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The effect of environmental distractors incorporation into a CPT on sustained attention and ADHD diagnosis among adolescents☆

Itai Berger[a,*], Hanoch Cassuto[b]

[a] The Neuro-Cognitive Center, Pediatric Division, Hadassah-Hebrew University Medical Center, Jerusalem, Israel
[b] Pediatric Neurology Clinic, Leumit HMO, Jerusalem, Israel

HIGHLIGHTS

- Adolescents with ADHD are more easily distracted than controls.
- Incorporation of environmental distractors improves CPT validity.
- Visual distractors are more beneficial in terms of ADHD diagnosis than auditory distractors.

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ABSTRACT

Background: Diagnosis of ADHD in adolescents involves specific challenges. Conventional CPT's may fail to consistently distinguish ADHD from non-ADHD due to insufficient cognitive demands. The aim of this study was to explore whether the incorporation of environmental distractors into a CPT would increase its ability to distinguish ADHD from non-ADHD adolescents.
New method: Using the rate of omission errors as a measure of difficulty in sustained attention, this study examined whether ADHD adolescents are more distracted than controls and which type of distractors is more effective in terms of ADHD diagnosis. The study employed the MOXO-CPT version which includes visual and auditory stimuli serving as distractors. Participants were 176 adolescents aged 13–18 years, 133 diagnosed with ADHD and 43 without ADHD.
Results and comparison with existing methods: Results showed that ADHD adolescents produced significantly more omission errors in the presence of pure visual distractors and the combination of visual and auditory distractors than in no-distractors conditions. Distracting stimuli had no effect on CPT performance of non-ADHD adolescents. ROC analysis further demonstrated that the mere presence of distractors improved the utility of the test.
Conclusions: This study provides evidence that incorporation of environmental distractors into a CPT is useful in term of ADHD diagnosis. ADHD adolescents were more distracted than controls by all types of environmental distractors. ADHD adolescents were more distracted by pure visual distractors and by the combination of distractors than by pure auditory ones.

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is among the most common neurobehavioral disorders of childhood. In approximately 60% of children with ADHD, symptoms persist into adolescence and may continue into adulthood (Faraone et al., 2006; Kessler et al., 2006). Assessment of ADHD is always a complex task, which requires comprehensive investigation of multiple sources, such as clinical interviews, observations, reports of parents and teachers, psycho-educational assessment, and neuro-developmental examination. However, diagnosis of ADHD in adolescents involves specific challenges and obstacles. One of the difficulties is the complex presentation of the syndrome in adolescence. Research suggests that the symptoms manifestation of ADHD changes, sometimes dramatically, with developmental course: while hyperactivity often declines by adolescence, attention deficits appear to remain more constant, and impulsivity transforms into more overt difficulties in executive functions (Wasserstein, 2005). In addition, ADHD in adolescents and adults

* Corresponding author at: The Neuro-Cognitive Center, Pediatric Division Hadassah-Hebrew University Medical Center, P.O. Box 24035, Mount Scopus, Jerusalem 91240, Israel. Tel.: +972 2 584 4903; fax: +972 2 532 8963.
E-mail address: itberg@hadassah.org.il (I. Berger).

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is commonly nestled with other psychiatric comorbidities, such as substance abuse, antisocial behaviour, learning disabilities, conduct disorders, mood and anxiety disorders (Brown, 2000). Another common problem of evaluating ADHD in adolescence stems from typical biases of adolescents in self-reports scales. Adolescents are considered poor self-observers and often tend to underestimate their problems (Barkley et al., 1991; Wasserstein, 2005). The agreement between adolescents and their parents regarding the type of symptoms was found to be low (Rasmussen et al., 2002).

Due to the subjective nature of these instruments, computerized continuous performance tests (CPT) are frequently employed in clinical and diagnostic settings (Edwards et al., 2007). Typical CPT task requires the participant to sustain attention over a continuous stream of stimuli (single letters, shapes or digits which are presented serially) and to respond to a pre-specified target (Kelip et al., 1997; Shalev et al., 2011). Traditionally, inattention is assessed in CPT by the number of omission errors, indicating the number of times the target was presented, but the participant did not respond, or by its "inverse" measure calculating relative accuracy (the number of correct hits out of the total targets presented). Contextual factors, such as distracting stimuli in the environment, can contribute to increased inattention (Adams et al., 2011; Blakeman, 2000; López-Martín et al., 2013). Therefore, sustained attention can be broadly characterized as the ability to concentrate on a specific stimulus over a period of time while excluding distracting stimuli (Shalev et al., 2011).

Despite the popularity of the CPT in clinical contexts, many authors have identified concerns about its reliability and validity in the diagnosis of ADHD.

Test–retest reliability of the CPT varied considerably across studies. Several CPT's, such as the Test of Variables of Attention (T.O.V.A.) (Greenberg and Kindschi, 1998) and the Conners CPT-II (Conners, 2000) do not report test–retest reliability. In others, such as the AX' CPT test, test–retest reliability ranged between 0.14 and 0.94, dependent on CPT indices. Omission errors tend to have the lower reliability measures while commission errors and response times have moderate or high measures (Ogundele et al., 2011).

CPT's are often criticized for their low sensitivity and specificity rates (less than 70%) (Edwards et al., 2007; McGee et al., 2000; Riccio et al., 2001; Skounti et al., 2007). Many authors have questioned its ability to consistently discriminate ADHD children from normal controls, psychiatric controls or learning disabilities (DeShazo et al., 2001; Dickerson Mayes et al., 2001; Ogundele et al., 2011; Schachar et al., 1998; Skounti et al., 2007). Others reported a weak association between CPT performance and behavioural indices of ADHD (Christensen and Joschko, 2001; Epstein et al., 2009; McGee et al., 2000).

The validity of the CPT in the diagnosis of ADHD is even more controversial among teenagers (Robin, 1998). The Degraded Stimulus Continuous Performance Test (DS-CPT) was found to be insensitive to identifying sustained attention deficits in adolescent populations and failed to discriminate ADHD from controls (Rund et al., 1998). Similarly, Rucklidge (2006) reported that the Conners CPT-II (Conners, 2000) failed to identify many adolescents with ADHD, and was generally more sensitive to ADHD in males than in females. Recently, Diamond et al. (2012) have demonstrated that the correlation between neurologist's impression of the presence of attention deficit and the T.O.V.A. scores was weaker in adolescents (ages 13–18) than in younger children (ages 6–12). The Gordon Diagnostic System (GDS; Gordon and Mettelman, 1987), which is the only CPT that has been researched specifically with adolescents (also approved by the FDA), successfully discriminated ADHD adolescents from controls on the vigilance task, but not on the distractibility task (Robin, 1998).

Barkley (1991) has shown low correlations between CPT performance of adolescents and other measures of ADHD such as parents and teachers rating scales. It was suggested that the ecological validity of the CPT in adolescent samples is weaker than in younger children and that this shortcoming is crucial where prediction to school behaviour may be desired. Barkley (1991) emphasized the need to improve the ecological validity of the CPT by evaluating the child's behaviour in more natural settings. Nevertheless, even when noise-generated CPT was employed (Uno et al., 2006), the sensitivity of the test to ADHD in older children (ages 10–12) was lower than in younger children (ages 7–9). The authors suggested that the differences in attention span between ADHD and normal controls are reduced to a level undetectable by CPT, as a result of developmental changes.

Another possible explanation for the insensitivity of CPT in adolescents is the constant pace of stimuli presentation. Because the inter-stimulus interval in traditional CPT is typically fixed, it makes the task too easy for adolescents who quickly figure out the timing of stimulus appearance (Robin, 1998). Further support for the ceiling effect in CPT performance of adolescents arrives from imaging study that compared brain activation patterns in adolescents with and without ADHD while performing an attentional CPT (Epstein et al., 2009). The two groups performed similarly and activated similar regions during performance, but children with ADHD appear to maintain the use of right prefrontal regions beyond what is observed among normal controls. The difficulty to detect group behavioural differences was attributed to the low cognitive demands of the task. Taken together, these findings suggest that conventional CPT's may fail to consistently distinguish ADHD from non-ADHD teenagers due to insufficient cognitive demands and may not reflect the conditions in school.

The aim of this study was to explore whether the incorporation of environmental distractors into a CPT would increase its ability to distinguish ADHD adolescents from controls (ages 13–18). Assuming that distracting stimuli have an effect on sustained attention by increasing the rate of omission errors in CPT, we hypothesized that adolescents with ADHD would perform significantly more omission errors than their non-ADHD peers in the presence of distracting stimuli. We also examined which type of distractors would be more effective in terms of ADHD diagnosis.

2. Methods

2.1. Participants

Participants were 176 adolescents aged 13–18 years, 118 were boys and 58 girls. The clinical ADHD group was composed of 133 participants previously diagnosed with ADHD (Mean age = 14.64, S.D. = 1.43), and the control group included 43 participants without ADHD (Mean age = 15.08, S.D. = 1.71).

Participants in the ADHD group were recruited from adolescents referred to the out-patient clinics of a Neuro-Cognitive Centre, based in a tertiary care university hospital. The referrals to the centre were made by paediatrician, general practitioner, teacher, psychologist, or parents.

The following were the inclusion criteria for participants in the ADHD group.

Each participant met the criteria for ADHD according to DSM-IV-TR criteria [American Psychiatric Association (APA), 2000], as assessed by a certified paediatric neurologist. The diagnostic procedure included completion of a semi-structured interview (adolescent and parents) fulfilling the diagnostic guidelines as described in the clinical practice guideline for the diagnosis, evaluation, and treatment of ADHD in children and adolescents by the American Academy of Paediatrics (Wolraich et al., 2011) and mandatory rating scales for home and school (DuPaul et al., 1998), as well as medical/neurological examination.

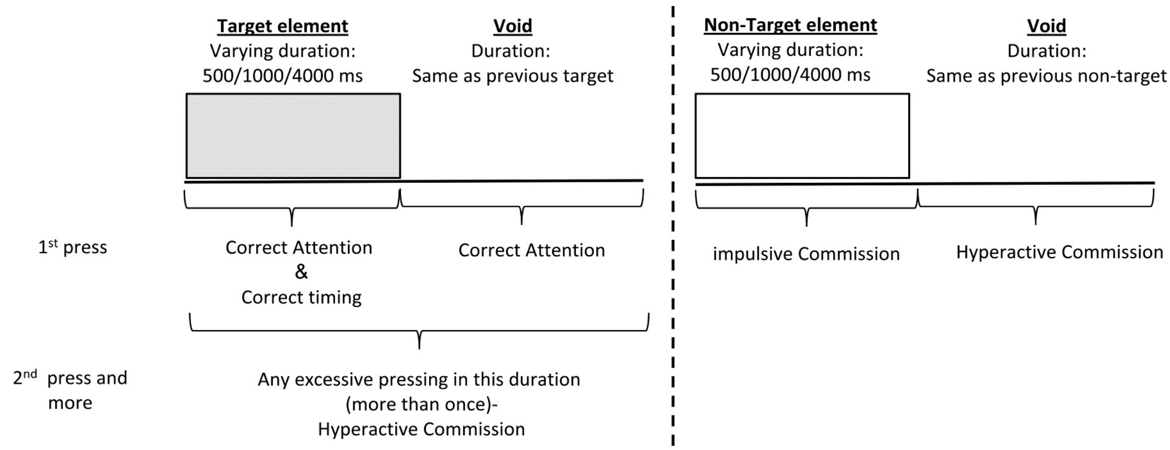

Fig. 1. Definition of the time line – target and non-target stimuli were presented for 500, 1000 or 4000 ms. Each stimulus was followed by a void period of the same duration. The stimulus remained on the screen for the full duration regardless the response. Distracting stimuli were not synchronized with target/non-target's onset and could be generated during target/non target stimulus or during the void period.

Participants in the control group were randomly recruited from regular school classes. The inclusion criteria for participants in the control group were: (1) score below the clinical cut off point for ADHD symptoms on ADHD/DSM-IV Scales (APA, 2000; DuPaul et al., 1998) and (2) absence of academic or behavioural problems based on parents and teachers reports. For this purpose the parents and teachers were asked to state (with the informed consent) that there are no behavioural/academic/social difficulties. Given these conditions, no additional physical/neurological examination was administered.

Assigning participants to ADHD/non-ADHD groups based on parents and teachers ratings of ADHD symptoms is a common and reliable method in the literature (e.g., Berwid et al., 2005; Uno et al., 2006; Van Mourik et al., 2007).

Exclusion criteria for all participants were: abnormal mental ability, other chronic (mental, health or developmental) condition, chronic use of medications, and primary psychiatric diagnosis (e.g., depression, anxiety, or psychosis). Since we worked in Jerusalem, our population was extremely heterogeneous, multicultural, and included a spectrum of families with regard to potentially confounding factors correlated with the diagnosis of ADHD (Wolraich et al., 2011). All participants agreed to participate in the study and their parents provided a written informed consent to the study, approved by the Helsinki committee (IRB) of Hadassah-Hebrew University Medical Centre Jerusalem, Israel.

2.2. Measures

Measurement of adolescent behaviour – the parent and teacher forms of the ADHD/DSM-IV scales were used to assess the level of participants' ADHD behaviours (APA, 2000; DuPaul et al., 1998).

The MOXO Continuous Performance Test – the study employed the MOXO-CPT version[1] (Berger and Goldzweig, 2010), which is a standardized computerized test designed to diagnose ADHD related symptoms. The test included visual and auditory stimuli that serve as distractors.

The total duration of the test was 18.2 min, and it is composed of eight levels (136.5 s, 59 trials each). In each trial a stimulus (target/non-target) was presented for 500, 1000 or 4000 milliseconds and then followed by a "void" period of the same duration (Fig. 1). The stimulus remained on the screen for the full duration no matter if a response was produced. This practice allowed the measuring of response timing (whether the response occurred during stimulus presentation or the void period) as well as the accuracy of the response.

In each level 34 target and 25 non-target stimuli were presented. Both target and non-target stimuli were cartoon pictures that do not include any letters. The absence of letters is important given the fact that ADHD patients tend to have learning difficulties (e.g., dyslexia, dyscalculia) that may be confound with CPT performance (Seidman et al., 2001). The stimuli were presented sequentially in the middle of a computer screen and the participant was instructed to respond as quickly as possible to target stimuli by pressing the space bar once, and only once. The participant was also instructed not to respond to any other stimuli except the target, and not to press any other key but the space bar.

Test level and distracting stimuli-In order to simulate everyday environment of adolescents, the MOXO-CPT contained distracting stimuli. This feature is unique to this specific CPT. Distractors were short animated video clips containing visual and auditory features which can appear separately or together. This enabled to present three types of distractions that characterize everyday environment: (a) visual distractors (e.g., animated barking dog); (b) auditory distractors (e.g., barking sound); and (c) combination of both visual and auditory distractors (e.g., animated barking dog with the sound of barking).

Overall, eight different distractors were included, each of them could appear as pure visual, pure auditory or as a combination of them. Different levels of the MOXO-CPT were characterized by a different set of distractors: levels 1 and 8 did not include any distractors but only target and non-target stimuli, levels 2 and 3 contained pure visual stimuli, levels 4 and 5 contained pure auditory stimuli, and levels 6 and 7 contained a combination of visual and auditory stimuli. Each distractor was presented for 8 s, with a fixed interval of 0.5 s between two distractors. Distractors' onset was not synchronized with target/non-target's onset and could be generated during target/non target stimulus or during the void period.

Visual distractors appeared at one of four spatial locations on the sides of the screen: down, up, left or right. The sequence of distractors and their exact position on the display were constant for each level. The burden of the distracting stimuli increased at the odd number levels; in the 2nd, 4th, and 6th level only one distractor was presented at a time, while in the 3rd, 5th, and 7th level two distractors were presented simultaneously.

[1] The term 'MOXO' derives from the world of Japanese martial arts and means a 'moment of lucidity'. It refers to the moments preceding the fight, when the warrior clears his mind from distracting, unwanted thoughts, and feelings.

Table 1
Differences in omission errors between ADHD and non-ADHD adolescents.

Distractors type	ADHD (N = 143)		Non-ADHD (N = 33)		Difference $t(172)$
	M	S.D.	M	S.D.	
No distractors	2.17	0.44	0.58	1.22	4.51, $p < 0.05$
Visual distractors	3.56	3.24	1.02	2.09	4.61, $p < 0.001$
Auditory distractors	2.46	2.95	0.81	2.14	3.17, $p < 0.05$
Combination of visual and auditory distractors	3.92	3.49	0.88	2.45	5.13, $p < 0.001$

M = mean; S.D. = standard deviation.

Performance indices – the MOXO-CPT included four performance indices: attention, timing, impulsivity, and hyperactivity. For detailed description of performance indices see Supplementary A.

2.3. Procedure

In the current study, the test was administered by a technician who made sure that the participant understood the instructions. The technician was present throughout the entire session. All participants (including the ADHD group) were drug naïve (not medicated at all) before and during their participation in the study.

2.4. Data analyses

All analyses were conducted with SAS software for Windows version 9.2.

A p-value of ≤0.05 was considered statistically significant. First, Chi-square analysis and t-test for unpaired samples were used to examine group differences in background variables. Second, effects of background variables, ADHD, and test level on omission errors were examined through a Linear Repeated Measures model with Tukey's correction for multiple comparisons. Omission errors were the dependant variable, whereas age, gender, group, level, and level × group interaction were the independent variables. Between and within group effects were measured in every CPT condition (no distractors, visual distractors, auditory distractors and a combination of visual and auditory distractors). For this purpose, every two identical levels were combined: levels 1 and 8 (no distractors), levels 2 and 3 (visual distractors), levels 4 and 5 (auditory distractors) and levels 6 and 7 (combination of visual and auditory distractors).

To determine which type of distractors was more useful in terms of ADHD diagnosis, we calculated the areas under the receiver operating characteristic (ROC) curves. After a ROC was generated for each distractor type, chi-square tests were performed in order to compare the utility of different test conditions in the diagnosis of ADHD.

3. Results

3.1. Effects of distractors on omission errors in ADHD and non-ADHD adolescents

In order to study the added value of the incorporation of distractors in the CPT for a better differentiation between ADHD and controls a linear repeated measures model with Tukey's correction for multiple comparisons was conducted.

This model included: (a) between groups analysis of the differences in the rate of omission errors between ADHD and non-ADHD adolescents and (b) within-group analysis of the differences in omission errors between no distractors conditions and the three conditions which contained distractors (visual, auditory and a combination of them). First, analyses showed that both gender [$F(1, 172) = 5.26$, $p < 0.05$] and age [$F(1, 172) = 9.10$, $p < 0.01$] were associated with CPT performance. That is, boys and younger children demonstrated higher omission errors. However, ADHD group did not differ from the non-ADHD group in age [$t(174) = 1.48$, $p = 0.097$] or gender distributions [$\chi^2(1, N = 176) = 0.19$, $p = 0.662$].

When controlling for age and gender, group affiliation had a significant effect on the rate of omission errors [$F(1, 172) = 28.45$, $p < 0.001$]. As can be seen in Table 1, ADHD adolescents demonstrated higher rate of omission errors than their unaffected peers in all CPT conditions (no distractors, visual distractors, auditory distractors and a combination of visual and auditory distractors). Most importantly, group × level interaction revealed that the difference between the two groups varied as a function of task demands [$F(3, 172) = 4.98$, $p < 0.01$]. Within-groups analysis indicated that in the ADHD group, omission errors were significantly higher in the presence of visual distractors and the combination of visual and auditory distractors than in no-distractors conditions. The presence of pure auditory distractors did not increase the amount of omission errors as compared to no-distractors. In the control group, distracting stimuli had no effect on CPT performance as compared to no-distractors conditions (Table 2).

3.2. ROC analyses

The discriminant ability of different distractors types was evaluated by a Receiver Operating Characteristic (ROC) curve analysis (Fig. 2). ROC analysis summarizes diagnostic efficiency with the area under the curve (AUC) statistic.

First, ROC analyses revealed that the mere presence of distractors (AUC = 0.890) significantly improved the AUC of the test, as compared to the absence of distractors (AUC = 0.784) [$\chi^2(1, N = 176) = 8.51$, $p < 0.01$]. Specifically, the AUC of combined visual and auditory distractors was the highest (AUC = 0.867). The combination of distractors significantly improved the utility of the test in the diagnosis of ADHD as compared to no-distractors [$\chi^2(1, N = 176) = 5.35$, $p < 0.05$]. Pure visual (AUC = 0.846) and pure auditory (AUC = 0.772) distractors did not yield any diagnostic

Table 2
Level Differences in omission errors within each study group.

Comparison $t(172)$	ADHD (N = 143)	Non-ADHD (N = 33)
No distractors vs. visual distractors	−6.59, $p < 0.0001$	−1.20, *N.S.*
No distractors vs. auditory distractors	−1.30, *N.S.*	−0.60, *N.S.*
No distractors vs. combined distractors	−6.65, $p < 0.0001$	−0.65, *N.S.*
Visual distractors vs. auditory distractors	5.70, $p < 0.0001$	0.62, *N.S.*
Visual distractors vs. combined distractors	−1.40, *N.S.*	0.30, *N.S.*
Auditory distractors vs. combined distractors	−6.12, $p < 0.0001$	−0.17, *N.S.*

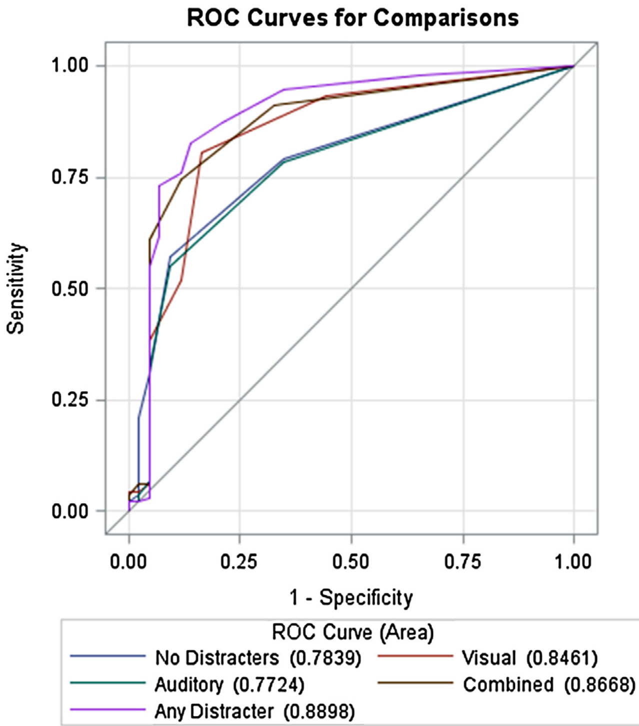

Fig. 2. ROC analyses.

advantage over no-distractors conditions. Although the combination of visual and auditory distractors was favourable in terms of sensitivity and specificity in comparison to pure auditory distractors [$\chi^2(1, N = 176) = 12.92$, $p < 0.001$], it was not beneficial over pure visual distractors [$\chi^2(1, N = 176) = 0.64$, N.S.].

4. Discussion

This study investigated the effects of environmental distractors on sustained attention of ADHD and non-ADHD adolescents (ages 13–18). Results showed that ADHD adolescents demonstrated higher rates of omission errors than their unaffected peers in all CPT conditions. In addition, ADHD adolescents produced significantly more omission errors in the presence of pure visual distractors and the combination of visual and auditory distractors than in no-distractors conditions. In contrast, distracting stimuli had no effect on CPT performance of non-ADHD adolescents. Findings from ROC analysis further demonstrated that independently of distractors type, impending distractors in CPT significantly improved the sensitivity and specificity of the test.

It is known that a variety of visual and auditory stimuli exists in the everyday environment of ADHD children and that problematic behaviour first appear in the presence of such stimuli. Thus, our results support the idea that ADHD is indeed marked by high distractibility and that teenagers with ADHD have difficulties to sustain attention in the presence of irrelevant environmental stimuli. These findings are in line with studies of younger children with ADHD, which demonstrated high distractibility during CPT and non-CPT tasks (Adams et al., 2011; Gumenyuk et al., 2005; Parsons et al., 2007; Pelham et al., 2011). Parsons et al. (2007), who used a virtual reality technology to simulate everyday distractibility in ADHD, have shown that during distracting conditions, ADHD children were more hyperactive and produced more omission errors on the Conners' CPT-II as compared to non-ADHD children. On the other hand, our findings are inconsistent with other studies which indicated that auditory and visual distractors did not impair cognitive performance of ADHD children or even improved it (Abikoff et al., 1996; Uno et al., 2006; Van Mourik et al., 2007). This diversity may result from the type of distractors used. While some studies have used neutral stimuli (neutral tone/letter) as distractors (Gordon and Mettelman, 1987; Uno et al., 2006; Van Mourik et al., 2007), the MOXO-CPT used more ecologically valid stimuli that are typically found in the child's environment. Since ADHD children have more difficulties in filtering meaningful distractors (Blakeman, 2000) they may fail to inhibit response to relevant, everyday stimuli rather than to neutral information.

Another factor that may contribute to the high distractibility of ADHD adolescents in this study is the method of distractors presentation. In several studies, auditory distractors served as a background noise while children performed another cognitive task (Abikoff et al., 1996; Pelham et al., 2011). In contrast, distractors in the MOXO-CPT vary in their type, in their length of presentation and in their location on the screen. This mode of presentation did not allow adjustment or de-sensitization to the distractors, therefore kept them salient.

The current study revealed that the distractibility of ADHD adolescents varied across the distractors' modality. The fact that visual stimuli appeared as more potent distractors for ADHD adolescents than auditory distractors is consistent across studies with ADHD children (Pelham et al., 2011). The most straightforward hypothesis is that because the MOXO-CPT is a visual task that includes visual input and processing, it might be more vulnerable to visual distractors that use the same cognitive modality (Wickens, 1984, 2002). It is also possible that due to impaired visual attention in ADHD (Kofler et al., 2008), additional visual information easily overload the cognitive/physiological system, thus interfering with performance (Armstrong, 1993; Armstrong and Greenberg, 1990).

The effect of auditory distractors on ADHD children and adolescent remains unclear. While the current study failed to show any effect of auditory distractors on cognitive performance in ADHD adolescents, others have found that auditory distractors could either interfere or improve it (Abikoff et al., 1996; Pelham et al., 2011; Söderlund et al., 2007). Uno et al. (2006) who specifically tested the effect of auditory noise on CPT performance, found that ADHD children produced fewer omission errors in the presence of auditory noise than in the no-noise condition. The positive effect of distracting auditory stimuli on the cognitive performance of ADHD patients is usually attributed to the increased arousal provoked by a novel signal (Uno et al., 2006; Van Mourik et al., 2007). It is possible that distractors in the MOXO-CPT failed to improve attention in ADHD adolescents because of the little information they conveyed for the participant. It has been suggested (Parmentier et al., 2010) that the degree to which a novel, unexpected auditory sound may optimize performance depends on the amount of information it conveys. When a novel sound predicts another relevant stimulus, the system can take advantage of the auditory distractors to improve its functioning. In contrast to other CPT (Uno et al., 2006; Van Mourik et al., 2007) distractors in the MOXO-CPT did not precede the target or were generated stimulatingly with it, but rather were unsynchronized with it. This fact may lower the extent to which the sound included information necessary to optimize performance and may explain why auditory distractors did not improve sustained attention in our study.

Several limitation of this study should be considered. First, participation in the study was based on a voluntary agreement of children and their parents. This self-selected sampling strategy tends to be biased towards favouring more cooperative and motivated individuals. Therefore, it is impossible to determine whether this sample also represents other children that were not recruited and whether cooperation is confounded with ADHD variables. This limitation is typical to most clinic-based ADHD studies around the world (Gau et al., 2010; Lee and Ousley, 2006). In addition, the clinics from which ADHD children were recruited were based in tertiary care hospital. This population has heterogeneous background characteristics including those correlates of ADHD. Finally, the exclusion of ADHD children with severe comorbidities may limit the generalization of our results.

Overall, our findings showed that independently of distractor type, ADHD teenagers were more distracted than healthy controls during CPT performance, ADHD adolescents produced more omission errors in the presence of visual environmental stimuli or the combination of visual and auditory stimuli in comparison to no-distractors conditions. In terms of ADHD diagnosis, the mere presence of distractors improved the utility of the test relative to no distractors.

Visual environmental stimuli emerged as better distractors than auditory ones and combining visual and auditory distractors was not beneficial in terms of validity, as compared to pure visual distractors.

In contrast to the majority of cognitive tasks, distracting stimuli in the MOXO-CPT were external to the task (i.e., not conflicting with task demands). The fact that adolescents with ADHD were distracted by external stimuli suggests that in everyday life these individuals may be more distracted by irrelevant stimuli in the classroom (e.g., someone talks in the next room) rather than background stimuli (e.g., music) or distractors that are part of the cognitive task. Hence, reducing irrelevant environmental stimuli or learning how to regulate their influence on attention functions, may assist adolescents with ADHD in coping with distractibility problems.

Finally, this study lends further support for using the CPT as an aiding tool in the diagnosis of ADHD in teenagers, once employing appropriate task demands that better simulate distractibility in everyday life.

Future research should address the diagnostic utility of the test in larger spectrum of age and in different populations (e.g., ADHD with comorbid features).

Another question that should be further explored is how distractibility is marked in different subtypes of ADHD. Previous studies examining ADHD subtype differences in neuropsychological functioning are limited and inconsistent (Booth et al., 2007; Lockwood et al., 2001; Nikolas and Nigg, 2013; Schwenck et al., 2009) It has been long debated whether one category is capable to describe the high heterogeneity in symptom presentation and impairments of ADHD (Nigg et al., 2010). Moreover, it is still unclear whether different ADHD subtypes reflect unique configurations of the syndrome or simply various degrees of behavioural and neuropsychological weaknesses (Nikolas and Nigg, 2013). Thus, it would be highly important to examine if specific subtypes of ADHD are more distracted than others (Keage et al., 2006; Mayes et al., 2009). While some authors suggested that distractibility relates to difficulty in response inhibition (Oades et al., 2002) and therefore characterizes ADHD predominantly hyperactive and combined subtypes (Carlson and Mann, 2000; Lahey et al., 1997), others proposed that distractibility has more to do with inattentiveness problems, hence is more expected in ADHD predominantly inattentive subtype (McBurnett et al., 2001; Milich et al., 2001). It is a purpose of future research, and beyond the scope of this study, to explore the neuropsychological correlates of distractibility in CPT and how they are pronounced in different ADHD subtypes. Although the current study points out a potential association between distractibility and inattention, the effect of distractors on other CPT measures (e.g., commission errors) is equally important.

Conflicts of interest statement

Itai Berger serves in the scientific advisory board to Neuro-Tech Solutions Ltd. Hanoch Cassuto declared no potential conflicts of interest with respect to this study.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jneumeth.2013.10.012.

References

Abikoff H, Courtney ME, Szeibel PJ, Koplewicz HS. The effects of auditory stimulation on the arithmetic performance of children with ADHD and nondisabled children. J Learn Disabil 1996;29:238–46, http://dx.doi.org/10.1177/002221949602900302.

Adams ZW, Roberts WM, Milich R, Fillmore MT. Does response variability predict distractibility among adults with attention-deficit/hyperactivity disorder? Psychol Assess 2011;23:427–36, http://dx.doi.org/10.1037/a0022112.

American Psychiatric Association. Diagnostic and statistical manual of mental disorders text revision (DSM-IV-TR). 4th ed. – text revision Washington, DC: American Psychiatric Association; 2000.

Armstrong GB. Cognitive interference from background television: structural effects on verbal and spatial processing. Commun Studies 1993;44:56–70, http://dx.doi.org/10.1080/10510979309368382.

Armstrong GB, Greenberg BS. Background television as an inhibitor of cognitive processing. Hum Commun Res 1990;16:355–86, http://dx.doi.org/10.1111/j.1468-2958.1990.tb00215.x.

Barkley RA. The ecological validity of laboratory and analogue assessment methods of ADHD symptoms. J Abnorm Child Psychol 1991;19:149–78, http://dx.doi.org/10.1007/BF00909976.

Barkley RA, Anastopoulos AD, Guevremon DC, Fletcher K. Adolescents with ADHD: patterns of behavioural adjustment, academic functioning, and treatment utilization. J Am Acad Child Adolesc Psychiatry 1991;30:752–61, http://dx.doi.org/10.1097/00004583-199109000-00009.

Berger I, Goldzweig G. Objective measures of attention-deficit/hyperactivity disorder – a pilot study. Isr Med Assoc J 2010;12:531–5.

Berwid OG, Curko Kera EA, Marks DJ, Santra A, Bender HA, Halperin JM. Sustained attention and response inhibition in young children at risk for Attention Deficit/Hyperactivity Disorder. J Child Psychol Psychiatry 2005;46:1219–29.

Blakeman RS. ADHD and distractibility: the role of distractor appeal. Diss Abstr Int B Sci Eng 2000;61(1-B):517.

Booth JE, Carlson CL, Tucker DM. Performance on a neurocognitive measure of alerting differentiates ADHD combined and inattentive subtypes: a preliminary report. Arch Clin Neuropsychol 2007;22:423–32, http://dx.doi.org/10.1016/j.acn.2007.01.017.

Brown T. Attention-deficit disorders and comorbidities in children, adolescents and adults. Washington, DC: American Psychiatric Press; 2000.

Carlson CL, Mann M. Attention-deficit/hyperactivity disorder, predominantly inattentive subtype. Child Adolesc Psychiatr Clin N Am 2000;9:449–510.

Christensen KM, Joschko M. Construct validity of the continuous attention test for children. Clin Neuropsyc 2001;15:203–9, http://dx.doi.org/10.1076/clin.15.2.203.1899.

Conners CK. Conners' CPT II for Windows. North Tonowada, NY: MultiHealth System; 2000.

DeShazo TB, Grofer LK, Lyman RD, Bush D, Hawkins L. Visual selective attention versus sustained attention in boys with Attention-Deficit/Hyperactivity Disorder. J Affect Disord 2001;4:193–202, http://dx.doi.org/10.1177/108705470100400401.

Diamond G, Badir M, Savilla P, Inbar D, Gadoth N. Comparison between neurological examination and computerized test of attention for suspected ADHD: implications for assessment of a common childhood disability. Int J Disability Human Dev 2012;12:289–95, http://dx.doi.org/10.1515/ijdhd-2012-0113.

Dickerson Mayes S, Calhoun SL, Crowell EW. Clinical validity and interpretation of the Gordon Diagnostic System in ADHD assessments. Child Neuropsychol 2001;7:32–41, http://dx.doi.org/10.1076/chin.7.1.32.3151.

DuPaul GJ, Power JD, Anastopouls AA, Reid R. ADHD Rating Scale-IV: checklists, norms and clinical interpretation. New York: The Guilford Press; 1998.

Edwards MC, Gardner ES, Chelonis JJ, Schulz EG, Flake RA, Diaz PF. Estimates of the validity and utility of the Conner's CPT in the assessment of inattentive and/or hyperactive impulsive behaviors in children. J Abnorm Child Psychol 2007;35:393–404.

Epstein JN, DelBello MP, Adler CM, Altaye M, Kramer M, Mills NP, et al. Adolescents with ADHD demonstrate differential developmental patterns of functional activation in right prefrontal cortex compared to non-ADHD controls. Neuropediatrics 2009;40:1–5, http://dx.doi.org/10.1055/s-0029-1220686.

Faraone SV, Biederman J, Mick E. The age-dependent decline of attention deficit hyperactivity disorder: a meta-analysis of follow-up studies. Psychol Med 2006;36:159–65, http://dx.doi.org/10.1017/S003329170500471X.

Gau S, Lin Y, Shang C, Liu S, Chiu Y, Soong W. Emotional/behavioral problems and functional impairment in clinic and community-based children with attention-deficit/hyperactivity disorder in Taiwan. J Abnorm Child Psychol 2010;38:521–32, http://dx.doi.org/10.1007/s10802-009-9381-6.

Gordon M, Mettelman BB. Technical guide to the Gordon Diagnostic System. New York: Gordon Systems; 1987.

Greenberg L, Kindschi C. Test of variables of attention. Edmonton, Canada: Universal Attention Disorders, Inc; 1998.

Gumenyuk V, Korzyukov O, Escera C, Hämäläinen M, Huotilainen M, Häyrinen T, et al. Electrophysiological evidence of enhanced distractibility in ADHD children. Neurosci Lett 2005;374:212–7, http://dx.doi.org/10.1016/j.neulet.2004.10.081.

Keage HA, Clark CR, Hermens DF, Kohn MR, Clarke S, Williams LM, et al. Distractibility in AD/HD predominantly inattentive and combined subtypes: the P3a ERP component, heart rate and performance. J Integr Neurosci 2006;5:139–58, http://dx.doi.org/10.1142/S0219635206001070.

Kelip JG, Herrera J, Stritzke P, Cornblatt BA. The continuous performance test, identical pairs version (CPT-IP). III. Brain functioning during performance of numbers and shapes subtasks. Psychiatry Res 1997;74:35–45, http://dx.doi.org/10.1016/S0925-4927(96)02881-8.

Kessler RC, Adler L, Barkley R, Biederman J, Conners CC, Demler O, et al. The prevalence and correlates of adult ADHD in the United States: results from the National Comorbidity Survey Replication. Am J Psychiatry 2006;163:716–23, http://dx.doi.org/10.1176/appi.ajp.163.4.716.

Kofler MJ, Rapport MD, Alderson RM. Quantifying ADHD classroom inattentiveness, its moderators, and variability: a meta-analytic review. J Child Psychol Psychiatry 2008;49:59–69, http://dx.doi.org/10.1111/j.1469-7610.2007.01809.x.

Lahey BB, Carlson CL, Frick PJ. Attention-deficit disorder without hyperactivity. In: Widiger TA, Frances AJ, Pinicus HA, Ross R, First MB, Davis W, editors. DSM-IV Source Book. Washington, D.C.: American Psychiatric Press; 1997. p. 163–88.

Lee DO, Ousley OY. Attention-deficit hyperactivity disorder symptoms in a clinic sample of children and adolescents with pervasive developmental disorders. J Child Adolesc Psychopharmacol 2006;16:737–46, http://dx.doi.org/10.1089/cap.2006.16.737.

Lockwood KA, Marcotte AC, Stern C. Differentiation of Attention Deficit/Hyperactivity Disorder subtypes: application of a neuropsychological model of attention. J Clin Exp Neuropsychol 2001;23:317–30.

López-Martín S, Albert J, Fernández-Jaén A, Carretié L. Emotional distraction in boys with ADHD: neural and behavioral correlates. Brain Cogn 2013;83:10–20, http://dx.doi.org/10.1016/j.bandc.2013.06.004.

Mayes SD, Calhoun SL, Chase GA, Mink DM, Stagg RE. ADHD subtypes and co-occurring anxiety, depression, and oppositional-defiant disorder: differences in Gordon diagnostic system and Wechsler working memory and processing speed index scores. J Atten Disord 2009;12:540–50, http://dx.doi.org/10.1177/1087054708320402.

McBurnett K, Pfiffner LJ, Frick PJ. Symptom properties as a function of ADHD type: an argument for continued study of sluggish cognitive tempo. J Abnorm Child Psychol 2001;29:207–21.

McGee RA, Clark SE, Symons DK. Does the Conners' continuous performance test aid in ADHD diagnosis? J Abnorm Child Psychol 2000;28:415–42.

Milich R, Balentine AC, Lynam DR. ADHD combined type and ADHD predominantly inattentive type are distinct and unrelated disorders. Clin Psychol Sci 2001;8:463–88, org/10.1093/clipsy.8.4.463.

Nigg JT, Tannock R, Rohde LA. What is to be the fate of ADHD subtypes? An introduction to the special section on research on the ADHD subtypes and implications for the DSM-V. J Clin Child Adolesc Psychol 2010;39:723–5, http://dx.doi.org/10.1080/15374416.2010.517171.

Nikolas MA, Nigg JT. Neuropsychological performance and attention-deficit hyperactivity disorder subtypes and symptom dimensions. Neuropsychology 2013;27:107–20, http://dx.doi.org/10.1037/a0030685.

Oades RD, Slusarek M, Velling S, Bondy B. Serotonin platelet-transporter measures in childhood attention-deficit/hyperactivity disorder (ADHD): clinical versus experimental measures of impulsivity. World J Biol Psychiatry 2002;3:96–100, http://dx.doi.org/10.3109/15622970209150607.

Ogundele MO, Ayyash HF, Banerjee S. Role of computerised continuous performance task tests in ADHD. Prog Neurol Psychiatry 2011;15:8–13, http://dx.doi.org/10.1002/pnp.198.

Parmentier FBR, Elsley JV, Ljungberg JK. Behavioral distraction by auditory novelty is not only about novelty: the role of the distractor's informational value. Cognition 2010;115:504–11, http://dx.doi.org/10.1016/j.cognition.2010.03.002.

Parsons TD, Bowerly T, Buckwalter JG, Rizzo AA. A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. Child Neuropsychol 2007;13:363–81, http://dx.doi.org/10.1080/13825580600943473.

Pelham WE, Waschbusch DA, Hoza B, Gnagy EM, Greiner AR, Sams SE, et al. Music and video as distractors for boys with ADHD in the classroom: comparison with controls, individual differences, and medication effects. J Abnorm Child Psychol 2011;39:1085–98, http://dx.doi.org/10.1007/s10802-011-9529-z.

Rasmussen ER, Todd RD, Neuman RJ, Heath AC, Reich W, Rohde LA. Comparison of male adolescent-report of attention-deficit/hyperactivity disorder (ADHD) symptoms across two cultures using latent class and principal components analysis. J Child Psychol Psychiatry 2002;43:797–805, http://dx.doi.org/10.1111/1469-7610.00081.

Riccio CA, Waldrop JJ, Reynolds CR, Lowe P. Effects of stimulants on the continuous performance test (CPT): implications for CPT use and interpretation. J Neuropsychiatry Clin Neurosci 2001;13:326–35, http://dx.doi.org/10.1176/appi.neuropsych.13.3.326.

Robin AL. ADHD in adolescents: diagnosis and treatment. New York: The Guilford Press; 1998.

Rucklidge JJ. Gender differences in neuropsychological functioning of New Zealand adolescents with and without Attention Deficit Hyperactivity Disorder. Int J Disabil Dev Educ 2006;53:47–66, http://dx.doi.org/10.1080/10349120600577402.

Rund BR, Zeiner P, Sundet KS, Øie M, Bryhn G. No vigilance deficit found in either young schizophrenic or ADHD subjects. Scand J Psychol 1998;39:101–7, http://dx.doi.org/10.1111/1467-9450.00062.

Schachar R, Logan G, Wachsmuth R, Chajczyk D. Attaining and maintaining preparation: a comparison of attention in hyperactive, normal, and disturbed control children. J Abnorm Child Psychol 1998;16:361–78, http://dx.doi.org/10.1007/BF00914169.

Schwenck C, Schmiedeler S, Zenglein Y, Renner T, Romanos M, Jans T, et al. Reflective and impulsive reactions in ADHD subtypes. Atten Defic Hyperact Disord 2009;1:3–10, http://dx.doi.org/10.1007/s12402-009-0002-6.

Seidman LJ, Biederman J, Monuteaux M, Doyle AE, Faraone SV. Learning disabilities and executive dysfunction in boys with attention deficit hyperactivity disorder. Neuropsychology 2001;15:544–56, http://dx.doi.org/10.1037//0894-4105.15.4.544.

Shalev L, Ben-Simon A, Mevorach C, Cohen Y, Tsal Y. Conjunctive Continuous Performance Task (CCPT) – a pure measure of sustained attention. Neuropsychologia 2011;49:2584–91, http://dx.doi.org/10.1016/j.neuropsychologia.2011.05.006.

Skounti M, Philalithis A, Galanakis E. Variations in prevalence of attention deficit hyperactivity disorder worldwide. Eur J Pediatr 2007;166:117–23, http://dx.doi.org/10.1007/s00431-006-0299-5.

Söderlund G, Sikström S, Smart A. Listen to the noise: noise is beneficial for cognitive performance in ADHD. J Child Psychol Psychiatry 2007;48:840–7, http://dx.doi.org/10.1111/j.1469-7610.2007.01749.x.

Uno M, Abe J, Sawai C, Sakaue Y, Nishitani A, Yasuda Y, et al. Effect of additional auditory and visual stimuli on continuous performance test (noise-generated CPT) in AD/HD children – usefulness of noise-generated CPT. Brain Dev 2006;28:162–9, http://dx.doi.org/10.1016/j.braindev.2005.06.007.

Van Mourik R, Oosterlaan J, Heslenfeld DJ, Konig CE, Sergeant JA. When distraction is not distracting: a behavioral and ERP study on distraction in ADHD. Clin Neurophysiol 2007;118:1855–65, http://dx.doi.org/10.1016/j.clinph.2007.05.007.

Wasserstein J. Diagnostic Issues for adolescents and adults with ADHD. J Clin Psychol 2005;61:535–47, http://dx.doi.org/10.1002/jclp.20118.

Wickens CD. Processing resources in attention. In: Parasuraman R, Davies R, editors. Varieties of attention. New York: Academic Press; 1984. p. 63–101.

Wickens CD. Multiple resources and performance prediction. Theor Issues Ergon Sci 2002;3:159–77, http://dx.doi.org/10.1080/14639220210123806.

Wolraich M, Brown L, Brown RT, DuPaul G, Earls M, Feldman HM, et al. Subcommittee on Attention-Deficit/Hyperactivity Disorder; Steering Committee on Quality Improvement and Management, ADHD: clinical practice guideline for the diagnosis, evaluation, and treatment of attention-deficit/hyperactivity disorder in children and adolescents. Pediatrics 2011;128:1007–22.