanoreceptors of the crayfish (Douglass, Wilkens, Pantazelou, & Moss, 1993); and in the feeding behavior of the paddlefish (Russell, Wilkens, & Moss, 1999). SR is in particular found in the nervous system, distinguished by its all-or-none nature of action potentials.

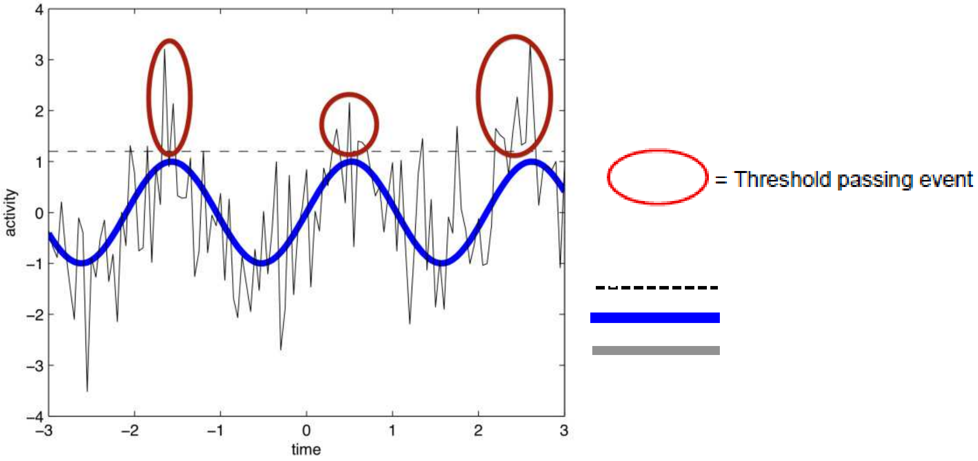

Fig. 1. Stochastic resonance where a weak sinusoidal signal goes undetected as it does not bring the neuron over its activation threshold. With added noise, the same signal results in action potentials.

In humans SR has been found in different modalities: in touch, where tactile random stimulation made skin receptors more sensitive (Wells, Ward, Chua, & Timothy Inglis, 2005); in audition, where white noise improves auditory detection in a group with normal hearing (Zeng, Fu, & Morse, 2000), and in participants with cochlear implants (Behnam & Zeng, 2003); in vision, where visual (flickering) noise improved detection of weak signals (Simonotto et al., 1999). Interestingly, cross modal SR has been found, where weak visual signals became detectable when participants where exposed to loud auditory white noise (Manjarrez, Mendez, Martinez, Flores, & Mirasso, 2007). SR can improve motor control and balance as well. Elderly, diabetics, and Parkinson patients' performance was enhanced through stochastic noise transmitted by vibrating soles (Novak & Novak, 2006; Priplata, Niemi, Harry, Lipsitz, & Collins, 2003; Priplata et al., 2006). In neurodegenerative disorders galvanic stimulation of the vestibular organs improved motor control considerably (Pan, Soma, Kwak, & Yamamoto, 2008; Yamamoto, Struzik, Soma, Ohashi, & Kwak, 2005). To sum up, SR is present in the entire nervous system in all modalities, and it seems that the nervous system can take advantage of noise both in sensory discrimination and motor control. SR is usually quantified by plotting detection of a weak signal, or cognitive performance, as a function of noise intensity. This relation exhibits an inverted U-curve, where performance peaks at a moderate noise level. That is, moderate noise is beneficial for performance, whereas too much, or too little noise attenuates performance.

While less known, empirical evidence also suggest that SR improves central processing in the brain and thus improves cognitive performance. For example a facilitating effect of cognitive SR has been found where auditory noise improved the speed of arithmetic computations in a normal group of school pupils (Usher & Feingold, 2000). In a visual task, face recognition, response times got shorter when the vestibular organs where stimulated by a weak stochastic galvanic current (Wilkinson, Nicholls, Pattenden, Kilduff, & Milberg, 2008) finally, figure copying became more accurate when exposed to galvanic stimulation

(Wilkinson, Zubko, Degutis, Milberg, & Potter, 2009). This indicates that also higher cognitive processing is susceptible for SR.

3. Individual differences in SR and the Moderate Brain Arousal Model (MBA)

Most of the above-referred references of the SR-effect are made with normal populations, and the revealed effects of noise are found to be valid for the entire population. Our research group has focused on cognitive effects of SR in particular groups with attentional problems, like in ADHD, where we have found differential effects of noise on cognitive performance. Some groups of participants improve their performance, whereas the performance other groups deteriorate when exposed to noise. The question is how these differentiations can be explained. We propose the Moderate Brain Arousal model (MBA) which is developed to address and explain these differences (Sikström & Söderlund, 2007). The MBA model was developed to respond to the limitation of standard psychophysical models in explaining the noise facilitating effect in children with attention problems. The model is based on established facts concerning SR; *first*, that the SR phenomenon is highly sensitive to the intensity of the signal and; *second*, the intensity of the noise, where the cognitive or perceptual performance shows an inverted U-shaped curve when plotted against noise intensity (e.g. Moss, et al., 2004). Thus, a moderate level of noise is beneficial for performance. Too little noise does not add sufficient input to bring the signal over the activation threshold, and too much noise overpowers the signal – in both cases leading to deterioration in attention and performance. The crucial and innovative insight of the MBA model is that there are individual differences in the benefit of noise; some people need just a small amount of noise and some need a lot of noise to achieve optimal performance (see Figure 2). This is because individuals differ in internal levels of background noise and signal levels in their neural systems. That is, where noise levels are low, external noise has to be added to reach an optimal performance, and to achieve a moderate brain arousal level. Furthermore, required noise levels are linked to neurotransmitter function and in particular to dopamine. A hypo-functioning dopamine system is linked to inattention, and recent research suggests that ADHD possess low levels of extracellular dopamine (Solanto, 2002; Volkow et al., 2009; Volkow et al., 2007). The MBA model proposes that noise, as an alternative to stimulant medication, can compensate for low dopamine levels (Sikström & Söderlund, 2007).

In summary, the MBA model posits that cognitive performance in ADHD and inattentive children benefits from noisy environments because the dopamine system modulates the SR phenomenon. It suggests that the stochastic resonance curve is right shifted in persons with a ADHD diagnose due to lower gain or lower dopamine. levels The MBA model predicts that for a given cognitive task ADHD children and inattentive children require more external noise or stimulation compared to control children, in order to reach optimal (i.e. moderate) brain arousal level (see Figure 2). This prediction has been tested and confirmed in several different settings with various participant groups and tasks. Word recall tests in children with ADHD (Söderlund, et al., 2007), non-clinical, inattentive school children (Söderlund, et al., 2010), and low performing school children (Söderlund & Sikström, 2008). The effect has also been found in a dichotic listening task, and in a visuo-spatial working memory task in a normal student population, where half of the participants rated themselves as inattentive (Söderlund, et al., 2009). At the moment we have preliminary data showing significant effects of noise on three different cognitive tasks in parity with, or even larger, than the effects of stimulant medication (Söderlund et al., in progress).

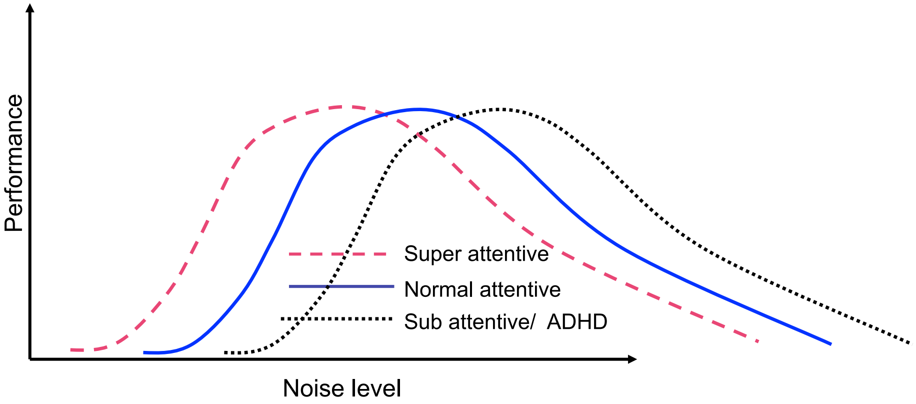

Fig. 2. The relationship between noise levels, attention ability, and cognitive performance. Sub-attentive participants (e.g. ADHD) require more noise for maximal performance according to the MBA model.

4. The difference between distractors and noise

As shown in numerous experiments, environmental auditory noise exerts a negative influence on schoolwork and on cognitive performance in general. Comparisons have been made with various sounds that are proposed to have a negative impact on different kinds of intellectual work. Both irrelevant meaningful speech and road traffic noise have been found ta have a detrimental effect on both semantic and episodic memory recall in adults (Hygge, Boman, & Enmarker, 2003). Also school children were susceptible to these kinds of distractors when performing mathematical computations (Ljung, Sörqvist, & Hygge, 2009). Aircraft noise seems to be detrimental during most kinds of work that require attention (Hygge, Evans, & Bullinger, 2002; Matheson, et al., 2010; Stansfeld, et al., 2005), even the day after the noise exposure (Stansfeld, Hygge, Clark, & Alfred, 2010). Semantically meaningful irrelevant information is found to be distracting, but does also interact with working memory capacity; persons that possess a high working memory capacity were less distracted by irrelevant speech than peers with lower capacity (Sörqvist, 2010a, 2010b; Sörqvist, Ljungberg, & Ljung, 2010).

In the present study we further investigated different environmental soundscapes that have ecological relevance out of a school perspective, and their impact on a demanding working memory task. For this purpose we created four different background noises or soundscapes that could occur in a classroom setting: 1) speech or classroom noise; 2) white noise; 3) a mix of speech + white noise; and finally 4) a silent condition. We posed the question whether pure noise is the best way of introducing cognitive enhancement in inattentive children, or whether ecologically valid soundscapes could produce similar cognitive enhancement.

We predicted that auditory environmental stimuli would have a positive effect on inattentive persons and be detrimental to the attentive persons. In particular, based on previous data, we predicted this effect to occur for white noise. However, we posed no direct prediction on whether speech might produce cognitive enhancement effects on inattentive children.

5. Methods

5.1 Participants

Twenty-two primary school children between 7 and 10 years old (M = 8.3 yrs) participated in the present study (14 boys and 8 girls). The twenty-two participants were screened and selected out of a group of 33 participants according their attention ability as reported by their teachers. The eleven that scored lowest on the attention scale where selected for the inattentive group while the ones that scored high on attention formed the attentive group. What was considered normal or above average in attention was decided according to their teacher's judgments. For this purpose a SNAP score with 18 questions were used (Swanson et al., 2007). Mean score for the inattentive group was 28.8 and for the attentive 1.5. 28 points is slightly below the cut off point for ADHD diagnosis (36). None of the participants were consequently diagnosed with ADHD or any other neuropsychiatric diagnoses. Participants were also considered to be within a normal range with regard to general school performance.

5.2 Materials

A visuo-spatial working memory (vsWM) test was used (spanboard; Westerberg, Hirvikoski, Forssberg, & Klingberg, 2004). This test is a sensitive measure of cognitive deficits in ADHD. The test determines working memory capacity without being affected by previous skills or knowledge. The visuo-spatial WM task consists of red dots (memory stimuli) that are presented one at a time at a computer screen in a four by four grid. Inter-stimulus-intervals were 4 seconds, target is shown for 2.225 sec and a 1.725 sec pause is given before the next target turns up. Participants are asked to recall location, as well as the order in which the red dots appear. The working memory load increases after every second trial, and the working memory capacity is estimated based on the number of correctly recalled dots. Dependent variable was total number of correctly recalled dots.

All noise conditions were recorded and reproduced on a CD player. The speech part of the speech and noise condition was recorded at a café at Stockholm University, where five students discussed films, books, and what they did over the weekend. The equivalent continuous sound level of the white noise was set to 78 dB(A) in the three noise conditions, in accordance with findings from earlier studies (Söderlund, et al., 2007; Söderlund, et al., 2010).

5.3 Design

We used a 2 x 4 design, where sound environment (silence vs. white noise; silence vs. speech; silence vs. speech + white noise) was the within group variable. The between group variable was teacher rated classroom attention level (attentive vs. inattentive)

5.4 Procedure

The testing was conducted at the children's school, following permission from parents and children. The regional ethic board in Stockholm approved the study. The participants were tested individually in a room during the school day.

The participants were tested individually in a room during the school day. All participants used the same 15′ laptop PC for the visuo-spatial test (span-board). Headphones provided the noise, and dB levels where checked for all participants ahead of every session. Before starting the experiment proper, two practice trials were conducted. The time taken to complete each test was approximately 5 minutes, depending on the performance level (the better performance the longer time). Altogether, the testing sessions lasted approximately 30 minutes including instructions and test trials. The noise conditions were presented in random order so each condition appeared equally many times in each position (first, second, third, and forth).

6. Results

A 2 x 4 mixed ANOVA was conducted including all noise conditions. No main effect of noise was found, but a significant overall interaction was found between noise and group (F(18,3)= 3.44, p= .039, eta^2 = .365). The difference between groups was also significant, where the attentive group outperformed the inattentive group in all conditions (F(20,1) = 12.63, p = .002, eta^2 .387)

Thereafter we conducted three separate 2 x 2 mixed ANOVA's, one for each noise condition. It comprised one between-subject factor, *group* (attentive vs. inattentive) and one within-subjects factor, *encoding stimulation condition* (silence vs. white noise; silence vs. speech; silence vs. speech + white noise). The data from these tests are presented in the three graphs below. In neither of the three noise conditions we found a main effect of noise, but in two out of three conditions we found a robust noise x group interaction.

In the first ANOVA, (silence vs. white noise, Figure 3) we found an interaction between group and noise. The inattentive group improved its performance whereas the attentive

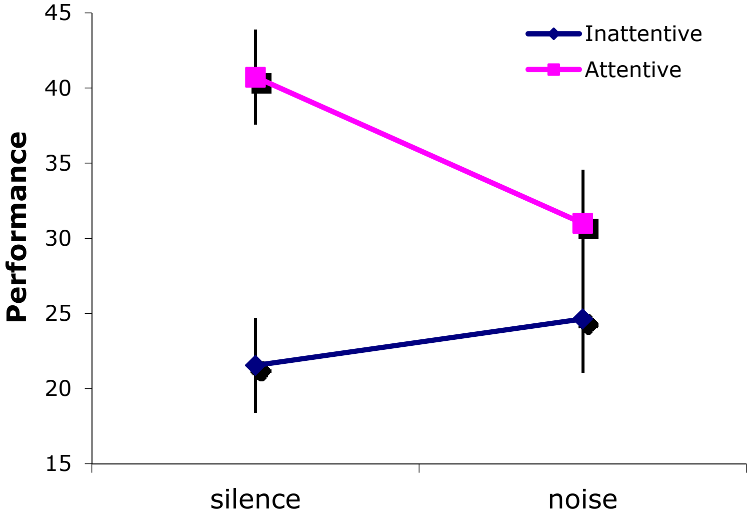

Fig. 3. Number of correctly recalled items in a visuo-spatial working memory task as a function of noise condition; silence vs. white noise in two groups: attentive (N=11) and inattentive (N=11).

group declined under the white noise condition (F(20, 1)= 8.17, p = .010, eta^2 = .290). A one-way ANOVA showed that the difference between groups in the silent condition disappeared in the noise condition (p < .001 vs. p= .222)

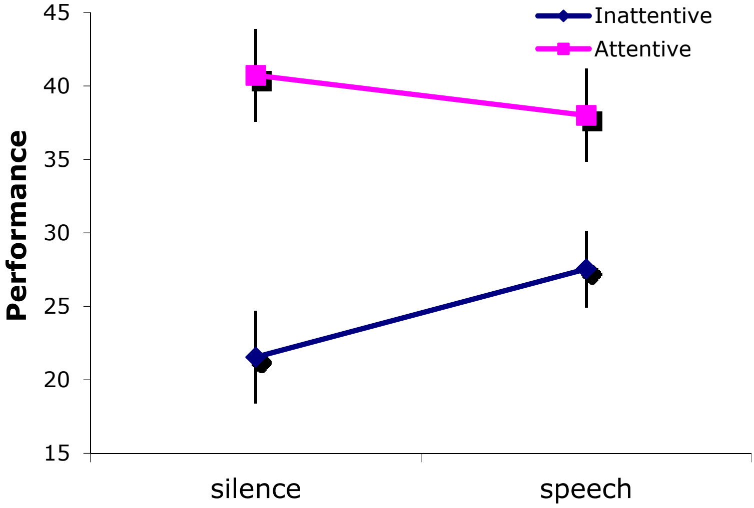

Fig. 4. Number of correctly recalled items in a visuo-spatial working memory task as a function of noise condition; silence vs. speech noise in two groups: attentive (N=11) and inattentive (N=11).

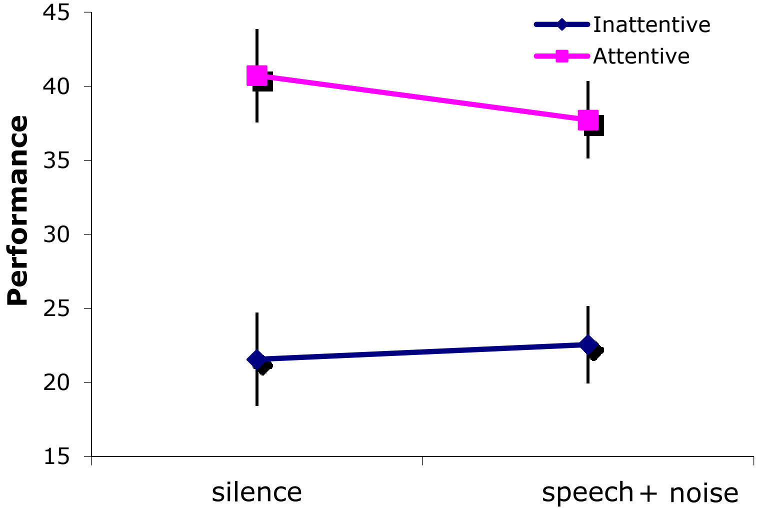

Fig. 5. Number of correctly recalled items in a visuo-spatial working memory task as a function of noise condition; silence vs. speech noise in two groups: attentive (N=11) and inattentive (N=11).

A paired samples test, testing groups separately, revealed that the decrease for the attentive group was significant (t(10)= -2.95, p = .015), whereas the increase in performance for the inattentive group did not reach significance (t(10)= 1.02, p = .333; Figure 3).

The second ANOVA (silence vs. speech, Figure 4) also showed a significant interaction, in this case, between group and speech (F(20, 1)= 6.15, p = .019, eta^2 = .246). The inattentive group performed better and the attentive group performed worse in the speech condition as compared to performance in the silent condition.

A paired samples test, testing groups separately, revealed that the increase for the inattentive group was significant in the speech condition (t(10)= 3.01, p = .013) whereas the decrement for the attentive group was not (t(10)= .981, p = .350). Finally, the one-way ANOVA showed that, despite the improvement for the inattentive group, in the speech condition the difference between groups remained significant (F(20, 1)= 5.43, p = .030).

In the last ANOVA (silence vs, speech + noise, Figure 5) there was no interaction between the group and noise condition The robust different between groups remained in the speech + noise condition (F(20, 1)= 16.94, p = .001). Neither did a paired sample t-test reveal a difference between groups as an effect of noise, both groups performed at the same level in silence as in the speech + noise condition (p= .766 vs. p = .368)

7. Conclusions and future challenges

As predicted, the results shown above confirm earlier findings showing different effects of white noise on attentive and inattentive children selected from a normal population. The sub-clinical inattentive group did indeed benefit from noise, while their attentive peers did not. Interestingly, the speech (classroom noise) condition did not lead to any detrimental effects for the inattentive group, but improved their performance as well. These results suggest that the beneficial effects of auditory environmental stimulation on inattentive people are found not only in pure noise conditions, as has been found previously, but generalize to broader sets of environmental sounds. In particular, this study demonstrates that noise enhancement can be found for speech. To what extent noise enhancement effects generalize to other auditory stimuli is still unexplored. However, these results suggest that we need to be open to the idea that wider sets of environmental stimulation may serve the benefit of cognitive enhancement in inattentive people. The cafeteria/classroom noise condition improved working memory performance for the inattentive group, whereas the attentive participants' performance decreased.

The reviewed literature has found inconsistent results regarding the effect of noise on performance in cognitive tasks. Studies have shown detrimental effects, no effects, and that noise interacts with other variables such as gender or time of the day (Baker & Holding, 1993; Baker, Holding, & Loeb, 1984; Belleville, et al., 2003; Boman, Enmarker, & Hygge, 2005; Rouleau & Belleville, 1996). It is plausible that controlling for participant characteristics such as age, attention ability and working memory capacity would provide other results. Differential effects of noise can be hidden in group means, were some participants improve while the performance of others is impaired.

Our findings suggest a need for further studies of psychoacoustics on different soundscapes. Previous research has focused on testing different noise levels (amplitudes in dB) over larger samples of participants. However, the data presented here propose that different sounds need to be investigated in relation SR. White noise might be tiring to listen to for extended periods. Future research needs to address the question of whether sounds from waterfalls, shivering leafs or sounds from bamboo grass could be beneficial as well. These noise-like sounds possibly include sufficient variability in both amplitude and frequencies to induce the required increase of variability into the nervous system.

Future studies should investigate the neurophysiological traces set by noise by EEG measures. Earlier studies have shown that ADHD patients display elevated relative theta power, theta/alpha, and theta/beta ratios during rest (Barry, Clarke, & Johnstone, 2003). We have reason to believe that noise exposure could normalize these anomalies, and increase the level of beta and gamma activity particularly. Beta and gamma activity is crucial for higher mental activities, such as focused attention. Furthermore, the expanding field of neuro-feedback is providing /investigating interesting tools to improve attention; however, small effect sizes have been shown this far (Arns, de Ridder, Strehl, Breteler, & Coenen, 2009; Gevensleben et al., 2009). The outcome effects of neuro-feedback might get boosted if combined with noise exposure and may, in particular, shorten the time needed to obtain robust and long-lasting effects. The field of noise-induced improvement is still in its infancy, and a lot of research is needed to get a good picture of the potential contributions from this new field. Nevertheless, we find the results very promising this far, and foresee a growing field of possible applications. In Swedish education and elsewhere, school failures increase. Current figures show that about 25% do not achieve a complete exam from compulsory or upper secondary school (Skolverket, 2005). Individually adapted study environments, utilizing the benefits of noise, may be one possibility to turn this downward trend.

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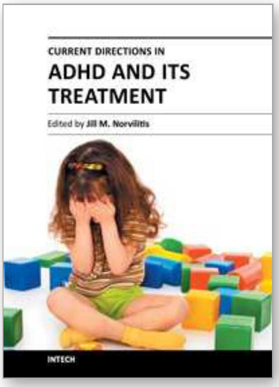

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The treatment of Attention Deficit Hyperactivity Disorder is a matter of ongoing research and debate, with considerable data supporting both psychopharmacological and behavioral approaches. Researchers continue to search for new interventions to be used in conjunction with or in place of the more traditional approaches. These interventions run the gamut from social skills training to cognitive behavioral interventions to meditation to neuropsychologically-based techniques. The goal of this volume is to explore the state-of-the-art in considerations in the treatment of ADHD around the world. This broad survey covers issues related to comorbidity that affect the treatment choices that are made, the effects of psychopharmacology, and non-medication treatments, with a special section devoted to the controversial new treatment, neurofeedback. There is something in this volume for everyone interested in the treatment of ADHD, from students examining the topic for the first time to researchers and practitioners looking for inspiration for new research questions or potential interventions.

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