

Abstract

**Objective:** An ecologically valid adaptation of the irrelevant sound effect paradigm was employed to examine the relative roles of short-term memory, selective attention and sustained attention in ADHD. **Method:** Thirty-two adults with ADHD and 32 control participants completed a serial recall task in silence or whilst ignoring irrelevant background sound. **Results:** The serial recall performance in adults with ADHD was reduced relative to controls in both conditions. The degree of interference due to irrelevant sound was greater for adults with ADHD. Furthermore, a positive correlation was observed between task performance under conditions of irrelevant sound, and the extent of attentional problems reported by patients on a clinical symptom scale.

**Conclusion:** The results demonstrate that adults with ADHD exhibit impaired short term memory and a low resistance to distraction; however, their capacity for sustained attention is preserved as the impact of irrelevant sound diminished over the course of the task.

**Keywords:** adult attention deficit hyperactivity disorder, irrelevant sound effect, selective attention, sustained attention, short term memory

### Vulnerability to the Irrelevant Sound Effect in Adult Attention Deficit Hyperactivity Disorder

Attention deficit hyperactivity disorder (ADHD) is a heterogeneous clinical condition, particularly in neuropsychological terms (Doyle, 2006; Wahlstedt, Thorell, & Bohlin, 2009). Conventional neuropsychological tests tend to lack the sensitivity and specificity needed to gain a better understanding of the cognitive deficits associated with the disorder, leading some authors to propose the use of paradigms derived from experimental cognitive psychology (Pritchard, Neumann, & Rucklidge, 2008; Seidman, 2006). Such an approach would undoubtedly address the need for a more accurate identification of the cognitive processes affected in ADHD (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006), but it is questionable whether laboratory studies offer ecological validity (Barkley & Murphy, 2010; Tucha et al., 2009). Experimental tasks are already used in ADHD studies, particularly with children (see e.g., Nigg, 2001), however these do not directly address the specific cognitive complaints raised by patients, and consequently decrease the generalisability and the clinical impact of the results. Experimental paradigms can offer better ecological validity if they assess cognitive processes that relate closely to the specific difficulties reported by adults with ADHD. In the current study, we exploit the irrelevant sound effect (ISE) paradigm as a sensitive and innovative experimental approach to studying the issues of distractibility in adults with ADHD. The ability to block out task-irrelevant sound is highly relevant given that among the main symptoms of ADHD (DSM-IV-TR; American Psychiatric Association, 2000), inattention and distractibility are frequently reported complaints (Hervey, Epstein, & Curry, 2004; Lapointe, Heald, Stierwalt, Kemker, & Maurice, 2007). Furthermore, the ISE is an appropriate choice of paradigm because neuropsychological measures that challenge auditory processing by presenting distracting and

target stimuli concurrently were found to produce some of the largest effects in a previous meta-analysis (Hervey et al., 2004).

#### *Irrelevant sound effect paradigm*

The ISE paradigm, initially developed by Colle and Welsh (1976), is well established in experimental cognitive psychology. The basic procedure is to remember the order of a sequence of visually-presented items under conditions of either quiet or background sound. Participants are told to ignore any interfering auditory stimuli and that they will not be questioned about them at any point in the task. The ISE refers to the reduction in serial recall performance in the presence of irrelevant sound relative to quiet.

The degree of disruption to short-term memory (STM) by the mere presence of background sound varies depending on the properties of the sound and the nature of the primary task (Jones, 1995; Roer, Bell, Dentale, & Buchner, 2011; Szalma & Hancock, 2011). The ISE is not affected by the intensity of sounds (Ellermeier & Hellbruck, 1998), their meaning (words or non-verbal sounds; e.g., Jones & Macken, 1993), their phonological or semantic similarity with the to-be-remembered (TBR) items (Jones & Macken, 1993), or the timing of presentation (before or during presentation of TBR items; Miles, Jones, & Madden, 1991). However, it is clear that memory for order is more disrupted by sound sequences involving acoustic variation, compared to a constant sound or repeated token (Bell, Dentale, Buchner, & Mayr, 2010). This acoustic change in the sound sequence – known as *changing state* – is a key factor in determining auditory distraction. Regarding the critical properties of the focal task, the ISE mainly affects performance on tasks that require ‘seriation’; that is, the recall of items in serial order (e.g., recalling the chronology of a story, mental arithmetic, etc). Under these conditions,

the irrelevant sound affects selective attention and causes a marked disruption in STM performance.

*Advantages of the ISE paradigm for studying ADHD*

*Sensitivity and specificity.* The majority of traditional neuropsychological tests show a ceiling effect in adults with ADHD (Hervey et al., 2004; Schoechlin & Engel, 2005) and do not embrace a cognitive-process approach. Although the Delis-Kaplan Executive Function System (Delis, Kaplan, & Kramer, 2001) was designed to provide a higher level of task and contrast measures, no clinically significant impairment seems to emerge in ADHD adults with this battery (Lloyd, 2010). Thus, the use of a laboratory task affords greater control over the test parameters, allowing one to adjust the difficulty level and to evaluate hypotheses about specific cognitive processes. Applying more precise paradigms in the assessment of ADHD-related attentional difficulties is particularly called for, given current advances in cognitive neuroscience (Pritchard et al., 2008). Tasks that use the ISE paradigm impose a high level of difficulty, with auditory interference disrupting serial recall performance by about 30 to 50% in the normal population (Ellermeier & Zimmer, 1997). Since the ISE has a marked effect on the performance of normal participants, one might suppose that this paradigm will be even more sensitive when evaluating the problems of distractibility in adults with ADHD. Within the ISE paradigm, performance on the serial recall task in quiet provides a basic measure of STM capacity, while the addition of background sound allows us to examine the ability to inhibit irrelevant stimuli and to attend selectively. Moreover, the ISE paradigm usually causes no habituation in the normal population, because the negative impact of to-be-ignored irrelevant sound is stable and persists over time (Roer et al., 2011; Tremblay & Jones, 1998). Thus, unlike conventional neuropsychological tests, the ISE paradigm allows one to assess the capacity of selective and sustained attention of adults

with ADHD by evaluating performance over the course of the whole task, whilst maintaining difficulty level.

*Ecological validity.* Although borne from the laboratory, the ISE paradigm can display ecological validity if one considers the particular type of background sound and the primary task used. Several ISE studies have used ambient noise or realistic office environments which foster a good generalization of results from the laboratory to daily life (Banbury & Berry, 1997; Banbury & Berry, 1998; Buchner, Bell, Rothermund, & Wentura, 2008; Klatte, Lachmann, Schlittmeier, & Hellbrück, 2010). The need to recall items in order is integral to many academic or professional tasks, for example, reading comprehension, arithmetic calculations, or following instructions. Indeed, memory for order is involved in numerous everyday activities. Language, motor activities (e.g., dance, sports), music, and social interactions all depend strongly on the recall of the order of their constituent elements (Lewkowicz, 2004). It is therefore possible to draw an analogy between the task characteristics of the ISE and many activities of everyday life whose implementation can be disrupted by the presence of interfering auditory stimuli, an experience which is often the source of complaints from adults with ADHD.

Despite the advantages of this paradigm, few researchers have studied the ISE phenomenon with a clinical population and only one study has used a similar approach in the assessment of adults with ADHD. Dige, Maahr and Backenroth-Ohsako (2010) administered a dichotic memory task whereby participants learnt word lists presented to one ear, whilst ignoring irrelevant verbal stimuli presented in the opposite ear. Adults with ADHD demonstrated significantly reduced performance compared with the control group on all measures (learning, delayed recall, percentage correct recall). The use of realistic irrelevant auditory stimuli is one of the strengths of Dige et al.'s (2010) study, however the lack of a basic silent condition means

that it is not possible to determine whether the difficulties of adults with ADHD are related to problems of learning and storage in memory, or to a greater susceptibility to distraction. The ISE paradigm will allow us to assess separately the basic STM ability of participants, as well as their performance under conditions of distraction. Our approach can also be differentiated from that of Dige et al. (2010) in the way that two distinct neuroanatomical networks are implicated in the processing of irrelevant auditory stimuli for the ISE and for dichotic listening paradigms (Beaman, Bridges, & Scott, 2007).

In sum, adults with ADHD report high distractibility that affects their accomplishment of everyday tasks, but studies to date have not identified the cognitive mechanisms underlying such attentional problems. The ecological adaptation of an experimental task that relies on a well established paradigm in cognitive psychology provides an innovative approach for the methodological and clinical study of ADHD. Although the ISE paradigm cannot capture the full construct of attention and STM in a single task, this paradigm seems to offer significant benefits to improve the sensitivity, specificity, and ecological validity of neuropsychological measures. Experimental cognitive psychology has the potential to address the limitations of classical neuropsychology by allowing a systematic analysis of the cognitive mechanisms involved in psychopathology. The identification of specific constructs of a heterogeneous condition such as ADHD can help refine the understanding of the disorder, improve the psychometric measures used, and guide the development of clinical interventions.

#### *The current study*

The current study aims to clarify the nature of the attentional disorders experienced by adults with ADHD using an ecological adaptation of the ISE paradigm. This experimental task will test whether, compared with control participants, the performance of adults with ADHD is

more affected by problems with STM, selective attention, sustained attention, or an impairment of all these processes. Based on previous research using memory-span tests, we might expect that STM will not be impaired in adults with ADHD (Dige, Maahr, & Backenroth-Ohsako, 2008). In meta-analyses of neuropsychological studies, attentional deficits seem to represent a core feature of ADHD in adults (Balint et al., 2009; Hervey et al., 2004; Schoechlin & Engel, 2005), though it is not clear which attention subdomains are impaired (Balint et al., 2009). Consequently, the main prediction in the present research is that serial recall performance of adults with ADHD will be more affected by the presence of irrelevant sound than for control participants, indicating an impairment of selective attention. In addition, serial recall performance for the ADHD group should decrease as the task progresses, indicating a problem of sustained attention.

#### Method

##### *Participants*

Thirty-two adults with inattentive or combined type ADHD and 32 control participants took part in this study. The adults with ADHD were recruited at the Institut universitaire en santé mentale de Québec (IUSMQ). The diagnosis of ADHD had been made by a psychiatrist following a full psychiatric assessment based on guidelines from the Canadian Attention Deficit Hyperactivity Disorder Resource Alliance (CADDRA: 2006) and the diagnostic criteria of DSM-IV-TR (American Psychiatric Association, 2000). Participants comprising the control group were recruited through advertisements addressed to students and employees at Université Laval and the IUSMQ.

Exclusion criteria for all participants were: (a) history of alcohol or substance dependence; (b) neurological illness; (c) hypertensive, thyroid, renal or hepatic disease; (d) head injury with a loss of consciousness; (e) psychiatric condition, excluding ADHD for the clinical group; (f) education less than nine years; (g) age over 59 years; (h) intelligence quotient (IQ)

below 85. At the time of the study, 12 patients (37.5%) had never been treated or were intolerant to medication, while 20 patients (62.5%) were receiving a psychostimulant as a pharmacological treatment for ADHD, for which the dosage had been unchanged and was stable for a period of over two months. The patients agreed to stop taking the psychostimulant 24 hours before the start of the experiment. The control participants took no medication. All participants confirmed no drug use or alcohol consumption before the experimentation. The study met the requirements of the institution's ethics committee and all participants gave their written consent after being informed about the details of the research project.

#### *Materials and procedure*

*Clinical measures.* To verify eligibility for the study, a brief telephone interview was conducted with interested participants regarding the main inclusion and exclusion criteria. During the experiment, IQ was assessed using the Wechsler Adult Intelligence Scale (WAIS-III: Wechsler, 1997) dyad including Vocabulary and Matrix reasoning subtests (Sattler & Ryan, 1999). ADHD symptoms were measured with the Barkley childhood symptom scale (Barkley & Murphy, 1998), Adult ADHD Self-Report Scale (ASRS v1.1: Kessler et al., 2005) and Conners' Adult ADHD Rating Scale (CAARS: Conners, Erhart, & Sparrow, 1999). The assessment of psychopathology and functional difficulties that may be associated with ADHD were evaluated with the Mini International Neuropsychiatric Interview (MINI: Sheehan et al., 1998), Beck Depression Inventory-II (BDI-II: Beck, Steer, & Brown, 1996), Beck Anxiety Inventory (BAI: Beck & Steer, 1990), Weiss Functional Impairment Rating Scale - Self Report (WFIRS-S: Weiss, Wasdell, & Bomben, 2005) and the Behavior Rating Inventory of Executive Function - Adult Version (BRIEF: Roth, Isquith, & Gioia, 2005). Aside from the MINI interview that was administered to verify the absence of comorbidity at the time of the evaluation, all the clinical

measures were used to estimate the intensity of symptoms and not for diagnostic purposes. In total, the estimate of intellectual functioning and evaluation of clinical symptoms took approximately one hour.

*Experimental task.* The experimental task was developed with E-Prime software on a PC computer. Participants were required to remember sequences of visually-presented letters that appeared in the center of a 17 x 17 cm matrix. The series of TBR items consisted of seven consonants selected from a set of nine (B, F, H, J, K, M, Q, R, T). Letters were displayed in black 45-point Arial font on a white background. The order of items in the sequence was randomly generated for each experimental condition. The sequences were the same for all participants, but were presented in random order. Each item was presented at a rate of one letter per second (800 milliseconds with an interstimulus interval of 200 milliseconds). Following the presentation of all TBR items, a blank screen was displayed throughout a 10 seconds retention interval before a recall prompt appeared on the screen, instructing participants to write down the order in which items were presented. An answer sheet was provided for this purpose.

In the control condition, the letter sequences were presented in silence. In the experimental (irrelevant sound) condition, ambient sounds were broadcast over headphones throughout the presentation of visual stimuli and during the retention phase. The sounds were recorded using the three-dimensional *Neuman KU 100* audio recording system. The sound recording was made in a work environment at the IUSMQ comprising ambient conversation and office equipment. The sounds were edited with Sound Forge for a maximum intensity of 65 dB. The order of the two conditions (silence/irrelevant sound) was counterbalanced for all participants. Each condition included two practice trials and 25 experimental trials in five blocks of five trials, which allowed for the assessment of performance over time.

Before starting the task, participants read through on-screen instructions requiring them to memorize the order of the items whilst ignoring the presence of any background sound. Pressing the spacebar initiated each new trial. There was no time limit, but the participant was asked to respond as quickly and accurately as possible. If in doubt about the serial position of an item, the participant was encouraged to attempt a response. No feedback was given with respect to performance. The duration of the experimental task was about 30 minutes.

All participants completed elements of the study in the same sequence, starting with clinical measurements, performing the experimental task, and finally completing a battery of neuropsychological tests (these neuropsychological test scores are part of a larger clinical research project and are not reported in the current article).

*Statistical method of analysis.* The socio-demographic and clinical characteristics of control participants and adults with ADHD were compared using *t*-tests and chi-square. For the experimental task, repeated measures Analyses of Variance (ANOVAs) were conducted on the percentage of correct responses to assess STM ability both with and without auditory distraction. Performance in the irrelevant sound condition relative to quiet provided a measure of selective attention, while performance over the five blocks of trials allowed for a measure of sustained attention.

The pattern nature of errors made in the serial recall task was also examined. Three types of errors were computed: omissions (no response), intrusions (recalled of a letter not previously presented) and transpositions (recalled of a presented letter, but in the wrong serial position). For the omissions and intrusions errors, the proportion of errors was calculated according relative to the number of items presented in the sequence (number of errors ÷ 7), whereas the number of transpositions was calculated by dividing by the number of correctly

recalled items, after exclusion of the other types of errors. The mean proportions of the three types of errors were compared between the two groups and conditions, using independent t-tests.

Finally, a Pearson's correlation tested whether participant's' distractibility (as indexed by the difference in performance between the quiet and irrelevant soundISE conditions) was associated with the degree of their self-reported clinical symptoms. We also tested whether participants' distractibility (i.e., their recall performance in the presence of irrelevant sound) was associated with the degree of their self-reported ADHD clinical symptoms by using Pearson's correlations on the data. Finally, a discriminant analysis was also performed using this distractibility index as the potential classifying variable for assigning participants to either the ADHD or control group.

## Results

### *Sociodemographic and clinical characteristics*

The main characteristics of the sample are reported in Table 1. Comparisons made using *t*-tests and chi-square showed that both groups were equivalent in age, sex, years of education and estimated IQ. Adults with ADHD reported significantly higher levels of symptoms associated with ADHD (child and adult), depression, and problems with everyday and executive functioning. Only the Beck Anxiety Inventory (Beck & Steer, 1990) revealed no significant difference between the two groups in terms of the physiological manifestations of anxiety. These clinical differences were observed in the absence of active comorbidity at the time of evaluation, as revealed by a semi-structured psychiatric MINI interview (Sheehan et al., 1998).

### *Experimental task*

The percentage of correct answers was recorded for each condition according to a strict serial recall criterion (i.e., each item in the sequence was scored as correct only if it was recalled

in its exact position). A 2 x 2 x 5 mixed design ANOVA was performed on the percentage of correct responses, including one inter-group factor: Group (Control/ADHD) and two intra-group factors: Condition (silence/irrelevant sound) and blocks (blocks of trials 1 to 5). The alpha level of .05 was chosen. When required, the effects of interactions were decomposed using t-tests, with an alpha level adjusted according to a Bonferroni correction for multiple comparisons. Figure 1 shows the performance of both groups, according to test block and experimental condition.

The main effect of Group was significant,  $F(1, 62) = 13.09, p < .001$ , with serial recall performance of adults with ADHD lower than that of control participants. The main effect of condition was also significant,  $F(1, 62) = 26.29, p < .001$ , showing that serial recall performance is reduced in the irrelevant sound condition relative to quiet. The significant main effect of block,  $F(1, 62) = 8.25, p < .001$ , demonstrated that serial recall performance tended to improve over the course of the experiment. Most importantly, there was a significant Group by Condition interaction,  $F(1, 62) = 6.47, p < .05$ . This key interaction was examined further using independent samples t-tests. The serial recall performance of adults with ADHD was lower than that of control participants, both in the quiet control condition,  $t(62) = 2.63, p < .05, d = 0.66$ , and in the irrelevant sound condition,  $t(62) = 4.29, p = .001, d = 1.07$ . Paired t-tests then compared the average difference in performance between the two conditions for each group. The effect of interference – that is, the comparison between quiet and irrelevant sound conditions – was significant for both control participants,  $t(31) = 2.08, p < .05, d = 0.21$ , and adults with ADHD,  $t(31) = 4.89, p < .001, d = 0.58$ , though the effect size was greater for the group of adults with ADHD.

The Condition by Block interaction was also significant,  $F(1, 62) = 2.41, p < .05$ .

Performance tended to improve over time for both conditions (silence/irrelevant sound), but especially so in the irrelevant sound condition: In the last test block, performance with irrelevant sound no longer differed significantly from performance obtained in the silence condition,  $t(63) = 0.90, p = .37$ . Finally, there was no interaction between the factors Group and Block,  $F(1, 62) = 0.64, p = .634$ , and the triple interaction between Group, Blocks, and Condition was not significant,  $F(1, 62) = 1.93, p = .106$ .

The mean proportions of each type of errors made in the serial recall task are reported in Figure 2 for both groups and conditions. Independent t-tests analyses indicateds that adults with ADHD made a greater number of omissions than healthy controls for both conditions [:- Silence,  $t(62) = -2.69, p < .01, d = 0.68$ ; and Irrelevant sound,  $t(62) = -3.99, p < .001, d = 1.01$ ], and also more. The proportion of transpositions errors also differ between groups in the two conditions [:- Silence,  $t(62) = -2.08, p < .05, d = 0.53$ ; and Irrelevant Ssound  $t(62) = -2.00, p < .05, d = 0.51$ ]. The number of intrusions errors however, did not differ between the two groups for both in either conditions: Ssilence  $t(62) = 0.16, p = .88, d = 0.04$ , and Irrelevant Ssound  $t(62) = -0.93, p = .93, d = -0.02$ .

#### *Relation between ADHD symptoms and ISE.*

A distractibility index illustrating the effect of irrelevant sound was obtained by calculating the difference in performance between the two conditions (silence/irrelevant sound), divided by performance in the silent control condition (see Surprenant, Neath, Bireta, & Allbritton, 2008). Correlational analyzes were conducted to evaluate the relationship between the distractibility index ISE performance and DSM clinical symptoms measured by the CAARS. The Pearson correlation coefficients are reported in Table 2. Positive associations were observed

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between [the level of distractibility in the experimental task](#) ~~recall performance in the ISE condition~~ and DSM inattention symptoms of the CAARS, but only for the ADHD group. No significant association was obtained between distractibility and symptoms of hyperactivity / impulsivity, or total ADHD symptoms. In order to determine if performance in the ISE condition could predict group classification (ADHD / Control), a discriminant analysis was then performed. The discriminant function showed a significant global Wilks' lambda,  $\Lambda = .895771$ .  $\chi^2(1, N = 64) = 6.814597, p < .001$ , suggesting that recall performance in the presence of background sound can be used to distinguish the two groups. Recall performance with irrelevant sound correctly classified 61.6 % of adults with and without ADHD.

#### Discussion

The aim of the present study was to clarify the nature of attentional difficulties experienced by adults with ADHD, by measuring the impact of distractibility (selective attention) on serial recall performance and sustained attention. To this end, an ecologically valid version of the ISE paradigm was used and as predicted, results confirmed the greater susceptibility to distraction of adults with ADHD compared to control participants. However, contrary to initial assumptions, adults with ADHD demonstrated a lower baseline STM performance relative to controls, and auditory distraction was found to have little effect on their levels of sustained attention.

#### *Selective attention and ADHD*

Adults with ADHD experienced greater interference from irrelevant sound than control participants, with their serial recall performance significantly reduced in the presence of auditory distraction. Our results using the ISE paradigm are consistent with Dige, et al.'s (2010) dichotic memory study in demonstrating that adults with ADHD have more difficulty in filtering out irrelevant information whilst performing a primary task.

In contrast, serial recall of control participants was unaffected by irrelevant sound, which is unusual considering the marked deterioration of performance generally expected with the ISE paradigm. Indeed, the impact of irrelevant sound in control participants was rather low compared to results reported in a recent literature review from the normal population (Surprenant, Neath, Bireta, & Allbritton, 2008). One possibility is that in our strive for ecological validity, the naturally occurring sound sequences used did not contain a sufficient dose of verbal and nonverbal sounds to cause significant disruption to serial memory in the group of control participants. Indeed, it has been shown that the degree of interference and the level of acoustic variation are modulated by the number of auditory segments (Bridges & Jones, 1996). Most laboratory-based ISE studies involve continuously played irrelevant speech or edited sequences of individual sound tokens, thus providing a higher dose of acoustic variation than our recording of general office sounds and occasional conversation. Although some studies using office or classroom sounds (with or without verbal stimuli) have obtained significant irrelevant sound effects (Banbury & Berry, 1998; Buchner et al., 2008), they have not always been fully replicated when sounds have been recorded with a three-dimensional audio system similar to that used in the current study (Klatte et al., 2010). In both cases, it is possible that the sounds were perceived as a succession of isolated events rather than a single varying sequence; thus they did not sufficiently fulfill the principle of acoustic variation which is necessary to create conflicting order cues and interfere with the process of serial recall.

According to Hughes, Vachon and Jones (2007; see also Klatte et al., 2010; Sorqvist, 2010), the effect of irrelevant sound on serial recall performance arises from two distinct mechanisms, acting alone or in combination, which is similar to the conceptualization embodied in the duplex-mechanism account. First, sounds with acoustic variation automatically interfere

with the representation of serial items to be retained in STM (see, e.g., Jones, Hughes, & Macken, 2006). Then, the auditory stimuli – unexpected, unusual, or from an environment with various noise sources – represent a new and isolated series of acoustic events that capture attention. The role of attention in the ISE depends on the nature of the sounds, but also upon the attentional skills of participants (Klatte et al., 2010). In this study, the marked distractibility of adults with ADHD supports the greater susceptibility to distraction that has often been associated with this clinical population.

Furthermore, a positive association was found between the impact of the ISE and the attentional problems reported by adults with ADHD in a measure of clinical symptoms.

Moreover, vulnerability to the ISE led to the correct classification of 61.6 % of adults with and without ADHD in a discriminant analysis. These results suggest that auditory distraction is an important feature of ADHD and that our experimental task using irrelevant sound has some ecological validity for adults with ADHD, making it possible to objectify their frequently reported cognitive complaints. In contrast, the results of conventional neuropsychological tests show limited or no association with clinical, cognitive or daily functioning symptoms reported by ADHD patients (Barkley & Fischer, 2011; Barkley & Murphy, 2011; Stavro, Ettenhofer, & Nigg, 2007).

#### *Sustained attention and ADHD*

Assessing performance across several blocks of trials allows us to examine the capacity of sustained attention. Contrary to expectation, serial recall performance of adults with ADHD (and control participants) tended to improve over time to the extent that the impact of irrelevant auditory stimuli was eliminated by the last block of trials. This was surprising given that the effect of habituation is not generally applicable to the ISE paradigm (Banbury, Macken,

Tremblay, & Jones, 2001). However, according to Cowan's model (1995), a person can habituate to information which is repeated frequently and varies little over time, since it appears similar to stored representations in long-term memory and is processed automatically without being selected for attentional focus. From this perspective, participants may have shown habituation by the end of the task due to the repetition of the auditory sequences presented in the current study. Indeed, the irrelevant sound consisted of five different sequences of environmental sounds, each randomly presented five times, over a total of 25 trials. With overexposure to the same sequence, it is possible that the neural representation of sound becomes increasingly familiar and as such decreases the orienting response towards it, thus no longer affecting the activation of TBR items in attentional focus. In line with this habituation account, a recent study demonstrates that the ISE is significantly reduced after repetitions of complex speech distractors during a preexposure phase (Bell, Roer, Dentale, & Buchner, 2012). Note, however, that problems with sustained attention may have emerged in the ADHD group over time if the sound sequences had each been novel.

An alternative explanation for preserved sustained attention is that the irrelevant sound stimulated the cognitive activation level of adults with ADHD and exerted a positive effect on their performance. In fact, a previous study showed that noise could facilitate the cognitive performance of children with ADHD (Soderlund, Sikstrom, & Smart, 2007). Consequently, in the ISE condition, it is impossible to determine if the improvement in recall performance over time was caused by a habituation effect or an activation phenomenon in the presence of sound. Whatever the reason for the improved performance in the ISE condition, the interpretation that adults with ADHD demonstrate preserved sustained attention remains relevant, because their performance was not impaired in the Silence condition either. Furthermore, our results are

consistent with those of Tucha et al. (2009) who reported preserved sustained attention in adults with ADHD while performing a computerized vigilance task. The finding that adults with ADHD had a lower resistance to auditory interference – but an equivalent capacity to control participants to habituate to repeated and familiar irrelevant sounds – is important in the context of work environments. This suggests that different techniques for masking background sound (e.g., adding a continuous sound) may be relevant to test in the adult ADHD population.

#### *Short term memory and ADHD*

Adults with ADHD demonstrated lower serial recall performance than control participants, even in the absence of distraction. [The pattern of errors made by adults with ADHD is also characterized by more omissions \(loss of information - item memory\) and transpositions \(errors of order – serial memory\) than control participants.](#) Thus, it is difficult to determine whether the observed disruption is related to a problem of limited capacity (space) or limited processes (strategies) in STM (Cowan, 2010). First, it is possible that ADHD and control participants differ in the amount of information they can maintain in STM. However, the simple act of maintaining information in STM is not generally thought to affect neurocognitive functioning of adults with ADHD (Dige et al., 2008). The existing literature is based primarily on the results of digit span subtests from the Wechsler test batteries which demonstrate small effect sizes among adults with ADHD (Balint et al., 2009; Hervey et al., 2004). [In children with ADHD, a recent meta-analysis point out demonstrates that the active manipulation of information in working memory is more affected than the processes of storage-/rehearsal \(Kasper, Alderson, & Hudec, 2012\).](#) This working memory deficit has garnered particular attention in the ADHD literature because [it is now considered as a potential endophenotype of the disorder, and it's commonly related to an executive deficit that takes a prominent place in etiological models of](#)

ADHD. However, few studies have examined the unique contribution of storage/rehearsal and manipulation processes of working memory deficits in adults with ADHD. With this objective in mind, Alderson et al. (2013) have demonstrated that adults with ADHD exhibit significant performance deficits in a phonological working memory task, of which storage/rehearsal and manipulation processes were both impaired to a similar degree, with a effect size of similar magnitude (effect sizes  $d = 0.63$  ;  $d = 0.64$ , respectively). In our study, Like Alderson et al. (2013), the short term memory recall task used in our study. Indeed, in the present study, both groups of participants showed equivalent STM on a digit span subtest (these neuropsychological test scores are part of a larger clinical research project and are not reported in the current article). It is therefore more likely that the experimental task of serial recall imposed a greater load on STM compared to conventional digit span tests, making it therefore. It is thus more sensitive and better able to highlight a limited storage/rehearsal STM capacity in adults with ADHD, than conventional memory span subtests which may have obscured any difference. According to a recent study by Finke et al. (2011), STM ability could even be an endophenotype or biomarker of ADHD in adults. Moreover, the largerst number of omission errors made by adults with ADHD – despite the fact that item the memory of item was not highly solicited in our task (same items with serial order randomly generated) – suggests a loss of information infrom short term memorySTM, thusat supporting the hypothesis of a limited capacity.

Nevertheless, no task can be really completely pure, because sEven simple span tasks may also impliesinvolve attentional executive strategies, andwhile working memory tasks that imposedrequiring the active manipulation of informationitems in memory requireswill also necessarily entail the temporary maintain-maintenance and storage of information-in mind. ButHowever, the presence of increased transposition errors made by adults with ADHD relative

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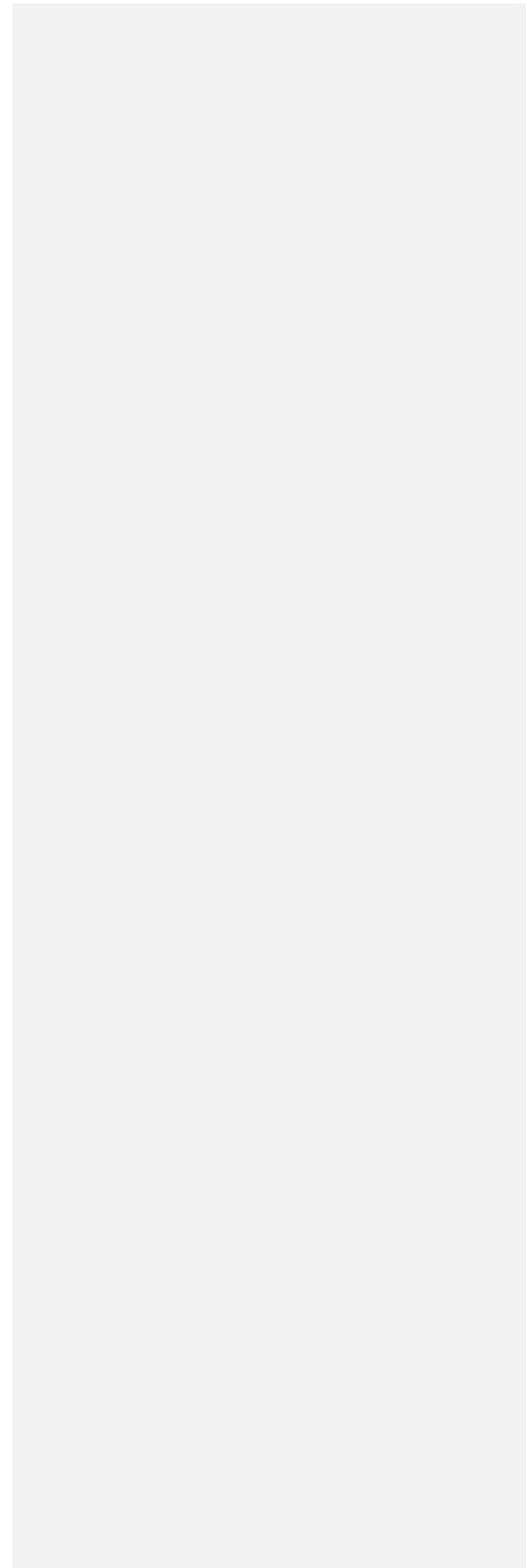
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[to controls, indicates that they also have difficulty with holding a specific order of elements online in working memory.](#) An alternative explanation to the capacity problem is that adults with ADHD may have more difficulties in generating or using efficient strategies in STM. This may be an interesting avenue for further research since the methodology used in this study did not allow us to distinguish between the two groups in terms of different STM processing strategies (e.g., rehearsal, chunking, visual imagery). Finally, even though no external auditory stimulus was presented during the quiet control condition, we cannot exclude the possibility that STM performance of adults with ADHD may be affected by an internal source of interference (e.g., intrusive thoughts), considering the difficulty of adults with ADHD to inhibit distractions.

#### Conclusion

For the first time, an ecologically valid adaptation of the ISE experimental paradigm was applied to adults with ADHD. The results show that compared to control participants, adults with ADHD have a lower STM capacity and a greater susceptibility to distraction (impaired selective attention), despite a preserved ability of sustained attention. The impact of irrelevant sound also shows a positive relationship with inattentive symptoms reported by adults with ADHD in a clinical questionnaire. This study supports the benefit of experimental paradigms to contribute towards a more sensitive, specific and ecologically valid assessment of cognitive difficulties in adults with ADHD. In addition, the ISE paradigm used in the present study illustrated that fundamental "non-executive" cognitive processes are involved in ADHD, in contrast with etiological models postulating a single deficit in executive functioning (e.g., Barkley, 1997; Brown, 2005). Future research using this paradigm with other experimental manipulations could further examine the cognitive processes underlying the effect of irrelevant sound in adults with ADHD and to better distinguish the relative contribution of STM and attentional processes. These cognitive problems are also relevant to consider in the development of non-

pharmacological intervention techniques for ADHD, in order to more effectively manage endogenous and exogenous distractions that may affect cognitive performance.



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Footnote

The same significant effects were obtained when comparing only the untreated sub-group of ADHD patients ( $n = 12$ ) to the healthy controls ( $n = 32$ ). There were main effects of group,  $F(1, 42) = 7.83, p < .01$ , condition  $F(1, 42) = 18.33, p < .001$ , and block,  $F(1, 42) = 6.82, p < .001$ . The group by condition interaction was significant,  $F(1, 62) = 5.81, p < .05$ , with the finding that the untreated ADHD participants differed significantly from controls in the ISE condition:  $t(42) = 3.33, p < .01, d = 1.03$ , but not in silence:  $t(42) = 1.94, p = .059, d = 0.60$ . Non-significant interactions were obtained for block x group,  $F(1, 42) = 0.29, p = .855$ , condition x block:  $F(1, 42) = 1.64, p = .179$ , and condition x group x block:  $F(1, 42) = 1.16, p = .327$ .

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Table 1

*Demographic and clinical characteristics of healthy controls and adults with ADHD*

	Controls ( <i>n</i> = 32)	ADHD ( <i>n</i> = 32)
	<i>M</i> ± <i>SD</i>	<i>M</i> ± <i>SD</i>
Demographic characteristics		
Gender (male/female)	16/16	20/12
Age	35.44 ± 11.10	34.44 ± 11.23
Education (years)	15.13 ± 1.86	14.88 ± 3.85
Estimated IQ (WAIS-III dyad)	108.13 ± 8.06	109.09 ± 9.72
Clinical symptoms		
Barkley childhood symptom scale *	9.97 ± 6.31	32.69 ± 10.78
ASRS total score*	19.00 ± 8.43	41.31 ± 10.14
CAARS total score (T score)*	43.69 ± 10.77	70.69 ± 13.36
BDI-II*	6.19 ± 6.56	12.72 ± 9.40
BAI	4.94 ± 6.69	7.31 ± 8.22
WFIRS-S*	23.28 ± 15.40	54.03 ± 23.19
BRIEF-A (T score)*	47.38 ± 9.14	69.16 ± 12.65

*Note.* ASRS: Adult ADHD Self-Report Scale; CAARS: Conners' Adult ADHD Rating Scale; BDI-II: Beck Depression Inventory-II; BAI: Beck Anxiety inventory; WFIRS-S: Weiss Functional Impairment Rating Scale-Self Report; BRIEF-A: Behavior Rating Inventory of Executive Function-Adult Version.

\* *p* < .01

Table 2

Pearson's correlations between ~~recall performance in the~~ irrelevant sound effect (ISE) ~~index condition~~ and ADHD DSM symptom scales of the CAARS for healthy controls and adults with ADHD

ADHD Symptoms	ISE condition	
	Controls	ADHD
DSM - Inattentive Symptoms	<del>-0.0267</del>	0. <del>376425</del> *
DSM - Hyperactive/Impulsive Symptoms	0. <del>138259</del>	0. <del>106035</del>
DSM - Total ADHD Symptoms	0. <del>025283</del>	0. <del>158275</del>

Note. CAARS: Conners' Adult ADHD Rating Scale. \* $p < .05$

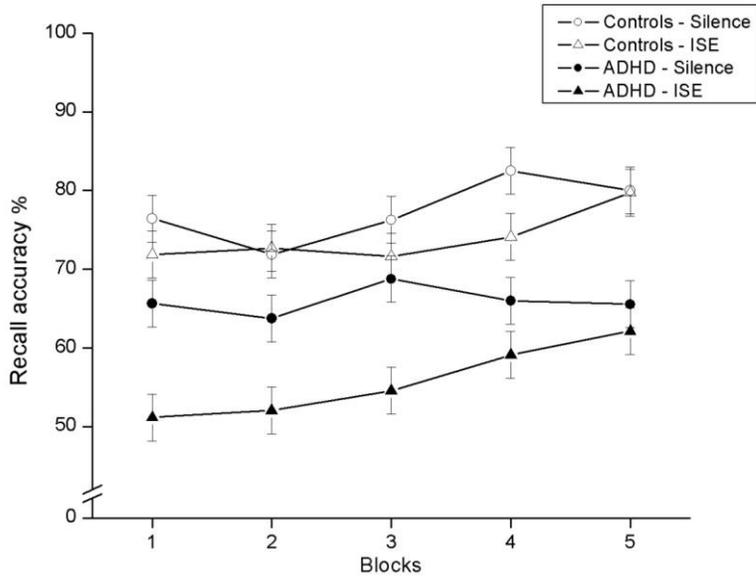
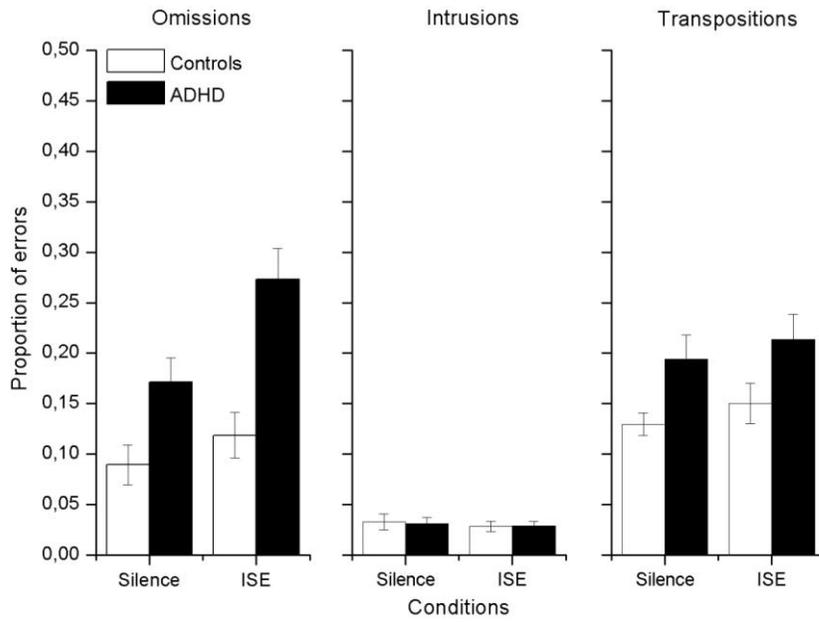


Figure 1. Mean percentage of serial recall accuracy between control participants and adults with ADHD as a function of blocks of trials across the two conditions (Silence and ISE). Errors bars represent 95% confidence interval.



*Figure 2.* Proportion of omission, intrusion and transposition errors produced by healthy controls and adults with ADHD for both conditions of the serial recall task. Error bars represent standard error of the mean (SEM).