Different Effects of Adding White Noise on Cognitive Performance of Sub-, Normal and Super-Attentive School Children

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Abstract

1 **Objectives:**

2 Noise often has detrimental effects on performance. However, because of the phenomenon

3 of stochastic resonance (SR), auditory white noise (WN) can alter the "signal to noise" ratio

4 and improve performance. The Moderate Brain Arousal (MBA) model postulates different

5 levels of internal "neural noise" in individuals with different attentional capacities. This in turn

6 determines the particular WN level most beneficial in each individual case – with one level of

7 WN facilitating poor attenders but hindering super-attentive children.

8 **Methods:**

9 Participants were teacher-rated super- (N=36); normal- (N=29) and sub-attentive (N=25)

10 children (aged 8 to 10 years). Two non-executive function (EF) tasks (a verbal episodic recall

11 task and a delayed verbal recognition task) and two EF tasks (a visuo-spatial working

12 memory test and a Go-NoGo task) were performed under three WN levels. A non-WN

13 condition was used to control for potential differences in background noise in the group

14 testing situations.

15 **Results:**

16 There were different effects of WN on performance in the three groups – adding moderate

17 WN worsened the performance of super-attentive children for both task types and improved

18 EF performance in sub-attentive children. The normal-attentive children's performance was

19 unaffected by WN exposure. The shift from moderate to high levels of WN had little further

20 effect on performance in any group.

21 **Significance**

22 The predicted differential effect of WN on performance was confirmed. However, the failure to

23 find evidence for an inverted U function challenges current theories. Alternative explanations

24 are discussed. We propose that WN therapy should be further investigated as a possible non-

25 pharmacological treatment for inattention.

26

1 **Introduction**

2 Under most circumstances, information processing is disturbed by environmental noise and

3 other non-task compatible distractors [1,2]. Children with attention problems are, under many

4 conditions, especially vulnerable to distraction [e.g. 3]. However, researchers have recently

5 reported that under certain circumstances individuals with attention problems appear to

6 benefit from the addition of specific forms of environmental noise. Typically, this facilitative

7 effect has been limited to non-vocal background music on simple arithmetic task performance

8 [4,5] but, more recently Stansfeld et al. [6] found that under certain conditions even road

9 traffic noise can improve performance on episodic memory tasks, particularly in children at

10 risk for attention problems and academic under-achievement.

11

12 Furthermore, Söderlund et al. [7] demonstrated that adding auditory white noise (WN) to the

13 environment, enhanced the memory performance of children with ADHD-type problems but

14 disrupted that of non-ADHD control children. These effects were replicated in a second study

15 for children with sub-clinical attention problems [8]. These results raise two obvious questions.

16 First, how or by what mechanism does WN improve performance? Second, why does the

17 same level of WN have such apparently different effects on children with different levels of

18 attentional problems?

19

20 The exact mechanism behind WN benefits is not yet known. It has been proposed that

21 random noise enhances neural communication via the phenomenon of stochastic resonance

22 (SR). The phenomenon of SR is observed when an increase in the level of unpredictable

23 fluctuations, e.g. WN, causes an increase in a metric of the quality of signal transmission or

24 signal detection, or in other words increases the signal-to-noise ratio. SR is usually quantified

25 by plotting detection, or cognitive performance, as a function of WN intensity. The SR effect

26 appears highly sensitive to the intensity of the signal and this relationship follows an inverted

27 U-curve function, where performance peaks at moderate noise levels. That is, a moderate

28 level of WN is beneficial for performance whereas too little does not add the power required to

29 take the signal over the threshold and too much overpowers the signal, leading to a

30 deterioration in attention and performance [9,10]. Signaling in the brain is characterized by

1   noisy inputs and outputs. The task of the central nervous system is to distinguish between the

2   signal, the information-carrying component, and noise (meaningless neural inputs that

3   interfere with the signal). However, noise is an integral part of interneuronal communication

4   and a sufficient amount of noise may be necessary for the normal functioning of the nervous

5   system [11,12]. This in turn modulates neural synchronization whereby particular brain

6   regions sub-serving specific functions establish transient networks that accomplish

7   perception, cognition, or action [13]. Thus, it has been shown that random noise enhances

8   detection of weak sensory signals like hearing [24], touch [25], vision [26] through SR. "Touch

9   WN" improved vibrotactile sensitivity in healthy young people [25], vibrating soles improved

10   motor performance in elderly [27], in stroke patients [28], and those with Parkinson's disease

11   [29]. High level performance can also be improved by WN (e.g., face recognition [30] and

12   arithmetic computations (77 dB) [31]). Moreover, SR can work across modalities such that

13   detection of weak visual signals improved considerably when exposed to supra threshold

14   noise (75 dB) [32]. To sum up, the concept of SR attempts to explain the paradox that the

15   brain seems to utilize WN to differentiate the signal in the targeted stimuli from non-target

16   noise [20]. WN accordingly improves or increases the signal-to-noise ratio.

17

18   How can we explain individual differences in WN effects? Sikström & Söderlund [14]

19   proposed that individual differences arise because each person has a certain level of

20   background "noise" intrinsic to his or her neural system associated with neurotransmitter

21   function. Dopamine was hypothesized to be especially important because it modulates the

22   neural cell's response to the environment and determines the probability that it will fire

23   following the presentation of salient stimuli [15]. Dopamine function is related to individual

24   differences in attention [16] and cognition [17]. Dysfunction is found among ADHD patients

25   [18]. Stimulant medication, acting via the dopamine system, ameliorates symptoms of

26   inattention and poor cogntive performance within normal populations [19,20] and in patients

27   with an ADHD diagnosis [21,22]. In the Moderate Brain Arousal Model (MBA; [14] internal

28   neural noise and external WN are hypothesized to act additively in relation to SR. Thus,

29   where there are low levels of neural noise, i.e. low continuous dopamine activity, more

30   external WN the facilitative SR effect is predicated to require greater levels of WN. But where

1   high internal noise levels are present, i.e. high continuous dopamine activity, less external

2   WN will be required. Low accuracy in neural communication is associated with low levels of

3   extracellular dopamine distinguished by neurons firing at random causing inattention and in

4   accordance with Servan-Screiber et al.'s [15] terminology this is a "low gain" state. From this it

5   is concluded WN benefit only occurs when a nervous system is not working at its optimum

6   [23,24]. This leads to the prediction that inattentive children will benefit more from higher

7   levels of environmental WN than attentive children, for whom such noise levels will have a

8   detrimental effect on performance.

9

10   The goal of the current study was to test the hypothesis that different intensities of WN will

11   exert differential effects on children with different levels of attention-ability through the

12   differential action of SR in a way predicted by the MBA hypothesis. Despite the current

13   categorical approach to the diagnosis of ADHD, attentional problems appear to display a

14   dimensional rather than a categorical structure [25]. This conclusion is supported by

15   taxometric studies that have failed to find evidence for an attention deficit taxon [26,27] as

16   well as behavioral genetic studies that suggest heritability is similar across different ranges of

17   symptom severity [28]. Different severities of inattentiveness, distractibility, and associated

18   academic problems are distributed quasi-normally throughout populations. Children who do

19   not meet the full ADHD criteria may still suffer significant impairment. In fact, there is a

20   number of implications of this conceptualization of attention problems for the current study. In

21   particular it means that the comparison of the moderating effect of attentional abilities on the

22   effects of WN on performance should not be limited to a binary comparison of attentive vs.

23   inattentive or ADHD vs non-ADHD children. From a dimensional perspective the comparison

24   of WN effects across sub-attentive vs. normal attentive vs. super-attentive children would be

25   most appropriate. Assuming that the mechanisms governing the link between attentiveness,

26   internal noise and external WN noise holds across the full range of attentional abilities we

27   would predict different levels of WN being optimal for these different groups of children.

28   Consistent with the MBA hypothesis we predict that the inverted U function of WN is right

29   shifted for sub-attentive children and left-shifted for super-attentive children compared to

30   children with normal attention. The past focus on binary conceptualizations of attention

1 problems has meant that no studies, as far as we are aware, have examined either the neuro-

2 psychological profiles of super-attentive children or the impact of environmental context on

3 performance. In order to make such a comparison possible we used the *Strengths and*

4 *Weakness of ADHD-symptoms and Normal-behaviors* (SWAN) rating scale [29] to define

5 attention problems. This measure differs from standard attention rating scales in that it

6 identifies both strengths and weaknesses in attention-related behaviors and can be used to

7 select children that are above average in their attention.

8

9 Our specific predictions are; (i) that, in general, super-attentive children will have superior task

10 performance compared to normal attentive children who will in turn out perform sub-attentive

11 children; (ii) moderate to high levels of WN will have facilitative effects on attention and

12 related task performance for sub-attentive children but will disrupt performance in super-

13 attentive children with normal attentive children lying somewhere in between. To test these

14 predictions we extended previous studies of WN, attention and performance by; i) comparing

15 children with normal, sub-, and super-normal attention as defined by teachers; ii) extending

16 the set of signal-to-noise ratios tested by studying multiple WN levels and observing the effect

17 on performance and iii) exploring the generalization of the WN effect across a range of

18 different tasks. Specifically, the original WN studies employed a verbal memory task [7,8].

19 However, tests of executive function (EF) have been more heavily implicated in attention

20 deficits and have been shown to differentiate inattentive from attentive children [30].

21 Therefore in addition to the memory task employed in the original study we include two EF

22 measures in our test battery. The literature describes two kinds of WN facilitation; threshold

23 SR and supra threshold SR (SSR) – differentiated by the nature of the relationship between

24 the strength of the signal and the noise required for SR to occur [24,31]. For example, in

25 auditory threshold SR the signal should be presented just below the hearing threshold (20-35

26 dB, depending on age and frequency) and the noise should be within the same range (20-30

27 dB) for SR to occur. In supra threshold SR this will occur when all noises added equal the

28 signal mean [31,32]. This means that both signal and noise can be far above the hearing

29 threshold. The current study focuses on supra-threshold SR using a lowest WN level of 65

30 dB.

1

2

3   **Method**

4   **Study recruitment and screening**

5   Ethical approval was obtained from the University of Southampton Psychology Ethics

6   Committee. Written consent was obtained from the school's head teacher on behalf of the

7   children, and written assent was obtained from the children themselves. Prior to the study

8   start, parents were sent information forms about the study and were given the option to opt

9   their children out of the study. Copies of the written consent/assent forms are stored in a

10 locked filing cabinet. This consent procedure was approved by the University of Southampton

11 Psychology Ethics Committee. All children were recruited from a single local junior school;

12 children from years 4 and 5 and their parents were sent information letters and, in accordance

13 with the head teachers' preferences, were given the option to opt-out of the study. Only one

14 child opted out of the study. All remaining year 4 and 5 children (N = 150: 58 boys, 92 girls)

15 were screened for levels of attention at school using the teacher-report SWAN rating scale

16 [29]. The SWAN has 18 items probing attention and behavior. On the basis of the teacher-

17 ratings on the attention items of this scale, 36 sub-attentive (bottom 20 percent of scores), 29

18 average (middle 20 percent), and 25 super-attentive (top 20 percent) children were selected

19 for the study. The groups were matched for age, but were unable to be matched for gender

20 as very few boys were rated in the super-attentive range (only 2 boys out of the 150 screened

21 children were rated as being in the top quintile for attention).

22

23 **Test Battery**

24 Four laboratory tests, two EF and two non-EF tasks, including the memory task used in the

25 original study [7], were employed. These tasks were presented in a fixed order; participants

26 completed them in small groups (3-4) on individual laptops in a quiet classroom with two

27 experimenters present.

28

29 **Non-EF verbal memory tasks**

1   *i) Verbal episodic memory task (5 minutes;* [8]*).* Lists of nouns were presented to the

2   participants in the auditory mode using a laptop. Participants were asked to remember as

3   many nouns as possible. Two lists of 10 nouns (ISI 5 seconds) were presented in each WN

4   condition: five of these words were low frequency words (frequency <100 per million) and five

5   high frequency words (frequencies > 200 per million: as determined by the children's printed

6   word database [33]). Each list was matched for word frequency, word length and syllable

7   number. Immediately after each list, participants were asked to perform a written free recall

8   test. Balanced Latin squares were used to ensure that each word list was equally likely to be

9   heard in each noise condition, and within each list, words were presented in a random order

10 to each child.

11 *ii) Verbal recognition task (5 minutes)*: This task tested the recognition of the words presented

12 in the verbal episodic memory task above. The 20 words presented in the verbal episodic

13 memory task and 20 other words (matched to the initial lists on frequency, word length and

14 number of syllables) were presented in the auditory modality via a laptop. Participants were

15 required to indicate whether a word had been presented in the previous task by pressing

16 symbols of either a tick or a cross on computer keyboard. The ISI was 3 seconds and words

17 were presented in a random order for each child.

18

19 **EF tasks**

20 *i) Visuo-spatial working memory test* (*Spanboard*; [34]; 5 minutes). Participants were asked to

21 remember the location of dots that appeared in a 4 x 4 grid (16 squares) presented on a

22 computer screen and to recall this sequence using the computer mouse to click the correct

23 grid locations. In the first trial, the array consisted of two dots (ISI was 3 seconds, 2250 ms

24 dot exposure, 750 ms pause). On every second successive trial, one dot was added until the

25 participant made an error in both trials on that particular level.

26 *ii) The Go/No-Go Task* [35]. The Go/No-Go task required a motor response (pressing the right

27 or left mouse button) to either be selectively executed or inhibited depending on whether a Go

28 (left/right green arrow: 75% trials) or No-Go (double-ended green arrow: 25% trials) stimulus

29 appeared on the computer screen. The inter-stimulus interval (ISI) was 1500 ms: A 100 ms

1   stimulus duration followed by a blank screen for 1400 ms. For the purposes of the current

2   analysis the dependent variable for each of these tasks was the number of correct responses.

3

4   **Simple two-choice RT task** (2-CR RT) [36]. This task was used to validate the attentional

5   ability groupings and so was presented under normal background noise (NBN) condition only.

6   Participants responded to a computer presentation of a green target arrow that pointed left or

7   right. The target arrow was presented in the center of the computer monitor. Participants

8   responded, by pressing a right or left keyboard button, to indicate the direction of each arrow.

9   Each trial lasted 1500 ms (stimulus presentation time 400 ms, inter-stimulus interval 1100

10   ms). The task duration was 5 minutes and a total of 200 trials were presented. Dependent

11   variables were number of omission and commission errors.

12

13   **Experimental Design**

14   Each task was performed under three WN levels. Using high quality headphones participants

15   received WN separately in each ear. The WN was mixed in adobe audition and was in phase

16   across ears. Output signal was measured with a standard dB meter. For the two EF tasks

17   these levels were 65dB, 75dB and 85dB. The non-EF tasks were performed under slightly

18   lower WN levels - 65dB, 70dB and 75dB. This was necessary as the words were not audible

19   when louder WN levels were used. The order in which noise levels were presented was

20   counterbalanced using a Latin Square. For all tasks the performance was also measured

21   under normal background noise conditions to allow the effect of different levels of background

22   noise on performance, which may vary as a function of time of day and classroom setting, to

23   be controlled in the analyses.

24

25   **Analytical strategy**

26   All outliers (> 2 SD from the group mean for each condition) and any missing data were

27   replaced with the group mean for that condition. The SWAN groupings were validated by

28   comparing performance on the four experimental tasks and the simple two choice reaction

29   time tasks in the NBN condition using a one-way ANOVA. We examined the correlations

30   between EF and non-EF measures with a view to combining them to create two dependent

1 variables. Because a different range of WN levels were used for EF and non-EF tasks we first

2 ran two separate ANOVAs looking at the effects of noise level (65dB vs 75dB vs 85dB for EF

3 tasks; 65dB vs 70dB vs 75dB for non-EF tasks) and group (sub-, vs normal- vs super-

4 attentive) on EF and non-EF performance. We also ran a single three way ANOVA using the

5 two noise levels that were common for tasks: group (sub-vs normal vs super-attentive), noise

6 level (65dB vs75dB) and task type (EF vs non-EF) were included as factors. In all analyses

7 performance under normal background noise was used as a covariate.

8

9 **Results**

10 Table 1 reports the performance on the five tasks in the normal background noise condition

11 for the three groups. On all tasks there was a large and significant effect of group. More

12 specifically, the sub-attentive group always performed less well than the average attentive

13 group, with the super-attentive group performing the best. The differences between sub- and

14 average/super attentive children were significant for all tasks. The super-attentive children

15 were only significantly better than the average attentive children on the two EF tasks. These

16 effects were unchanged when age, gender and school performance were added as

17 covariates. The correlational analysis supported the combining of the EF ($r = .222$, $p< .001$)

18 and non-EF task pairs ($r = .276$, $p< .001$) to give two measures. These were created using the

19 factor loadings obtained from factor analysis as weights.

20

21 For non-EF there was a significant effect of group ($F_{(2,86)} = 5.69$, $p < .005$), an effect of WN

22 ($F_{(2,86)} = 3.09$, $p = .048$) and a trend for a significant interaction between group and WN

23 ($F_{(4,172)} = 2.19$, $p = .072$), see Figure 1. Adding moderate levels of WN had a different effect

24 on the three groups. For the super-attentive there was a significant decline in performance

25 ($F_{(2,46)} = 4.42$, $p = .018$), for the average group there was a small, non-significant decline in

26 performance ($F_{(2,56)} = 1.21$, $p = .305$, ns), and for the sub-attentive group there was a small,

27 non-significant increase in performance ($F_{(2,66)} = .385$, $p = .682$, ns). This meant that the

28 significant group difference seen at low WN levels (65dB $F_{(2,86)} = 8.18$, $p = .001$) was no

29 longer present at the moderate or the high WN levels (70dB $F_{(2,86)} = 1.88$, $p = .159$, ns:

30 75dB $F_{(2,86)} = .587$, $p = .558$, ns), see Figure 1.

1   *** Figure 1. about here ****

2   For the EF tasks, although the pattern of performance changes was similar, the patterns of

3   statistical significance were different, see Figure 2. There was only a trend for an effect of

4   group (F(2,86) = 2.71, p = .073), and no significant effect of WN (F(2,86) = 1.89, p = 154, ns).

5   There was however a significant interaction between group and WN (F(4,174) = 2.49, p =

6   .045). Again, the shift from low to moderate levels of WN had a different effect on the three

7   groups. The sub-attentive participants displayed a significant improvement in performance

8   (F(2,66) = 7.39, p = .001), the average attention group showed a small, non-significant

9   improvement in performance (F(2,56) = .230, p = .795, ns), and for the super-attentive group

10 there was a small, non-significant decline in performance (F(2,46) = .202, p = .818, ns).

11 Again, the significant group difference seen at low WN levels was no longer present at the

12 moderate or the high WN levels (65dB F(2,86) = 6.36, p = .003: 75dB F(2,86) = .490, p =

13 .615, ns : 85dB F(2,86) = .206, p = .814, ns), see Figure 2.

14 *** Figure 2. about here ***

15 Table 2 shows the results of the Noise X Group X Task Type repeated measures ANOVA. A

16 significant main effect of Group emerged, and again the super-attentive children performed

17 better than the average attentive children, who outperformed the sub-attentive children

18 (although the difference between the sub-attentive children and the normal attentive children

19 did not reach statistical significance). There was also a significant interaction between WN

20 and Group (Figure 1). The performance of the super-attentive group declined as the WN level

21 increased to 75db (t(24) = 3.744, p = .001); the average attention group was unaffected (t(29)

22 = .369 p = .715) while the sub-attentive group improved (t(34) = -2.247, p = .010).

23

24 **Discussion**

25 The current paper tested the hypothesis that increasing WN levels will differentially affect

26 children's performance as a function of their attention abilities (as rated by teachers). Based

27 on the MBA model we predicted that high levels of WN will have a facilitative effect on task

28 performance for sub-attentive children but will disrupt performance in super-attentive children.

29 In line with this prediction, when all tasks were combined, adding WN disrupted the

30 performance of the super-attentive group but improved the performance of the sub-attentive

1   group. These findings extend those found in previous studies showing the differential effects

2   of WN on sub- and normal attentive groups [7,8] in a number of ways: including a super

3   attentive group, extending the range of tasks, and extending the noise range.

4

5   First, by including a super-attentive group we were able to demonstrate that response to WN

6   varied differentially according to the degree of attentiveness and to show that the children

7   who were rated by their teachers as being the best able to pay attention were generally the

8   most negatively affected by increasing levels of WN, in contrast those who were least able to

9   pay attention were those that gained the most benefit from increasing levels of WN. This

10   suggests that the mechanisms governing the link between attentiveness, internal noise and

11   external noise operate across the full range of attentional abilities.

12

13   Second, by extending the battery of tasks we were able to both; (i) examine the effects of WN

14   on executive and non-executive tasks and (ii) improve the reliability of measurement of the

15   impact of WN. Although there was an overall facilitative effect of moderate WN on sub-

16   attentive children and a disruptive effect on the super-attentive children, the patterns of

17   significance were somewhat different when the effects of EF and non-EF tasks were

18   examined. For the non-EF tasks, the shift from low to moderate levels of WN was

19   characterized by a significant decline in performance in the super-attentive group however for

20   the EF tasks this shift from low to moderate levels of WN was characterized by a significant

21   improvement in performance in the sub-attentive group.

22

23   It is possible that the effect of WN on EF tasks is qualitatively different from the effect of WN

24   on non-EF tasks. So that on the non-EF tasks moderate levels of WN are generally disruptive,

25   particularly for the super attentive children, however sub-attentive individuals are protected

26   from the disruptive effects of these levels of WN. In contrast, on the EF tasks moderate levels

27   of WN actually have a facilitative effect on the sub-attentive children. However we cannot be

28   certain of this as there are factors other than the EF/non EF distinction that differ between

29   these two groups: the modality of the tasks (auditory delivered versus visually delivered) and

30   that the tasks were performed under different ranges of WN. The non-EF verbal tasks were

1   performed under lower levels of WN (65dB, 70dB and 75dB) than the EF tasks (65dB, 75dB

2   and 85dB) because the words presented in the non-EF tasks were not audible over louder

3   noise levels. It may be that the more fine grained but restricted range of WN levels adopted

4   for the non-EF measures may allow the identification of different aspects of the noise-

5   attention relationship. Or it may be that the auditory non-EF tasks were harder to perform

6   under increasing WN levels, as the words became more difficult to hear. Of great importance

7   to note is the cross modal nature of the WN effects seen for the EF tasks, auditory WN

8   exerted an effect on the processing of visual stimuli, this has been shown earlier on signal

9   detection [37] but here, to our knowledge for the first time, on EF. In the non-executive tasks

10   noise and signal were exposed within the same modality and results could indicate that lower

11   levels of WN are required for SR to occur within the same modality. Future research that

12   replicates these effects in non-auditory modalities, such as in a word recall tasks, in which the

13   words are presented visually, will help to clarify this.

14

15   Third, we extended previous research by adding multiple noise levels that gave us more

16   power to both; (i) examine the inverted U function of the effects of WN as predicted by SR

17   models and (ii) to identify more subtle differences in the WN-performance relationship and

18   how this might change with increasing noise intensities. In this regard, the following findings

19   were notable. Moving to the highest levels of WN intensity had little effect on performance of

20   any of the groups. There was little evidence for the inverted WN-performance U-function as

21   predicted by the MBA model, where performance peaks at moderate noise levels but too

22   much will cause performance to deteriorate. We further predicted that this inverted U shaped

23   function of performance across different WN intensities would be right shifted for sub-attentive

24   children and shifted left for super-attentive children compared to children with normal

25   attention, as inattentive children should require more environmental WN than attentive

26   children for optimal performance in cognitive tasks, and conversely these inattentive children

27   should be able to tolerate greater levels of WN before performance deteriorates. However,

28   the super attentive group showed a general pattern of decline across all three WN levels and

29   the normal attentive group tended to exhibit consistent performance across the three noise

30   levels, only the sub-attentive group showed an improvement in performance as noise levels

1   increased. In summary, the specific differential patterns of effects of increasing WN levels,

2   which we had predicted did not materialize; this could indicate that supra threshold SR acts

3   differently compared to threshold SR [38].

4

5   An alternative explanation to consider is that rather than inducing SR, WN increased arousal

6   in participants, which in turn affected information processing in different ways for the two

7   groups. Such an explanation is consistent with the state regulation deficit model of attention

8   deficits [39] derived from cognitive energetic theory [40]. This theory posits that children with

9   attention problems have difficulty modulating their levels of arousal and activation to adjust to

10   changing circumstances and patterns of external stimulation – in particular they have difficulty

11   maintaining arousal levels on challenging and boring tasks. It further predicts that these

12   difficulties are ameliorated by the addition of external stimulation. The finding in the current

13   study that the performance of the sub-attentive group improved with moderate levels of WN is

14   consistent with this prediction. Arousal might also offer an alternative explanation for the WN-

15   related deterioration in the super-attentive children's performance. It is possible that arousal

16   levels are optimal for this group at the lowest level in the current study and that they become

17   over-aroused by increases in WN. Alternatively it is possible that their performance

18   deteriorates because they find the noise annoying and distracting. This possibility needs to be

19   investigated in future research using human and animal models directly measuring known

20   neural and physiological markers in experiments employing manipulations of alternative

21   factors (event rate or stimulant medication) known to change energetic levels [40-52].

22

23   Another possible explanation is that WN benefit results from auditory masking, if the masker

24   is different from the signal it can facilitate signal detection [53]. It has been shown that if the

25   masker was predictable ADHD participants behave less impulsively [54] and exhibit improved

26   signal detection [55]. Masking effects have been shown in both the visual [56] and tactile

27   modalities [57]. In both SR and in masking, task irrelevant stimulation in different modalities

28   increases the signal-to-noise ratio and thus improves performance on various tasks. To

29   determine the importance of masking it would be useful to compare the effects of WM with

30   sensory noise without sound masking properties like in vestibular noise [58-60].

1

2 Although our methodology improved on previous studies in a number of ways a number of

3 limitations need to be acknowledged. *First*, we were unable to match the attention groups for

4 sex of participant. Our super attentive group included far more girls (N=23) than boys (N=2)

5 and the sub attentive group included more boys (N=22) than girls (N=14). We controlled for

6 the effects of gender in our analysis but it would be preferable to have the groups matched for

7 gender to more cleanly look at the effects of attention. However we screened a high number

8 of children (N=150) and it may be that preponderance of super-attentive individuals amongst

9 girls is part of the normal variation within the classroom and this is highly interesting per se if it

10 holds for true. *Second*, the experiments were conducted in a classroom setting where

11 participants accomplished tests at their own school in groups of approximately five pupils

12 could partly explain the poor results of the sub-attentive group – one might expect that they

13 became more distracted by their class mates than the others. In order to investigate noise

14 benefit in a lower range of WN we need to conduct lab studies where we can hold constant

15 the ambient noise (NBN) at a very low level (40 dB), this will give us an opportunity to find out

16 if normal- and super-attentive individuals could benefit from WN. *Third*, we failed to produce

17 an inverted U-curve, as predicted, in either of the participating groups. We cannot rule out the

18 possibility that adding lower intensity noise levels (e.g. 55 and 60 dB) might have produced

19 improvements in the super-attentive group and thus produced an inverted U-curve in this

20 group. SR research, that finds U-curves, is normally done in normal populations, the MBA-

21 model [14] predicts a deviant pattern for inattentive (i.e. low dopamine) subjects. *Forth*, the

22 three WN levels were determined a-priori and were identical for all participants; it may be that

23 if participants had been able to select their own levels of WN, they would be able to produce

24 an optimal level and thus produce greater WN benefits. Future studies that allow participants

25 to individually adjust the levels of WN exposure may help to clarify this effect further. *Fifth*,

26 there were different patterns of WN effects for the different tasks, EF and non-EF. This may

27 be a modality-related effect. There are few studies that investigate cross modal SR [e.g. 37].

28 There are good reasons to believe that when you present target and noise in the same

29 modality you need less noise to obtain the same SR effect. For instance in our own data

30 (unpublished) we find this effect with auditory noise on visual word recall tasks (instead of

1   reading out words they are shown on a computer screen). Future studies should be designed

2   to disentangle the effects of modality and task domains.

3

4

5   The beneficial effects of moderate levels of WN raise the question of its therapeutic potential

6   for children with attention problems. Our data suggest that sub-attentive children benefit from

7   the addition of moderate levels of auditory WN, particularly in tasks that require EFs. If this

8   could be applied in a classroom setting, it may have important practical implications for

9   improving the performance and outcome of children who typically find it difficult to pay

10   attention. It is however unclear whether these effects will also apply to individuals with more

11   extreme problems and clinical diagnoses. Previous research [e.g.4] has shown that

12   background noise can have a beneficial effect on patients with ADHD. Given the sub-attentive

13   children in the current study were selected because they were in the lowest quintile for

14   attention ability it seem likely that these effects will also apply to clinical populations of

15   patients with ADHD, and might offer an alternative therapy to children who do not respond to

16   stimulant medication [61]. Upcoming research that employs clinical patients with ADHD and

17   compares the efficacy of WN and stimulant medication will elucidate this. It will also be

18   important to carefully tailor and monitor these interventions given the highly heterogeneous

19   nature of ADHD. It is unlikely that all clinical cases will benefit from the same WN intensity,

20   and some cases may not respond to noise at all.

21

22   In summary, we demonstrated that adding moderate levels of WN could benefit the

23   performance of sub-attentive children (as rated by their teachers), while similar changes can

24   impair children with already good levels of attention. Increasing WN past moderate levels has

25   little further effect.

26

Figure legends:

Figure 1. Performance on executive function tasks as a function of attention ability and noise level.

*Note: White noise levels were 65, 75, 85 dB; * indicates a significant difference between groups in the 65 dB condition* (F(2,86) = 6.36, p= .003)

Figure 2. Performance on non-executive function tasks as a function of attention ability and noise level.

*Note: White noise levels were 65, 70, 75 dB, speech level ≈ 75 dB; * indicates a significant difference between groups in the 65 dB condition* (F(2,86) = 8.18, p= .001)

Table 1: Group characteristics – Sub-attentive (Sub), normal-attention (Normal) and Super-attentive groups (Super)

	Sub (N=36) Mean (SD)	*Normal (N=29)* Mean (SD)	*Super (N=25)* Mean (SD)	*Test*	*Test statistic*	*p*	*Post-hoc comparisons*
Number girls	11	18	23	$X^2(2)$	22.9	<.001	
Age	9.36 (.64)	9.67 (.59)	9.60 (.53)	$F(2,89)$	2.4	.096	
Two CR RT task	8.14	4.21	3.32	$F(2,89)$	11.4	<.001	Sub < N, Sp
Omission errors	(5.51) 42.72	(3.54) 33.97	(2.72) 29.68	$F(2,89)$	5.10	<.008	Sub < N, Sp
Directional errors	(17.09)	(16.37)	(15.33)				
Normal background noise condition	2.64 (2.37)	3.97 (2.33)	5.32 (2.11)	$F(2,89)$ $F(2,89)$	10.1 22.9	<.001 <.001	Sub< N <Sp Sub< N <Sp
Span	105.8	143.1	164.2	$F(2,89)$	13.1	<.001	Sub< N, Sp
Go/No-Go	(33.1)	(39.3)	(27.9)	$F(2,89)$	13.2	<.001	Sub< N, Sp
Verbal episodic memory	6.14 (2.63) 25.8	8.80 (2.59) 28.7	9.44 (2.90) 31.5				
Verbal recognition task	(4.62)	(3.64)	(4.41)				

Note. Post-hoc comparisons are shown where p < .05; Sub = Sub-attentive, N = normal attention, Sp= Super-attentive

Table 2: Main effects and interactions from Group X Noise X Task Type repeated

measures ANOVA

	df	F	p
Main Effects			
Group	1,85	5.53	.006*
Noise	1,85	1.25	.267
Task Type	1,85	.521	.472
Two Way Interactions			
Noise X Group	2, 85	4.30	.017*
Task Type X Group	2, 85	.016	.984
Task Type X Noise	2, 85	4.94	.029*
Three way interactions			
Group X Noise X Task type	2, 85	.594	.554

Note. * = $p < .05$

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