Journal of Cognitive Psychology

ISSN: 2044-5911 (Print) 2044-592X (Online) Journal homepage: www.tandfonline.com/journals/pecp21

Differential impacts of addition and omission deviants on the working memory performance of adults with and without self-reported ADHD

Pia Elbe, John Everett Marsh, Daniel E. Sörman, Lars Nyberg, Mariana Vega-Mendoza & Jessica K. Ljungberg

To cite this article: Pia Elbe, John Everett Marsh, Daniel E. Sörman, Lars Nyberg, Mariana Vega-Mendoza & Jessica K. Ljungberg (12 Oct 2025): Differential impacts of addition and omission deviants on the working memory performance of adults with and without self-reported ADHD, Journal of Cognitive Psychology, DOI: 10.1080/20445911.2025.2563538

To link to this article: https://doi.org/10.1080/20445911.2025.2563538

JOURNAL OF COGNITIVE PSYCHOLOGY
https://doi.org/10.1080/20445911.2025.2563538

Routledge
Taylor & Francis Group

Differential impacts of addition and omission deviants on the working memory performance of adults with and without self-reported ADHD

Pia Elbe [a,b,c], John Everett Marsh [a,d], Daniel E. Sörman [a,c], Lars Nyberg [a,e,f,g,h], Mariana Vega-Mendoza [a] and Jessica K. Ljungberg [a]

[a]Department of Health, Education, and Technology, Luleå University of Technology, Luleå, Sweden; [b]Department of Psychology, University of Konstanz, Konstanz, Germany; [c]Department of Psychology, Umeå University, Umeå, Sweden; [d]Department of Psychology, University of Central Lancashire, Preston, UK; [e]Department of Radiation Sciences, Radiology, Umeå University, Umeå, Sweden; [f]Center for Lifespan Changes in Brain and Cognition, University of Oslo, Oslo, Norway; [g]Umeå Center for Functional Brain Imaging, Umeå University, Umeå, Sweden; [h]Department for Integrative Medical Biology, Umeå University, Umeå, Sweden

ABSTRACT
Many individuals usebackground noise to aid concentration on tasks, yet its effect on workingmemory, especially for those with ADHD, is not well understood. This studyexamined how background white noise influences short-term serial recall inadults with self-reported ADHD (n = 66) and those without (n = 66), controllingfor anxiety and depression. Participants performed a visual-verbal serialshort-term memory task under two conditions: continuous white noise interruptedby quiet intervals (omission deviant) and continuous quiet interrupted by whitenoise (addition deviant). Results showed that addition deviants disruptedperformance more in non-ADHD adults, while omission deviants had a greater disruptiveeffect on adults with self-reported ADHD. These findings suggest thatinterruptions in background sound may differently affect individuals with ADHDsymptoms. Exploratory analyses showed the absence of a primacy effect in adultswith self-reported ADHD. Future research might explore optimal auditoryenvironments tailored to attention differences in those with and without ADHD.

ARTICLE HISTORY
Received 17 February 2025
Accepted 17 July 2025

KEYWORDS
ADHD; visual-verbal serial recall; working memory; auditory distraction; environmental noise

It is widely recognised that background noise often disrupts performance on tasks that require focused attention, especially in cognitive domains such as memory and comprehension (Babisch, 2005; Dalton & Behm, 2007). However, this effect is not universal. Certain properties of background noise, such as acoustic variation (Hughes et al., 2007) and semantic relevance (Marsh & Jones, 2010), can play a critical role in determining its impact. Equally important is the specific cognitive demand of the task at hand. For example, background sequences with marked acoustic changes – such as changing-state sequences – are known to impair short-term memory tasks that require recall of sequential order (Jones & Tremblay, 2000; Marsh et al., 2009). In contrast, steady-state sound, which lacks frequent acoustic shifts, has minimal effect on such tasks. Moreover, while meaningful background speech disrupts tasks requiring semantic processing (e.g. reading comprehension), speech in an unfamiliar language poses little disruption (Marsh et al., 2008, 2009; Martin et al., 1988).

Relatively less studied, however, is the potential for background sound to *enhance* task performance, particularly among those who prefer working with auditory stimulation over silence (cf. Ball et al., 2014). Some studies suggest that low-level ambient noise can improve creativity (Mehta et al., 2012), implying that sound without distinct tonal patterns, like aperiodic white noise, may support sustained focus on cognitive tasks. In this study, we investigate whether background sound and its variations can aid or impair task performance in adults with and without ADHD. Notably, no prior research has examined how brief moments of quiet, embedded within continuous white noise, influence task performance in adults with ADHD. While a steady-state white noise background might create a stable auditory environment, intermittent quiet periods could disrupt this stability, potentially diverting attention

CONTACT Pia Elbe pia.elbe@ltu.se, pia.elbe@uni-konstanz.de Department of Health, Education, and Technology, Luleå University of Technology, Luleå, 97187, Sweden
Supplemental data for this article can be accessed online at https://doi.org/10.1080/20445911.2025.2563538.

from the task. Given that children with ADHD may perform better with continuous white noise (for a review see Nigg et al., 2024), interruptions in this auditory stimulation may have distinct effects for ADHD and non-ADHD individuals. In this study we compare the impact of continuous white noise, quiet interrupted by white noise, and white noise with brief silences on visual-verbal serial recall in self-reported ADHD and non-ADHD adults. By examining the impact of these variations on visual-verbal serial recall, insights into how auditory context influences focus and distraction may be uncovered. The findings could have practical implications for optimising study and work conditions for individuals who rely on background sound for concentration.

The influence of background white noise

Several studies within cognitive science have examined white noise – a sound that combines a mixture of frequencies across the auditory spectrum – and its potential effects on cognitive functions. White noise has been investigated not only for its physiological benefits but also for its role in modulating attentional and executive functions, particularly in individuals with ADHD, where it has been proposed as a therapeutic tool to improve attention (Pickens et al., 2019). Research on its effects on sensorimotor tasks and cognitive flexibility has revealed that white noise may influence performance by altering neural dynamics; specifically, studies suggest it may enhance cognitive functions through mechanisms involving stochastic resonance, which can potentially foster neural plasticity (Pellegrino et al., 2022).

However, the role of white noise in cognitive enhancement remains complex, with evidence both supporting and refuting its positive impact. For instance, findings in vigilance tasks are mixed, showing both improved (Poulton, 1977) and reduced performance (Broadbent, 1979).), depending on noise characteristics and task demands. Further, white noise introduced during mental arithmetic or tasks requiring attention to spatial and verbal information disrupts performance if it interferes with critical stages of processing or response execution (Hockey & Hamilton, 1970; Woodhead, 1964). Not much is known about the disruptive potential of high-intensity white noise on cognitive tasks, especially above 95 dB(A), due to ethical considerations around its sustained use (Jones & Broadbent, 1991; Smith & Jones, 1992). Long-term environmental noise exposure, such as aircraft noise, has been shown to detract from cognitive development, notably affecting learning and memory (Hygge et al., 2002; Klatte et al., 2013).

Despite these caveats, white noise may offer specific cognitive benefits for children with ADHD, where theories such as the moderate brain arousal model propose that white noise can help regulate attention by modulating dopaminergic pathways through stochastic resonance (Cheon et al., 2003; Mortimer et al., 2019; Spencer et al., 2005). Experimental studies in ADHD contexts show promising but varied results. For example, Söderlund and Sikström (2010) found that white noise enhanced free recall in children with inattention when used at 78 dB, whereas typically attentive children performed better in silence. Another study using a go/no-go task reported improved vigilance and inhibitory control in some children with ADHD when exposed to white noise, suggesting a targeted benefit for specific executive functions (Baijot et al., 2016). These findings imply that, under certain conditions, white noise may serve as a non-invasive cognitive enhancer for attentional control in ADHD, particularly where pharmacological interventions are unsuitable (Pickens et al., 2019). However, therapeutic recommendations must await further research, as white noise has yet to be validated in formal clinical ADHD interventions (Lambez et al., 2020; Núñez-Jaramillo et al., 2021).

The observed cognitive benefits of broadband noise, especially in ADHD populations, lend credence to its potential for enhancing focus and reducing distractibility. Still, before therapeutic applications can be confidently designed for populations such as individuals with ADHD, additional research is warranted, ideally focusing on white noise within robust memory and distraction paradigms.

The irrelevant sound paradigm

The effects of background sound on cognitive performance have typically been studied using the irrelevant sound paradigm, in which participants are tasked with recalling a list of approximately 6–8 sequentially presented verbal items (usually digits) in strict serial order (Colle & Welsh, 1976; Salamé & Baddeley, 1982). Although participants are instructed to ignore the background sound, its mere presence disrupts serial recall. A key finding is that a sequence of speech tokens or tones with appreciable changes in acoustic properties (e.g. "v k q h … ", or a sequence of tones varying in frequency) produces more disruption than a continuous or repeating sequence of stimuli (e.g. "v v v v … ", or a repeated tone), known as the changing-state effect (Jones et al., 1992).

The leading explanation for this effect is interference-by-process (Jones & Tremblay, 2000): as a by-product of the perceptual organisation process (cf. Bregman, 1990), the order of acoustic changes within a sound sequence is processed, creating cues that conflict with the deliberate seriation process required for the ordered recall of visual items (Jones & Tremblay, 2000). On this view, continuous sounds such as white noise fail to disrupt serial recall because they lack the acoustic changes necessary to register order cues that would conflict with the serial rehearsal process crucial for accurate recall. Supporting the interference-by-process account, several studies have shown that continuous background pink noise does not disrupt serial recall (Ellermeier & Zimmer, 1997; Marsh et al., 2009). Additionally, other studies have found that even loud background white noise produces only minimal disruption in serial recall (e.g. Baddeley & Salamé, 1986), or that the extent of disruption depends on the timing between the presentation of to-be-remembered visual items and bursts of white noise (Salamé & Wittersheim, 1978).

Disruption of serial recall by intermittently presented sounds relates to another disruptive effect of background sound readily captured within the irrelevant sound paradigm – the deviation, or oddball effect (Hughes et al., 2005, 2007). In this case, an infrequent or unexpected acoustic change (i.e. deviation) following a repeated or continuous auditory input captures attention away from the serial recall task, resulting in task disruption. This effect is thought to occur because a neural model representing the predictable pattern or regularity in the sounds is established, and the deviant captures attention by violating this pattern (e.g. Bendixen et al., 2006; Vachon et al., 2012; Winkler et al., 2009). Notably, the auditory deviation or oddball effect is independent of the specific physical properties of the deviant sound itself.

Deviants that consist of rare changes embedded within an otherwise continuous pattern of the same acoustic token, or those presented in a context of quiet, both lead to behavioural disruption (Berti, 2013). Additionally, the unexpected omission of an acoustic token (e.g. ABABABABA_AB) also constitutes a deviant event (an omission deviant; Chouiter et al., 2015; Todorovic & de Lange, 2012). Deviants can thus be broadly classified into two types: addition or omission of some aspect of the stimulus (Raij et al., 1997). The brain's use of past patterns to build expectations for future events is well-documented, with research showing that cortical activity is similar between omission and addition deviants across sensory modalities (Andersen & Lundqvist, 2019), suggesting a unified response to pattern violations. Omission and addition deviants also evoke topographically similar mid-latency ERP responses (H. C. Hughes et al., 2001), indicating a shared process in short-term memory for auditory events.

It is widely accepted that when an incoming sound (or its absence) mismatches a short-lived memory representation of the recent auditory sequence, an orienting response is triggered, leading to attentional capture and task disruption (Cowan, 1995; Schröger, 1997; Sokolov, 1963). The repetition or continuation of a stimulus allows it to be included in the neural model, thus preventing a mismatch with incoming auditory information. This reduces or eliminates the orienting response (e.g. Cowan, 1995; Elliott & Cowan, 2001; Lange, 2005; Mackworth, 1969; Waters et al., 1977). Such habituation of the orienting response is observed through a reduced disruptive effect of an auditory sequence on serial recall performance over the course of a trial block (e.g. Bell et al., 2012; Röer et al., 2014). Continuous or repetitive sounds, such as white noise or steady-state tones, often result in lower levels of distraction over time because they lack the variation needed to continually re-engage the orienting response. Habituation to deviant events, such as addition or omissions, are particularly relevant to working memory, as sustained task performance amid background noise can demand attentional control to block the capture of attention they produce (e.g. Hughes et al., 2013). The extent to which an individual habituates to deviant sounds thus depends on their working memory capacity (Hughes et al., 2013; Marsh et al., 2018; Sörqvist, 2010; but see Korner et al., 2019) which is linked to trait capacity for attentional control (Hughes et al., 2013).

ADHD impacts working memory

Deviant stimuli in short-term memory tasks reliably elicit an orienting response, a reaction that is consistently replicated in laboratory settings (e.g. Bell et al., 2019; Hughes, 2014). Among psychiatric conditions marked by attentional-control difficulties, ADHD shows replicated evidence of heightened vulnerability to auditory deviance distraction, even when working-memory capacity is taken into account (e.g. Blomberg, et al., 2022; Gumenyuk et al., 2005; Tegelbeckers et al., 2022; Van Mourik et al., 2007). Accordingly, we chose ADHD as an a priori test case in which to examine how unexpected sounds interact with task demands to shape distractibility. But how does this reaction to deviant stimuli relate to ADHD symptoms as experienced in daily life? The answer lies in how these paradigms capture the heightened distractibility and attentional control challenges often faced by individuals with ADHD. Two key perspectives support this rationale. First, at a behavioural level, adults with ADHD often show a persistent pattern of inattention and/or impulsivity, key diagnostic criteria for the disorder (American Psychiatric

Association, 2013). Specifically, ADHD symptoms often include difficulties in maintaining focused attention on a single task and a strong proclivity for distraction, two attentional aspects known to be impaired in ADHD (Wetzel et al., 2012). Second, studies using distraction paradigms in controlled environments have demonstrated that adults with ADHD show marked decreases in short-term memory performance, particularly when irrelevant sounds are present, which may highlight broader deficits with executive function and cognitive control (Pelletier et al., 2016). Moreover, recent findings suggest that individuals with ADHD may exhibit unique attentional challenges in orienting and re-orienting focus in response to irrelevant auditory stimuli, with some studies even identifying distinct neural markers, such as ERP components, as indicators of these deficits (Gumenyuk et al., 2023). While attentional impairments vary among individuals with ADHD, these findings highlight measurable differences in cognitive processes that can be specifically observed in controlled settings.

Working memory deficits in ADHD extend across both visuospatial and phonological domains (Alderson et al., 2013). While behavioural studies consistently identify these impairments, recent evidence also highlights neural inefficiencies in attentional control, which may contribute to working memory challenges in ADHD. For instance, one key marker, the Contralateral Delay Activity (CDA), reflects reduced working memory capacity in ADHD and may represent an enduring neural characteristic of the disorder (Luo et al., 2019; Wiegand et al., 2016). Similarly, inefficient encoding in working memory tasks among adults with ADHD has been evidenced in eye-tracking studies, further supporting the notion of attentional control differences rather than an overall reduction in capacity (Jayawardena et al., 2019; Kim et al., 2014). While some studies report inconsistent neural findings, an overall pattern suggests that working memory impairments in ADHD may stem primarily from attentional control deficits, particularly regarding interference control during task demands (Ko et al., 2013; Stroux et al., 2016). For example, research has shown that verbal recall is notably impacted in ADHD, further reflecting the attentional demands involved in working memory (Lundervold et al., 2019). In children with ADHD, motivational deficits appear to influence short-term memory performance, with cumulative effects observed in visuospatial working memory tasks (Dovis et al., 2013). These studies collectively indicate that while working memory capacity is affected, it is the attentional control aspect within working memory that primarily contributes to performance differences in ADHD under conditions of distraction.

The present study

This study investigates the impact of background white noise versus quiet, along with the presence of omission and addition deviants, on verbal working memory performance in individuals self-reporting an ADHD diagnosis. Specifically, it addresses the following research questions: (1) Is there a relationship between ADHD and working memory performance, measured by serial recall accuracy? (2) Does ADHD influence susceptibility to distraction by omission and addition deviants? (3) How does background noise (quiet vs. white noise) affect working memory performance? (4) Is there a relationship between ADHD and habituation to distraction across trials in a serial recall task? Additionally, we explore whether ADHD is associated with serial position effects (i.e. average accuracy of each digit position within a trial across trials).

Guided by prior research on attentional deficits in children and the moderate brain arousal model (Sikström & Söderlund, 2007), as well as evidence of working memory capacity limitations (e.g. Luo et al., 2019) and challenges with re-orienting attention (Gumenyuk et al., 2023) in ADHD, we hypothesised that individuals with ADHD would demonstrate *improved* recall performance in a continuous white noise condition compared to a quiet condition. Based on findings in typically-developing adults using similar paradigms (e.g. Berti, 2013), we further hypothesised that individuals without ADHD would show either reduced or unchanged recall performance in white noise relative to quiet.

We also examined the impact of deviants between ADHD and control groups. We hypothesised that the omission deviant (a brief silence within continuous white noise) would be more salient for the self-reported ADHD group, resulting in greater disruption for this group than for the self-reported non-ADHD group. This hypothesis is based on the stabilising effect that continuous white noise has been shown to have on individuals with ADHD, as steady-state, continuous auditory input can enhance attentional focus by creating a consistent sensory background that minimises distractions and helps regulate cognitive processes (Sikström & Söderlund, 2007).

In contrast, we expected the addition deviant (a brief noise burst) presented in quiet to disrupt the self-reported non-ADHD group more than the self-reported ADHD group. The basis of this hypothesis is that quiet conditions may not provide the same level of cognitive stability for ADHD than non-ADHD participants, as the former often benefit from continuous, moderate stimulation (Sikström & Söderlund, 2007). The moderate brain arousal model posits that such background stimulation can help individuals with ADHD reach an optimal arousal level, enhancing focus and attentional engagement. Consequently, a sudden noise burst in a quiet environment may be less disruptive to them, as their attentional system may not be as finely attuned to changes in a quiet background, given their lower baseline arousal in quiet settings. Thus, differences in predicted effects between ADHD and non-ADHD individuals depend crucially on sensory processing differences and baseline levels of attentional engagement.

When considering habituation to auditory deviations, we anticipate that the impact will differ depending on both the type of deviant and the participant group. Specifically, in the context of white noise, we hypothesise that the omission deviant (a brief silence within continuous noise) will be particularly disruptive for individuals with ADHD, as this group may rely on continuous auditory input to stabilise their attentional focus. Because this interruption to the white noise stream disrupts the steady-state environment that individuals with ADHD often benefit from, it is likely to elicit a stronger orienting response, potentially reducing habituation over repeated exposures. In contrast, the addition deviant (a brief noise burst in quiet) is expected to have a more pronounced effect on non-ADHD participants, who generally maintain optimal cognitive performance in quiet environments. Given that ADHD participants may be less sensitive to a sudden noise burst in quiet due to their sensory processing preferences, habituation to this deviant may be more prominent for non-ADHD participants, as their orienting response to the sound diminishes with repeated exposure. Further, given the reduced capacity for cognitive control and attentional engagement in ADHD participants, we expected the extent of their habituation to the omission deviant, to be less that the extent of habituation of non-ADHD participants to the addition deviant. Thus, we predicted that the extent of habituation would depend on the specific interaction between auditory conditions and group differences in attentional processing and baseline arousal levels.

Methods

Design

This study used a between-participants design to investigate the impact of auditory conditions on serial recall accuracy. Participants self-reported either an ADHD diagnosis or no diagnosis, forming two primary groups. Each group was then exposed to one of four auditory conditions: continuous quiet, continuous white noise, quiet with a brief noise burst (addition deviant), or continuous white noise with a brief silent period (omission deviant). Performance was measured by accuracy of correct serial recall across these conditions. The study protocol and analysis plan are preregistered (osf.io/hk7wa).

Participants

Data collection was completed online using the Prolific Academic participant recruitment service (www.prolific.co) between 27 January and 23 March 2023. The inclusion criteria for participant recruitment were as follows: (1) Participants must be at least 18 years old and no older than 55 years old to participate. (2) For the ADHD group, participants must answer "yes" to having ADHD in the demographic survey of Prolific prior to participation ("Do you consider yourself to have attention deficit disorder (ADD)/attention deficit hyperactivity disorder (ADHD)?") (3). Participants must be located in an English-speaking country (4). Participants must answer "no" to having the following conditions: Autism Spectrum Disorder, Mild Cognitive Impairment/Dementia, Depression, Anxiety, Dyslexia, and Head injury (5). Participants must have normal or corrected to normal vision and hearing. The inclusion criteria for the control group are identical, except for the question about ADHD. We used the software programme G*Power to conduct a power analysis. Our goal was to obtain .95 power to detect a medium effect size of .25 at the standard .05 alpha error probability. Sixty-six individuals with self-reported ADHD and 66 individuals without self-reported ADHD were recruited through Prolific.

Sixty-six participants with ADHD and 66 control neurotypical group participants were recruited and took part in the study. The mean age of participants who self-reported having ADHD was 33.05 (SD = 10.11), and the mean age of participants who self-reported not having ADHD was 37.88 (SD = 9.95). The group of participants with ADHD was 41.79% female and the control group was 41.54% female. In the total sample of 132 individuals, 57.58% reported living in the United Kingdom, 26.51% lived in the United States, and 15.91% lived in a third country. In the demographic survey, 66.67% of the included participants reported "white" as their ethnicity, 12.88% reported "black" as their ethnicity, 9.85% reported "Asian" as their ethnicity, 8.33% reported "mixed" as their ethnicity, and 2.27% reported "other" as their ethnicity.

Anxiety and depression were controlled for in this study due to their known effects on working memory (e.g. Moran, 2016; Rock et al., 2014) and susceptibility to auditory distraction (Desseilles et al., 2021; Eysenck et al., 2007). Both conditions are associated with reduced working memory capacity (Moran, 2016; Rock et al., 2014), heightened sensitivity to environmental stimuli (Eysenck et al., 2007; Safra et al., 2019), and attentional lapses (Pacheco-Unguetti et al., 2010; Snyder, 2013), which can mimic or amplify attentional difficulties seen in ADHD. By controlling for these factors, we aimed to more accurately assess the effects of ADHD on short-term memory and auditory distraction, reducing the likelihood that observed differences are driven by anxiety- or depression-related attentional and memory influences rather than ADHD-specific processes.

Participants received a reward of 6.75 GBP through Prolific Academic. Participants provided informed consent online, prior to beginning the experiment. Ethical approval for this study was obtained from the University of Central Lancashire.

Materials

Serial recall task

The serial recall task is programmed using labjs, a graphical user interface for Javascript experiments (Henninger et al., 2022). Participants were asked to recall eight digits, presented visually in the centre of the screen in 72-point black Arial font on a white background in a serial order without replacement. In each of 84 trials, participants were randomly presented a series of 8 out of 9 non-repeating digits for 800 milliseconds each with 200 milliseconds of blank screen between digits. The programme did not allow trials starting with the digit 1 and digits were not numerically adjacent (e.g. a 4 could never follow a 3). After each presentation of digits, a number line was presented in ascending order, with one button per digit, and participants were asked to use a mouse or trackpad to navigate and click on the digits in the order they were presented. It was not possible to make changes and the next trial could only begin once 8 digits had been selected, eliminating the occurrence of missing information. The main outcome variable in the serial recall task is accuracy.

Auditory stimuli

During the serial recall task, auditory background noise was present. Participants were required to pass a headphone calibration, to ensure correctly adjusted volume and ensure binaural headphone use. Compliance was measured after the task using a headphone check described in an online feasibility study by Elliott et al. (2022). In the headphone calibration, participants were instructed to set their volume to a comfortable listening level first. Participants then responded to 6 trials, in each of which 3 tones were presented. Participants did not receive feedback on their accuracy in these trials. After each set of 3 tones, participants had to respond which of the tones was the quietest. If a participant responded incorrectly to more than one of the six trials, they were given a message that their audio set-up was insufficient and not allowed to participate further. According to Elliott et al, this calibration achieved comparable results in relation to online testing of the same auditory serial recall paradigm we employed in this study to offline studies (2022), ensuring high data quality for this task. In the task, twenty-percent of trials, quasi-randomly assigned using a random number generator (with the condition that distraction trials could not occur consecutively), contained a brief deviant distractor starting at the sixth digit in the series, in each of two conditions: a silent background noise condition with a white noise distractor, and a white background noise condition with a silent distractor. In the white background noise condition, the noise was present from the beginning to the end of each encoding phase. The main outcome variable is the deviant effect, measured by taking the difference between deviant and non-deviant auditory distraction trials, with a higher deviant effect indicating a greater impact of the deviant.

Adult ADHD self-report scale (ASRS)

In order to verify between-group differences in ADHD symptom severity, we used the ADHD self-report scale (ASRS; Kessler et al., 2005). This self-reported screening scale includes 18 items about frequency of recent symptoms of adult ADHD. The screening part of this Likert-type questionnaire includes 6 items with 68.7% sensitivity, 98.3% specificity, 97.9% total classification accuracy, and substantial inter-rater reliability ($\kappa = 0.76$). The ASRS screener shows strong concordance with clinical diagnoses (area under the receiver operating characteristic curve = 0.90), with recommended use even in community epidemiological surveys (Kessler et al., 2007).

Depression, anxiety, and stress scale (DASS)

In order to measure depression and anxiety symptoms in our sample, we chose the Depression, Anxiety, and Stress (DASS) scale (Lovibond & Lovibond, 1995). The 21-item DASS scale has excellent internal consistency (depression $\alpha = .95$; anxiety $\alpha = .93$; Zlomke, 2009), and good psychometric properties across cultures (Bibi et al., 2020).

Procedure

After participants opened their link for participation, they viewed an information screen. This page provided details in the format of frequently asked questions such as "What is the study's purpose?". Contact information for the researchers and explanations of what to do if there is a problem or concern were also given. On the next page, the participants gave consent to take part in the study, after which they were asked to answer demographic questions. Then, the headphone screening occurred. This screening is designed to ensure the audio system is functioning adequately for each participant. Once this calibration occurred, participants performed the serial recall task. Half of the participants in the ADHD-diagnosed group and half of the participants in the control group completed the condition with background noise and silent distracters first (omission deviation), while the other half completed the condition with white noise distracters on a silent background first (addition deviation). In each background noise condition, there were 240 non-distracter trials and 80 trials with a distracter present. After the serial recall task, participants were given a final audio check to ensure that the audio was functioning throughout the task. Next, participants were asked to answer two questionnaires: the ASRS and the DASS. This was followed by questions about their experience, which are provided in the supplementary materials. The final screen the participants viewed before exiting the study was the debrief screen where information about the study and researchers was provided.

Results

The preliminary details of 132 participants, separated by whether or not they reported a diagnosis of ADHD in an online survey prior to recruitment, are summarised in Table 1. In this online task, there was no attrition and no missing data, because participants could only move to the next screen with each step once they gave a full response.[1] The median completion time was 45 min. To test each of our hypotheses, we ran a series of linear mixed effects models. The detailed findings of these models will be described in-text below, followed by a presentation of two additional exploratory analyses.

Preregistered analysis

To test each of our hypotheses, we ran a series of linear mixed effects models. The detailed findings of these models will be described in-text below, followed by a presentation of two additional exploratory analyses. Further details about the models can be found in the supplementary materials.[2]

In order to test the first hypothesis about the impact of ADHD status on accuracy performance in serial recall, we conducted a linear mixed model analysis to examine the effect of ADHD status, anxiety scores, depression scores, and age on response accuracy in the serial recall task, with random intercepts for participant (Model A). Results indicated a significant effect of age on response accuracy in serial recall in this model ($F = 4.41$, $p < 0.05$), but no significant fixed effect of age on response accuracy in serial recall ($\beta = 0.04$, $SE = 0.03$, $t(94) = 1.63$, $p = .11$). This could be explained by the interaction effect between age and depression in this model ($F = 4.00$, $p < 0.05$). No other effects were significant in Model A.

To test the second hypothesis about the impact of ADHD status on the deviant effect (accuracy on standard trials minus accuracy on deviant trials), we conducted a linear mixed model analysis to examine the effect of ADHD status, anxiety scores, depression scores, and age on deviant effect in serial recall task, with random intercepts for participant (Model B). Results indicated a significant effect of age on deviant effect in serial recall ($F = 415.54$, $p < 0.001$), and a significant effect of ADHD on the deviant effect in serial recall ($F = 594.48$, $p < 0.001$). There was also a significant interaction effect between age and ADHD on deviant effect in Model B ($F = 270.78$, $p < 0.001$). In Model B, the significant fixed effects estimates were the same as the model effects, with age ($\beta = -0.004$, $SE = 0.0002$, $t(411.91) = -20.39$, $p < 0.001$), ADHD ($\beta = 0.09$, $SE = 0.002$, $t(40.16) = 24.38$, $p < 0.001$), and age*ADHD ($\beta = -0.004$, $SE = 0.0002$, $t(411.91) = -16.46$, $p < 0.001$) being significant predictors of the deviant effect in serial recall task. The direction of these effects is as follows: having ADHD was associated with a larger deviant effect (lower performance in deviance distraction in serial recall measured by taking the difference between standard and deviant trials across the task) and being older was associated with a smaller deviant effect (higher performance in deviance distraction in serial recall). The interaction between age and ADHD

[1]Box and density plots for descriptive purposes are included in the supplementary materials. Despite the exclusion criteria of anxiety and depression, a Welch's t test showed a significant between-group difference in the DASS sub-scales of anxiety ($t(84421.15) = -60.40$, $p < .001$) and depression ($t(80526.45) = -67.40$, $p < .001$) in ADHD compared to non-ADHD diagnosed individuals, indicating a small effect size for the impact of anxiety ($d = -0.41$) and depression ($d = -0.46$). Individuals who reported being diagnosed with ADHD scored higher in both anxiety and depression. A small to moderate significant effect ($d = 0.49$) of age on ADHD status was found ($t(86445.49) = 72.18$, $p < 0.001$). The sample of participants with ADHD were younger on average. Therefore, the variables of anxiety score, depression score, and age will be included in the analysis.

[2]There was also an impact of age as follows: in the ADHD group, younger individuals were more likely to have a higher deviant effect. In the group without ADHD, older individuals were more likely to have a higher deviant effect. This supports the idea that in individuals with ADHD, symptoms of inattention decrease across the lifespan. To support this finding, a longitudinal study with a bigger age range would be preferable, rather than this cohort sample.

Table 1. Participant demographics and task performance.

	ADHD group ($n = 66$)				Control group ($n = 66$)			
	Median	Mean	SD	Range	Median	Mean	SD	Range
ASRS screener	21.00	21.55	4.40	12–30	13.00	13.60	3.67	7–21
ASRS Total	61.50	60.84	12.61	32–89	38.00	40.092	10.16	20–67
DASS-Anxiety	3.00	4.47	4.89	0–21	0.00	2.60	4.21	0–17
DASS-Depression	4.50	6.63	7.64	0–37	1.00	3.51	5.84	0–33
Omission Deviation Effect	0.15	0.24	0.53	−0.67–1.63	−0.10	−0.05	0.70	−1.43–2.10
Addition Deviation Effect	−0.12	−0.17	0.61	−1.93–0.93	0.13	0.26	0.59	−0.80–1.70
Habituation rate	0.00	0.00	0.01	−0.01–0.06	0.00	0.00	0.04	−0.01–0.06

Note: SD = standard deviation. ASRS Screener = ADHD screening tool of the Adult ADHD Self-Reported Scale. ASRS Total = ADHD total score of the Adult ADHD Self-Reported Scale. DASS-Anxiety = DASS Anxiety scale. DASS-Depression = DASS Depression scale. Omission Deviation Effect = difference in average accuracy between standard and deviant trials when the background noise condition is white noise. Addition Deviation Effect = difference in average accuracy between standard and deviant trials when the background noise condition is silence. Habituation rate = the deviant effect per trial number.

indicates that deviance distraction (indicated by the effect of the deviant on accuracy) is different in people with and without ADHD depending on their age. Since the beta coefficient is negative for this interaction term, it indicates that the effect of age on the deviant effect is weaker for individuals with ADHD compared to those without ADHD. In Model C (see Table S3), following Barr's guidelines for the most parsimonious model, the predictors depression score and anxiety score were removed, since they were not significant. Model C resulted in lower AIC and BIC scores (−0.000002122 for Model B compared to −0.000002359 for Model C), indicating that the simplified model is likely the most parsimonious.

Thirdly, we wanted to find the possible influence of background white noise or quiet on task accuracy. Model D therefore includes background noise condition as a fixed effect, in addition to the effects in Model A. Continuous background noise did not have a significant effect on accuracy in the serial recall task.

To test the hypothesis about which type of deviant (omission vs. addition) is more distracting for individuals with and without ADHD, we conducted a linear mixed model analysis.[3] In the resulting model (Model G), the only significant effect is an interaction effect between background noise condition and ADHD status ($F = 22.0$, $p < 0.001$, $\beta = 0.18$, $SE = 0.04$, $t(254) = -4.69$, $p < 0.001$). This indicates that the influence of the background noise is different for individuals with and without ADHD (see Figure 1). The positive beta coefficient ($\beta >$ 0) indicates that individuals with ADHD had a smaller deviant effect (addition deviant) in the quiet condition compared to the noise condition (omission deviant). For individuals without ADHD, the effect of background noise is in the opposite direction compared to individuals with ADHD, meaning that those without ADHD had a smaller deviant effect in the noise condition (omission deviant) compared to the quiet condition (addition deviant).

Habituation effects were examined over the course of the task to determine whether patterns differed between individuals with and without ADHD. The variable we used to look at habituation is the trial number, whereby a higher trial number corresponds to a later time across the task. The simple question of whether or not habituation, as revealed by an increase in accuracy scores over the course of the task, occurred was addressed with a Kendall's Tau-b correlation, and no significant relationship was found, $\tau b = 0.00$, $p = 0.99$, $n = 86689$. The habituation rate was calculated by taking the slope of accuracy across time (See Table 1). In order to see if the habituation rate is related to ADHD status, we performed a generalised linear regression model analysis (Model H; see Table S8), with habituation rate as the dependent variable, and the following fixed effects: depression, anxiety, age, and ADHD status. No variables were significant predictors of habituation rate.

Exploratory analysis

As an exploratory analysis, we tested the impact of ADHD group on the serial position effect. A linear mixed model (Model J; see Table S9) was created to examine the effect of ADHD status and serial position, with random intercepts for each participant. Results indicated no significant effect of ADHD ($\beta = 0.005$, $SE =$ 0.013, $t(127.15) = 0.36$, $p = 0.719$), but a significant effect of serial position on response accuracy in serial recall in this model ($F = 58.79$, $p < 0.001$). A significant interaction effect between ADHD and serial position

[3]Model E is identical to Model D with the outcome variable deviant effect, including background noise as a fixed effect. The resulting Model E did not have significant predictors of the deviant effect and no significant fixed effects (see Table S5). In order to find the most parsimonious model, Model F included only the predictors used in Model C (meaning that depression and anxiety were excluded) with the addition of background noise condition. Model F (see Table S6), resulted in a singular model fit, so the random effects structure should be reduced. By comparing the AIC and BIC of Model F to a new model, Model G (removing the influence of Age, see Table S7), we can see that Model G has slightly better fit.

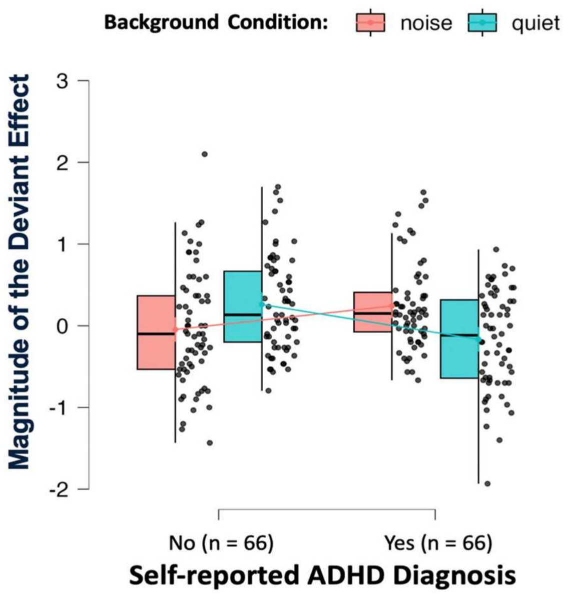

Figure 1. Magnitude of the deviant effect, ADHD group, and Background noise condition. Note: Magnitude of the deviant effect = average difference between deviant and non-deviant trial accuracy. Error bars show standard error of the mean.

was found in this model ($F = 6.80$, $p < 0.001$). Figure 2 shows significant fixed effects of each serial position except serial position 5 ($\beta = 0.002$, $SE = 0.008$, $t(127.13) = 0.32$, $p = 0.75$). Fixed interaction effects were present between each serial position and ADHD status, except at serial position 4 ($\beta = -0.009$, $SE = 0.007$, $t(130.43) = -1.40$, $p = 0.17$). The fixed interaction effects indicate that participants with ADHD responded significantly less accurately at the first and second serial positions, significantly more accurately at the third, fifth, sixth, and seventh serial position. There was no difference between ADHD and non-ADHD participants at the fourth serial position.

A second exploratory analysis was to test adult self-reported ADHD symptom severity using the ASRS in more detail and relate these sub-scales to the deviant effects in the addition and omission deviant conditions using Pearson correlations. See Table 2 for a correlation matrix. The following scores of the ASRS were included: (1) ASRS Total Score, (2) ASRS 6-item Screener, (3) ASRS Inattention Sub-scale, (4) ASRS Hyperactivity Sub-scale, (5) ASRS Motor score of the Hyperactivity Sub-scale, and (6) ASRS Verbal score of the Hyperactivity Sub-scale. Results indicate no significant simple correlations between the effect of the deviants and ADHD symptom severity.

General discussion

This study aimed to explore how continuous background noise with deviant auditory interruptions, compared to continuous silence with deviant white noise interruptions, affect serial recall accuracy in adults with and without self-reported ADHD. Based on prior research, we hypothesised that continuous white noise might stabilise attention and enhance recall performance in ADHD participants, while sudden deviations – such as omissions or additions – would heighten distraction due to attentional re-orienting challenges. Below, we discuss each major finding in relation to these

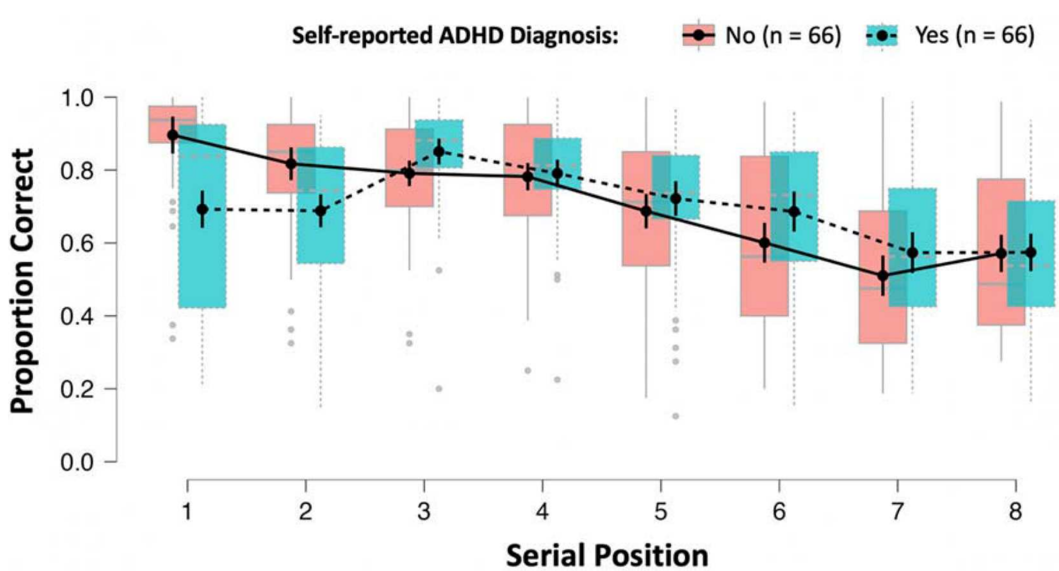

Figure 2. Serial position effect by ADHD group. Note: Proportion correct = the proportion of correct responses where 1.0 is a perfect score and 0.0 represents no correct digits per trial. Serial position = the serial position of the digits across one trial. Error bars show standard error of the mean.

Table 2. Correlation matrix of ADHD symptom severity, sub-scales, and working memory performance.

Variable		1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Age	*r*	–										
	p-value	–										
2. Omission deviant effect	*r*	−0.14	–									
	p-value	0.46	–									
3. Addition deviant effect	*r*	−0.26	0.66***	–								
	p-value	0.15	<.001	–								
4. ASRS (total score)	*r*	−0.30***	−0.09	−0.15	–							
	p-value	<.001	0.64	0.42	–							
5. ASRS (6-item screener)	*r*	−0.34***	−0.24	−0.25	0.95***	–						
	p-value	<.001	0.17	0.16	<.001	–						
6. ASRS (inattention sub-scale)	*r*	−0.31***	−0.19	−0.23	0.93***	0.93***	–					
	p-value	<.001	0.30	0.20	<.001	<.001	–					
7. ASRS (hyperactivity sub-scale)	*r*	−0.24**	0.01	−0.06	0.93***	0.84***	0.75***	–				
	p-value	0.01	0.97	0.74	<.001	<.001	<.001	–				
8. ASRS (motor score)	*r*	−0.29***	−0.03	−0.04	0.88***	0.82***	0.69***	0.95***	–			
	p-value	<.001	0.85	0.83	<.001	<.001	<.001	<.001	–			
9. ASRS (verbal score)	*r*	−0.15	0.07	−0.09	0.88***	0.74***	0.72***	0.921***	0.76***	–		
	p-value	0.085	0.69	0.63	<.001	<.001	<.001	<.001	<.001	–		
10. Anxiety (DASS)	*r*	−0.23**	−0.10	−0.24	0.46***	0.47***	0.46***	0.405***	0.44***	0.31***	–	
	p-value	0.007	0.59	0.19	<.001	<.001	<.001	<.001	<.001	<.001	–	
11. Depression (DASS)	*r*	−0.15	−0.33	−0.24	0.42***	0.43***	0.47***	0.31***	0.33***	0.24**	0.70***	–
	p-value	0.07	0.06	0.18	<.001	<.001	<.001	<.001	<.001	0.005	<.001	–

Note: Significant *p*-values are flagged: *$p < .05$, **$p < .01$, ***$p < .001$. Pearson's *r* was used.

hypotheses and existing theories of attentional control and sensory processing.

Our first hypothesis predicted improved recall performance for ADHD participants in continuous white noise, based on the moderate brain arousal model (Sikström & Soderlund, 2010). However, we found no significant difference in recall accuracy across conditions for self-reported ADHD versus non-ADHD participants on non-deviant trials, whether with or without background noise. This null finding might be due to the intermittent presentation of background noise, as the absence of noise during the order reconstruction phase could have reduced its stabilising effect. Continuous noise throughout all trial phases may be required to fully assess this potential benefit of white noise for ADHD-related working memory performance.

Secondly, we hypothesised that individuals with ADHD would exhibit a larger deviant effect, particularly for omission deviations within continuous white noise. Our results supported this prediction, showing that ADHD participants had lower performance on deviant trials compared to non-deviant trials, suggesting a greater sensitivity to auditory disruptions. This aligns with the stabilising role that continuous auditory input may play for individuals with ADHD, with omissions disrupting this steady-state and triggering an orienting response that draws attention away from the primary task.

Thirdly, we examined the influence of background noise on distraction susceptibility, predicting that addition deviations in silence would disrupt non-ADHD participants more than those with ADHD. Our findings supported this hypothesis: non-ADHD participants were more distracted by addition deviations in quiet than in white noise, while ADHD participants showed the opposite pattern, being more affected by omission deviations in the white noise condition. This finding is consistent with studies suggesting that white noise supports attentional engagement in non-clinical populations (Baijot et al., 2016; Söderlund et al., 2016) and that ADHD participants may rely more on a continuous auditory background to manage sensory sensitivities.

Finally, our hypothesis on habituation, predicted different patterns of habituation to omissions versus additions across groups. While we expected habituation to addition deviations in quiet for non-ADHD participants and reduced habituation to omissions for ADHD participants, our findings showed no significant habituation effects over time. This result suggests that neither group habituated to the deviant sounds, possibly due to the specific characteristics of the task or differences in attentional demands. This finding contrasts with that reported by Pelletier et al. (2016) who observed that the impact of an irrelevant background sound diminished at a similar rate in ADHD participants and controls, concluding that sustained attention across the task does not deteriorate in participants with ADHD (Pelletier et al., 2016). Although the ADHD sample in this study exhibit on average high ADHD symptom severity, they may have been highly motivated to perform well given that they registered to the participant recruitment service Prolific Academic. However, all participants had the knowledge that the monetary reward was not dependent on their performance. Future research could explore how varying the encoding load or task difficulty might influence habituation rates, particularly in ADHD populations whereby reduced working memory capacity (Jayawardena et al., 2019; Kim et al., 2014; Luo et al., 2019; Wiegand et al., 2016), may increase vulnerabilities to the disruptive effects of auditory deviations (Hughes et al., 2013; Labonté et al., 2021).

In addition to these findings, we observed a novel serial position effect in ADHD participants, who compared with the non-ADHD participants, did not show the typical primacy effect seen in serial recall (Murdock, 1962). Instead, they performed better on middle list positions. There are several plausible explanations for this pattern. For example, the lack of the primacy effect may involve ADHD-related tendencies for internally directed attention (Gibson et al., 2019), where individuals may take longer to focus on each item, thereby missing the initial items. This explanation also coheres with the idea that individuals with ADHD struggle with initial attentional control due to a slower build-up of task engagement (Sonuga-Barke et al., 2010). The variability in attentional allocation may thus reflect an initial difficulty in focusing on, or fully engaging with the task at the onset of each trial. Another possibility is that the position-specific accuracy demonstrated by individuals with ADHD reflects a problem with attentional persistence. For example, according to the dual pathway model (Sergeant, 2005) ADHD is characterised by both attentional lapses and moments of compensatory over-focus. The impoverished recall of positions 1 and 2 might reflect early lapses, coupled with compensatory focus on later positions where attention may be re-engaged in response to the demands of the task. Further research could explore whether working memory training or other compensatory strategies could harness these potential differences to improve task focus in ADHD.

Our findings can be further examined in the context of the moderate brain arousal model (Söderlund & Sikström, 2010). While we did not observe significant differences in recall accuracy rates between noise conditions or between groups, we found notable differences in distraction levels, evidenced by the interaction effect. Previous studies in children with ADHD symptoms found that white noise facilitates accuracy in free recall (Söderlund & Sikström, 2010) and reduces omission errors in tasks requiring cognitive control (Baijot et al., 2016). Although a direct comparison to our findings is limited due to age differences, both studies indicate that individual differences in focused attention based on ADHD status persist across age groups. Future studies should explore whether aspects of cognitive control that are useful in memory recall are facilitated by white noise, or whether the effects are observed on broader cognitive functions.

While attentional control differences and background noise conditions are the primary factors explored in this study, other variables may also influence the relationship between distraction by deviant sounds and ADHD. However, some factors can be ruled out based on our findings. For instance, prior research shows that positive or negative affect does not significantly impact the level of distraction caused by auditory deviants in serial recall tasks (Kaiser et al., 2021). This suggests that differences in affect are unlikely to account for the attentional discrepancies observed here between ADHD and non-ADHD groups. Importantly, whether white noise is experienced as facilitative or aversive hinges on its loudness level, where low-to-moderate intensities (<65 dB) can enhance attention and dampen stress, but exposures above approximately 80–90 dB elicit physiological stress (Awada et al., 2022; Liu et al., 2007). While our instructions and validated headphone check advised participants to maintain the volume at a comfortable level for the entire experiment, we can't be certain whether or not loudness may have had some impact in this online study. Additionally, there is mixed evidence on whether distraction by deviants reflects an automatic response independent of cognitive load, or whether it can be modulated through cognitive control (Hughes et al., 2013; Labonté et al., 2021). Therefore, it remains uncertain whether individuals with ADHD can effectively manage distractibility through task selection that increases cognitive demands or through enhanced focus. Further research is required to clarify these dynamics and to understand the specific conditions under which cognitive load may reduce or amplify distraction in ADHD. Specific subtypes of ADHD may have differential effects on the deviance distraction in serial recall, which this study did not find significant support for (see correlation matrix in Table 2). Further testing with larger samples and more heterogeneous ASRS symptom classifications could help shed more light on the influence of symptom severity and symptom categories.

Finally, one area we did not explore is encoding speed in working memory. Previous studies suggest that encoding speed variability can impact short-term memory capacity (AuBuchon et al., 2020; de Jong et al., 2023). Capacity decreases when the speed of encoding increases, so variability in the speed of the input, and the speed of the rehearsal, might both impact short-term memory capacity (AuBuchon et al., 2020). Understanding how variable encoding speeds influence ADHD individuals' recall performance could be a valuable addition to behavioural management strategies for working memory in daily life.

There are some limitations of the participant sample that should be addressed in future research. For example, the sample does not reflect any particular geographic or occupational group as is typical in many convenience samples. Also, the results are not generalisable to individuals with ADHD worldwide, since we only selected from English-speaking countries and based on self-reported ADHD diagnoses. There are differences in ADHD diagnostic procedures on a global level, so care should be taken when interpreting the findings on a local level. Our sample may include individuals who are diagnosed by a general practitioner, a psychiatrist, a psychotherapist, or even those who lack any formal diagnosis. The age of diagnosis may have been long ago in childhood or recently in adulthood. It is also possible that other neuropsychiatric symptoms influenced the results, as we chose not to rule out all comorbid conditions. Another noteworthy limitation is that adults who have ADHD could present higher symptom severity or different symptomatology compared to children, so the findings should not be generalised to children or adolescents.

Conclusion

In conclusion, this study suggests that differential responses to omission and addition deviations may distinguish individuals with ADHD from those without, potentially offering a novel behavioural marker for ADHD diagnostics. Additionally, our findings imply that using white noise to enhance on-task focus must be carefully managed, as interruptions in noise delivery (e.g. connectivity drop-outs) may be more detrimental for ADHD participants than sudden noise onset in silence, with the opposite effect for non-ADHD participants. These results underscore the importance of considering individual differences in ADHD when designing optimal working environments for tasks requiring sustained working memory, with implications for both practical applications and future research directions.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

John E. Marsh's contribution to this article was supported by a grant received from the Bial Foundation [grant number: 201/20]. Prof. Jessica K. Ljungberg and Daniel Eriksson Sörman are funded by a grant from VINNOVA [grant number: 2021-02361]. Daniel Eriksson Sörman is also supported by the Swedish Research Council for Sport Science [grant number: P2021-0103].

Data availability statement

The data that support the findings of this study are available from the corresponding author, PE, upon reasonable request.

ORCID

Pia Elbe http://orcid.org/0000-0003-1717-240X
John Everett Marsh http://orcid.org/0000-0002-9494-1287
Daniel E. Sörman http://orcid.org/0000-0002-2709-9966
Lars Nyberg http://orcid.org/0000-0002-3367-1746
Mariana Vega-Mendoza http://orcid.org/0000-0003-2511-1631
Jessica K. Ljungberg http://orcid.org/0000-0001-5546-3270

References

Alderson, R., Kasper, L., Hudec, K., & Patros, C. (2013). Attention-deficit/hyperactivity disorder (ADHD) and working memory in adults: A meta-analytic review. *Neuropsychology*, *27*(3), 287–302. https://doi.org/10.1037/a0032371

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders: DSM-5* (Vol. 5).

Andersen, L. M., & Lundqvist, D. (2019). Somatosensory responses to nothing: An MEG study of expectations during omission of tactile stimulations. *NeuroImage*, *184*, 78–89.

AuBuchon, A. M., McGill, C. I., & Elliott, E. M. (2020). Decomposing the role of rehearsal in auditory distraction during serial recall. *Auditory Perception & Cognition*, *3*(1–2), 18–32. https://doi.org/10.1080/25742442.2020.1842996

Awada, M., Becerik-Gerber, B., Lucas, G., & Roll, S. (2022). Cognitive performance, creativity and stress levels of neurotypical young adults under different white noise levels. *Scientific Reports*, *12*(1), 14566. https://doi.org/10.1038/s41598-022-18862-w

Babisch, W. (2005). Guest editorial: Noise and health. *Environmental Health Perspectives*, *113*(1), A14–A15. https://doi.org/10.1289/ehp.113-a14

Baddeley, A. D., & Salamé, P. (1986). The unattended speech effect: Perception or memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *12*, 525–529.

Baijot, S., Slama, H., Söderlund, G., Dan, B., Deltenre, P., Colin, C., & Deconinck, N. (2016). Neuropsychological and neurophysiological benefits from white noise in children with and without ADHD. *Behavioral and Brain Functions*, *12*(1), 11. https://doi.org/10.1186/s12993-016-0095-y

Ball, L. J., Marsh, J. E., Litchfield, D., Cook, R. L., & Booth, N. (2014). When distraction helps: Evidence that concurrent articulation and irrelevant speech can facilitate insight problem solving. Thinking and Reasoning, 21(1), 76–96.

Bell, R., Mieth, L., Röer, J. P., Troche, S., & Buchner, A. (2019). Preregistered replication of the auditory deviant effect: A robust benchmark finding. *Journal of Cognition*, *2*(1), 13. https://doi.org/10.5334/joc.64

Bell, R., Röer, J. P., Dentale, S., & Buchner, A. (2012). Habituation of the irrelevant sound effect: Evidence for an attentional theory of short-term memory disruption. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(6), 1542–1557. https://doi.org/10.1037/a0028459

Bendixen, A., Grimm, S., & Schröger, E. (2006). The relation between onset, offset, and duration perception as examined by psychophysical data and event-related brain potentials. *Journal of Psychophysiology*, *20*(1), 40–51.

Berti, S. (2013). The role of auditory transient and deviance processing in distraction of task performance: a combined behavioral and event-related brain potential study. *Frontiers in Human Neuroscience*, *7*.

Bibi, A., Lin, M., Zhang, X. C., & Margraf, J. (2020). Psychometric properties and measurement invariance of depression, anxiety and stress scales (DASS-21) across cultures. *International Journal of Psychology*, *55*(6), 916–925. https://doi.org/10.1002/ijop.12671

Blomberg, R., Signoret, C., Danielsson, H., Perini, I., Rönnberg, J., & Capusan, A. J. (2022). Aberrant resting-state connectivity of auditory, ventral attention/salience and default-mode networks in adults with attention deficit hyperactivity disorder. *Frontiers in Neuroscience*, *16*.

Bregman, A. S. (1990). Auditory scene analysis: The perceptual organization of sound. Cambridge, MA: MIT Press.

Broadbent, D. E. (1979). *Handbook of noise control* (Vol. 1, pp. 17.1–17.20). McGraw Hill.

Cheon, K.-A., Ryu, Y. H., Kim, Y.-K., Namkoong, K., Kim, C.-H., & Lee, J. (2003). Dopamine transporter density in the basal ganglia assessed with [123I]IPT SPET in children with attention deficit hyperactivity disorder. *European Journal of Nuclear Medicine and Molecular Imaging*, *30*(2), 306–311. https://doi.org/10.1007/s00259-002-1047-3

Chouiter, L., Tzovara, A., Dieguez, S., Annoni, J. M., Magezi, D., De Lucia, M., & Spierer, L. (2015). Experience-based auditory predictions modulate brain activity to silence as do real sounds. *Journal of cognitive neuroscience*, *27*(10), 1968–1980.

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior*, *15*(1), 17–31. https://doi.org/10.1016/S0022-5371(76)90003-7

Cowan, N. (1995). Verbal working memory: A view with a room. *The American Journal of Psychology*, *108*(1), 123–129. https://doi.org/10.2307/1423105

Dalton, B. H., & Behm, D. G. (2007). Effects of noise and music on human and task performance: A systematic review. *Occupational Ergonomics*, *7*(3), 143–152. https://doi.org/10.3233/OER-2007-7301

de Jong, J., van Rijn, H., & Akyürek, E. G. (2023). Adaptive encoding speed in working memory. *Psychological Science*, *34*(7), 822–833. https://doi.org/10.1177/09567976231173902

Desseilles, M., Muñoz-Moldes, S., & Duprat, R. (2021). The impact of depression on distraction and attention control: Insights from experimental and real-world measures. *Neuroscience & Biobehavioral Reviews*, *127*(1), 545–559.

Dovis, S., Van der Oord, S., Wiers, R. W., & Prins, P. J. M. (2013). What part of working memory is not working in ADHD? Short-term memory, the central executive and effects of reinforcement. *Journal of Abnormal Child Psychology*, *41*(6), 901–917. https://doi.org/10.1007/s10802-013-9729-9

Ellermeier, W., & Zimmer, K. (1997). Individual differences in susceptibility to the "irrelevant speech effect". *The Journal of the Acoustical Society of America*, *102*(4), 2191–2199. https://doi.org/10.1121/1.419596

Elliott, E. M., Bell, R., Gorin, S., Robinson, N., & Marsh, J. E. (2022). Auditory distraction can be studied online! A direct comparison between in-person and online experimentation. *Journal of Cognitive Psychology*, *34*(3), 307–324. https://doi.org/10.1080/20445911.2021.2021924

Elliott, E. M., & Cowan, N. (2001). Habituation to auditory distractors in a cross-modal, color–word interference task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *27*(3), 654–667. https://doi.org/10.1037/0278-7393.27.3.654

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Gibson, B. S., Healey, M. K., & Gondoli, D. M. (2019). ADHD reflects impaired externally directed and enhanced internally directed attention in the immediate free-recall task. *Journal of Abnormal Psychology*, *128*(2), 173–183. https://doi.org/10.1037/abn0000393

Gumenyuk, V., Korzyukov, O., Escera, C., Hämäläinen, M., Huotilainen, M., Häyrinen, T., Oksanen H., Näätänen R., von Wendt L. & Alho, K. (2005). Electrophysiological evidence of enhanced distractibility in ADHD children. *Neuroscience Letters*, *374*(3), 212–217. https://doi.org/10.1016/j.neulet.2004.10.081

Gumenyuk, V., Korzyukov, O., Tapaskar, N., Wagner, M., Larson, C. R., & Hammer, M. J. (2023). Deficiency in re-orienting of attention in adults with attention-deficit hyperactivity disorder. *Clinical EEG and Neuroscience*, *54*(2), 141–150. https://doi.org/10.1177/15500594221115737

Henninger, F., Shevchenko, Y., Mertens, U. K., Kieslich, P. J., & Hilbig, B. E. (2022). lab.js: A free, open, online study builder. *Behavior Research Methods*, *54*(2), 556–573. https://doi.org/10.3758/s13428-019-01283-5

Hockey, R., & Hamilton, P. (1970). Arousal and information selection in short-term memory. *Nature*, *226*, 866–867.

Hughes, H. C., Darcey, T. M., Barkan, H. I., Williamson, P. D., Roberts, D. W., & Aslin, C. H. (2001). Responses of human auditory association cortex to the omission of an expected acoustic event. *Neuroimage*, *13*(6), 1073–1089. https://doi.org/10.1006/nimg.2001.0766

Hughes, R. W. (2014). Auditory distraction: A duplex-mechanism account. *PsyCh Journal*, *3*(1), 30–41.

Hughes, R. W., Hurlstone, M. J., Marsh, J. E., Vachon, F., & Jones, D. M. (2013). Cognitive control of auditory distraction: Impact of task difficulty, foreknowledge, and working memory capacity supports duplex-mechanism account. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 539–553. https://doi.org/10.1037/a0029064

Hughes, R. W., Vachon, F., & Jones, D. M. (2005). Auditory attentional capture during serial recall: Violations at encoding of an algorithm-based neural model?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *31*(4).

Hughes, R. W., Vachon, F., & Jones, D. M. (2007). Disruption of short-term memory by changing and deviant sounds: support for a duplex-mechanism account of auditory distraction. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33(6), 1050–1061.

Hygge, S., Evans, G. W., & Bullinger, M. (2002). A prospective study of some effects of aircraft noise on cognitive performance in schoolchildren. *Psychological Science*, *13*(5), 469–474. https://doi.org/10.1111/1467-9280.00483

Jayawardena, G., Michalek, A., & Jayarathna, S. (2019). Eye tracking area of interest in the context of working memory capacity tasks. *2019 IEEE 20th International Conference on Information Reuse and Integration for Data Science (IRI)*, 208–215. https://doi.org/10.1109/IRI.2019.00042

Jones, D., Madden, C., & Miles, C. (1992). Privileged access by irrelevant speech to short-term memory: The role of changing state. *The Quarterly Journal of Experimental Psychology Section A*, *44*(4), 645–669. https://doi.org/10.1080/14640749208401304

Jones, D. M., & Broadbent, D. E. (1991). Handbook of acoustical measurements and noise control (Vol. 1, pp. 24.1–24.24). McGraw-Hill.

Jones, D. M., & Tremblay, S. (2000). Interference in memory by process or content? A reply to Neath (2000). *Psychonomic Bulletin & Review*, *7*(3), 550–558. https://doi.org/10.3758/BF03214370

Kaiser, S., Buchner, A., & Bell, R. (2021). Positive and negative mood states do not influence cross-modal auditory distraction in the serial-recall paradigm. *PLoS One*, *16*(12), e0260699. https://doi.org/10.1371/journal.pone.0260699

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M. J., Jin, R., Secnik, K., Spencer, T., Ustun, T. B., & Walters, E. E. (2005). The World Health Organization adult ADHD self-report scale (ASRS): A short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256. https://doi.org/10.1017/S0033291704002892

Kessler, R. C., Adler, L. A., Gruber, M. J., Sarawate, C. A., Spencer, T., & Van Brunt, D. L. (2007). Validity of the World Health Organization adult ADHD self-report scale (ASRS) screener in a representative sample of health plan members. *International Journal of Methods in Psychiatric Research*, *16*(2), 52–65. https://doi.org/10.1002/mpr.208

Kim, S., Liu, Z., Glizer, D., Tannock, R., & Woltering, S. (2014). Adult ADHD and working memory: Neural evidence of impaired encoding. *Clinical Neurophysiology*, *125*(8), 1596–1603. https://doi.org/10.1016/j.clinph.2013.12.094

Klatte, M., Bergstroem, K., & Lachmann, T. (2013). Does noise affect learning? A short review on noise effects on cognitive performance in children. *Frontiers in Psychology*, *4*. https://doi.org/10.3389/fpsyg.2013.00578

Ko, C.-H., Yen, J.-Y., Yen, C.-F., Chen, C.-S., Lin, W.-C., Wang, P.-W., & Liu, G.-C. (2013). Brain activation deficit in increased-load working memory tasks among adults with ADHD using fMRI. *European Archives of Psychiatry and Clinical Neuroscience*, *263*(7), 561–573. https://doi.org/10.1007/s00406-013-0407-2

Körner, U., Röer, J. P., Buchner, A., & Bell, R. (2019). Time of presentation affects auditory distraction: Changing-state and deviant sounds disrupt similar working memory processes. *Quarterly Journal of Experimental Psychology*, *72*(3), 457–471.

Labonté, K., Marsh, J. E., & Vachon, F. (2021). Distraction by auditory categorical deviations is unrelated to working memory capacity: Further evidence of a distinction between acoustic and categorical deviation effects. *Auditory Perception and Cognition*, *4*(3–4), 139–164.

Lambez, B., Harwood-Gross, A., Golumbic, E. Z., & Rassovsky, Y. (2020). Non-pharmacological interventions for cognitive difficulties in ADHD: A systematic review and meta-analysis. *Journal of Psychiatric Research*, *120*, 40–55. https://doi.org/10.1016/j.jpsychires.2019.10.007

Lange, E. B. (2005). Disruption of attention by irrelevant stimuli in serial recall. *Journal of Memory and Language*, *53*(4), 513–531. https://doi.org/10.1016/j.jml.2005.07.002

Liu, X., Iwanaga, K., Shimomura, Y., & Katsuura, T. (2007, March). Comparison of stress responses between mental tasks and white noise exposure. *Journal of Physiological Anthropology*, *26*(2), 165–171. https://doi.org/10.2114/jpa2.26.165

Lovibond, S. H., & Lovibond, P. F. (1995). *Manual for the depression anxiety stress scales* (2nd ed.). Psychology Foundation of Australia.

Lundervold, A. J., Halleland, H. B., Brevik, E. J., Haavik, J., & Sørensen, L. (2019). Verbal memory function in intellectually well-functioning adults with ADHD: Relations to working memory and response inhibition. *Journal of Attention Disorders*, *23*(10), 1188–1198. https://doi.org/10.1177/1087054715580842

Luo, X., Guo, J., Liu, L., Zhao, X., Li, D., Li, H., Zhao, Q., Wang, Y., Qian, Q., Wang, Y., Song, Y., & Sun, L. (2019). The neural correlations of spatial attention and working memory deficits in adults with ADHD. *NeuroImage: Clinical*, *22*, 101728. https://doi.org/10.1016/j.nicl.2019.101728

Mackworth, J. F. (1969). Vigilance and habituation: A neuropsychological approach. *New York and London: Penguin Books*, *1*(1), 1–240.

Marsh, J. E., Hughes, R. W., & Jones, D. M. (2009). Interference by process, not content, determines semantic auditory distraction. *Cognition*, *110*(1), 23–38. https://doi.org/10.1016/j.cognition.2008.08.003

Marsh, J. E., & Jones, D. M. (2010). Cross-modal distraction by background speech: What role for meaning. Noise and Health, 12(1), 210–216.

Marsh, J. E., Vachon, F., & Jones, D. M. (2008). When does between-sequence phonological similarity promote irrelevant sound disruption? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(1), 243–248. https://doi.org/10.1037/0278-7393.34.1.243

Marsh, J. E., Yang, J., Qualter, P., Richardson, C., Perham, N., Vachon, F., & Hughes, R. W. (2018). Postcategorical auditory distraction in short-term memory: Insights from increased task load and task type. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(6).

Martin, R. C., Wogalter, M. S., & Forlano, J. G. (1988). Reading comprehension in the presence of unattended speech and music. *Journal of memory and language*, *27*(4), 382–398.

Mehta, R., Zhu, R. J., & Cheema, A. (2012). Is noise always bad? Exploring the effects of ambient noise on creative cognition. *Journal of Consumer Research*, *39*(4), 784–799. https://doi.org/10.1086/665048

Moran, T. P. (2016). Anxiety and working memory capacity: A meta-analysis and narrative review. *Psychological Bulletin*, *142*(8), 831–864. https://doi.org/10.1037/bul0000051

Mortimer, N., Ganster, T., O'Leary, A., Popp, S., Freudenberg, F., Reif, A., Soler Artigas, M., Ribasés, M., Ramos-Quiroga, J. A., Lesch, K.-P., & Rivero, O. (2019). Dissociation of impulsivity and aggression in mice deficient for the ADHD risk gene Adgrl3: Evidence for dopamine transporter dysregulation. *Neuropharmacology*, *156*, 107557. https://doi.org/10.1016/j.neuropharm.2019.02.039

Murdock, B. B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, *64*(5), 482–488. https://doi.org/10.1037/h0045106

Nigg, J. T., Bruton, A., Kozlowski, M. B., Johnstone, J. M., & Karalunas, S. L. (2024). Systematic review and meta-analysis: Do white noise or pink noise help with task performance in youth with attention-deficit/hyperactivity disorder or with elevated attention problems? *Journal of the American Academy of Child & Adolescent Psychiatry*, *63*(8), 778–788. https://doi.org/10.1016/j.jaac.2023.12.014

Núñez-Jaramillo, L., Herrera-Solís, A., & Herrera-Morales, W. V. (2021). ADHD: Reviewing the causes and evaluating solutions. *Journal of Personalized Medicine*, *11*(3), 166. https://doi.org/10.3390/jpm11030166

Pacheco-Unguetti, A. P., Acosta, A., Callejas, A., & Lupiáñez, J. (2010). Attention and anxiety: Different attentional functioning under state and trait anxiety. *Psychological Science*, *21*(2), 298–304. https://doi.org/10.1177/0956797609359624

Pellegrino, G., Pinardi, M., Schuler, A.-L., Kobayashi, E., Masiero, S., Marioni, G., di Lazzaro, V., Keller, F., Arcara, G., Piccione, F., & Di Pino, G. (2022). Stimulation with acoustic white noise enhances motor excitability and sensorimotor integration. *Scientific Reports*, *12*(1), Article 1. https://doi.org/10.1038/s41598-022-17055-9

Pelletier, M. F., Hodgetts, H. M., Lafleur, M., Vincent, A., & Tremblay, S. (2016). Vulnerability to the irrelevant sound effect in adult ADHD. *Journal of Attention Disorders*, *20*(4), 306–316. https://doi.org/10.1177/1087054713492563

Pickens, T. A., Khan, S. P., & Berlau, D. J. (2019). White noise as a possible therapeutic option for children with ADHD. *Complementary Therapies in Medicine*, *42*, 151–155. https://doi.org/10.1016/j.ctim.2018.11.012

Poulton, E. C. (1977). Arousing Stresses Increase Vigilance (Vol. 3, pp. 1–9). Springer. https://doi.org/10.1007/978-1-4684-2529-1_21

Raij, T., Mcevoy, L., Mäkelä, J. P., & Hari, R. (1997). Human auditory cortex is activated by omissions of auditory stimuli. *Brain Research*, *745*(1-2), 134–143.

Rock, P. L., Roiser, J. P., Riedel, W. J., & Blackwell, A. D. (2014). Cognitive impairment in depression: A systematic review and meta-analysis. *Psychological Medicine*, *44*(10), 2029–2040. https://doi.org/10.1017/S0033291713002535

Röer, J. P., Bell, R., & Buchner, A. (2014). Evidence for habituation of the irrelevant-sound effect on serial recall. *Memory & Cognition*, *42*(4), 609–621. https://doi.org/10.3758/s13421-013-0381-y

Safra, L., Chevallier, C., & Palminteri, S. (2019). Depressive symptoms are associated with blunted reward learning in social contexts. *PLoS Computational Biology*, *15*(7), e1007224. https://doi.org/10.1371/journal.pcbi.1007224

Salamé, P., & Baddeley, A. (1982). Disruption of short-term memory by unattended speech: Implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior*, *21*(2), 150–164. https://doi.org/10.1016/S0022-5371(82)90521-7

Salamé, P., & Witterseim, G. (1978). Selective noise disturbance of the information input stage in short-term memory. *Quarterly Journal of Experimental Psychology*, *30*, 693–704.

Schröger, E. (1997). On the detection of auditory deviations: A pre-attentive activation model. *Psychophysiology*, *34*(3), 245–257. https://doi.org/10.1111/j.1469-8986.1997.tb02395.x

Sergeant, J. A. (2005). Modeling attention-deficit/hyperactivity disorder: A critical appraisal of the cognitive-energetic model. *Biological Psychiatry*, *57*(11), 1248–1255.

Sikström, S., & Söderlund, G. (2007). Stimulus-dependent dopamine release in attention-deficit/hyperactivity disorder. *Psychological Review*, *114*(4).

Smith, A. P., & Jones, D. M. (1992). Noise and performance. In Handbook of Human Performance (1 Vol. 1, pp. 1–27). London: Academic Press.

Snyder, H. R. (2013). Major depressive disorder is associated with broad impairments on neuropsychological measures of executive function: A meta-analysis and review. *Psychological Bulletin*, *139*(1), 81–132. https://doi.org/10.1037/a0028727

Söderlund, G., & Sikström, S. (2010). Positive effects of noise on cognitve performance: Explaining the moderate brain arousal model. *Behavioral and Brain Functions*, *6*(55), 1–10.

Söderlund, G. B. W., Björk, C., & Gustafsson, P. (2016). Comparing auditory noise treatment with stimulant medication on cognitive task performance in children with attention deficit hyperactivity disorder: Results from a pilot study. *Frontiers in Psychology*, *7*(1), 1–10. https://doi.org/10.3389/fpsyg.2016.01331

Sokolov, E. N. (1963). *Perception and the conditioned reflex*. Pergamon Press.

Sonuga-Barke, E., Bitsakou, P., & Thompson, M. (2010). Beyond the dual pathway model: Evidence for the dissociation of timing, inhibitory, and delay-related impairments in attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry*, *49*(4), 345–355.

Sörqvist, P. (2010). High working memory capacity attenuates the deviation effect but not the changing-state effect: Further support for the duplex-mechanism account of auditory distraction. *Memory and Cognition*, *38*(5), 651–658.

Spencer, T. J., Biederman, J., Madras, B. K., Faraone, S. V., Dougherty, D. D., Bonab, A. A., & Fischman, A. J. (2005). In vivo neuroreceptor imaging in attention-deficit/hyperactivity disorder: A focus on the dopamine transporter. *Biological Psychiatry*, *57*(11), 1293–1300. https://doi.org/10.1016/j.biopsych.2005.03.036

Stroux, D., Shushakova, A., Geburek-Höfer, A. J., Ohrmann, P., Rist, F., & Pedersen, A. (2016). Deficient interference control during working memory updating in adults with ADHD: An event-related potential study. *Clinical Neurophysiology*, *127*(1), 452–463. https://doi.org/10.1016/j.clinph.2015.05.021

Tegelbeckers, J., Brechmann, A., Breitling-Ziegler, C., Bonath, B., Flechtner, H. H., & Krauel, K. (2022). Neural mechanisms underlying the effects of novel sounds on task performance in children with and without ADHD. *Frontiers in Human Neuroscience*, *16*, 878994. https://doi.org/10.3389/fnhum.2022.878994

Todorovic, A., & De Lange, F. P. (2012). Repetition suppression and expectation suppression are dissociable in time in early auditory evoked fields. *Journal of Neuroscience*, *32*(39), 13389–13395.

Vachon, F., Hughes, R. W., & Jones, D. M. (2012). Broken expectations: violation of expectancies, not novelty, captures auditory attention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1).

Van Mourik, R., Oosterlaan, J., Heslenfeld, D. J., Konig, C. E., & Sergeant, J. A. (2007). When distraction is not distracting: A behavioral and ERP study on distraction in ADHD. *Clinical Neurophysiology*, *118*(8), 1855–1865. https://doi.org/10.1016/j.clinph.2007.05.007

Waters, W. F., McDonald, D. G., & Koresko, R. L. (1977). Habituation of the orienting response: A gating mechanism subserving selective attention. *Psychophysiology*, *14*(3), 228–236. https://doi.org/10.1111/j.1469-8986.1977.tb01166.x

Wetzel, N., Widmann, A., & Schröger, E. (2012). Distraction and facilitation—Two faces of the same coin? *Journal of Experimental Psychology: Human Perception and Performance*, *38*(3), 664–674. https://doi.org/10.1037/a0025856

Wiegand, I., Hennig-Fast, K., Kilian, B., Müller, H. J., Töllner, T., Möller, H.-J., Engel, R. R., & Finke, K. (2016). EEG correlates of visual short-term memory as neuro-cognitive endophenotypes of ADHD. *Neuropsychologia*, *85*, 91–99. https://doi.org/10.1016/j.neuropsychologia.2016.03.011

Winkler, I., Denham, S. L., & Nelken, I. (2009). Modeling the auditory scene: Predictive regularity representations and perceptual objects. *Trends in Cognitive Sciences*, *13*(12), 532–540.

Woodhead, M. M. (1964). The effect of bursts of noise on an arithmetic task. American Journal of Psychology, 77(1), 627–633.

Zlomke, K. R. (2009). Psychometric properties of internet administered versions of Penn State worry questionnaire (PSWQ) and depression, anxiety, and stress scale (DASS). *Computers in Human Behavior*, *25*(4), 841–843. https://doi.org/10.1016/j.chb.2008.06.003