Tracking Multiple Objects in Space: Similarities Between Children with Attention Deficit Hyperactivity Disorder and Typically Developing Children

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Abstract

The marked behavioral difficulties displayed by children with Attention Deficit Hyperactivity Disorder (ADHD) have been proposed to be the result of an impaired attentional system, specifically in terms of the ability to sustain, select, and divide attention (Rapport, 2013). However, impaired performance on experimental attention tasks has only been modestly associated with observed behavioral patterns reported by parents and teachers (e.g., Barkley 1991; Nigg, 2005; Jonsdottir, Bouma, Sergeant, & Scherder, 2006). Thus, the focus of this study was to examine attention abilities among children with ADHD with an experimental task that more closely captures the dynamic nature of attention that is needed in the real-world environment. The multiple object tracking (MOT) task was proposed to serve this purpose, as the tracking of multiple moving objects reflects the navigation required in a typical dynamic environmental context. As such, performance on the "Catch the Spies" variant of the MOT task (Trick, Jaspers-Frayer, & Sethi, 2005), including immediate and delayed report conditions, was compared between children with ADHD of an average CA of 10.3 years and a matched group of TD children. Furthermore, the ecological validity of the MOT task was examined by comparing the tracking performance and behavioral ratings of all participants. The results suggest that multiple object tracking may be developmentally appropriate in children with ADHD, as the level of accuracy on the task was similar for the two groups. In addition, performance on the MOT task was not correlated with attention problems ratings from a clinical measure across the two groups. These findings suggest that the behavioral symptoms that are essential for the diagnosis of ADHD may not be related to a difficulty monitoring the moving objects in their environment.

Résumé

Il a été proposé que les difficultés comportementales observées chez les enfants atteints d'un trouble déficitaire de l'attention avec hyperactivité (TDAH) sont le résultat d'un système attentionnel avec facultés affaiblies, particulièrement en termes de capacité de maintenir, sélectionner et diviser l'attention (Rapport, 2013). Cependant, les performances lacunaires sur les tâches d'attention en psychologie expérimentale n'ont été que modestement associées à des modèles de comportement observés par les parents et les enseignants (e.g., Barkley, 1991; Nigg, 2005; Jonsdottir, Bouma, Sergeant, & Scherder, 2006). Ainsi, l'objectif de cette étude était d'examiner les capacités d'attention chez les enfants atteints de TDAH à travers une tâche expérimentale dans un contexte qui capte la nature dynamique de l'attention, ce qui est nécessaire dans l'environnement du monde réel. A cette fin, les tâches de suivi multi-objet (MOT) ont été proposées comme moyen d’évaluation, en raison de leurs capacités de refléter la navigation requise dans un contexte dynamique et de l'environnement typique. Ainsi, les performances de la variante "Catch the Spies" de la tâche MOT (Trick, Jaspers-Frayer, et Sethi, 2005), y compris les conditions de rapport immédiates et retardées, ont été comparées entre des enfants ayant le TDAH et une moyenne d’âge chronologique de 10,3 ans et un groupe apparié d’enfants à développement normal. En outre, la validité écologique de la tâche MOT a été examinée en comparant la capacité à suivre des objets et le rapport d’évaluation comportementale de tous les participants. Les résultats suggèrent que le suivi d'objets multiples peut être intacte chez les enfants atteints de TDAH, puisque le niveau de précision sur la tâche était similaire pour les deux groupes. En outre, la performance sur la tâche MOT n'est pas corrélée avec les rapports de problèmes d'attention relevés par une évaluation clinique chez les deux groupes. Les résultats suggèrent que les symptômes comportementaux qui sont essentiels pour le diagnostic de TDAH peuvent ne pas être liés à une difficulté du suivi des objets en mouvement dans l’environnement.

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Tracking Multiple Objects in Space: Similarities Between Children with Attention Deficit Hyperactivity Disorder and Typically Developing Children

Attention Deficit Hyperactivity Disorder (ADHD), one of the most common and highly heritable child neurodevelopmental disorders (Heaton et al., 2001), is characterized by a persistent pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development. The behavioral symptoms necessary for the diagnosis are typically measured through documentation provided by parents, teachers and objective observers. According to diagnostic criteria, these symptoms are present in two or more settings (e.g., at home, school or work), and negatively impact directly on social, academic, or occupational functioning (DSM-V, American Psychiatric Association, 2013). In attempts to identify the core contributors to the behavioral patterns and functional challenges, impairments in specific components of attention have been cited (Mason, Humphreys, & Kent, 2004; Rapport, 2013). In particular, selective, sustained, and divided attention abilities have been identified as potential sources of difficulty among children with ADHD (Rapport, 2013).

Deficits in sustained attention, which is the ability to maintain focus during a prolonged and sustained mental activity, have been consistently found in children with ADHD (Holmes et al., 2010; Huang-Pollock et al., 2012). In contrast, the experimental evidence is mixed with regard to selective attention, which is the ability to selectively attend to what is relevant in the current environment, and divided attention, which is the ability to simultaneously attend and respond to multiple task demands. Despite evidence outlining deficits in sustained, selective and divided attentional components, performance on experimental tasks has only been modestly associated with clinical ratings of behavior patterns reported by parents and teachers (e.g., Barkley 1991; Doyle, Biederman, Seidman, Weber, & Faraone, 2000; Jonsdottir, Bouma, Sergeant, & Scherder, 2006; Nigg, 2005).

The inconsistent relationship between experimental task performance and how children behave in the real-world environment may reflect the fact that the majority of attention tasks are designed for the study of individual attentional components in isolation from each other (Birmingham, Ristic, Kingstone, 2012; Ristic & Enns, 2015). Furthermore, these tasks generally measure the ability to selectively attend and sustain attention to objects in a static display, whereas elements of the real-world environment commonly must be attended to in motion. Accordingly, Ristic and Enns (2015) suggest that one way to try to find a link between experimental and real-world behavior is to study attention as a dynamic system with multiple interacting components. Therefore, evaluating attentional functioning in a visual scene with moving targets and distractors, is likely better suited to assess attention deficits in general and specifically as they relate to the attentional processing of children with a diagnosis of ADHD.

The investigation of how people track multiple moving objects in their environment may offer this opportunity due to the complex demands on the attentional system that it requires. The tracking of multiple objects in space over time requires the use of visual attention to monitor the positions of a number of target items as they move in space among distractors (Pylyshyn & Storm, 1988). Several components of attention (i.e., selective, sustained and divided) have been identified as being required to successfully locate and track the position of multiple independent objects simultaneously over time (Trick, Hollinsworth, & Brodeur, 2009). The complexity of this task highlights the multidimensional nature of attention, as it draws on the use of multiple components of attention, and provides an opportunity to examine how individuals perform when these attentional components must be integrated. The dynamic interplay among the relevant attentional components is what makes the study of attending to multiple objects in space a relatively ecologically valid way to study attention.

In this study, multiple object tracking abilities of children with ADHD were compared to typically developing (TD) children using the Catch the Spies variant (Trick, Perl, & Sethi, 2005). The attentional components thought to be impaired among children with ADHD are presumed to be required to successfully complete the Multiple Object Tracking (MOT) task. Therefore, performance on a complex task that requires attention to be allocated to multiple moving objects in order to effectively track their location was expected to be poorer in children with ADHD as compared to typically developing children (TD; those without a diagnosis of ADHD or any other diagnosed psychiatric or psychological conditions). Furthermore, in order to determine whether the MOT task serves as a more ecologically valid index of attentional problems than typical static experimental tasks, the relationship between MOT performance and a behavioral rating of attention problems was examined.

Attentional Abilities in ADHD

The diagnosis of ADHD includes two symptom domains: inattention, and impulsivity and hyperactivity (American Psychiatric Association, 2013). The symptom domain of inattention refers to difficulties in sustaining attention, particularly with tasks that require effortful mental processing, easy distraction by extraneous stimuli, disorganization and difficulty focusing attention resulting in careless mistakes (Koschack, Kunert, Derichs, Weniger, & Irle, 2003). Standardized neuropsychological tests are used to measure the specific attentional components thought to be responsible for the behavioral symptoms that are documented by parents, teachers, and objective observers. These attentional components have been defined as selective attention, sustained attention, and divided attention.

Sustained attention. Sustained attention refers to the process involved in maintaining the appropriate level of attention necessary for completing given tasks (Collings, 2003). Among children with ADHD, it has typically been examined using vigilance paradigms, that are constructed to examine the ability to maintain attention over a prolonged period during which infrequent response-demanding events occur (Tucha et al., 2009). One commonly used task is the Continuous Performance Test (CPT), which requires subjects to detect a rare target among rapidly presented non-targets over the course of 10-30 minutes (Huang-Pollock et al., 2012). Children with ADHD have been consistently found to commit more errors of both omission and commission on this task compared to TD comparison subjects (Corkum & Siegal, 1993; Holmes et al., 2010; Huang-Pollock et al., 2012). For example, in their meta-analysis of studies examining visual CPT performance, Huang-Pollock et al. (2012) found large effect sizes for omissions, commissions, and reaction times, indicating that children with ADHD committed more errors and had slower/more variable reactions times than TD children.

Despite more errors being consistently considered as indicative of deficits in sustained attention on the CPT, Van der Meere and Sergeant (1988) argued that in order to make such a conclusion, a decrease in performance over time needs to be present with a greater decrease in the ADHD group performance. Similarly, Tucha et al. (2009) argued that a summary of the commission or omission errors committed across the task by children with ADHD is not truly indicative of a deficit in sustained attention, because there is no indication of a deterioration of performance over time. This was highlighted in their study in which the performance of children and adults with ADHD was compared to that of TD children and adults on a 15-minute vigilance task during which the participants had to indicate when no change of pattern location in two adjacent boxes occurred. Consistent with previous studies, Tucha et al. (2009) found that both the children and adults with ADHD performed significantly poorer, as evidenced by higher rates of errors of both omission and commission, on the task as compared to the TD participants. Yet, no greater decrement in sustained attention was observed among the ADHD groups than the TD groups.

This methodological issue was highlighted by Huang-Pollock et al. (2012) who found in their review of CPT performance in children with ADHD, that only six of the 47 studies included omission performance across time and only five included commission performance across time. However, significant group over time interactions were reported in several studies suggesting a sustained attention deficit in children with ADHD (Börger et al., 1999; Hooks, Milich, & Lorch, 1994; Huang-Pollock, Nigg, & Halperin, 2006; Seidel & Joschki, 1990). For example, Huang-Pollock et al. (2006) found a significant group x time interaction for errors of both commission and omission, with a significantly larger increase in errors across time but no significant change in reaction time. In contrast, Böger et al. (1999) found that children with ADHD committed significantly more omission errors than TD children but there was no difference between groups in errors committed over time. However, the reaction times and time-on-task of the children with ADHD were found to significantly decrease over time as compared to those of the TD children. Accordingly, despite some methodological issues limiting the validity of much of the sustained attention findings, performance on vigilance tasks, such as the CPT, suggest that a deficit in sustaining attention is a core symptom of children with ADHD.

Selective attention. Selective attention involves focusing on and attending to relevant stimuli while ignoring irrelevant and distracting stimuli (Steinmayr, Ziegler, & Träuble, 2010). In line with the general notion that children with ADHD are easily distracted stimuli in their environment, selective attention deficits have been reported (Booth et al., 2005; Brodeur & Pond, 2001; dos Santos Assef, Capovilla, & Capovilla, 2007; Gomarus, Wijers, Minderaa, & Althaus, 2009; Jonkman et al. 1999). For example, Gomarus et al. (2009) examined selective attention in children with ADHD and Pervasive Developmental Disorder – Not Otherwise Specified (PDD-NOS) as compared to a TD group using a visual search task in which the participants were shown three target letters in juxtaposition and then had to indicate whether one of these letters appeared in a set of four simultaneously presented letters. The demands on selective attention were further manipulated based on the relevance (i.e., same or different colors) of the targets. The results revealed that the children with ADHD committed significantly more false alarms for same-color non-targets and omissions than TD children, suggesting a difficulty with selectively discriminating between targets and non-targets (Gomarus et al., 2009). However, deficits in selectively attending to targets were not found in other studies (Heaton et al., 2001; Huang-Pollock et al., 2005; Koschack et al., 2003). In one example, Huang-Pollock et al. (2005) examined the selective attention abilities among children with ADHD using a selective attention paradigm with differing load demands. This reaction time based task required participants to identify the target letter (either X or N) in an array of either alone, grouped with one, three, or five non-target letters. A large incompatible (X or N) or neutral target (T or L) also appeared to the periphery of the visual scene. Huang-Pollock et al. (2005) found no difference in mean reaction time or total number of errors/omissions between the children with ADHD and the TD participants.

The inconsistent evidence of selective attention deficits across studies could be attributed to the diversity of tasks and methods used to assess selective attention. For example, Brodeur and Pond (2001) found that children with ADHD were more disrupted by the presence of distractors than the TD group on a flankers task, but also highlighted that test parameters, such as distractor modality (i.e., auditory vs visual) and distractor meaning (i.e., relevant vs irrelevant), as well as age affected selective attention performance. Specifically, the children with ADHD were equally distracted by relevant and irrelevant distractors, whereas the TD children performed better with the presence of irrelevant distractors. Furthermore, the younger children were more affected by the visual distractors than the auditory distractors, whereas the older children were similarly affected by both modalities. Chan et al. (2009) also found greater distractor interference among children with ADHD when targets were presented on the left side of a flanker display under low but not high-perceptual load. These findings indicate that selective attention deficits may be limited to or more pronounced in the left visual field, consistent with previous lateralization findings in individuals with ADHD (Booth et al. 2005; Geeraerts, Lafosse, Vaes, Vandenbussche & Verfaillie, 2007). Therefore, evidence of selective attention deficits in children with ADHD compared to TD children appears to be uniquely dependent on the characteristics of the task.

Divided attention. The ability to divide attentional resources among children with ADHD has been primarily investigated using visual search tasks and dual-task paradigms. Visual search tasks of divided attention, such as the Trail Making Part B (TMT B), typically require attention to be divided between two different sets of stimuli (e.g., numbers and letters) in order to complete a trail by connecting alternating stimuli in sequence (e.g., 1-A-2-B) that are scattered around the page (Arbuthnott & Frank, 2000). In some studies, children with ADHD have been found to take significantly longer than TD children to complete this task (Boucugnani & Jones, 1989; Pasini, Paloscia, Alessandrelli, Porfirio, Curatolo, 2008; Shue & Douglas, 1992), suggesting a difficulty in maintaining both sets of stimuli. This was highlighted by Pasini et al. (2007) in their study of young boys with ADHD and TD participants who completed a large battery of executive function and attention tasks, including the TMT. They found that despite no difference between the groups in the ability to complete a trail of consecutive stimuli (i.e., 1, 2, 3), the children with ADHD needed considerably more time than the TD children to complete the TMT B. This difference remained when age and Performance IQ were controlled, although Performance IQ explained part of the variance (Pasini et al., 2007). However, in others studies, the groups did not differ in completion time although the children with ADHD committed significantly more errors (Grodzinsky & Diamond, 1992; Holmes et al., 2010). These findings suggest that the division of attention is more difficult for children with ADHD, with some opting for a slower speed to accurately complete the trail and some sacrificing accuracy for a higher speed.

The ability to divide attention has been considered an indicator of attentional capacity (Koschack et al., 2003). In this context, the ability to effectively divide attention has also been measured among children with ADHD using the dual task paradigm which involves the comparison of the simultaneous performance of two tasks as compared to a performance on a single-task. The performance of children with ADHD in relation to TD children on the dual task paradigm has ranged from poor (e.g., Fuggetta 2006; Karatekin, 2004; Savage, Cornish, Manly, & Hollis, 2006) to the same (Lajoie et al., 2005; Schachar & Logan, 1990) to better than TD children (Koschack et al., 2003). In a study using a dual-task, in which participants were required to press one of two keys matching the letter displayed on the screen (primary) but withhold the response to letters when a stop-signal tone is heard (secondary), Schachar and Logan (1990) found similar reaction times between ADHD and TD children on the secondary task. However, a closer look revealed that the ADHD groups reaction times for the primary task significantly increased compared to that of the TD children with the inclusion of the secondary task. Schachar and Logan (1990) suggested that children with ADHD may not have an attentional capacity shortage but instead allocate their resources inefficiently. In a more recent study by Fuggetta (2006), using a dual-task in which the primary task involved discriminating between two digits and the secondary task involved saying aloud the color of the stimulus, children with ADHD were found to react more slowly than TD children, despite making a similar amount of errors. Taken together, the findings of the visual search tasks suggest that children with ADHD may have difficulty accurately monitoring multiple stimuli when their attention is divided and the dual-task findings suggest that this is due to an inefficient allocation of their attention.

The present review of the literature indicates that some but not all attentional functions are impaired in children with ADHD. This population has shown consistent deficits in sustained attention and in some selective attention tasks but have been found to respond faster and make fewer mistakes in divided attention tasks (Sagvolden, Johansen, Aase, & Russell, 2005). This cognitive profile suggests that there is a different distribution of attentional resources in children with ADHD despite a narrower time constant (López et al., 2004).

Attention Deficits in the Real-World Context

Although sustained and selective attention have been commonly found to be impaired in children with ADHD using experimental tasks, performance on these tasks has not been consistently found to predict clinical behavioral ratings of attention symptoms of these children (Barkley 1991; Doyle et al., 2000; Jonsdottir et al., 2006; Nigg, 2005; Toplak, West, & Stanovich, 2013). In the cases where performance on tasks, such the CPT, are found to be related to parent and teacher ratings of attention, they are typically weakly to moderately correlated (e.g., Epstein et al., 2003). Although some have suggested that this may imply that attention deficits may only be a secondary symptom of this disorder, with behavioral inhibition being the underlying deficit (Barkley 1997), these findings may have been limited by the lack of ecological validity of the attentional tasks (Barkley, 1991). Growing evidence suggests that attention is achieved through the interaction of many attentional subcomponents and involves a complex and dynamic interplay of various neuroanatomical networks (Bartolomeo, de Schotten, & Chica, 2012; Koschack et al., 2003; Ristic & Enns, 2015; Talsma, Senkowski, Soto-Faraco, &Woldorff, 2010). Therefore, the measurement of attention using tests that isolate the components of attention may not in turn capture the the real-world demands on the attentional system that ultimately influence behavior. For example, in typical attention tasks, such as the ones previously described, participants are given a cue indicating a region of interest and then a target is briefly presented in that location (Cavanagh & Alvarez, 2005). Although this procedure may be effective in measuring a child's ability to selectively attend to static stimuli, targets of attention in the real-world, such as cars or classmates, are typically in motion. Accordingly, evaluating the ability to select and sustain attention to multiple objects that are in motion should reflect attentional functions on a daily basis.

Multiple Object Tracking

In the real-world environment, such as the classroom or playground, children are constantly presented with an extraordinary amount of visual information, much of which is in motion, and the ability to filter out the irrelevant and monitor the location of the relevant is essential for successful navigation. This ability is referred to as multiple object tracking (MOT) and specifically involves simultaneously monitoring the location of multiple objects amongst distractors. Pylyshyn and Storm (1988) introduced an experimental task designed to measure MOT, with the purpose of testing their theory of visual indexing, referred to as FINST theory (i.e., FINgers of INSTantiation). Pylyshyn proposed that MOT relies on a pre-attentive spatial-indexing mechanism that assigns indexes to a small number of objects, allowing for the attentional focus to be simultaneously divided among objects. These indexes allow the observer to refer to the objects without relying on positional or property information (Trick et al., 2009), and are suggested to have a limited capacity of roughly four indexes to be allocated to items in the visual field (Pylyshyn & Storm, 1988). Pylyshyn (1994) has since reevaluated the view of object tracking as being primarily a pre-attentive operation, acknowledging that visual indexing may be the first, pre-attentive stage, but the task of tracking (i.e., maintaining the index) requires the allocation of attentional effort. This post-index stage may require cognitive intervention and attentional effort to periodically refresh the index in order to prevent decay or to recover lost targets during motion (Pylyshyn, 1994). The original version of this task required observers to track between one and five identical targets situated on a visual field with identical distractors, with a total of 10 independently moving items. During the period of tracking, a white square appeared around a single item and the observers were required to indicate if this object was a target by pressing a response button. Pylyshyn and Storm (1988) found that adult (i.e., university students) observers were successful in identifying up to five targets with 85% accuracy, however the accuracy and speed of responses decreased with the increase in number of targets being tracked.

Many variants of the paradigm have been developed with procedural and characteristic differences, such as the number of targets and distractors (Sears & Pylyshyn, 2000), distractor characteristics (Feria, 2012), the speed of which the objects travel in the visual field (Feria, 2013), dimensions of the objects (i.e., 3D; Rehman, Kihara, Matsumoto, & Ohtsuka, 2015), and the nature of the reporting of targets (Trick et al., 2009). In order to study the MOT abilities in younger children, Trick et al. (2005) developed a variant called “Catch the Spies”, which included the same stringent conditions used with adults, but that included an engaging backstory and involved tracking and reporting the position of sinister spies who disguise themselves within a crowd of happy faces. This variant also included a full report procedure, in which participants needed to identify the location of all the targets at once, as opposed to simply deciding whether one specific item was a distractor or target. Using this variant of the MOT paradigm, Trick et al. (2005) found significant improvements in tracking performance in late childhood into adolescents, with 6- and 8-year-old children successfully tracking two objects, 10- and 12-year-olds tracking three objects, and 19-year-olds tracking four objects. Similar increases in MOT ability across childhood have been identified in other studies (e.g., Dye & Bavalier, 2010; Trick et al., 2009).

Another variant to the MOT protocol is the inclusion of immediate and delayed report conditions. The immediate report requires the observer to report the location of all four targets immediately following the encoding of their positions among distractors, whereas the delayed report requires the observers to report the location of the targets after a 10 second delay. These conditions were originally developed by Trick et al. (2009) to account for the potentially confounding requirement of reporting the location of the targets, a factor that is unrelated to the ability to track multiple objects. For example, Trick et al. (2009) found that report performance improved with age into young adulthood and remained stable thereafter, whereas tracking performance followed a similar improvement but decreased in old age. Furthermore, delayed report performance did account for some of the variability in tracking performance, potentially reflecting the involvement of memory.

Visual Attention Components Required for MOT

Through the use of multiple variants of the MOT task, selective, divided and sustained attention have been identified as being required for the successful tracking of multiple objects

(Scholl, 2009). Specifically, selective attention is particularly involved during the initial stage of the task when the target objects are indicated. The effective selection of the targets is required in order to prevent the intrusion of irrelevant distractors throughout movement of the objects (Franconeri, Jonathan, & Scimeca, 2010). Tracking multiple moving objects also requires the use of divided attention, which allows for a more global registration of the visual field (Srinivasan, Srivastava, Lohani, & Baijal, 2009), as attention is shared among multiple relevant objects within the field. The FINST theory suggests that there is a finite number of visual items upon which the attentional focus can be distributed (Pylyshyn & Storm, 1988; Scholl, 2001), with empirical evidence of a capacity of four items (e.g., Cavanaugh & Alvarez, 2005; Trick et al., 2005). In order to successfully track the selected objects, performance must be sustained throughout the duration of the task. The decrease in task performance with an increase in tracking duration suggests a limit to the amount of effort available for maintenance and processing in MOT.

Due to the wide range of cognitive and attentional components shown to be measured by the variants of the MOT paradigm, they have been used to explore how the development of attention differs in atypical populations (Brodeur, Trick, Flores, Marr, & Burack, 2013; Jiang, Capistrano, & Palm, 2014; O'Hearn, Hoffman, & Landau, 2010). In the only study with adults with ADHD to date, Laasonen et al. (2012) found their tracking ability to be similar to that of TD participants. Specifically, adults with ADHD were able to successfully track between one and seven targets in a display with a total of 16 moving stimuli at a similar level of accuracy as TD participants.

The Present Study

The goal of this study was to explore the attention abilities of children with ADHD using an experimental task that more closely captures the dynamic nature of attention in the real-world environment. The MOT task is proposed to serve this purpose as the tracking of multiple moving objects reflects the navigation required in a typical dynamic environmental context. As many of the components of attention presumed to be involved in MOT (e.g., sustained, selective, and divided attention) have been found to be limited in children with ADHD, this group was expected to display worse performance on a multiple object tracking task compared to TD children matched on chronological age (CA), Full scale IQ, Verbal Comprehension and Perceptual Reasoning, in that their mean accuracy of reporting would be lower than TD children. In addition, children with ADHD would not be expected to perform as well as TD children on MOT if they have difficulty selecting (i.e., indexing) or sustaining attention for the duration of the tracking period, as measured by the report tasks (Trezise, Gray, & Sheppard, 2008). Therefore, deficits in MOT in children with ADHD were expected to be related to deficits in immediate and delayed report for static items.

The secondary goal of this study was to evaluate the claim that multiple object tracking, as measured by the Catch the Spies task, provides a more ecologically valid measurement of attentional components. Although the most extreme and noteworthy attentional difficulties are typically studied in the context of ADHD, there is much variability in the level of attentional problems and distractibility that children display (Arcos-Burgos & Acosta, 2007). As such, the ADHD diagnostic label may create an artificial dichotomy that may not allow for the true relationship between attention problems and multiple object tracking to be captured. Therefore, a continuous measure of behavioral attention problems was used to characterize both the TD and

ADHD groups as a whole in order to determine whether the MOT task serves as a more ecologically valid measure of attention. Thus performance on the multiple object tracking task was expected to significantly predict ratings of attention problems in children. Specifically, higher teacher ratings of attention problems were expected to be related to poorer object tracking performance.

Method

Participants

The participants included 11 boys with a formal diagnosis of ADHD made by either a psychiatrist or psychologist according to their school records, with no additional diagnoses reported, and 11 typically developing boys with no reported diagnosis according to their school records. The participants ranged in age from 8 to 13 years (M = 10.35, SD =1.27). The groups were well matched on CA (t (20) = -.510, p = .615), as well as on Full Scale IQ, (FSIQ; t (20) = .000, p = 1.00), Verbal Comprehension Index (VCI; t (20) = .174, p = .864), and Perceptual Reasoning Index, (PRI; t (20) = -.162, p = .873), as measured by the Wechsler Abbreviated Scale of Attention – Second Edition (WASI-II). Please see Table 1 for details on sample characteristics. The ADHD participants were tested off their medication. Although their vision was not explicitly measured, only significant impairments would have made viewing the display difficult under the conditions used in the experiment. All of the participants were recruited through the referral by resource teachers and school psychologists from elementary schools in a local public school board.

Measures

The Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II; Wechsler, 2011)**.** The WASI-II, a brief, standardized, and norm-referenced measure of general intelligence, was administered individually to all participants. This measure is designed for children and adults 6-89 years of age, and assessment time ranged from 30 to 45 minutes depending on performance. Four subtests comprise the WASI-II: Block Design, Vocabulary, Matrix Reasoning, and Similarities. Scores on these measures are combined to generate a Full Scale Intelligence Quotient (FSIQ) score. The WASI-II also provides composite scores that are used to estimate general intelligence ability in the areas of verbal comprehension (VCI) and perceptual reasoning (PRI). The FSIQ, VCI, and PRI are considered reliable measures of intelligence in a child sample ($r = .96$, $r = .94$, $r = .92$ respectively).

Behavioural Assessment System for Children - Second Edition, Teacher Rating Scales (BASC-2 TRS; Reynolds & Kamphaus, 2004). The BASC-2 TRS consists of 139 items that assess adaptive and problem behaviors in the school setting. The items are used to assess specific behaviours that are rated on a 4-point scale according to frequency, from N (never), S (sometimes), O (often), to A (almost always). Composite scale scores are obtained for Adaptive Skills, Behavioural Symptoms Index, Externalizing Problems, Internalizing Problems, and School Problems. For the purpose of this study, the Attention Problems subscale scores were used to establish the continuum based on the student's tendency to be distracted and unable to concentrate for an extended period of time. This subscale includes seven questions (e.g., "Has a short attention span") with a *T*-score range of 34-75, and higher scores indicating more attention problems. Teacher ratings on the Attention Problems subscale was demonstrated to be a reliable measure with an alpha of .95 and a test-retest correlation of .85 (Reynolds & Kamphaus, 2004).

Stimuli and Apparatus

The MOT task was administered on a MacIntosh AirBook using the track pad for making responses. The participants sat at a table in front of the computer, 45cm from the viewing screen.

The tracking field upon which the stimuli were presented was a black rectangle occupying 22.96° x 17.33° visual angle when viewed from 45cm. A 0.18° white outlined squared served as the pretrial central fixation point. The stimuli used in the report and tracking tasks, as depicted in Figure 1, included happy-faces (1.45° blue circles outlined by 0.18° white contours) and spies (1.53° black squares with 0.18° white contours, forming faces wearing spy-like fedora hats). Across each trial, 10 randomly positioned happy-faces appeared on the tracking field. The happy-faces (which could be distractors or targets), moved independently, bouncing off each other and the walls of the tracking field. Their movements were constructed in such a way that they touched but never occluded. Each happy-face had its own rate of movement that changed every frame (every 16.5 ms), with values somewhere between 0 and 9.35° visual angle per second. In every frame there was a 1/100 chance that the item would spontaneously change direction without bouncing off anything.

Procedure

All of the participants were tested at the school in which they attend within the Lester B. Pearson School Board and each child's homeroom teacher completed the BASC-2. The testing took place in a private room made available by the school staff. Ethical consent was obtained from parents and the researchers obtained verbal assent from each participant. Three conditions of the Catch the Spies task were administered in the following order: immediate report, delayed report, and MOT. Across all of the condition, the goal of the task was for participants to indicate the locations of the spies (targets) that had disguised themselves as regular civilians (happy faces) in a display of regular civilians (distractors). Each task condition included four or more of the following stages in each trial. In the initialization phase, the participants hit the spacebar to initiate the trial, upon which 10 static happy-faces were presented for 1105 ms in random location on the tracking field. Next, during the target encoding phase, one to four of the happy-faces flashed back and forth between happy-face and spy form for a total of 1650ms. This indicated to the observer that those items were spies (i.e., targets). Then, in the post-encoding display phase, all 10 items returned to the happy-face form and remained static for 495 ms. In the item movement phase, all 10 happy-faces (both targets and distractors) moved randomly and independently around the tracking field. After 10s of movement, all item motion stopped and the participants used the laptop track pad to select the happy-faces that were "really spies" (targets). Once the appropriate number of items were selected the participants pressed the spacebar and the actual targets revealed themselves as spies (i.e., Feedback phase).

All three conditions of the Catch the Spies task included the initialization, target encoding, post-encoding display, report and feedback phases. For the immediate report condition, the participants completed the report phase immediately after the post-encoding display phase, whereas for the delayed report condition, there was a 10s delay, during which the items remained static, following the post-encoding display phase before completing the report phase. The item movement phase only occurred during the MOT condition, across a 10s period between the post-encoding display and report phases. The immediate and delayed report conditions always involved four targets, with participants completing two practice trials and eight experimental trials. The MOT condition involved between one and four targets per trial, with the number of targets varying from trial to trial in random order. In this condition, participants first completed eight practice trials (two trials for each target number in ascending order), after which they completed 20 experimental trials (five trials for each target number).

Results

Report Tasks

The children with ADHD were compared to the TD children on measures of accuracy (per cent correct) for immediate and delayed report tasks. A 2 x 2 mixed design analysis of variance was performed, with Group as the between-group factor with two levels (ADHD and TD) and Task as the within-subjects factor with two levels (immediate and delayed). No group differences were found, F (1, 20) = .04, $p > .05$, $\eta_p^2 = 0.002$, but there was a main effect for Task, F (1, 20) = 15.88, $p = .001$, $\eta_p^2 = 0.44$, with performance being better on immediate than delayed report (*M* = 98.02%, *SD* = 0.03 and *M* = 91.06%, *SD* = 0.09 respectively). There was no Group x Task interaction, F (1, 20) = .06, $p > .05$, $\eta_p^2 = 0.003$. Overall, these findings suggest that the ADHD and TD children were similar in terms of their ability to report the location of up to four static targets items (spies) among distractors both immediately and after a 10 second delay.

Multiple Object Tracking Task

Group differences in tracking performance were analyzed in a 2 x 4 mixed-design analysis of variance with Group as the between-group factor with two levels (ADHD and TD) and Number of Targets as the within-subjects factor with four levels. A significant main effect for Number of Targets was found, F (3, 60) = 43.11, $p < .001$, $\eta_p^2 = 0.68$. Further inspection of the within subjects contrasts indicated that this effect followed a quadratic pattern (F (1, 20) = 42.78, $p < .001$, $\eta_p^2 = 0.68$, with accuracy decreasing with increasing Numbers of Targets. Overall, the tracking performance of the children with ADHD and the TD children was the same, as indicated by the lack of a significant main effect of Group, F (1, 20) = 0.001, $p > .05$, $\eta_p^2 =$

0.00, or a Group x Number of Targets interaction, *F* (3, 60) = .23, $p > .05$, $\eta_p^2 = 0.012$. Performance on the tracking task for each group is illustrated in Figure 2.

For both groups, tracking performance for four targets was significantly below the immediate report of the location of four static targets (ADHD: *M* difference = 44.84% *SD* of difference = 18.4; TD: *M* difference = 44.83% *SD* of difference = 10.15; $p < .001$ for both) as well as for the delayed report of the location of four static targets (ADHD: *M* difference = 38.31% *SD* of difference = 15.64; TD: *M* difference = 37.44% *SD* of difference = 11.32; $p < .001$ for both). Tracking of four moving targets was significantly more difficult than reporting the locations of four static targets immediately and following a delay equivalent to the duration of the tracking interval.

In order to investigate the impact of the possible relations between report task performance and MOT, a 2 (Group) x 4 (Number of Targets) analysis of covariance was conducted with performance from both immediate and delayed report tasks included as covariates. The immediate report was not a significant covariate, *F*(1, 18) = 1.04, $p > .05$, η_p^2 = 0.05, but the delayed report was marginally significant, *F*(1, 18) = 3.57, *p* =.075, $\eta_p^2 = 0.17$, suggesting that there may be a relationship between memory and tracking performance. The covariance did not substantially change the main effects for Group nor the Group x Number of Targets interaction, with both remaining not significant (*F* (1, 18) = 0.01, $p > .05$, *F* (3, 54) = 0.20, $p > .05$ respectively). However, the covariance was found to account for the significant difference that was found among targets, *F* (3, 54) = 0.81, *p* = .497, $\eta_p^2 = 0.04$. An examination of the correlations between the delay report scores and the target conditions for each group separately revealed that this shared variance is attributed to the significant relationship between the delayed report and the one target condition for the TD children, and instead the three target condition for the children with ADHD. Please see Table 2.

Attention Problems and MOT tasks

In order to examine the relationship between behavioral ratings of attention and MOT performance, two multiple regression analyses were conducted. The first analysis examined the relationship between attention ratings and tasks that tap three components of MOT independently. Namely, the immediate task measures the ability to individuate items, the delayed task taps the ability to retain individuated items in memory, and the one target tracking condition taps the ability to track a single item. This analysis was conducted with the BASC2 attention problem ratings as the dependent variable. CA and PRI were entered on the first step to control for their influence and on the second step immediate and delayed report tasks, and the one target tracking condition were entered. Simple correlations for these variables are reported in Table 3. The only significant correlations were between the delayed report task and CA, and the delayed report task and simple tracking. The multiple regression analysis revealed the regression model including immediate report, delayed report, and one target condition did not predict behavioral ratings of attention, adjusted $R^2 = -.24$, $F(5, 21) = .19$, $p > .05$. The coefficient of determination suggested that only 5.6% of the variation in the attention problem scores could be accounted for by reporting and single object tracking. Furthermore, none of the predictors significantly contributed to the model (see Table 4).

The second analysis examined the relationship between attention ratings and tasks that require multiple object tracking; namely, the two to four target tracking conditions. This analysis was conducted with the BASC2 attention problems ratings as the dependent variable. CA and PRI were entered on the first step to control for their influence and on the second step the two, three and four target tracking conditions were entered. Simple correlations for these variables are reported in Table 5. Significant relationships with the three target tracking condition were noted for both CA and PRI. The MOT conditions were also correlated with each other. The multiple regression analysis revealed the regression model including two, three, and four targets did not predict behavioral ratings of attention, adjusted $R^2 = -.11$, $F(5, 21) = .57$, $p > .05$. The coefficient of determination suggested that 15% of the variable in attention problem scores could be accounted for by performance on the MOT task. Furthermore, none of the Number of Targets significantly contributed to the model (see Table 6). Therefore, contrary to the hypothesis, performance on the MOT task did not significantly predict ratings of behavioral attention problems.

Exploratory Analysis

The significant correlations between the three target tracking condition for both CA and PRI were further examined. In the investigation of CA, PRI was entered on the first step to control for the influence and on the second step the two, three and four target tracking conditions were entered. The multiple regression analysis revealed the regression model including two, three, and four targets did not predict CA, adjusted $R^2 = .13$, $F(4, 21) = 1.75$, $p > .05$. In the investigation of PRI, CA was entered on the first step to control for the influence and on the second step the two, three and four target tracking conditions were entered. The multiple regression analysis revealed the regression model including two, three, and four targets significantly predicted PRI, adjusted $R^2 = .28$, $F(4, 21) = 3.04$, $p = .046$. The coefficient of determination suggested that 42% of the variable in PRI scores could be accounted for by performance on the MOT task. Furthermore, the three target condition was found to significantly contribute to the model (see Table 7).

Discussion

In the current study, the Catch the Spies variant of the MOT task, including immediate and delayed report conditions, was applied to explore the ability to track multiple objects moving in space among children with ADHD of an average CA of 10.3 years in relation to a matched group of TD children. As many of the components of attention presumed to be involved in MOT (e.g., sustained, selective, and divided attention) have been found to be impaired in ADHD, the performance of the children with ADHD group was expected to be worse than that of the TD children. The findings did not support this hypothesis as the level of accuracy on the task was similar for the two groups. Furthermore, performance on the delay report condition was found to account for the difference between targets, suggesting that the ability to hold the location of the targets in memory in order to report their location significantly contributed to the performance of both groups.

Implications for Children with ADHD

The findings indicate that children with ADHD are capable of tracking multiple moving objects at a similar level of accuracy as TD children. Based on Pylyshyn's theory (Storm & Pylyshyn, 1988) that MOT relies on a pre-attentive spatial-indexing mechanism that assigns indexes to a small number of objects, the findings suggest the visual indexing mechanism is intact for children with ADHD, implying that they are capable of effectively dividing their attention among multiple moving objects in their visual environments, such as cars when crossing the street or friends while playing tag. This example of efficient allocation of attention is inconsistent with evidence that children with ADHD experience difficulty selectively attending to targets among irrelevant distractors (Booth et al., 2005; Brodeur & Pond, 2001; dos Santos Assef et al., 2007; Gomarus et al., 2009; Jonkman et al. 1999). One potential explanation for this discrepancy could be the differences in the presentation of the stimuli. Whereas the stimuli in traditional attention tasks are typically briefly presented in a designated location, all the objects in a MOT task remain visible throughout the target identification and movement phases. This constant presentation of the stimuli may improve selective attention as it reduces the burden of processing novel stimuli in the visual field and allows for more time for the visual indexes to be distributed amongst the targets (Bradley, 2009). This task parameter may differentially influence selective attention abilities in addition to those identified by Brodeur and Pond (2001), such as distractor relevance.

As attention on an MOT task must be sustained continuously for 10 seconds throughout the movement phase of each trial, as well as approximately 10 minutes across all trials, the findings that the children with ADHD displayed a similar target report accuracy as the TD children is inconsistent with evidence of difficulty sustaining attention over time (Corkum & Siegal, 1993; Holmes et al., 2010; Huang-Pollock et al., 2012). The enhanced ability to sustain attention to multiple moving objects may in part reflect the nature of the Catch the Spies MOT variant. The inclusion of the Catch the Spies backstory made the task of locating the targets (i.e., spies) more relevant and goal-oriented than simply instructing the children press a button when they see the letter X, as is typical for CPT protocols when measuring sustained attention. Children with ADHD are suggested to have a reduced capacity to induce motivation, particularly during repetitive tasks, and therefore have a greater dependence on external sources to sustain the effort in goal-directed actions (Barkley, 1997). Therefore, the increase in motivation elicited by the relevance of the task may have limited the impact of an apparent sustained attention deficit among the children with ADHD. This also highlights the practical need for environments, such as the classroom, to be engaging in order to help facilitate the sustained attention abilities in children with ADHD.

The inclusion of the immediate and delayed conditions allowed for a more precise examination of the tracking performance, as they were used to account for the requirement of reporting the location of the targets, a factor that is unrelated to the ability to purely track multiple objects (Trick et al., 2009). For the TD children, the variance in tracking a single item was shared with both the immediate and delayed report tasks, suggesting that individuation and reporting contributed to their performance in this condition. This was not the case for the conditions which involved the tracking of more than one target, suggesting their performance reflects pure object tracking. In contrast, the delayed report was found to share significant variance with the four target tracking condition performance in children with ADHD. This suggests that memory for location particularly impacted their performance when there were four targets to report.

MOT and Attention Problems

As a secondary focus of this study, the MOT task was suggested to be an ecologically valid measure of attention due to the movement of the objects, which requires attention to be allocated as it would be in a real-world, dynamic environment. Therefore, attention abilities, as measured by the MOT, were expected to be related to clinical behavioral ratings of attention. The BASC-2 teacher ratings of attention problems from both groups were combined to represent attention difficulties across a continuum. The results did not support the hypothesis, in that performance on the multiple object tracking conditions (i.e., two, three, and four targets) did not significantly predict the teacher's ratings of attention problems. Specifically, those who displayed greater difficulty in tracking multiple objects did not necessarily display more attention problems on a daily basis in the school environment. This lack of relationship may suggest that attention does not play as significant of a role in MOT and performance may depend on other cognitive mechanisms, such as pre-attentive visual indexes (Pylyshyn & Storm, 1988) or working memory (e.g., Fougnie & Marois, 2006). An alternative interpretation is that the attention difficulties that children display are not related to a difficulty in monitoring the moving objects in their environment.

MOT and Perceptual Reasoning Abilities

An exploratory analysis of the significant correlations between MOT and individual difference measures revealed that performance on the tracking conditions predicted PRI score from the WASI-II, which is intended to measure the ability to understand, think, and learn using visual and spatial information, and considered an overall indicator of visuospatial abilities (Wechsler, 2011). Specifically, PRI was significantly predicted by performance on the three target condition, indicating that those who were better at tracking three moving targets also had better developed perceptual reasoning abilities.

Limitations

The present study is limited in ways that are inherent to experimental research with children with ADHD. One, the present study is limited by the small number of participants in each group, resulting in diminished statistical power and limiting the generalizability of the findings. However, the number of participants was similar to other investigations examining differences in multiple object tracking in special populations and TD individuals (e.g., Brodeur et al., 2013, O'Hearn, Landau, & Hoffman, 2005). Two, the specific subtype of the ADHD diagnoses (i.e., primarily inattentive, hyperactive/impulsive, or combined type) was not specified during the recruitment of the participants. The difference in symptomology may differentially influence multiple object tracking performance, as the children with the different subtypes have been found to perform differently on measures of sustained and selective attention (Collings, 2003; Huang-Pollock et al., 2006; Schmitz et al., 2002). In future studies, the different subtypes of ADHD should be examined separately to explore how hyperactivity/impulsivity and inattention impact the ability to track multiple moving objects.

Although both groups had similar tracking accuracies for each target condition, the parameters of the task prevented the investigation of performance across time. Given the deficits in sustained attention in children with ADHD (Huang-Pollock et al., 2012), it is possible that the duration of the task may have differentially impacted the tracking performance of the groups. Due to the random order in which the trials are presented, with potentially more targets or less targets being tracked in the later portion of the task, the groups could not be compared based on performance across time. A comparison using a set order of presentation across participants in future studies would allow for a more precise depiction of the impact of sustained attention on MOT performance.

The single measure of attention problems taken from the BASC-2 may have limited the scope of the investigation of the relationship between MOT performance and real-world attentional behavior. In future studies, MOT performance should be studied in relation to to a more comprehensive rating of attention, such as the Conners' rating scales (Conners, 2001), which is more commonly used in the diagnosis of ADHD.

Conclusion

The present study has provided initial evidence indicating that the multiple object tracking abilities in children with ADHD may be similar to TD children matched on CA and IQ. Furthermore, performance on the MOT task did not predict teacher ratings of attention problems.

These findings suggest that the behavioral symptoms that are essential for the diagnosis of ADHD may not be related to a difficulty monitoring the moving objects in their environment.

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Table 1

Mean and Standard Deviations of the Sample Characteristics for Children with ADHD and TD Children

	ADHD	TD
Chronological Age (SD)	10.49 (1.31)	10.21 (1.28)
Full Scale IQ (SD)	97.82 (11.70)	97.82 (12.02)
Verbal Comprehension (SD)	98.09 (10.78)	98.81 (8.76)
Perceptual Reasoning (SD)	98.55 (14.03)	97.55 (14.90)
Attention Problems Scale (SD)	62.81 (6.52)	43.63 (9.11)

Table 2

Correlations Between Report Conditions and Target Conditions for Children with ADHD and TD Children Separately

	ADHD		TD	
	Immediate Report	Delayed Report	Immediate Report	Delayed Report
One Target	-.296	.009	.798**	.695*
Two Target	.438	.219	.090	.515
Three Target	.400	.263	.258	.220
Four Target	.219	.603*	.177	.406

Notes. * $p < .05$, ** $p < .01$

Table 3

Simple Correlations between Attention Problems, Chronological Age, Perceptual Reasoning, Immediate and Delayed Report, and the One Target Tracking Condition for Combined Groups

Variable	1	2	3	4	5	6
1. Attention Problems	1	-.119	.144	-.128	-.145	-.030
2. Chronological Age	-	1	.122	.374	.507*	.340
3. Perceptual Reasoning	-	-	1	.144	.066	.178
4. Immediate Report	-	-	-	1	.421	.156
5. Delayed Report	-	-	-	-	1	.467*
6. One Target	-	-	-	-	-	1

Note. * $p < .05$

Table 4

Multiple Regression Analysis Predicting Attention Problems Ratings from Immediate Report, Delayed Report, and One Target Tracking Performance when Chronological Age and Perceptual Reasoning are held Constant for Combined Groups

Predictor	ΔR^2	*B*	SE B	β
Step 1	.04			
Chronological Age		-1.36	2.23	-.14
Perceptual Reasoning		.14	.20	.16
Step 2	.02			
Chronological Age		-.63	2.88	-.06
Perceptual Reasoning		.15	.22	.17
Immediate Report		-43.32	130.62	-.09
Delayed Report		-13.40	45.43	-.09
One Target		2.09	29.58	.02

Notes. Total adjusted $R^2 = -.24$ $p > .05$, CA

Table 5

Correlations Among Attention Problems, Chronological Age, Perceptual Reasoning, and One, Two, and Three Target Tracking Conditions for Combined Groups

Variable	1	2	3	4	5	6
1. Attention Problems	1	-.119	.144	-.057	-.030	.127
2. Chronological Age	-	1	.122	.267	.497*	.412
3. Perceptual Reasoning	-	-	1	.238	.546**	.143
4. Two Targets	-	-	-	1	.344	.509*
5. Three Targets	-	-	-	-	1	.634**
6. Four Targets	-	-	-	-	-	1

Notes. * $p < .05$, ** $p < .01$

Table 6

Multiple Regression Analysis Predicting Attention Problems Ratings from One, Two, and Three Target Tracking Performance when Chronological Age and Perceptual Reasoning are held Constant for Combined Groups

Predictor	ΔR^2	*B*	SE B	β
Step 1	.04			
Chronological Age		-1.36	2.23	-.14
Perceptual Reasoning		.14	.20	.16
Step 2	.11			
Chronological Age		-.10	2.70	-.10
Perceptual Reasoning		.32	.27	.36
Two Targets		-17.27	21.13	-.23
Three Targets		-28.58	27.82	-.41
Four Targets		41.41	29.43	.49

Note. Total adjusted R^2 = -.11, $p > .05$

Table 7

Multiple Regression Analysis Predicting Perceptual Reasoning from One, Two, and Three Target Tracking Performance when Chronological Age is held Constant for Combined Groups

Predictor	ΔR^2	*B*	SE B	β
Step 1	.015			
Chronological Age		1.35	2.27	.12
Step 2	.403			
Chronological Age		-1.92	2.41	-.17
Two Targets		18.33	18.69	.21
Three Target		64.29	19.92	.82
Four Targets		-39.27	25.01	-.41

Note. Total adjusted $R^2 = .28$ $p > .05$

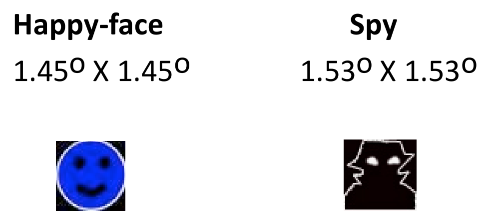

Figure 1. Items used in the 3 conditions of the Catch the Spies task: happy-faces and spies.

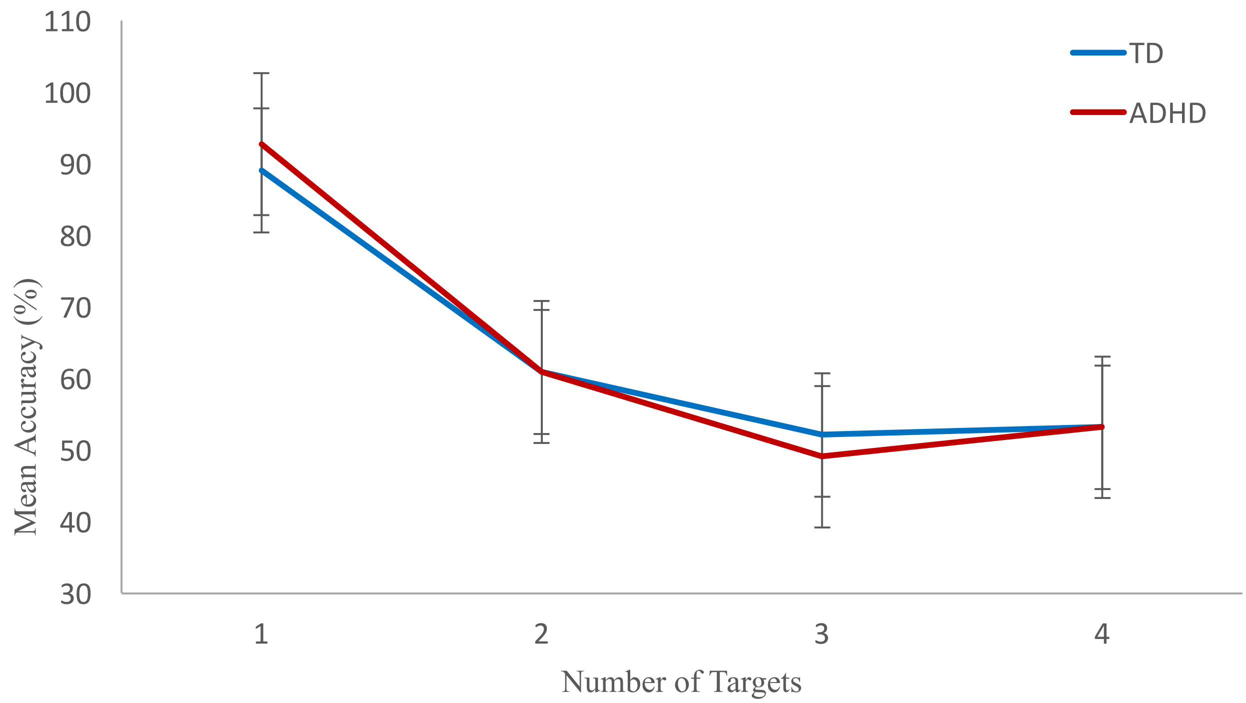

Figure 2. Mean accuracy (% correct) of responses for the Multiple Object Tracking task as a function of Number of Targets and Group.