Positive effects of noise on cognitve performance: Explaining the Moderate Brain Arousal model

Göran Söderlund[1*], Sverker Sikström[2]

1 Department of Linguistics, Stockholm University, Sweden and School of Psychology, University of Southampton, UK

2 Lund University Cognitive Science (LUCS), Sweden

* corresponding author: e-mail: goran@ling.su.se

ABSTRACT

Distractors and environmental noise has long been regarded as detrimental for cognitive processing. In particular children with Attention Deficit Hyperactivity Disorder (ADHD) are extremely sensitive to distraction from task irrelevant stimuli. However, recently it has been shown that exposure to auditory white noise facilitated cognitive performance in ADHD children whereas control children performed worse. The Moderate Brain Arousal (MBA) model (Sikström & Söderlund 2007) suggest that this selective effect of noise adheres from stochastic resonance (SR). This phenomenon occurs in any system where a signal plus noise requires passing of a threshold, for example the all or none nature of action potentials in neural systems. The basic assumption is that noise in the environment, through the perceptual system introduces noise in the neural system. According to the SR phenomenon moderate noise is beneficial for cognitive performance whereas both excessive and insufficient noise is detrimental. The MBA model suggests that the amount of noise required for optimal cognitive performance is modulated by levels of dopamine. The model predictes that low dopamine children, as in ADHD, require more noise compared to high dopamine children for optimal cognitive performance; in short, when dopamine is low noise is good.

Keywords: ADHD, noise, episodic memory, dopamine, model

INTRODUCTION

It has long been known that, under most circumstances, cognitive processing is easily disturbed by environmental noise and non-task compatible distractors (Broadbent 1958). This effect is believed to be due to competition for attentional resources between the distractor and the target stimuli. The distractor effects hold across a wide variety of tasks, distractors and participant populations (Belleville et al. 2003; Boman et al. 2005; Hygge et al. 2003; Rouleau & Belleville 1996; Shidara & Richmond 2005). Children with attentional problems such as ADHD are more vulnerable to distraction compared to normal control children (Corbett & Stanczak 1999; Geffner et al. 1996). In contrast to the main body of evidence regarding distractors and noise, there have been a few reports of contradictory findings, although these findings have not been satisfactory explained. Specifically that under certain circumstances children with attentional problems (such as ADHD), rather than being distracted, actually benefit from environmental noise presented concurrently with the target task. Until recently the facilitative effect of non-task related environmental stimulation has been limited to the effects of background music on simple arithmetic task performance (Abikoff et al. 1996; Gerjets et al. 2002). More recently, Stansfeld et al. (2005) found that under certain conditions even road traffic noise can improve performance on episodic memory tasks, especially in children with low socio-economic status and from crowded households, groups that are likely to be distinguished by attentional problems and academic under-achievement. However, these earlier studies did not use or introduce SR as theoretical account for the beneficial effect of noise.

The aim of this manuscript is to show that auditory white noise can, under certain prescribed circumstances, improve attention and cognitive performance in inattentive children. Our research group has found compelling data supporting the counterintuitive notion that noise exposure under certain conditions can be beneficial for performance in cognitive tasks, in particular for individuals with attentional problems such as Attention Deficit/Hyperactivity Disorder (ADHD). The purpose of this presentation is to overview a model and findings showing a link between noise stimulation and cognitive performance. This is accomplished in the Moderate Brain Arousal model (Sikström & Söderlund 2007), which suggests a link between attention, dopamine transmission, and external auditory noise (white noise) stimulation.

The Moderate Brain Arousal model

Signaling in the brain is characterized by myriads of noisy inputs and outputs with a poor fidelity. The capacity of the central nervous system to distinguish between the information-carrying component of the neuronal signaling and the noisy racket of neuronal inputs is a remarkable feature, which includes an ability to deal with noisy signals and to use them to its advantage to increase the signal-to-noise ratio (SNR). A fundamental mechanism that contributes to this process is the phenomenon of stochastic resonance (SR), which is a core concept of the MBA model. SR is the counterintuitive statistical phenomena where signals that are too weak to be detected become detectable when a random (stochastic) noise is added, see Figure 1. Although SR is a paradoxical phenomenon, it is well established across a range of settings; it exists in any threshold-based system where noise and signal are required to pass a threshold for the registering of a signal. The concept of SR was originally introduced to explain climate changes (Benzi et al., 1982), it has been identified in a number of naturally occurring phenomena, like bistable optical systems (Gammaitoni et al. 1998); mechanoreceptors of the crayfish (Douglass et al. 1993); and the feeding behavior in the paddlefish (Russell et al. 1999). In particular SR has been found in neural systems and in behavior.

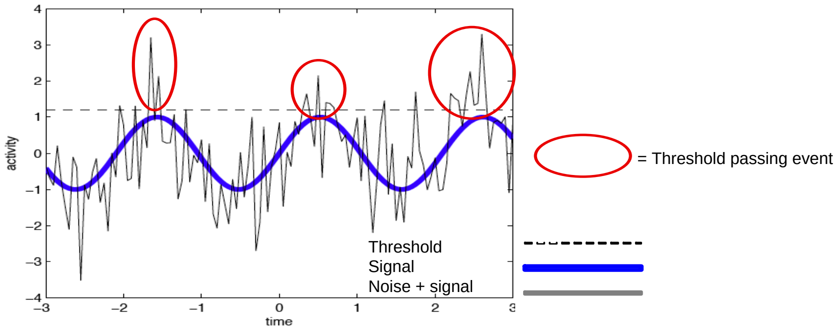

Figure 1: Stochastic resonance where a weak sinusoidal signal goes undetected as it does not bring the neuron over its activation threshold. With added noise, the same signal results in action potentials

Threshold phenomena in neural systems are found in the all-or-none nature of action potentials. They can be modeled by a non-linear activation function, for example the sigmoid function, that simulates the probability that a neural cell will fire (Servan-Schreiber et al. 1990). The firing probability is influenced by the gain parameter that modifies how responsive a neural cell is to stimulation.

In humans SR has been found in: touch (Wells et al. 2005), auditive (Zeng et al. 2000), and visual (Simonotto et al. 1999) sensory modalities, where moderate noise improves sensory discrimination. In fMRI scans a moderate noise level increased neural cortical activity in visual cortex (Simonotto et al. 1999). Most SR studies are done in perception tasks, requiring a detection of weak peripheral sensory inputs. However less known, empirical evidence suggests that SR also improve central processing and cognitive performance, For example, SR has been found in cognitive tasks where auditory noise improved the speed of arithmetic computations in a normal group (Usher & Feingold 2000).

Our research group has focused on cognitive effects of SR in particular groups with attentional problems like in ADHD. The attentional problems in ADHD are associated with impairment in multiple behavioral paradigms and also depends on the subtype of ADHD diagnosis (Nigg 2005). The implicated domains include; delay aversion, deficit in arousal/activation regulation, and executive function/inhibitory deficits (Castellanos & Tannock 2002). Delay aversion refers to an intolerance for waiting and has been used to explain difficulty in sustaining attention on long and boring tasks (Sonuga-Barke 2002). Poor regulation of activation or arousal are also associated with inattention (Castellanos & Tannock 2002) where hyperactivity may be seen as a form of self-stimulation to achieve a higher arousal level. Executive deficits are predominantly linked to impairments in working memory and effortful attentional control shown in the difficulty to stop an ongoing response and response shift (Casey et al. 1997).

In the framework of MBA, the attentional problem comes from overactive response from environmental stimuli caused by too low levels of extracellular dopamine. Dopamine signaling consists of two components; a stimulus independent tonic firing that determines concentration of dopamine in the extra-cellular fluid and a spike (stimulus) dependent phasic dopamine release. Tonic levels are continuous and modulate phasic reactivity. Autoreceptors in the pre-synaptic cell are activated when the tonic level is too high and suppresses spike-dependent phasic dopamine release, whereas low tonic levels increase phasic release (Grace 1995). Excessive tonic firing is suggested to cause inhibited phasic release and is associated with cognitive rigidity. Low tonic levels, in contrast, cause neuronal instability and boosted phasic responses (Grace et al. 2007). Excessive phasic transmission is suggested to cause instability in neuronal activation and is associated with cognitive symptoms such as failure to sustain attention, distractibility and excessive flexibility, symptoms that are hallmarks of ADHD. ADHD suffers from low tonic dopamine levels (Volkow et al. 2002) and consequently excessive phasic dopamine release causing the behavioral problems seen in ADHD. Furthermore, we suggest that ADHD symptoms should not be seen as a discrete category, but rather as a continuous dimension. This view implies that ADHD like symptoms are distributed in populations and can explain inattention and hyperactivity seen in normal populations as well. A major insight gained from the MBA model is that individual differences in the level of background noise within the neural system (linked to differences in dopamine signaling) will be reflected in different effects of environmental noise on performance.

Neurocomputational modeling of the MBA model shows that a neural system with low dopamine levels (low gain parameter), requires more noise for an optimal performance. Therefore inattentive and ADHD children, with low levels of dopamine, require more environmental noise than attentive children for optimal performance in cognitive tasks. Attentive children are suggested to possess sufficient internal noise levels for a high performance. Thus, neural systems with low levels of noise require more external noise for the facilitating effect of SR to be observed. Systems with high internal noise levels require less external noise. In this sense the individual levels of neural noise, and the individual SR curve, influence the external noise and performance differently. The size of the effect of noise on performance follows an inverted U-shaped curve. That is, a moderate noise is beneficial for performance whereas too little and too much noise attenuates performance. Levels of noise that enhance performance of children with low internal noise attenuate performance for children with higher levels of internal noise. Input parameters to the MBA model are external noise and signal that activates internal neural noise and signal. Through the SR phenomenon these provide an output measured by cognitive performance. Thus, this provides a straightforward prediction of noise-induced improvement in cognitive performance in ADHD and inattentive children.

In summary, the MBA model predicts 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 ADHD due to lower gain or lower dopamine. 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. This prediction was experimentally tested in three studies presented below.

Experimental support of the MBA model

The affirmed predictions of the MBA model have been experimentally tested in an episodic memory task consisting of learning of word pairs. The main manipulations have been auditory noise and grouping of children based on ADHD and other behavioral testing. Participants are presented with verbal commands, simple verb – noun sentences such as “roll the ball” or “break the match” (Nilsson 2000). At the subsequent memory test, participants are instructed to remember as many of the verbal commands presented as possible.

METHODS

Participants

Study 1. Forty-two, 9.4 – 13.7 years (M=11.2), children participated in the study. The ADHD group consisted of 21 boys, and no girls. This group was diagnosed by pediatricians (in Hospitals or local neuro-teams) according to the guidelines of DSM IV (APA 1994) Fifteen of the children were diagnosed ADHD-combined type (ADHD-C) and six as predominantly inattentive (ADHD-I). Seven children where medicated during the experiment (methylphenidate), and their results were analysed seperatly. The ADHD group was recruited from special schools or classes in Stockholm and the control group from ordinary schools in the same district matched after gender, age, and school performance level.

Study 2. Thirty-two secondary school pupils (Sogndal, Norway) between 10-12 years (M=11.5) participated in the study. The group consisted of 22 boys and 10 girls. Participants where divided into groups after achievements or scholastic skills by judgment of their teachers for abilities concerning general school performance in three levels: below average, average, and above average relatively to what are expected from this age group. School performance were merged into two groups (below/average and above average achievers) while the below average group only consisted of four participants.

Study 3. Fifty-one secondary school pupils (Sogndal, Norway, different school from study one) between 11-12 years (M=11.7) participated in the study. The group consisted of 25 boys and 26 girls. Participants where divided into groups in three levels after three different criteria: 1) school performance (teachers judgments); 2) Raven scores (Raven 1995); and 3) attention and/or hyperactivity (teachers judgments, scoring high in either of these behaviors or in both).

Design and materials

The design of the study was a 2 x 2, where no noise vs. noise was the within subject's manipulation. The between group variable where in study 1: ADHD vs. control. In study 2 and 3 the between group variable was based on cognitive performance as described above.

The to-be-remembered (TBR) items consisted of 96 sentences divided into 8 separate lists with 12 verb-noun sentences in each list. Each sentence consisted of a unique verb and a unique noun (e.g., "roll the ball"). The sentences were placed in random order. All to-be-remembered sentences were recorded on a CD. In the no noise conditions the sentences were read in absence of noise and in the noise conditions they were read in presence of white noise. The equivalent continuous sound level of the white noise and the speech signal was 81 and 80 dB respectively, thus signal-to noise-ratio was -1 dB in study 1. In study 2 and 3 noise and speech levels where 78 and 86 dB, respectively and the signal-to-noise ratio was 8 dB. However, in all conditions the signal was sufficiently strong so that all participants could errorless perceive the content of the words (i.e., the tests were a cognitive memory test and not a perceptual test). The affirmed noise levels were chosen to correspond to levels where earlier studies have found effect of SR on cognition in an arithmetic's test for a normal population (Usher & Feingold 2000) and on working memory for Alzheimer patients (Belleville et al. 2003). Recordings were made in a sound studio.

Procedure

In all studies the participants were tested individually in a room. The test lasted for about 45 minutes including instructions. Before starting the experiment proper, two practicing sentences were presented. All TBR items were recorded on a CD, a new item was read every 9th second. Time taken to present each list was approximately 1 min. 40 s. The noise exposure was continuous during the encoding phase and was present every second list. Directly after presentation of the last item subjects performed a free recall test in which they spoke out loud as many sentences as possible, in any order.

RESULTS

Results from the studies are summarized in Figures 2 to 4 below. For a more extensive description of study 1 see Söderlund et al. (2007), study 2 and 3 see Söderlund et al. (in preparation).

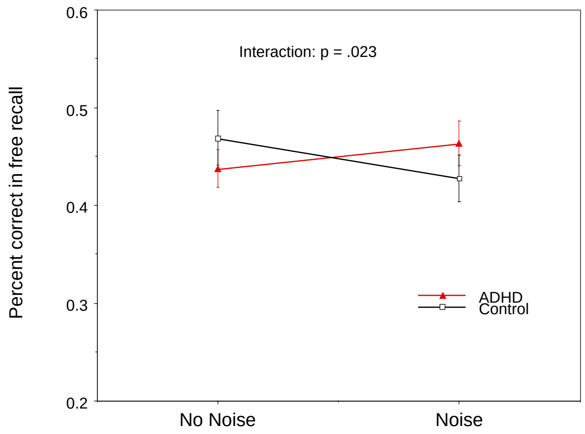

Figure 2: Study 1; Percentage correct recall as a function of noise and group (ADHD vs. Control)

The interaction between noise and group is significant when the medicated children where excluded while medication could be a possible confound. ($F(1,33)= 5.73$, $p= .023$, eta^2= .15) (see Figure 2). When medicated group was included, to see if noise effect was present in this group too, in the assessment the interaction between noise and group became stronger ($F(1,40) = 8.41$, $p = 0.006$, eta^2= .17).

Study 2 comprised a normal population of school children. In this study cognitive performance was measured by teacher's judgment of general scholastic skills in three levels: average, above and below average. While the below group only consisted of four participants the below and average groups were merged together Figure 3A shows that the interaction between noise and group is significant ($F(1,30) = 5.92$, $p = 0.021$, eta^2= .14). The significant difference between groups in the no noise condition ($t(30)= 3.67$, $p= .001$) disappears in the noise condition (Figure 3A)

Study 3 consisted of a normal population of school children. The children were grouped according to (1) teachers' judgments of general school performance, (2) teacher judgments of inattention/hyperactivity, and (3) the score on a Raven test. The results are presented in figures 3B, 4A, and 4B (below), note that group sizes differ between the figures.

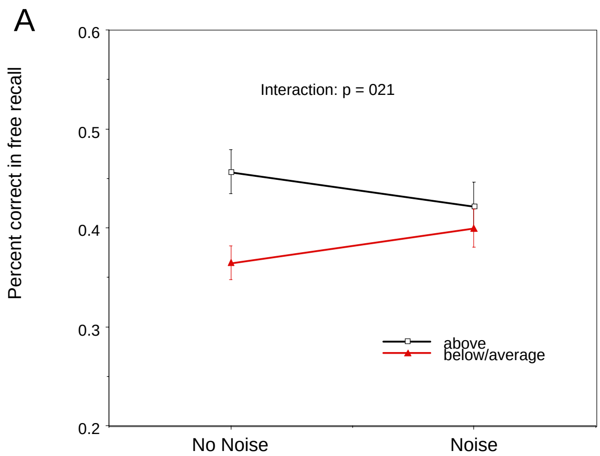

Figure 3A: Study 2: Recall performance as a function of noise and school performance in two groups (teachers judgments: above N= 12, below/average N= 20)

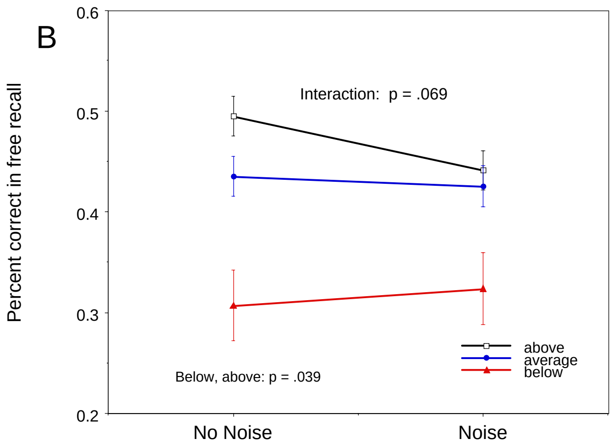

Figure 3B: Study 3: Recall performance as a function of noise and school performance (teachers judgments in three groups: above N= 22; average N= 22; below N= 7)

In Study 3, there was a significant interaction effect between noise and below/above groups, however, there was no interaction effect involving the middle group (Figure 3B). Note that the memory performance level was significantly lower for the below group as compared to the average and above groups (*F*(2,48)= 8.51, *p*= .001).

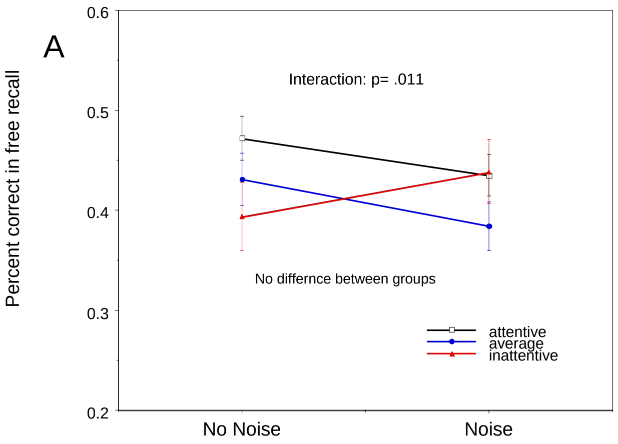

Figure 4A: Study 3: Recall performance as a function of noise and attention/hyperactivity (teachers judgment: attentive N= 24; average attentive N= 17; inattentive/hyperactive N= 10

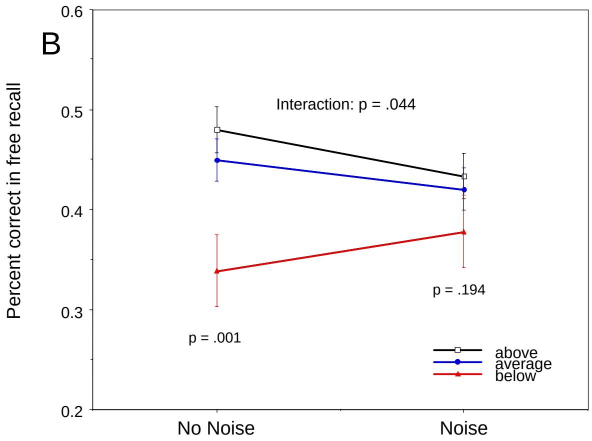

Figure 4B: Study 3: Recall performance as a function of noise and Raven score (above N= 19; average N= 24; below N= 8)

In Study 3, the interaction between noise and Raven score was significant (F(2,48)= 3.35, p= .044, eta2=.12) (Figure 4B). Note that the difference in memory performance between below and high performing groups disappeared with noise exposure when t-tested separately. Figure 4A shows the lowest p-value in the interaction between attention and noise (F(2,48)= 4.99, p= .011, eta2=.17). Inattentive children did benefit most from noise and there was no main effect on performance of group, all groups performed at the same level (F(2,48) = 1.28, p = .288).

CONCLUSIONS

Taken together the results presented above provide support for the predictions of the MBA model showing selective effects of noise on performance. This effect is present in comparisons between ADHD/control groups, a normal population divided into inattentive/attentive, below/above average scholastic skills, and high/low performers on the Raven test. This supports the MBA model suggesting that the endogenous neural noise level in children in several different groups is sub-optimal. MBA accounts for the noise-enhancing phenomenon by stochastic resonance (SR). Noise in the environment introduces internal noise to the neural system through the perceptual system. Of particular importance is that the peak of the SR curve depends on the dopamine level, so participants with low dopamine levels (inattentive, ADHD) require more noise for optimal cognitive performance compared to attentive controls.

There is now good evidence that ADHD is a hypo-dopaminergic disorder (Solanto 2002). Both hyper- and hypo-functioning of the dopamine system causes impairments in cognitive performance while dopamine modulates neuron responses by increasing the SNR through enhanced differentiation between background efferent (internal) firing and afferent (external) stimulation (Goldman-Rakic et al. 2000). A question to address in the future is whether inattention, low achievement in school and demanding cognitive tasks such as Raven is to some extent caused by insufficient dopamine signaling.

Although a number of studies demonstrates improved CNS function in clinical groups with stochastic stimulation e.g., in diabetes and stroke (Priplata et al. 2006), in elderly (Priplata et al. 2003), or in Parkinson's disease (Yamamoto et al. 2005) the action mechanisms at the system level are poorly understood. Little is known about which parts of the brain (other than primary and secondary afferent neurons) that are activated by stochastic noise stimulation. Furthermore, little is known about how SR interferes with normal CNS processing and if SR stimulation restores low dopamine levels (gain) or if it works by other means.

There are limitations in present studies and many important queries remain to be solved, e.g.: 1) to map out the inverted u-curve for the stochastic resonance by studying several noise levels for participants with different cognitive capacities; 2) to explore the generalization of the SR effect over different cognitive tasks; 3) to examine whether the SR effect has an effect on higher cognition supplied in different modalities and if SR works cross modal.

The finding reviewed here strongly suggests that noise is not always bad for cognitive performance. However, the positive effect of noise depends on individual factors. This suggests that factors such as noise, and cognitive abilities interact in a complex way that should be acknowledged in any future work measuring cognitive tasks. The inverted U-shape of the SR phenomenon suggests that interesting effects could be hidden in mean values, which may emerge as interesting findings when the data is divided into groups.

REFERENCES

Abikoff H, Courtney ME, Szeibel PJ, Koplewicz HS (1996). The effects of auditory stimulation on the arithmetic performance of children with ADHD and nondisabled children. J Learn Disabil 29: 238-246.

APA (1994). DSM-IV. Diagnostic and statistical manual of mental disorders. American Psychiatric Publ. Inc.

Belleville S, Rouleau N, van der Linden M, Collette F (2003). Effect of manipulation and irrelevant noise on working memory capacity of patients with Alzheimer's dementia. Neuropsychology 17: 69-81.

Benzi R, Parisi G, Sutera S, Vulpiani A (1982). Stochastic resonance in climatic change. Tellus 34: 10-16.

Boman E, Enmarker I, Hygge S (2005). Strength of noise effects on memory as a function of noise source and age. Noise & Health 7(27): 11-26.

Broadbent DE (1958). The effects of noise on behaviour. Elmsford, NY: Pergamon Press.

Casey BJ, Castellanos FX, Giedd JN, Marsh WL (1997). Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. J Am Aacd Child Adolesc Psychiatry 36: 374-383.

Castellanos FX, Tannock R (2002). Neuroscience of attention-deficit/hyperactivity disorder: the search for endophenotypes. Nature Rev Neurosci 3: 617-628.

Corbett B, Stanczak DE (1999). Neuropsychological performance of adults evidencing Attention-Deficit Hyperactivity Disorder. Arch Clin Neuropsychol 14: 373-387.

Douglass JK, Wilkens L, Pantazelou E, Moss F (1993). Noise enhancement of information transfer in crayfish mechanoreceptors by stochastic resonance. Nature 365(6444): 337-340.

Gammaitoni L, Hänggi P, Jung P, Marchesoni F (1998). Stochastic resonance. Rev Modern Physics 70: 223-287.

Geffner D, Lucker JR, Koch W (1996). Evaluation of auditory discrimination in children with ADD and without ADD. Child Psychiatry Hum Develop 26: 169-180.

Gerjets P, Graw T, Heise E, Westermann R, Rothenberger A (2002). Deficits of action control and specific goal intentions in hyperkinetic disorder. II: Empirical results/Handlungskontrolldefizite und störungsspezifische Zielintentionen bei der Hyperkinetischen Störung: II: Empirische Befunde. Z Klin Psychol Psychother 31: 99-109.

Goldman-Rakic PS, Muly EC 3rd, Williams GV (2000). D(1) receptors in prefrontal cells and circuits. Brain Res Rev 31: 295-301.

Grace AA (1995). The tonic/phasic model of dopamine system regulation: its relevance for understanding how stimulant abuse can alter basal ganglia function. Drug Alcohol Depend 37: 111-129.

Grace AA, Floresco SB, Goto Y, Lodge DJ (2007). Regulation of firing of dopaminergic neurons and control of goal-directed behaviors. Trends Neurosci 30: 220-227.

Hygge S, Boman E, Enmarker I (2003). The effects of road traffic noise and meaningful irrelevant speech on different memory systems. Scand J Psychol 44: 13-21.

Nigg JT (2005). Neuropsychologic theory and findings in attention-deficit/hyperactivity disorder: the state of the field and salient challenges for the coming decade. Biol Psychiatry 57: 1424-1435.

Nilsson LG (2000). Remembering actions and words. In: Tulving E, Craik FIM (eds.): The Oxford handbook of memory (pp 137-148). Oxford: Oxford Univ. Pr.

Priplata AA, Niemi JB, Harry JD, Lipsitz LA, Collins JJ (2003). Vibrating insoles and balance control in elderly people. Lancet 362(9390): 1123-1124.

Priplata AA, Patritti BL, Niemi JB, Hughes R, Gravelle DC, Lipsitz LA, Veves A, Stein J, Bonato P, Collins JJ (2006). Noise-enhanced balance control in patients with diabetes and patients with stroke. Ann Neurol 59: 4-12.

Raven JC (1995). Coloured progressive matrices. Oxford: Oxford Psychological Press.

Rouleau N, Belleville S (1996). Irrelevant speech effect in aging: an assessment of inhibitory processes in working memory. J Gerontol B: Psychol Sci Soc Sci 51: P356-P363.

Russell DF, Wilkens LA, Moss F (1999). Use of behavioural stochastic resonance by paddle fish for feeding. Nature 402(6759): 291-294.

Servan-Schreiber D, Printz H, Cohen JD (1990). A network model of catecholamine effects: gain, signal-to-noise ratio, and behavior. Science 249(4971): 892-895.

Shidara M, Richmond BJ (2005). Effect of visual noise on pattern recognition. Exp Brain Res 163: 239-241.

Sikström S, Söderlund GBW (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. Psychol Rev 114: 1047-1075.

Simonotto E, Spano F, Riani M, Ferrari A, Levero F, Pilot A, Renzetti P, Parodi RC, Sardanelli F, Vitali P, Twitty J, Chiou-Tan F, Moss F (1999). fMRI studies of visual cortical activity during noise stimulation. Neurocomputing 26-27: 511-516.

Söderlund GBW, Sikström S, Smart A (2007). Listen to the noise: Noise is beneficial for cognitive performance in ADHD. J Child Psychol Psychiatry 48: 840-847.

Söderlund GBW, Sikström S, Loftesnes JM (in preparation). Noise is not a nuisance: Noise improves cognitive performance in low achieving school children.

Solanto MV (2002). Dopamine dysfunction in AD/HD: integrating clinical and basic neuroscience research. Behav Brain Res 130: 65-71.

Sonuga-Barke EJ (2002). Interval length and time-use by children with AD/HD: a comparison of four models. J Abnorm Child Psychol 30: 257-264.

Stansfeld SA, Berglund B, Clark C, Lopez-Barrio I, Fischer P, Ohrstrom E, Haines MM, Head J, Hygge S, van Kamp I, Berry BF, RANCH study team (2005). Aircraft and road traffic noise and children's cognition and health: a cross-national study. Lancet 365(9475): 1942-1949.

Usher M, Feingold M (2000). Stochastic resonance in the speed of memory retrieval. Biol Cybern 83: L11-L16.

Volkow ND, Fowler JS, Wang G, Ding Y, Gatley SJ (2002). Mechanism of action of methylphenidate: insights from PET imaging studies. J Attent Disord 6(Suppl 1): S31-S43.

Wells C, Ward LM, Chua R, Timothy Inglis J (2005). Touch noise increases vibrotactile sensitivity in old and young. Psychol Sci 16: 313-320.

Yamamoto Y, Struzik ZR, Soma R, Ohashi K, Kwak S (2005). Noisy vestibular stimulation improves autonomic and motor responsiveness in central neurodegenerative disorders. Ann Neurol 58: 175-181.

Zeng FG, Fu QJ, Morse R (2000). Human hearing enhanced by noise. Brain Res 869: 251-255.