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Attention Deficit Hyperactivity Disorder-like traits and distractibility in the visual periphery

Maria Panagiotidi, Paul G. Overton and Tom Stafford

Department of Psychology, University of Sheffield, Western Bank, Sheffield, S10 2TN, UK

Address for correspondence:

Paul G. Overton,
Department of Psychology,
University of Sheffield,
Sheffield,
United Kingdom, S10 2TN.
Tel: +44 (0)144 222 6624
Fax: +44 (0)144 276 6515
p.g.overton@sheffield.ac.uk

Abstract. We examined the performance of non-clinical subjects with high and low levels of self-reported ADHD-like traits in a novel distractibility paradigm with far peripheral visual distractors, the likely origin of many distractors in everyday life. Subjects were tested on a Sustained Attention to Response Task with distractors appearing before some of the target/non-target stimuli. When the distractors appeared 80 ms before the targets/non-targets, participants with high levels of ADHD-like traits were less affected in their reaction times than those with lower levels. Reducing the distractor-target/non-target interval to 10 ms removed tSChe reaction time advantage for the high group. We suggest that at 80 ms the distractors were cueing the arrival of the target/non-target and that those with high levels of ADHD-like traits were more sensitive to the cues. Increased sensitivity to stimuli in the visual periphery is consistent with hyper-responsiveness at the level of the superior colliculus.

Keywords: cueing, peripheral distractibility, superior colliculus, reaction time, accuracy

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is a behavioural disorder defined by either an attentional dysfunction, hyperactive/impulsive behaviour or both (DSM-V; American Psychiatric Association 2013). Attention-deficit hyperactivity disorder is the most common neurodevelopmental disorder (Faraone, Sergeant, Gillberg, & Biederman, 2003; Barkley 1997) and its worldwide prevalence in children and adolescents is between 0.85 % and 10 % (Tannock, 1998; Polanczyk, de Lima, Horta, Biederman, & Rohde, 2007), depending on where and how the studies were conducted and the diagnostic criteria employed. In roughly half of the children diagnosed with ADHD, symptoms persist into adulthood (Spencer et al. 2002), thus validating ADHD as an adulthood disorder (Faraone & Biederman, 2005). The symptoms remaining in adulthood include distractibility and difficulties with maintaining goal-directed behaviour rather than hyperactivity (Spencer, Biederman, Wilens, & Faraone, 2002).

Distractibility is one of the defining features of ADHD. Listed as a symptom in the DSM-V (American Psychiatric Association, 2013), the prominence of distractibility amongst the symptoms of ADHD can be traced back to the work of A.A. Strauss in the 1940s and 50s (Werner & Strauss, 1940). Reports from teachers and parents suggest that children with ADHD have difficulty paying attention to one task without getting distracted by external events (Adler, 2004), and clinical accounts commonly describe children with ADHD as distractible (e.g. Thorley, 1984). This manifestation of the disorder is likely to be an important factor contributing to the negative impact that ADHD has on academic and educational performance (Loe & Feldman, 2007) and social integration (Goodman, 2007).

Even though distractibility is a well-established symptom of ADHD, the conditions used to test distractibility in the laboratory are often a poor reflection of the circumstances that lead to distraction in everyday life. In laboratory tests of distractibility, a distinction has been made between distractors that occur within the task that is being undertaken (so called intra-task distractors) and those that occur outside the task that is being undertaken (so called extra-task distractors; Rosenthal & Allen, 1980). The former are usually temporally predictable and intrinsic to the task and the latter are usually unpredictable (unexpected) and extrinsic to the task. The majority of laboratory studies of distractibility in ADHD thus far have used distractors of the intra-task type, and although greater distractibility has been often reported for these distractor types (e.g. in relation to performance on the Stroop test, Carter, Krener, Chaderjian, Northcutt, & Wolfe, 1995; Reeve & Schandler, 2001), in everyday life distractors are more likely to resemble the extra-task type in being unexpected, unpredictable and unlikely to be related to whatever task a person is currently performing.

Although the general level of ecological validity of laboratory tests of cognitive function in ADHD has been criticized (Nichols & Waschbusch 2004; Barkley 1991), some researchers have found increased distractibility with more ecologically valid tests. So, Dykman, Walls, Suzuki, Ackerman and Peters (1970) and Gumenyuk et al. (2005) both report greater disturbances in performance (respectively pressing a telegraph key in response to a visual target and categorizing visual stimuli as animals or non-animals) in children with ADHD than controls when the children were exposed to unpredictable sounds unrelated to the task (a 90 dB hooter in Dykman et al., 1970, and 50 dB tones and novel real-world sounds in Gumenyuk et al., 2005). Uno et al. (2006), Cassuto, Ben-Simon and Berger (2013), and Berger and Cassuto (2014) report similar findings using a Continuous Performance Test and extend the result to unpredictable visual distractors. However, even in these studies where visual distractors have been used in a more ecologically valid manner, one very important stimulus characteristic has not been explicitly controlled, namely position in the visual field. Uno et al. (2006), Berger and Cassuto (2014) and Cassuto et al. (2013) all used centrally located (para-foveal) stimuli. Indeed, the majority of tasks used in empirical investigations of visual distractibility in ADHD present stimuli in the central visual field, with stimuli presented to the fovea or parafoveal area (e.g. 4-8 degrees, Loe, Feldman, Yasui, & Luna, 2009). The maximum eccentricity reported so far is 21 degrees in a study by Laasonen and colleagues (2012). However, a typical visual field is much larger than this, extending up to 200 laterally and 130 vertically (Henson, 2000). Whilst some distracting stimuli are likely to come from the central field, unexpected distracting visual stimuli are much more likely to come from the visual periphery.

Evidence suggests that processing of information from the central and peripheral visual fields proceeds somewhat in parallel (Ludwig, Davies, & Eckstein, 2014). Indeed, differences in central and peripheral processing begin at the retinal level, with the dominance of motion sensitive Y-type ganglion cells in the peripheral retina (Walsh & Polley, 1985) and - at least in the cat - the dominant population of neurons in the peripheral field representation in area 17 being motion sensitive (Stone and Dreher, 1973). Furthermore, in a range of species, the midbrain superior colliculus (SC) plays a particular role in detecting stimuli in the far periphery (Overton, Dean, & Redgrave, 1985 [rat]; Lomber & Payne, 1996 [cat]; Albano, Mishkin Westbrook, & Wurtz, 1982 [monkey]; Sylvester, Josephs, Driver, & Rees, 2007 [human]). This is especially important in the context of ADHD, given that the SC plays a central role in distractibility (Goodale, Foreman, & Milner, 1978; Milner, Foreman, & Goodale, 1978), and the fact that evidence is mounting that the colliculus may be dysfunctional in ADHD (reviewed by Overton, 2008; Overton & Clements, 2009).

To our knowledge, research on visual function in ADHD has involved only a small portion of the visual field and the sensitivity of non-central vision to task irrelevant distractors has not been examined before. Hence, we examined sensitivity to task irrelevant visual distractors in the far periphery in a non-clinical adult population with varying levels of ADHD-like traits. Although the participants were healthy and none were previously diagnosed with ADHD, ADHD psychopathology can also be viewed dimensionally, with inattentive and hyperactive-impulsive symptoms distributed continuously in the general population (Rodriguez et al., 2007). Evidence at the level of molecular genetics also provides support for the hypothesis that ADHD represents the extreme end of traits present in the general population (Martin, Hamshere, Stergiakouli, O'Donovan, & Thapar, 2014; Larsson, Anckarsater, Råstam, Chang, & Lichtenstein, 2012; Levy, Hay, McStephen, Wood, & Waldman, 1997). The dimensional approach has been widely used in studies on other developmental disorders such as autism spectrum disorder (ASD; Dickinson, Jones, & Milne, 2014) and has been recently employed by researchers investigating ADHD (Biehl, Ehlis, Müller, Niklaus, Pauli, & Herrmann, 2013; Polner, Aichert, Macare, Costa, & Ettinger, 2015). Furthermore, working with a non-clinical population avoids the major drawback of working with a clinical ADHD population, where the majority of individuals have been treated chronically with psycho-stimulant medication (the front-line treatment for ADHD; Arnsten, 2006), which is known to affect oculomotor function (e.g. Dursun, Wright, & Reveley, 1999).

To assess sensitivity to distractors, we looked at the impact of distractors on the performance on a Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The prediction based on everyday life was that subjects with high levels of ADHD-like traits would be more sensitive to peripheral distractors than people without. The present study makes two important contributions. Firstly, it details an ecologically valid paradigm that allows the exploration of distractibility in ADHD in areas of the visual field that have thus far not been explored. Secondly, given the dominant role of the SC in the visual far periphery (e.g. Overton et al., 1985) and the proposed role of the SC in ADHD (Overton, 2008), the study provides a test of the SC hypothesis. To facilitate this, checkerboard stimuli were used as distractors as these have been found to stimulate the superior colliculus in human subjects (Calvert, Campbell, & Brammer, 2000; Schneider & Kastner, 2005b).

Experiment 1

In our first experiment, we examined the relationship between ADHD-like traits, as assessed using a self-report questionnaire, and performance in a sustained attention task with task-irrelevant far-peripheral distractors.

2. Method

2.1 Participants

33 participants (23 female) were recruited from the volunteers' list at a university in the north of England. The ages of the participants ranged from 18 to 54 (M = 25.09, SD = 9.4). All subjects were right-handed, had normal or corrected-to-normal vision and were naive as to the purpose of the experiment. All the participants were healthy and none were previously diagnosed with ADHD or any mental illness. The subjects all gave their informed consent to take part in the experiment and the procedures were in accordance with the ethical standards of the Department of Psychology Ethics Sub-Committee and British Psychological Society guidelines.

2.2 Materials

The experiment took place in a modified immersive dome (Figure 1), which wrapped around the subject at a distance of 150 cm from the subject's head, and allowed images to be projected over a horizontal range of 240 degrees and a vertical range of 100 degrees (as described in Yates & Stafford 2011). All stimuli were presented on a black background and luminance was kept constant.

[Insert Figure 1 about here]

A modified version of the SART (Robertson et al., 1997) with far-peripheral distractors was administered. In the original task, participants were presented with a series of numbers from 1 to 9 and were instructed to respond by pressing a key whenever a number appeared but to withhold their response when the number 3 appeared. In our modified version, participants were instructed to respond to all numbers by pressing "c", except for the number 3, for which they needed to respond by pressing “m”. There were 225 stimuli overall and 11% were targets (number 3). Each stimulus remained on the centre of the screen for 1s and was followed by 1s of blank (black) screen. The participant was allowed to make a response until the next stimulus appeared. Far peripheral distractors were presented on some of the trials. Distractors appeared randomly with a probability of 10%, 80 ms before the onset of the central target. Their onset location was, with equal probability, in the left or right periphery, at 78 degrees horizontal displacement and 30 degrees elevation. The exact onset location was jittered at random by 10 degrees horizontally and vertically to prevent adaptation. The distractor consisted of a 16 degree x 16 degree black-white checkboard stimulus, with each component square sized 2 x 2 degrees. Upon onset, the stimulus moved by 2 degrees each frame for 7 frames (112 ms), in one of the four cardinal directions chosen at random, whilst reversing each step (i.e. every frame of 16 ms). Clinically, the central visual field is considered to encompass an area within 30 degrees of fixation, while the rest referred to as the peripheral visual field (Buckley, Codina, Bhardwaj, & Pascalis, 2010). Even though moving, given the start location of the distractors, they never appeared <60 degrees from the subject’s line of sight.

In the present study, we used healthy adult participants with a range of ADHD-like traits, as measured by the World Health Organization Adult ADHD Self-Report Scale

(ASRS; Kessler et al., 2005). The ASRS is a questionnaire which was developed in conjunction with the revision of the WHO Composite International Diagnostic Interview (CIDI) (Kessler & Üstün, 2004). The ASRS contains eighteen items from DSM-IV-TR (American Psychiatric Association, 2000) and measures the frequencies of the symptoms. The subjects are asked to report how often they experience each symptom in a period of six months on a five-point Likert scale which ranges from 0 for never, 1 for rarely, 2 for sometimes, 3 for often, and 4 for very often (Kessler et al., 2005). The ASRS has a two factor structure (Reuter et al., 2006), which includes an inattention subscale and a hyperactivity/impulsivity subscale, each containing nine items. The reliabilities (Cronbach's alpha) for the two subscales of inattention (.75) and impulsivity (.77) as well as for the total ASRS (.82) are satisfactory (Reuter, Kirsch, & Hennig, 2006). The original questionnaires are formatted with darkly shaded boxes in certain items which signify more severe symptoms. We removed the darkly shaded boxes in the ASRS to minimize any possibility that the darker shaded areas may motivate symptom exaggeration by the participants.

2.3 Procedure

Each participant was asked to complete a short practice modified SART with far-peripheral distractors (18 stimuli) before beginning the main task. After completion of the practice session, the full version of the task was administered. The total session lasted approximately 8 minutes, after which participants were given a questionnaire, which included the ASRS and some demographics questions. Finally, they were debriefed and thanked for their time.

2.4 Data Analysis

Reaction times (RTs) from erroneous trials (i.e. trials on which an incorrect response was made) were removed from the analysis. In addition to that, RTs over 1s (the duration each stimulus remained on screen) were not included in the analysis. Sensitivity to extraneous visual stimuli in the far periphery was investigated by looking at ‘RT distractor cost’ (defined as RTs on trials with distractors - RTs on trials without distractors), and ‘Accuracy distractor cost’ (defined as accuracy [i.e. percentage of correct responses] on trials with distractors minus accuracy on trials without distractors), with positive values indicating a detrimental effect of the distractor.

Intra-individual variability (IIV), an index of efficient cue utilization, was also calculated for each participant, measured by the standard deviation (SD) of the mean RT. The effect of the distractor on IIV was calculated by measuring the difference in variability on trials with distractors and trials without distractors (IIV on trials without distractors - IIV on trials without distractors).

3 Results and discussion

3.1 ASRS scores

Scores on the ASRS checklist varied from 3 to 55, with a mean of 35.45 (SD = 11.14). The mean score on the inattention subscale was 19.3 (SD = 6.64) and the hyperactivity subscale 16.18 (SD = 5.85), and the two subscales were correlated, $r(33) = .59$, $p < .01$ (2-tailed). The overall ADHD score was correlated with both the inattention ($r(33) = .90$, $p < .01$) and the hyperactivity subscale ($r(33) = .88$, $p < .01$). Since the two subscales were highly correlated with each other and the overall ASRS scores, only overall ASRS scores were used in our analyses. Participants with ASRS scores over 35 were assigned to the group with high levels of ADHD-like traits (referred to as the ‘Hi ADHD’ group for brevity; N = 13), and the remaining participants were assigned to the group with low levels of ADHD-like traits (the ‘control’ group; N = 20). The cutoff score was based on the results of a previous scoping study by the authors examining ADHD-like traits in a sample of 800 volunteers from the general population based in a city in the north of England (Panagiotidi, Overton, & Stafford, unpublished). In this relatively large sample, the mean ASRS score was 31.83, and a score of 35 (the cutoff in the current study) was at the 75th percentile. Previous studies have reported similar cutoff points (e.g. 34 according to Stark and colleagues, 2011).

3.2 Effect of ADHD status on RT distractor cost and Accuracy distractor cost

A paired samples t-tests were conducted to examine the effect of distractors on RT and accuracy in all participants. Overall, reaction times were significantly longer on trials with distractors than those without (M = 468.51 ms, SD = 68.27; M = 487.61 ms, SD = 72.84, respectively; $t(33) = -3.39$, $p < .01$). However, no difference was found between trials with distractors (M = 97.82, SD = 1.1) and those without distractors (M = 97.83, SD = .94) on accuracy ($t(33) = .02$, $p = .99$). Accuracy was high across participants on trials with (M = 99.04, SD = 2.7) and without distractors (M = 98.4, SD = 3.1).

The RT distractor cost (RTs on trials with distractors - RTs on trials without distractors) was significantly smaller in the Hi ADHD group (M = 2.5, SD = 33) compared to the control group (M = 29.9, SD = 27), $t(31) = 2.60$, $p < .05$. More specifically, participants in the Hi ADHD group had lower RT distractor costs (i.e. smaller RT differences between distractor and non-distractor trials). No statistically significant differences between the Hi ADHD group (M = -.27, SD = 1.6) and controls (M = .45, SD = 7.6) were found in the accuracy distractor costs (accuracy on trials with distractors - accuracy on trials without distractors), $t(31) = -.41$, $p = .69$.

The differences between groups in the effect of distractor on IIV were also examined. The Hi ADHD group (M = -15.9, SD = 35.2) had lower IIV scores on trials with distractors compared to the control group (M = 11.5, SD = 31.8), $t(31) = 2.30$, $p < .05$.

3.3 Interim Discussion

Healthy adult participants with high levels of ADHD-like traits and controls were tested on a modified SART and the effect of extraneous visual stimuli presented in the far periphery was assessed on various aspects of performance. A significant difference was found between controls and participants with high levels of ADHD-like traits on RT distractor cost (the difference between RTs on distractor and non-distractor trials). Although all participants were distracted by the distractor to some extent (RTs were significantly slower on distractor trials), contrary to our initial hypothesis, participants with higher ASRS scores appeared to be less distracted by the moving checkerboards than those with lower ASRS scores. Although unexpected, there are several possible explanations for our present findings. The temporal relationship between the distractor and the target/non-target was constant across all trials: the moving checkerboard always appeared 80 ms before the main stimulus. It is therefore possible that the distractor – rather than distracting – could have acted as a cue, allowing preparation for the upcoming target/non-target. Effective visual cueing of upcoming targets in normal participants requires stimulus onset asynchronies (SOAs) of >100 ms (Jaffard, Benraiss, Longcamp, Velay, & Boulinguez, 2007). However, our results suggest that cues are either detected more often and/or utilized more effectively by participants with high levels of ADHD-like traits, such that shorted SOAs are effective in these people. In support of this, efficient cue utilization would be predicted to reduce RT variability, possibly explaining the lower IIV in participants with high levels of ADHD-like traits. Accuracy was high on both distractor and non-distractor trials and hence the cue-related advantage did not translate into an accuracy advantage as manifest in the Accuracy distractor cost scores.

Previous studies have shown that the informational content of distractors influences their effect on task performance. More specifically, distractors external to the task, which might offer information regarding the time or probability of occurrence of a visual target, have been shown to have a facilitative effect (Wetzel, Widmann, & Schröger, 2012; Parmentier, R., Elsley, & Ljungberg, 2010). In the introduction, we referred to the idea that the SC might be dysfunctional in ADHD (reviewed by Overton, 2008). In particular, evidence suggests that the colliculus might be hyper-sensitive to sensory stimuli in ADHD (Gowan, Coizet, Devonshire, & Overton, 2008; Dommett, Overton, & Greenfield, 2009; Clements, Devonshire, Reynolds, & Overton, 2014). Our original hypothesis assumed that this hypersensitivity might manifest as an increase in distractibility. However, in a context in which there is information in the 'distractor' re the timing of an upcoming target/non-target, it would seem likely that a hypersensitivity to sensory stimuli would lead to an increase in the availability of this informational source in participants with high ASRS scores, hence the smaller RT distractor cost in the group with high levels of ADHD-like traits. That said, other explanations are also possible.

A number of studies have found that children with ADHD benefit from extra-task distraction even if it doesn't have any informational content (Zentall & Meyer, 1987; Abikoff, Courtney, Szeibel, & Koplewicz, 1996; van Mourik, Oosterlaan, Heslenfeld, Konig, & Sergeant, 2007). These findings support the 'optimal stimulation theory' (Zentall & Zentall, 1983) which postulates that the performance of children with ADHD benefits from extra-task distraction because this increases their arousal to an optimal level. The 'cognitive energetic model' (Sergeant, 2005) can also explain the results as it suggests that children with ADHD suffer from an energetical dysfunction and are, therefore, unable to adjust their activation level to meet task demands. Finally, if the distractor is viewed as 'noise', an optimal amount of noise may under certain circumstances improve cognitive performance

(Moss, Ward, & Sannita, 2004). White noise, in particular, can be beneficial for cognitive performance in ADHD (Sikstrom & Soderlund, 2007; Söderlund, Sikström, & Smart, 2007). Although white noise is a steady constant signal, whereas our distractors had a sudden, random onset, performance improvement by noise is thought to operate via the additive effect of the to-be-detected signal and the noise, which requires their temporal coincidence (Moss et al, 2004). Since our distractors were temporally coincident with the targets (they overlapped temporally with the targets), the additivity requirement is fulfilled. Differential susceptibility to and therefore benefit from distractor noise or the arousing/energizing effects of the distractor may explain the positive effects of high ASRS scores in our task. One way to choose between an explanation based the potential cueing properties of the distractor and an explanation based on more general features of the distractor would be to remove the informational content from the distractor, which is what we did in Experiment 2.

Experiment 2

In the first experiment we found that, contrary to our initial hypotheses, participants with high levels of ADHD-like traits were less distracted by intermittent far-peripheral distractors. We considered two possible explanations for this unexpected result. The first was that – because the distractor always appeared 80 ms before the target/non-target, rather than distracting, the distractor may have had a cueing effect re the upcoming target/non-target to which those with higher levels of ADHD-like traits were more sensitive. That explanation based around the potential informational content of the distractor can be contrasted with an alternative explanation based on the proposal that distractors are beneficial to performance in subjects with ADHD-like traits because they are energizing/arousing/add beneficial 'noise' into the processing stream (Zentall and Zentall, 1983; Sergeant, 2005; Söderlund et al., 2007). To allow us to discriminate between these two possibilities, we ran the same protocol again, but this time substantially reducing the temporal gap between distractor and target/non-target Under these circumstances, the distractor would still be energizing/arousing/noise, but lack its informational content.

4 Methods

4.1 Participants

60 healthy participants (51 female, 8 left-handed) were recruited. The ages of the participants ranged from 18 to 27 (M = 19.07, SD = 1.68). Data from 2 participants were not recorded due to equipment malfunction and data from one participant was not included in the analysis as they did not answer the ASRS. All subjects had normal or corrected-to-normal vision and were naive as to the purpose of the experiment. None of the subjects were previously diagnosed with ADHD or any other major mental illness. The subjects all gave their informed consent to take part in the experiment and the procedures were in accordance with the ethical standards of the Department of Psychology Ethics Sub-Committee and British Psychological Society guidelines. They were all awarded for their time with course credits needed for the completion of their undergraduate degree.

4.2 Materials

A modified version of the SART with far-peripheral distractors similar to the one used in Experiment 1 was administered. The onset of the distractors was altered to 10 ms before the appearance of the stimulus to control for possible cueing effects.

4.3 Procedure

Same as Experiment 1.

4.4 Data Analysis

Same as Experiment 1.

5 Results and discussion

5.1 ASRS Scores

Scores on the ASRS checklist varied from 16 to 56, with a mean score of 34.09 (SD = 8.66). The mean score on the inattention subscale was 19.46 (SD = 5.41) and the hyperactivity subscale 14.63 (SD = 4.46) and the two subscales were correlated, r(57) = .52, p < .01. The overall ADHD score was correlated with both the inattention (r(57) = .90, p < .01) and the hyperactivity subscale (r(57) = .84, p < .01). Again, since the two subscales were strongly correlated with each other and the overall ASRS scores, only overall ASRS scores were used in our analyses. As before, participants with ASRS scores over 35 were assigned to the Hi ADHD group (N = 28) and those with ASRS scores below that to the control group (N = 29).

5.2 Effect of ADHD status on RT distractor cost and Accuracy distractor cost

As in Experiment 1, no difference was found between groups in the Accuracy distractor cost, t(55) = .3, p = .77). Both the Hi ADHD (M = -.75, SD = 1.8) and control group (M = -.6, SD = 2.1) had slightly less accurate performance on distractor trials. However, unlike Experiment 1, RT distractor cost was not statistically significantly different between the Hi ADHD (M = 12.2, SD = 30) and control group (M = 14.7, SD = 26), t(55) = .33, p = .74, i.e. shortening the time window between distractor and target removed the RT advantage for participants with high levels of ADHD traits. The effect of the distractor on IIV was also not significantly different between groups, t(55) = 1.99, p = .051.

5.3 Interim Discussion

Experiment 2 was effectively a replication of Experiment 1, except for one change – we substantially shortened the temporal gap between distractor and target, thus removing any possibility that the distractor could be used as a cue for the upcoming target. By so doing, in this second Experiment, the effect of ADHD-like traits on RT distractor cost was no longer present. Reducing the temporal gap between distractor and target also eliminated the effect of ADHD on IIV (RT variability), again suggesting that the cueing effect of the distractor had now been removed and hence RTs were no longer being primed. These effects were found in a context in which the distractor presumably continued to have whatever arousing/energizing/ noise related effects it had in Experiment 1. In short, the result suggests that the cueing effects of the distractor explains its beneficial effects in Experiment 1 rather than more general effects of the distractor.

6 General discussion

This study is, to the best of our knowledge, the first investigation of the effect of task irrelevant, far-peripheral distractors on participants with high levels of ADHD-like traits. A new paradigm was employed to investigate the effect of intermittent far peripheral distractors on the performance of a sustained attention task. In the first experiment, the presence of far-peripheral distractors led to decreased distractibility in participants with high levels of ADHD-like traits as reflected in the diminished RTs in trials with distractors. This unexpected finding was further investigated in a second Experiment. In the second Experiment, the relationship between high levels of ADHD-like traits and distractibility on distractor trials was removed by modifying the timing of the distractor. More specifically, altering the onset of the distractor so that it no longer predicted the appearance of the next target/non-target stimulus removed the beneficial effect of the distractor for participants with high levels of ADHD-like traits. The results of our experiments suggest that ADHD-like traits are associated with an alteration in the processing of far-peripheral distractors. Distractors appearing a few ms before the main stimulus had a facilitating effect on participants with high levels of ADHD-like traits only when they could predict the appearance of the main stimulus, under which circumstances, the distractor appeared to act as a cue to the upcoming target/non-target. This is consistent with findings from studies using central and peripheral distractors (Forster & Lavie 2008; Doyle & Walker 2001), which have shown that in low workload conditions individuals tend to process task irrelevant stimuli.

As mentioned earlier, central and peripheral vision are subserved by different neural systems. In particular, the far peripheral visual field is the province of the SC (e.g. Overton et al., 1985), a structure concerned with the detection of the onset and offset of stimuli in a range of modalities (Dean, Redgrave, & Westby, 1989). Furthermore, there is mounting evidence to suggest that the SC is hyper-responsive to sensory stimuli in ADHD (reviewed by Overton, 2008), although much of the evidence thus far has been from studies in infra-human species or from the re-evaluation of studies in humans performed for other purposes. The distractors used in our paradigm are of a kind to which the human SC is supposed to be sensitive (moving checkerboards appearing in the visual periphery; Calvert, Campbell, & Brammer, 2000; Schneider & Kastner, 2005). Although somewhat speculative, our findings could be seen as preliminary evidence in support of the SC hypothesis of ADHD. The assumption would be that a hyper-sensitive SC would be more efficient at detecting the ‘distractors’ we used in Experiment 1. Where there was time to prepare in response to a cue, the hyper-sensitive SC allowed participants to use the distractor as a cue to the upcoming target/non-target. However, it is difficult to conclude definitively from the present study that the relationship between ADHD-like traits and performance is due to collicular hypersensitivity. Future studies could add convergent evidence by introducing distractors less sensitive to collicular function, for example coloured stimuli. Short-wave-sensitive cones (S-cone) are thought to not directly access the SC (Thirkettle, Walton, Shah, Gurney, Redgrave, & Stafford, 2013; White, Boehnke, Marino, Itti, & Munoz, 2009), so by comparing the effect of S-cone based distractors and those to which the colliculus is sensitive on task performance in participants with high and low levels of ADHD-like traits, we could more definitively establish whether the RT advantage in participants with high ASRS scores is driven by collicular function.

Conclusion: Our results offer preliminary evidence of increased sensitivity to stimuli in the visual periphery in ADHD, consistent with hyper-responsiveness at the level of the SC. The ASRS scores in our 'Hi ADHD' group fall well within the range of scores which the authors of the scale consider to indicate that the subject is 'highly likely to have ADHD' (Kessler et al., 2005). As a consequence, similar results might be expected in a clinical ADHD population in the absence of medication. Given that, our evidence that the SC might be hyper-responsive in ADHD takes us a step closer to identifying for the first time a dysfunctional neural locus in the disorder. Since the colliculus is tightly controlled by the prefrontal cortex (Gaymard, François, Ploner, Condy, & Rivaud-Péchoux, S., 2003) our results reconfirm the notion that enhancing prefrontal function might have a useful role to play in the treatment of ADHD.

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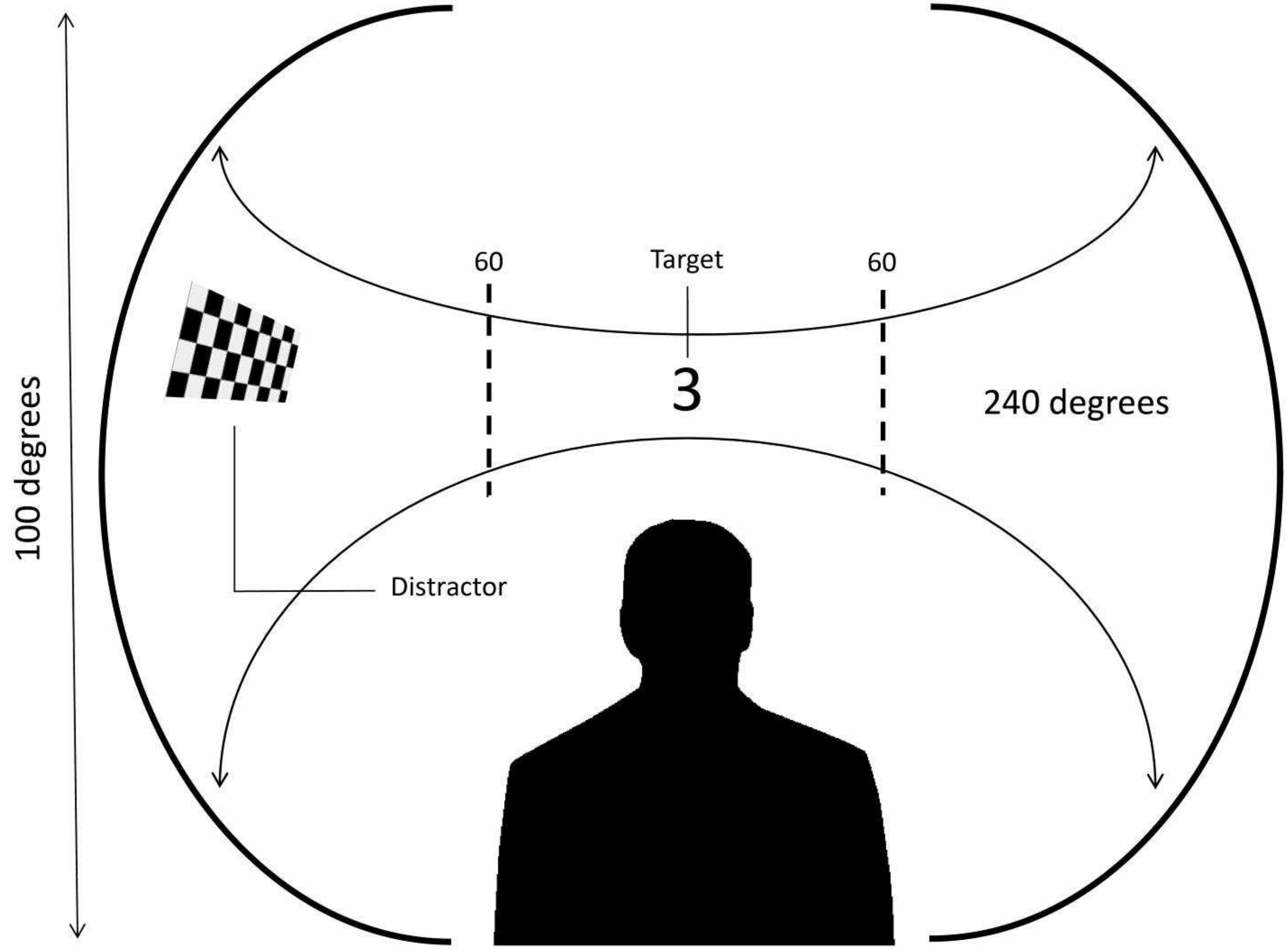
Figures

Figure 1

A custom-built immersive dome, which wrapped around the subject at a distance of 150 cm from the subject's head, allowed images to be projected over a horizontal range of 240 degrees and a vertical range of 100 degrees. Distractors were moving, reversing checkerboard stimuli presented at random locations >60 degrees from the subject's line of sight. Subjects performed a Sustained Attention to Response Task, requiring them to press key whenever a number appeared but to withhold their response when the number 3 appeared.


100 degrees
60
Target
60
3
240 degrees
Distractor