Visual Attention in Autism:
Cognitive Load and Feedback Manipulations in a 3D Multiple Object Tracking Task

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Abstract

Autism spectrum disorder (ASD) is characterized by differences in visuospatial perceptual and attentional abilities; with some evidence supporting enhanced perceptual capacity and some supporting decreased attentional capacity in individuals with ASD. Individuals with ASD often show superior performance on perceptual and attentional tasks such as visual search and the Embedded Figures Test (e.g., Jolliffe & Baron-Cohen, 1997), but greater susceptibility to distraction (e.g., Burack, 1994). They also respond differently to task feedback; with performance variation mediated by factors such as its type and timing, as well the difficulty of the task itself (e.g., van Noordt et al., 2017). There is a growing body of research linking these differences with primary characteristics of autism (e.g., van Noordt et al., 2017). Multiple object tracking (MOT) paradigms are ideal for assessing various aspects visuospatial attention and have begun to be used to examine ASD performance in these domains.

This dissertation aims to address two research questions: Study 1 assessed the effect of cognitive load on 3D-MOT performance in a sample of adolescents and adults with ASD, and Study 2 examined the role of feedback on performance using the same 3D-MOT task in a similar clinical sample. MOT paradigms are useful in addressing these two lines of inquiry, as completion of the task demands the use of sustained, selective, and distributed attention to dynamic visual information; and our variables of interest (cognitive load and feedback) can easily be manipulated and controlled. All groups were matched on gender, chronological age, and Wechsler IQ scores.

In Study 1, we administered a 3D-MOT paradigm with 4 cognitive loading levels (1, 2, 3, and 4 tracked items) to adolescents and adults with ASD (n = 15) and a group of typically developing (TD) controls (n = 15). In line with the load theory of attention (Lavie, 1995),
increasing the number of target items resulted in significantly worse performance on the 3D-MOT for both the ASD and TD groups as the number of tracked items increased. Contrary to our hypothesis that we would see differential performance at high versus low loading levels, performance at higher levels of cognitive loading was not relatively impaired for the ASD group. Thus, this result does not support the notion that individuals with ASD have a greater perceptual capacity or decreased attentional capacity as compared to neurotypicals. Though the TD group outperformed the ASD group at all loading levels, none of these differences was statistically detectable. We concluded that individuals with ASD are susceptible to load taxation in a dynamic visual attention task in ways that are comparable to neurotypicals.

In Study 2, using the same 3D-MOT paradigm, we asked adolescents and adults with (n = 27) and without (n = 28) ASD to track 1 (low difficulty) and 4 (high difficulty) target spheres over two randomized blocks. Half of the participants received trial-by-trial feedback on their performance, and half did not. A three-way interaction was found between diagnostic group (ASD vs. TD), feedback group (Feedback vs. No Feedback), and task difficulty (Low vs. High). Performance at tracking 4 targets was significantly decreased for all groups when compared with performance at tracking 1 target. Individuals with ASD who received feedback performed better than their peers who did not receive feedback, but only when task difficulty was low. Feedback did not significantly affect the performance of typically developing individuals, though a tendency towards feedback being detrimental to performance was found. When diagnostic groups were pooled, participants who received feedback demonstrated significantly larger gains in performance from the first block of trials to the second; thus, we concluded that feedback can be useful to task learning; even over the course of one session. In sum, the type of feedback used
in our study appears to impact individuals with ASD differently than neurotypicals; aiding individuals with ASD when task difficulty is manageable (i.e., low load).

*Keywords:* autism spectrum disorder (ASD), visual attention, multiple object tracking (MOT), cognitive load, feedback
Résumé

Les individus qui présentent un trouble du spectre autistique (TSA) démontrent un profil atypique de capacités visuo-spatiales perceptives et attentionnelles. Alors que certaines études leur attribuent une capacité perceptive accrue, d’autres leur attribuent une capacité attentionnelle diminuée. Les individus qui présentent un TSA démontrent souvent une performance supérieure sur certaines tâches perceptuelles et attentionnelles, telles que la recherche visuelle (« Visual Search ») et la tâche des figures incorporées (« Embedded Figures Test ») (ex : Jolliffe et Baron-Cohen, 1997). Cependant, ils démontrent aussi une plus grande susceptibilité à la distraction (ex : Burack, 1994). La rétroaction des tâches impacte différemment les personnes qui présentent un TSA aussi; en fonction de facteurs tels que le type de rétroaction, le moment auquel elle est présentée et la difficulté de la tâche elle-même (ex : van Noordt et al., 2017). Un nombre croissant d'études relie les différences mentionnées ci-dessus aux caractéristiques primaires de l'autisme (ex : van Noordt et al., 2017). Les paradigmes de suivi d'objets multiples (MOT) sont idéaux pour évaluer plusieurs aspects de l'attention visuo-spatiale, et commencent à être utilisés pour examiner les capacités perceptuelles et attentionnelles chez les individus qui présentent un TSA.

Cette thèse vise à répondre à deux questions de recherche : L'étude 1 évalue l'effet de la charge cognitive sur la performance 3D-MOT (suivi d'objets multiples en trois dimensions) chez un groupe d'adolescents et d'adultes avec un TSA, et l'étude 2 examine l’effet de la rétroaction sur la performance 3D-MOT chez un groupe clinique similaire à celui de l’étude 1. Les paradigmes MOT sont utiles pour répondre à ces deux problématiques, car ils exigent l'utilisation de l’attention soutenue, sélective et distribuée pour procéder au traitement d’information visuelle dynamique. De plus, nos variables d'intérêt (charge cognitive et rétroaction) peuvent y être
facilement manipulées et contrôlées. Tous les groupes ont été appariés en fonction du sexe, de l'âge chronologique et de scores QI à l'échelle de Wechsler.

Dans l'étude 1, nous avons administré une tâche 3D-MOT à 4 niveaux de charge cognitive (1, 2, 3 et 4 éléments cibles) à deux groupes distincts : un groupe d’adolescents et d’adultes qui présentent un TSA (n = 15) et un groupe contrôle neurotypique (n = 15; groupe « TD »). Conformément à la théorie de la charge attentionnelle (Lavie, 1995), l'augmentation du nombre d'éléments cibles a entraîné une performance significativement décroissante pour les groupes TD et TSA. Contrairement à notre hypothèse, nous n’avons pas constaté une diminution significative plus importante de la performance à la tâche pour le groupe TSA par rapport au groupe contrôle pour les niveaux de haute charge cognitive (3 et 4 cibles). Ce résultat n’appuie pas la notion d’une capacité perceptive plus robuste ou une capacité attentionnelle réduite chez les personnes atteintes de TSA par rapport aux neurotypiques. Bien que le groupe TD ait surpassé le groupe TSA à tous les niveaux de charge cognitive, aucune de ces différences était statistiquement détectable. Nous avons conclu que les personnes atteintes de TSA sont sensibles aux demandes de la charge cognitive, pour une tâche d'attention visuelle dynamique, de façon comparable aux neurotypiques.

Dans l'étude 2, en utilisant le même paradigme 3D-MOT, nous avons demandé aux adolescents et adultes présentant un TSA (n = 27) ainsi qu’à un groupe contrôle (n = 28) de suivre 1 élément cible (difficulté faible) et 4 éléments cibles (difficulté élevée) au cours de deux blocs randomisés. La moitié des participants ont reçu de la rétroaction sur leur performance (groupes « Feedback »), et la moitié n'en ont pas reçu (groupes « No Feedback »). Une interaction a été identifiée entre le groupe diagnostic (TSA vs. TD), la rétroaction (« Feedback » vs. « No Feedback ») et la difficulté de la tâche (faible vs. élevée). La performance du suivi de 4
cibles était significativement altérée pour tous les participants par rapport à la performance du suivis d’une cible. Le groupe TSA qui a reçu de la rétroaction a mieux réussi que le groupe TSA qui n’a pas reçu de rétroaction, mais seulement lorsque la difficulté de la tâche était faible. La rétroaction n'a pas affecté de façon significative la performance des neurotypiques, bien que l'on ait trouvé une tendance préjudiciable de la rétroaction à la performance. Lorsque les groupes de diagnostic ont été regroupés, les participants qui ont reçu de la rétroaction ont démontré des gains significativement plus importants entre le premier et le second bloc d'essais par rapport à ceux qui n’ont pas reçu de rétroaction. Nous en concluons que la rétroaction peut être utile à l'apprentissage des tâches, même au cours d'une séance. Le type de rétroaction utilisé dans notre étude semble avoir un impact différent sur les personnes atteintes de TSA par rapport aux neurotypiques; aidant les personnes atteintes de TSA lorsque la difficulté de la tâche est gérable (c.-à.d., basse charge cognitive).

*Mots clés : trouble du spectre autistique (TSA), attention visuelle, suivi d'objets multiples (MOT), charge cognitive, rétroaction*
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Contribution of Authors

Both manuscripts presented herein were written and edited by me. I collected all ASD (autism spectrum disorder) participant data, and analyzed all data for both manuscripts. My supervisor and co-author Dr. Armando Bertone conceived of both studies, and provided feedback and editorial support throughout. A grant awarded to Dr. Bertone covered subject fees for both studies. Co-author Domenico Tullo collected all TD (typically developing) participant data, trained me on the administration of the 3D-MOT task, and provided feedback and editorial support throughout. Co-author Dr. Jocelyn Faubert developed the NeuroTracker (3D-MOT task) used in both manuscripts. Co-author Dr. Laurent Mottron granted me access to the ASD participant database at Rivière-des-Prairies Hospital.
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CHAPTER 1: INTRODUCTION

Thesis Overview and Rationale for Dissertation

Autism spectrum disorder (ASD) is a neurodevelopmental disorder primarily characterized by deficits in social communication and social interactions; and restricted, repetitive patterns of behaviour, interests, or activities (American Psychiatric Association, 2013). Differences have been found in the domains of visual perception and attention in ASD as well, and there is a growing body of research linking these differences with primary characteristics of autism (e.g., van Noordt et al., 2017). Individuals with ASD often show superior performance on perceptual and attentional tasks such as visual search and the Embedded Figures Test (e.g., Jolliffe & Baron-Cohen, 1997), but greater susceptibility to distraction (e.g., Burack, 1994). They also respond differently to task feedback, depending on factors such as its type, timing, and the difficulty of the task (e.g., van Noordt et al., 2017).

The pattern of strengths in some areas of attention and weaknesses in others found in individuals with ASD might be explained by assuming either that they have a higher perceptual capacity than neurotypicals (Adams & Jarrold, 2012; Remington, Swettenham, Campbell, & Coleman, 2009; Remington, Swettenham, & Lavie; 2012), or that they possess fewer attentional resources than neurotypicals (Koldewyn, Weigelt, Kanwisher, & Jiang, 2013). A major aim of Study 1 was to assess the effect of cognitive load (i.e., increasing task difficulty by increasing the number of tracked targets) on attention in individuals with ASD using a three-dimensional multiple object tracking (3D-MOT) task. As described in subsequent sections, this research question is contextualized within two relevant theories. The first is the load theory of attention and cognitive control (Lavie, 1995), which has been used to explain some of the incongruities found in research on visual perceptual and attentional differences in ASD (Adams & Jarrold,
This theory purports that, when focusing attention on task-relevant stimuli when load is low, spare processing capacity shifts involuntarily to the perception of irrelevant stimuli. However, when focusing on task-relevant stimuli when load is high, processing capacity is reached and irrelevant stimuli are ignored. In other words, if a task exhausts an individual’s perceptual capacity (i.e., when load is high), they will not process distractors; but if full perceptual capacity has not yet been met (i.e., when load is low), they will process distractors. If individuals with ASD have greater load capacity, they will be more susceptible to processing distractors than typically developing individuals, which would manifest as poorer task performance. This theory is relevant in that it is specific to ASD, and has been used to explain findings of both increased and decreased performance on perceptual tasks in ASD (Remington et al., 2012).

A second theory that may elucidate the differences in attention between typically developing populations and individuals with ASD is the resource-based theory of attention, which describes attentional capacity (Alvarez & Cavanaugh, 2004). This theory was highlighted by research using multiple object tracking (MOT) paradigms to examine the limits of visual attention (Scholl, 2009). Described in more depth in later sections, MOT involves attending to target items while ignoring distractor items as they move around a space over a short period of time. Through the use of this paradigm, the resource-based theory was used to explain the possibility of splitting attention between multiple targets in relation to task demands (e.g., the number of target items; object speed; Alvarez & Franconeri, 2007). Specifically, this theory posits that attention is characterized as a pool of resources that can be divided equally among task demands (Alvarez & Cavanaugh, 2004). Therefore, if task demands do not use up all resources, then this should result in the successful completion of the task at hand. Conversely, if
task demands require more resources beyond the individual’s capacity, this may result in a failure to complete the attention-based task. It is possible that individuals with ASD perform worse on certain tasks because their attentional “pool” is shallower than that of neurotypicals. We argue that our MOT task is ideal for assessing the effects of cognitive load on visual attention in ASD because it allowed us to manipulate cognitive load (in our case, the number of target items) while keeping other variables constant at the inter-subject level.

The aim of Study 1 in the present dissertation is to assess the effect of cognitive load on 3D-MOT performance in a sample of adolescents and adults with ASD. In line with cognitive load theory, we hypothesized that performance on the 3D-MOT task would decrease as cognitive load increased for both our typically developing and ASD groups. In line with the enhanced perceptual capacity theory and the decreased attentional resource theory, we also hypothesized that individuals with ASD would show poorer task performance than typically developing individuals under high cognitive load. Under the enhanced perceptual capacity theory, worse performance at higher loading levels could be attributable to individuals with ASD continuing to process distractor items while neurotypicals’ perceptual capacity having been reached. Alternatively, if individuals with ASD possess fewer attentional resources (specifically with regard to selective and sustained attention), a similar pattern (i.e., worse performance at higher loading levels) would emerge.

In addition to the effect of load, performance on visual attention tasks (as well as other tasks) is affected by the presence and nuances of feedback. This is true for both neurotypicals and individuals with ASD; with differences found between groups. The provision of trial-by-trial feedback to typically developing adults can be conducive to better task performance and learning (Liu, Dosher, & Lu, 2014). However, feedback can also have a negative impact on learning
and/or performance based on moderating factors that include level, delivery modality, timing of feedback delivery, and task difficulty (Hattie & Timperley, 2007). Though the provision of feedback is common in behavioural research, examining the effect of the presence or absence of feedback on task performance is not usually a main aim in psychological experiments; particularly in autism research. There is growing evidence that individuals with ASD process certain forms of feedback differently than neurotypicals given certain parameters (e.g., Plaisted, O’Riordan, & Baron-Cohen, 1998), but feedback research in autism tends to focus on feedback valence (positive vs. negative; or social vs. nonsocial), and not the presence or absence of it.

The aim of Study 2 in the present dissertation lies in examining the role of feedback on performance using the same visual attention task used in Study 1 (3D-MOT). While the independent variable isolated in Study 1 is cognitive load, the main independent variable in Study 2 is the presence or absence of trial-by-trial feedback. In our study, feedback was also assessed as a factor of task difficulty (cognitive load) – one of the feedback factors known to affect task performance. Task difficulty is defined as the mental resources or effort needed to complete a cognitive task (Sweller, 1994), and the higher the task difficulty, the longer it takes for feedback to become beneficial (Hattie & Timperley, 2007; Perico, 2014). In previous studies in our lab, we found that trial-by-trial feedback actually resulted in a relatively decreased MOT performance in a typically developing sample (compared to a no feedback group) when MOT performance was initially tested within a single testing session. Although the feedback group eventually benefited from trial-to-trial feedback over several testing sessions (i.e., the rate of 3D-MOT performance increased significantly with feedback), the weaker initial performance could be attributed to feedback as an additional element of cognitive loading on attention (i.e., the mental resources of effort required to complete a cognitive task (Sweller, 1994)) (Perico, 2014).
We expected that the provision of feedback would contribute to weaker MOT performance over this single session for both the ASD and TD groups. However, given the type of our feedback (criterial, visual, computerized, and non-social in nature), we did not expect that the discrepancy between ASD groups (i.e., Feedback vs. No Feedback) would be significantly different from the discrepancy between TD groups (Feedback vs. No Feedback).

This dissertation contains six chapters; including this introductory first chapter presenting the rationale for investigating the effects of cognitive load (Study 1) and feedback (Study 2) on attentional task performance in ASD. The second chapter is a literature review covering research pertinent to both studies. The third chapter is a reproduction of an article (Levy, Tullo, Mottron, Faubert, & Bertone, 2017a) that will be submitted to the journal, *Autism Research* (Manuscript I – based on Study 1). The fourth chapter bridges Manuscript I (Study 1) and Manuscript II (Study 2). The fifth chapter is a reproduction of an article (Levy, Tullo, Mottron, Faubert, & Bertone, 2017b) that will be submitted to the *Journal of Autism Research and Developmental Disorders* (Manuscript II). The sixth and final chapter summarizes and synthesizes findings from both studies; and discusses their applications, contributions, and limitations.

Each manuscript contains its own literature review, method, results, and discussion sections. Similarities in the introduction and method sections will be noticeable between the two manuscripts, as certain aspects of ASD symptomatology and etiology are relevant to both; and, though they addressed different objectives (cognitive load in Manuscript I and feedback in Manuscript II) the main task (3D-MOT) was administered to all participants in both studies. While both manuscripts in this dissertation target visual attention in autism more broadly, the 3D-MOT task was ideal for isolating and manipulating variables (i.e., load and feedback) pertinent to each manuscript’s specific research questions.
CHAPTER 2: LITERATURE REVIEW

Autism spectrum disorder (ASD) is a heterogeneous neurodevelopmental disorder typically emerging in early childhood. Although statistics for prevalence rates in Canada are not yet available, a recent report from the Centers for Disease Control (2014) revealed that roughly 1.5% of individuals in the United States have a diagnosis of ASD, and that this rate is on the rise. The DSM-5 diagnostic criteria for ASD include: (1) persistent deficits in social communication and social interactions across multiple contexts; and (2) restricted, repetitive patterns of behaviour, interests, or activities; currently and/or historically. These criteria are rated by severity (e.g., high-functioning vs. low-functioning), and the diagnosis of ASD can be made with or without a language or intellectual impairment (American Psychiatric Association, 2013).

For decades, deficits in social cognition and communication have been the proverbial face of autism spectrum disorder. However, researchers have begun to recognize that atypicalities in visual perception and attention in ASD may be highly related to these social deficits, as well as non-social ones (e.g., repetitive behaviours, preoccupations with routine or sameness) (Allen & Courchesne, 2001; Elsabbagh et al., 2009; Elsabbagh et al., 2011; Grandin, 2009; Happé, 1999; Keen, Lincoln, Müller, & Townsend, 2010; Keen et al., 2017; Larson, South, Krauskopf, Clawson, & Crowley, 2011; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Osterling, Dawson, & Munson, 2002; Ronconi, Gori, Ruffino, Molteni, & Facoetti, 2012; Sinha et al., 2014; van Noordt et al., 2017; Zwaigenbaum et al., 2005).

Visual Perception and Attention in ASD: Links to Symptomatology

Perception in autism spectrum disorder. Many researchers have found superior performance (designated by faster speed) in visual search tasks such as the Embedded Figures Test in children and adults with ASD (Joseph, Keen, Connolly, Wolfe, & Horowitz, 2009;
Kaldy, Kraper, Carter, & Blaser, 2011; Kemner, van Ewijk, van Engeland, & Hooge, 2008; Manjaly et al., 2007; Mottron, Belleville, & Ménard, 1999; O’Riordan 2004; O’Riordan, Plaisted, Driver, & Baron-Cohen, 2001). Originally designed by Witkin in 1971, the Embedded Figures Test requires the identification of visual elements that are embedded within larger fields. Researchers have generally fallen into two camps when it comes to explaining this superior performance on visual search tasks, in which a more local (versus global) processing strategy is beneficial. Frith’s (1989) Weak Central Coherence (WCC) theory claims that individuals with ASD demonstrate a perceptual processing bias for featural or local information, and an inability to integrate this local information to obtain a more global picture (Happé & Frith, 2006).

However, some researchers discovered that global processing difficulties can be overcome when tasks specifically demand attention to the bigger picture (e.g., Happé & Frith, 2006; Koldewyn et al., 2013). Thus, over time, many researchers moved away from labelling this difference as a deficit in global processing (as in the WCC theory), and instead frame the difference as a strength in detail-focused processing. Researchers supporting this tenet are generally aligned with the Enhanced Perceptual Functioning theory of autism (e.g., Mottron et al., 2006).

Another difference is observed in the atypical visual exploratory behaviours common among young children with ASD (e.g., Mottron & Burack, 2001). These include longer fixations and lateral glances towards moving objects (i.e., observing objects with the pupils positioned in the corners of the eyes; e.g., Mottron et al., 2006). Given that lateral vision is associated with detail and movement processing, the authors suggest that lateral glances in early life may reflect attempts to regulate and/or optimize both excessive amounts of local information and diminished perception of movement (Mottron et al., 2006). Some of these atypicalities can ostensibly be linked to difficulties with social interactions. For instance, children with autism often fail to
orient to social stimuli in particular (such as their name being called), do not engage in shared
attention as much as children without ASD (Dawson, Meltzoff, Osterling, Rinaldi, & Brown,
1998), and are impaired at processing and understanding emotion-conveyed eye gaze and facial
expressions (Baron-Cohen, Jolliffe, Mortimore, & Robertson, 1997; Castelli, 2005). Atypical
responses to social stimuli have also been noted; including abnormal pupillary responses to
happy faces (Sepeta et al., 2012), and cortical connectivity in facial emotion processing (Yeung,
Han, Sze, & Chan, 2014). Consistent with the Enhanced Perceptual Functioning model of ASD,
Autism Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) scores
were associated with better performance on visuospatial items than on verbal/analytic items of
the Raven’s Advanced Progressive Matrices (DeShon, Chan, & Weissbein, 1995; Fugard,
Stewart, & Stenning, 2011).

Attention in autism spectrum disorder. Differences in domains of attention are among
the earliest indicators of autism spectrum disorder to emerge (Powell, Wass, Erichsen, & Leekam,
2016). Unlike deficits in social orienting (e.g., orienting to faces or social movement), which are
generally not seen at very early stages of development, young children who are later diagnosed
with ASD show deficits in non-social attention at a very early age (Powell et al., 2016). Two
notable examples include a slower disengagement of attention at 7 months (Elison et al., 2013),
and differences in micro-temporal eye movement patterns at 6 months (Wass et al., 2015). A
study by Swanson and Siler (2013) found that both children with ASD and neurotypical
children’s gaze patterns were reliably predicted by parent report measures of children’s SRS
Social Awareness scale; with social difficulties being associated with gaze modulation difficulty.

Attention modulation. Unique functioning in ASD is found over three cognitive
processes associated with attention modulation, which are supported by three distinct neural
networks (Posner & Fan, 2004; Posner & Peterson, 1990): *alerting* (reaching and maintaining a state of increased sensitivity to incoming information; Dawson & Lewy, 1989; Gold & Gold, 1975), *orienting* (disengaging, shifting, and reengaging attention; Ornitz, 1988), and *executive control* (inhibition, conflict resolution, planning, and cognitive flexibility; Ozonoff, Pennington, & Rogers, 1991) (Keehn et al., 2010). Researchers have found atypical arousal and lower sensitivity to novel stimuli (alerting network; e.g., Ciesielski, Courchesne, & Elmasian, 1990; Hirstein, Iversen, & Ramachandran, 2001; Keehn & Joseph, 2008); impaired or reduced shifting and disengagement of visual attention, including orienting to both social and non-social stimuli, and joint attention (orienting network; e.g., Dawson et al., 1998; Elsabbagh et al., 2009; Keehn et al., 2017). Finally, individuals with ASD have been shown to have intact inhibitory processing (Lopez, Lincoln, Ozonoff, & Lai, 2005; Ozonoff & Strayer, 1997), but impaired cognitive flexibility (executive control network; Courchesne et al., 1994; Ozonoff, Strayer, McMahon, & Filloux, 1994).

**Types of Attention Measurable with Multiple Object Tracking Tasks**

MOT paradigms in general (and our 3D-MOT task specifically) are accessible and adaptable, and can accurately measure selective, distributed, dynamic, and sustained attention.

**Selective attention.** Selective attention refers to the ability to focus on task-relevant stimuli while ignoring or suppressing task-irrelevant stimuli (Scholl, 2009). In an MOT task, participants must *selectively attend* to a target object or objects while ignoring distractor objects. A real-world example of selective attention at work is an individual’s ability to focus on a friend’s storytelling while filtering out extraneous conversations in a busy restaurant. A necessary assumption underlying this type of attention is that humans cannot consciously attend to all of their sensory input at the same time (Broadbent, 1958; Deutsch & Deutsch, 1963). Some
researchers have found deficits in selective attention and higher distractibility among individuals with ASD during visuospatial tasks (Belmonte & Yurgelun-Todd, 2003; Burack, 1994; Ciesielski et al., 1990).

**Distributed attention.** Distributed attention refers to attention that is dispersed or allocated over visual space to enable the processing of multiple stimuli (Srinivasan, Srivastava, Lohani, & Baijal, 2009). During the completion of an MOT task, *distributed attention* is tapped by spreading attentional resources across multiple objects. Though it was once believed that humans had a fixed object tracking limit (e.g., Cavanagh & Alvarez, 2005), current research has demonstrated that tracking resources are more flexible, evenly distributed among tracked objects, and moderated by task demands (Alvarez & Franconeri, 2007). While some research has found typical distributed attention in ASD (e.g., Bogte, Flamma, Van Der Meere, & Van Engeland, 2009; Rutherford, Richards, Moldes, & Sekuler, 2007), others have found deficits (e.g., Althaus, De Sonneville, Minderaa, Hensen, & Til, 1996; Ciesielski, Knight, Prince, Harris, & Handmaker, 1995).

**Dynamic attention.** Dynamic attention refers to the ability to track information in motion. In an MOT task, *dynamic attention* is tapped by tracking objects in 2D or 3D space. Objects vary in their speed and implied trajectory. Dynamic attention can be measured by manipulating target object speed in MOT studies (e.g., Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009; Doran & Hoffman, 2010; Oksama & Hyönä, 2004). As object speed increases, object discrimination and maintenance decrease (Tombu & Seiffert, 2008), and MOT performance decreases (Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009; Doran & Hoffman, 2010). Measuring speed discrimination and motion processing thresholds in children at slow (1.5 deg/sec) and high (6 deg/sec) speeds, Manning, Charman, and Pellicano (2013) found
that the ASD children had difficulty extracting motion coherence only at slow speeds. They were just as able as the typically developing children to extract speed information (Manning et al., 2013). At a more ecological level, the ability to navigate one’s vehicle safely through traffic is an example of the importance of intact dynamic attention (Jensen, Skov, & Thiruravichandran, 2010).

**Sustained attention.** Sustained attention refers to the ability to maintain attention for the duration of a task. It is also an essential component of attentional processing during MOT tasks (Buehner, Krumm, Ziegler, & Pluecken, 2006; Coull, 1998; Pylyshyn & Storm, 1988), and increasing trial duration typically decreases sustained attention in MOT tasks (Franconeri, Jonathan, & Scimeca, 2010; Oksama & Hyönä, 2004). Working memory in the visual domain is believed to depend greatly on sustained attentional capacity, and to be moderated by the ability to inhibit distractions (Cowan, 2001). On the Cambridge Neuropsychological Test Automated Battery, Chien and colleagues (2015) found impairment in visual memory and visual sustained attention in a sample of adolescents with ASD; which was moderated by age and IQ. Kasai and Murohasi (2013) examined ERP activity and Autism Quotient (AQ) scores in a sample of neurotypical adults in an attempt to determine whether enhanced local processing in ASD was the result of atypical bottom-up or top-down mechanisms using a sustained attention task. They found a significant link between higher AQ scores and bottom-up processing in perceptual organization (Kasai & Murohasi, 2013). Oksama and Hyönä (2004) determined that visuo-spatial working memory and attention switching tasks were significant predictors of MOT performance. This conclusion suggests that MOT taps higher level cognition such as working memory and attentional switching. Alvarez, Horowitz, Arsenio, DiMase, and Wolfe (2005) maintain that MOT and visual search draw on the same attention resource in typically developing individuals.
Like Oksama and Hyönä (2004), their work supports a top-down attention-switching mechanism for successful completion of tracking and then searching in tasks of visual selective attention (Alvarez et al., 2005).

**Two- vs. Three-Dimensional (3D) MOT**

Unlike most prior studies that used *two*-dimensional MOT paradigms -- in which depth is absent and objects do not interact with each other in real-world ways such as occluding and colliding with each other -- we used a *three*-dimensional MOT task to assess visuo-attentional abilities in individuals with and without ASD as a function of cognitive load (Study 1) and feedback (Study 2). Due to its greater empirical and ecological validity, a 3D-MOT paradigm is suggested to be an ideal measure of visual attention of objects in the real world (Scholl, 2009).

There is some precedent for using three-dimensional MOT paradigms; such as studies using the same software (NeuroTracker) employed in the studies that make up this dissertation (Chamoun et al., 2017; Faubert, 2013; Faubert & Sidebottom, 2012; Legault, Allard, & Faubert, 2013; Legault, Troje, & Faubert, 2012; Romeas, Guldner, & Faubert, 2016; Tullo, Faubert, & Bertone, 2015); or paradigms that approximate three-dimensional MOT tasks by using static spatial references (e.g., Jahn, Papenmeier, Meyerhoff, & Huff, 2012), depth planes (e.g., Ur Rehman, Kihara, Matsumoto, & Ohtsuka, 2015; Viswanathan & Mingolla, 2002), and/or occlusion (e.g., Vidaković & Zdravković, 2010). Using mirrors and two monitors, Ur Rehman and colleagues (2015) found that performance tended to be impaired when target depth planes were far apart (50 cm vs. 6 cm or 10 cm), and tracking targets on both planes was possible only when targets began on both planes (as opposed to a single plane). Viswanathan and Mingolla (2002) determined that depth cues and occlusion improved distinguishability between targets and
distractors, and Vidaković and Zdravković (2010) found that tracking was better when
occlusions occurred at different depth planes (mimicking real-world conditions).

**The NeuroTracker task.** Though it will be described in more detail in the Method
section of both manuscripts, the 3D-MOT task used herein uses manipulations of the
NeuroTracker task (https://neurotracker.net/) The benefits of using a 3D (as opposed to 2D- or
3D-approximating) MOT are not only intuitive, but also supported by better performance as
compared with 2D tasks due to the help of stereoscopy/binocular vision; including 50% gain in
*speed threshold* (defined in the Method sections of Manuscripts I and II) found by Tinjust, Allard,
and Faubert, 2008. The NeuroTracker task is currently being used to improve the performance of
professional athletes and military special forces, and has been shown to be useful as a cognitive
training tool for typically-developing individuals (see Chapter 6: General Discussion).

**Multiple Object Tracking in Autism Spectrum Disorder**

MOT tasks have recently been used to assess attentional abilities in individuals with ASD,
to two general aims: (1) investigating how grouping principles relate to local vs. global
processing style (Evers et al., 2014; O’Hearn, Franconeri, Wright, Minshew, & Luna, 2013; Van
der Hallen et al., 2015), and (2) determining whether differences exist in autism with regard to
sustained and/or dynamic attention (Jiang, Capistrano, & Palm, 2014; Koldewyn et al., 2013).

Expanding on decades of work supporting locally-oriented processing style in ASD,
Evers and colleagues (2014) presented ASD and TD children (6-10 years) with a modified MOT
paradigm (which included conditions in which targets were grouped in motion to other targets, or
to distractors; first used by Scholl, Pylyshyn, & Feldman, 2001) in addition to the traditional
ungrouped MOT paradigm. Using a typically developing adult sample, Scholl and colleagues
(2001) determined that only grouping cues that obey Gestalt grouping principles of
connectedness or plausible object shape influence performance on the modified MOT (e.g., “common fate”). Grouping can be beneficial or detrimental to MOT performance, either by facilitating individuation (when targets are paired with each other or distractor as paired with each other) or by rendering it more difficult (when targets are paired with distractors; elements that need to be differentiated from each other). Scholl and colleagues (2001) proposed that weaker MOT performance in the condition of targets grouped to distractors is a measure of the strength of a grouping cue.

In their study, Evers and colleagues (2014) found a reduced bias towards more global processing in the ASD group (i.e., reduced tracking performance when targets were grouped to distractors). O’Hearn and colleagues (2013) used a similar modified MOT (Scholl et al., 2001). Their aim was to explore how differences in individuation might affect MOT performance. Individuation refers to the ability to attentionally capture a small number of items at the same time; it is also often referred to as subitizing. In contrast to Evers and colleagues (2014), O’Hearn and colleagues (2013) found that ASD groups of various ages (9-12 years, 13-17 years, and 18-29 years) performed worse than their age-matched control groups overall, but did not find any effects of MOT condition (i.e., traditional vs. grouped). Van der Hallen and colleagues (2015) most recently used MOT to investigate the effect of object-based grouping in children with and without ASD and found that both showed adequate MOT performance (no group differences) and a similar amount of grouping interference. These studies provide some support for the notion that grouping local components (i.e., targets linked to distractors) modifies attention to those separate components.

The other two published studies using MOT in an ASD sample focused on determining whether differences exist in their attentional capacity in a dynamic, sustained attention task. In a
study by Jiang and colleagues (2014), though children (7-14 years) with ASD showed a lower tracking capacity overall on the MOT task than the typically-developing children, they displayed a greater deficit in a spatial working memory task than an MOT task; despite the latter placing heavier demands on sustained attention, location updating, and distractor inhibition. Koldewyn and colleagues (2013) found that 5- to 12-year-old children with ASD could track slightly fewer items than age-matched neurotypical children overall, but their performance was not particularly worse at higher speeds. The authors concluded that lower performance on the MOT task was not attributed to a specific deficit in dynamic attention, but rather a lower capacity to select and maintain attention to multiple targets (selective, sustained, and distributed attention) (Koldewyn et al., 2013).

In sum, multiple object tracking paradigms have been used to assess both perceptual (local vs. global perception) and visuo-attentional abilities (selective and sustained attention) in ASD. Though “load capacity” has been examined indirectly in children with ASD (Jiang et al., 2014; Koldewyn et al., 2013), no study has directly assessed the effects of cognitive load on visual attention in ASD using a 3D-MOT task. The use of an MOT task is ideal for doing so in that the load variable can be easily defined and manipulated by increasing the number of target items to be tracked. In addition, the same MOT paradigm can be used to assess the effects of feedback on visuo-attentional abilities in ASD by simply comparing performance with and without trial-by-trial feedback.

In the following sections, theories relevant to both of our research questions will be outlined and discussed. In Study 1, we assessed the effect of load manipulation on MOT performance in ASD, and in Study 2, we assessed the effect of feedback on MOT performance in ASD. We will begin with a description of the load theory of attention, which will be followed by
evidence supporting two theories that attempt to explain attentional functioning in ASD: (1) the argument for enhanced perceptual capacity, and (2) the argument for decreased attentional resources. This will be followed by a discussion of the differential effects of feedback on performance, in both neurotypicals and individuals with ASD.

**Attention and Load Theory**

The ability to focus on task-relevant stimuli while ignoring or suppressing task-irrelevant stimuli is crucial to the efficient navigation of our sensory world. The load theory of attention and cognitive control (originally proposed by Lavie, 1995) is a leading theory of attention that maintains that the efficacy of selective attention depends on the level of perceptual and cognitive load of the stimulus. As mentioned above, *selective attention* refers to the ability to attend to what is important and filter out what is not. Furthermore, our attentional capacity is limited (Broadbent, 1958; Lavie, 1995; Murphy, Groeger, & Greene, 2016). When presented with an abundance of information, it is necessary to be able to pick out what is essential and relevant from what is distracting and irrelevant. The processes involved in selective attention are dependent on both external properties (perceptual load) and internal properties (cognitive load) (Murphy et al., 2016). It is to the distinction between these types of load that we now turn.

**Perceptual load theory.** An ongoing debate in the field of attention pertains to how attention can affect perception. Researchers in the *early selection* camp maintain that allocating attention to a target stimulus can suppress the perception of irrelevant stimuli (Broadbent, 1958); while those in the *late selection* camp maintain that although attention cannot prevent perception of irrelevant stimuli, it can affect post-perceptual processes such as response selection and memory (Deutsch & Deutsch, 1963). Lavie (1995, 2005) proposed the perceptual load theory in an attempt to resolve this debate. In this hybrid theory of early and late selection views, when
focusing attention on task-relevant stimuli at low perceptual load, spare processing capacity shifts involuntarily to the perception of irrelevant stimuli (late selection). However, when focusing on task-relevant stimuli at high perceptual load, processing capacity is reached and irrelevant stimuli are ignored. Put differently, the manner in which distractors are processed depends heavily on the level and type of load involved in the processing of goal-relevant information. If a task exhausts an individual’s perceptual capacity (i.e., when load is high), distractors will not be processed; but if full perceptual capacity has not yet been met (i.e., when load is low), distractors will be processed.

Since first proposed by Lavie (1995), a multitude of studies in the visual domain have lent support to the perceptual load theory (Bahrami, Lavie, & Rees, 2007; Beck & Lavie, 2005; Carmel, Thorne, Rees, & Lavie, 2011; Cartwright-Finch, & Lavie, 2006; Konstantinou, Beal, King, & Lavie, 2014; Lavie, Beck, & Konstantinou, 2014; Lavie & de Fockert, 2003; Lavie, de Fockert, & Viding, 2004; Macdonald & Lavie, 2008; Wei, Kang, & Zhou, 2013). In most behavioural studies such as those cited above, perceptual load was manipulated either by varying the number of items in the display, varying the similarity of the target and non-target stimuli, or altering the task while keeping the display constant (Murphy et al., 2016).

**Manipulating perceptual load.** Many studies involving the first type of manipulation used a flanker task (Eriksen & Eriksen, 1974). In this task, participants must identify which of the target letters (usually “X” or “N”) is present in a visual display. Targets may appear alone in low perceptual load trials; while targets may be surrounded by, for example, other non-target letters in high perceptual load trials (e.g., Lavie & de Fockert, 2003). Many studies testing the effects of the second manipulation also use the flanker task, but vary the non-target letters by their featural dissimilarity to the target letters (e.g., Beck & Lavie, 2005). A low perceptual load
trial might use highly dissimilar non-target letters (such as “O”), while a high perceptual load trial may use more angular letters (such as “H”). Finally, studies in which the third manipulation is used often ask the participant to make judgments about an object (e.g., a cross, as in Cartwright-Finch & Lavie, 2006) based on a change in an aspect that is easily perceptible, like colour (low perceptual load) or in a change that would be harder to perceive, like length (high perceptual load). In most cases, the reaction time difference between trials using congruent and incongruent distractors is used as a measure of selective attention efficiency (Murphy et al., 2016).

Cognitive load theory. Increasing cognitive load -- the mental resources or effort needed to complete a cognitive task (Sweller, 1994) -- has been shown to have differing effects on distractor interference depending on the type of cognitive load manipulation. Sometimes these are congruent with the effect of perceptual load; while sometimes they reveal an opposite effect.

Manipulating cognitive load. Most studies have used verbal working memory tasks as a proxy for cognitive load in typically developing samples, and most have shown that increasing the cognitive load negatively impacts selective attention (Murphy et al., 2016). For instance, participants in de Fockert, Rees, Frith, and Lavie’s (2001) study were asked to remember a sequence of digits either in the same order in which they were learned (low cognitive load) or a different order in which they were learned (high cognitive load). While holding this sequence in memory, they then were required to complete a visual search task involving target and distractor faces and were asked about the sequence at the end of each trial. Higher cognitive load elicited greater interference effects from the distractor faces (de Fockert et al., 2001). Put differently, in these types of studies, increasing cognitive load had the opposite effect on distractor inhibition
than increasing perceptual load. Thus, when cognitive load is high, distractor interference is more likely; and vice versa.

Despite the largely congruent findings in studies using *verbal* working memory, more recent studies using different representations of cognitive load have yielded varying, or at least more complex, results. In a study that compared visual, spatial, and phonological working memory paired with a visual search task, Burnham, Sabia, and Langan (2014) found that only the visual and spatial working memory tasks interfered with attention. This result suggests that only working memory tasks that tap the same type of attentional resources as the competing task will be detrimental to attention. Rose, Schmid, Winzen, Sommer, and Büchel (2005) found an effect of cognitive load that was parallel to the effect of perceptual load. In a series of behavioural, fMRI, and EEG studies, an increase in cognitive load (*n*-back task) *decreased* the processing of task-irrelevant distractor stimuli (background images) in the same way that increasing perceptual load would (Rose et al., 2005).

**Attentional Resource Theory**

Though cognitive load theory can, in principle, be applied to many different types of tasks, the Attentional Resource Theory (e.g. Alvarez & Franconeri, 2007) is highly relevant to multiple object tracking paradigms, specifically. In typically developing individuals, earlier MOT studies have identified a fixed tracking limit of 4 objects (“fixed architecture model,” e.g., Intriligator & Cavanagh, 2001; Pylyshyn & Storm, 1988; Yantis, 1992). This “maximum” number is the same as the maximum number of items that can be subitized (O’Hearn et al., 2013). Pylyshyn (2000) suggested that both subitizing and MOT might be sensitive to a common performance limit on parallel individuation; and O’Hearn and colleagues (2013) found an upper limit of 3 subitized items in their ASD group. More recently though, Alvarez and Franconeri
(2007) determined that attentional capacity in MOT tasks is not fixed, but moderated by factors influencing load, such as object speed and spatial resolution of attention. Thus, the authors maintained that, instead of having a fixed object limit, MOT ability was better represented by the “flexible resource model” (Alvarez & Franconeri, 2007). Participants in Alvarez and Franconeri’s (2007) study were able to track more items at slower speeds, and vice versa. In MOT paradigms such as ours, the average speed at which all targets can be successfully tracked can be calculated and thus help form a picture of how difficult (i.e., how many attentional resources) are needed in order to successfully complete the task. Another way to conceptualize the “tax” on attentional resources that is not specific to visual attention paradigms such as MOT involves the amount of perceptual or cognitive “load” inherent in a stimulus or task.

**Manipulating Load in Autism Spectrum Disorder**

The aim of the first study (Manuscript I) was to examine the effect of increasing cognitive load on 3D-MOT task performance in our ASD sample as compared to our typically developing sample. As outlined above, individuals on the autism spectrum often show better performance on certain attentional tasks (e.g., visual search), yet greater distractibility than neurotypicals. These discrepant findings might be resolved if we assume that individuals with ASD have a higher perceptual capacity than typically developing individuals (Adams & Jarrold, 2012; Remington et al., 2009; Remington et al., 2012); or, if we assume that they have a lower attentional resource capacity than typically developing individuals (Koldewyn et al., 2013; Jiang et al., 2014). Load theory can apply to many different types of studies, such as those cited above; while attentional resource theory is inherently linked to studies of multiple object tracking.

**The argument for increased perceptual capacity.** Using a modified flanker task that varied in perceptual load, Remington and colleagues (2009) determined that individuals with
ASD required higher levels of perceptual load to be able to ignore irrelevant distractors, suggesting enhanced perceptual capacity for individuals with ASD. Remington and colleagues (2012) retested this hypothesis with a similar task and confirmed that, under higher levels of load, perceptual sensitivity was reduced in typical adults but not in adults with ASD. Subsequent studies have shown no differences between adults with ASD and neurotypicals under extremely high perceptual load (suggesting a limit to ASD superiority in visual search tasks) (Hessels, Hooge, Snijders, & Kemner, 2014); and less susceptibility to inattentional blindness overall, and as a function of perceptual load (interpreted as higher perceptual capacity) compared to neurotypicals (Swettenham et al., 2014). Even neurotypicals with above average AQ scores demonstrate greater distractor interference at high loading than those with below average AQ scores (Bayliss & Kritikos, 2011); providing additional support for the link between autism symptomology and individual differences in selective attention as a function of cognitive load.

**The argument for decreased attentional resources.** Given the mixed evidence from the two capacity-targeting MOT studies comparing children with ASD to neurotypical children, it is possible that adolescents and adults with autism have a different attentional resource capacity than typically developing adolescents and adults. To reiterate, Koldewyn and colleagues (2013) did not find a specific deficit in dynamic attention in their ASD sample, but argued that a deficit in selective attention was present. Jiang and colleagues (2014) found relatively spared sustained attention in their ASD sample, but overall worse performance on the MOT task as compared with neurotypicals. An alternative hypothesis to the increased capacity theory would be that adolescents and adults might have a weaker ability to select and maintain attention to multiple targets, and are those working from a smaller attentional resource pool when completing an MOT task.
While the first manuscript’s aim is to isolate and examine the role of cognitive load on attentional task performance, the second manuscript’s aim is to examine the role of feedback on attentional task performance. Though many experimental tasks build in the provision of immediate feedback, the effect of the presence or absence of feedback on task performance is not typically the focus of research. When feedback is a question of interest in the ASD literature, feedback valence (i.e., positive vs. negative feedback; or social vs. nonsocial types of feedback) tends to be the experimental target. We aimed to examine the role of the presence of trial-by-trial feedback on performance in adolescents and adults with ASD. Additionally, we wished to assess the impact of feedback while varying a factor that has been shown to impact the feedback effectiveness in neurotypicals: task difficulty. We now turn to a discussion of feedback in both typically developing and ASD populations.

Feedback

The second manuscript’s main aim is to examine the effect of feedback on 3D-MOT task performance in our ASD sample as compared to our TD sample. Feedback is defined as any type of information conveyed by a human (e.g., parent, teacher) or non-human (e.g., book, computer) mediator to an individual about their performance (Hattie & Timperley, 2007). On behavioural tasks, feedback is often provided visually and/or audibly within the experimental paradigm; for instance, the appearance of, “Right!” on the screen after a correct response, or the sound of a buzzer after an incorrect response.

Perceptual learning theory asserts that the perception of stimuli can be enhanced and/or accelerated through repeated exposure and response to incoming perceptual information with minimal explicit verbal instruction (Lu, Hua, Huang, Zhou, & Dosher, 2011). Perceptual learning
(and thus, performance accuracy) can often be strengthened with feedback in typically
developing adults (Liu et al., 2014).

**Feedback properties affecting task performance.** Feedback may have a positive or
negative impact on learning and/or performance; depending on its properties and the
circumstances under which it is provided. These moderating factors include, among others:
feedback level, delivery modality, timing of feedback delivery, and task difficulty. The latter
factor – task difficulty – is manipulated in our 3D-MOT task (see the Procedure section of
Manuscript II). Though this is the only factor listed above that is manipulated in our feedback
study (Study 2), it is important to outline where our 3D-MOT task falls along the spectrum of
each of the other factors as well.

**Feedback levels.** Hattie and Timperley (2007) identify four levels at which feedback can
work (i.e., types of feedback): the task level, the process level, the self-regulation level, and the
self level. Task level feedback (also known as, “criterial feedback”) provides information about
whether an individual’s work is correct or incorrect; process level feedback is linked to the
information processing and learning required to successfully complete a task (including error
correction); self-regulation level feedback encourages the individual to rely on their self-
monitoring, self-control, and self-discipline to continue and/or improve task performance; and
self level feedback is person-focused and irrelevant to the task itself (i.e., praise) (Hattie &
Timperley, 2007). Criterial feedback, specifically, is linked to increased perceptual learning
(Choi & Watanabe, 2012).

Greatest positive effect sizes have been found for task and process level feedback (Choi
& Watanabe, 2012; Kluger & DeNisi, 1996). In turn, good task performance also appears to lead
to perceptual learning; possibly due to the internal rewards that success brings (Choi &
Watanabe, 2012; Sasaki, Náñez, & Watanabe, 2010). Furthermore, different types of feedback can have differing impacts on learning and motivation. For instance, Wilbert, Grosche, and Gerdes (2010) determined that criterial feedback, specifically (i.e., feedback focused on task completion; similar to Hattie and Timperley’s (2007) task level feedback), significantly increased the rate of learning for university students. Wilbert and colleagues (2010) argue that the focus on task fulfillment elicited by criterial feedback (as opposed to social comparative feedback; similar to Hattie & Timperley’s (2007) self level feedback) activates the goal to complete the task and thus leads to higher task involvement and better participant performance. The type of feedback used in our task most closely resembles a hybrid of task (criterial) and process level feedback; as (1) it informs participants about the correctness of their performance on each trial, and (2) participants may utilize it to change their performance strategy during the course of the task.

**Delivery modalities and feedback timing.** In a review of 74 meta-analyses of various feedback delivery modalities, Hattie and Timperley (2007) determined that the most effective delivery modalities for classroom learners are of the video-, audio-, or computer-assisted instructional type. Computerizing the delivery of feedback ensures that it is delivered uniformly and reliably to all participants; thereby reducing human error. Feedback presented in a human-computer paradigm can also prove to be more intuitive and thus more valuable to the participant (Howie, Sy, Ford, & Vicente, 2000). The timing of feedback provision on different types of tasks can also differentially impact its efficacy. Hattie and Timperley (2007) explain that immediate feedback during task learning often results in faster rates of acquisition, but during tasks in which automaticity is the goal, immediate feedback may hamper performance. Our task, including the
mode in which feedback is delivered, is entirely computerized, and feedback occurs immediately after each trial (i.e., once the participant has made his or her selections).

**Task difficulty and feedback.** The ability to integrate feedback may also depend on the attentional resources of the individual at the time that feedback is introduced, and how the individual allocates these resources (Maddox, Bohil, & Ing, 2004; Zeithamova & Maddox, 2007). The mental resources or effort required to complete a cognitive task depend on the task’s difficulty, as discussed in the load section of this thesis (see Chapter 2). With regard to feedback, more difficult tasks demand longer processing time and more practice before feedback can become beneficial to performance (Hattie & Timperley, 2007; Perico, 2014). Age may be a moderating factor as well. For example, in a face perception task, Meinhardt-Injac, Persike, and Meinhardt (2014) found that while young adults benefitted from feedback under both low and high attentional demands, older adults demonstrated better performance only when feedback was presented at low attentional demand, and performed worse than a “No Feedback” group under high attentional demands. In the context of our multiple object tracking paradigm, task difficulty increases as the cognitive load of the task (number of targets) increases.

**Feedback and visual perception tasks.** The impact of feedback on performance on visual perception tasks has been mixed, but this is likely due to the nuances in feedback such as type, timing, attentional strain, and delivery method; discussed above. For instance, over the presentation of 9 blocks of a vernier acuity task (which asks participants to discern a misalignment between two line segments or gratings), Herzog and Fahle (1997) found that corrective feedback significantly improved performance and speed of learning; while manipulated, partial, and no feedback either slowed learning speed or did not facilitate task learning. In contrast, Petrov, Dosher, and Liu (2006) argue that human perceptual learning may
not always require feedback even in dynamic environments. They found comparable speed of learning and performance loss during changes in external noise context in feedback versus no feedback groups in a Gabor patch paradigm (which asks the observer to indicate the orientation of a target while ignoring background).

**Feedback and MOT tasks.** Our laboratory has been the first to investigate the role of feedback in a multiple object tracking task. Over the course of four training sessions, the provision of trial-by-trial (immediate) visual feedback increased task performance for on our 3D-MOT task for typically-developing adolescents and adults (Perico, 2014). We, thus, have evidence to support that the feedback used in our paradigm can be beneficial to task learning over time. However, feedback appeared to inadvertently decrease task performance in typically-developing participants completing just *one session* of our 3D-MOT task (Tullo et al., 2015); possibly because processing feedback acted as an additional tax on attentional and working memory resources (Wilbert et al., 2010; Zeithamova & Maddox, 2006; Zeithamova & Maddox, 2007).

Feedback processing on certain types of working memory tasks is integrated in a three-step process following feedback on an incorrect trial. First, the salience of the current strategy decreases for the individual completing the task. Second, the individual decides on whether to reuse the current strategy or generate a different one on the next trial. Finally, if the latter, the individual must shift his or her attention from the old strategy to the new one; a process that demands both time and attentional resources (Zeithamova & Maddox, 2007). Applying this theory to our 3D-MOT task, an individual’s strategy would be confirmed after a correct trial, but would perhaps demand revision after an incorrect trial. This revision, which would require the use of attentional resources, may lead to the generation of a different strategy to attempt on the
next trial. Over the course of several testing sessions, this tax on attention may diminish as strategies become exhausted, allowing the beneficial effects of our task’s feedback to be detected.

**Feedback in autism spectrum disorder.** As discussed above, there appears to be a link between atypicalities in visual perception and attention in ASD and social and non-social deficits.

**Differences in processing feedback and rewards.** Deficits in social interactions among individuals with high-functioning autism are purported to be influenced in part by lower ability to process feedback and rewards (Larson et al., 2011; McPartland, Crowley, Perszyk, Mukerji, & Naples, 2012; Sinha et al., 2014; van Noordt et al., 2017). It has been demonstrated that individuals with ASD exhibit atypical activation of reward circuitry during the anticipation and processing of monetary incentives and social cues (Dichter et al., 2012; Panasiti, Puzzo, & Chakrabarti, 2015; Rademacher, Schulte-Ruther, Hanewald, & Lammertz, 2016), but there is also evidence that the ability to process external, concrete feedback appears to be intact in ASD; while internal, more abstract feedback is weaker than in typically developing individuals (Larson et al., 2011). A recent EEG study of children and young adults with ASD revealed that although they are as sensitive to the valence of reward feedback compared to their neurotypical peers, individuals with ASD have reduced synchronization of medial frontal theta activity during feedback processing (van Noordt et al., 2017). The medial frontal cortex is sensitive to deviations from expected outcomes and are involved in updating expectations following prediction errors (van Noordt et al., 2017).

**Feedback valence.** Feedback valence (i.e., positive or negative) appears to impact learning in autism differently than in typically developing individuals. Negative auditory feedback (i.e., a “beep” sound for incorrect responses) on a visual search task was not found to be beneficial to a group of adults with ASD (Plaisted et al., 1998); and removing negative
feedback on the Wisconsin Card Sorting Task improved performance for the ASD group to TD levels (Broadbent & Stokes, 2013). It has also been shown that children with ASD place greater significance on positive versus negative feedback (Groen et al., 2008).

**Social vs. non-social feedback.** Much of the research addressing the effect of feedback on performance in ASD involves a comparison between social feedback (e.g., smiling faces for correct answers; frowning faces for incorrect ones) and non-social feedback (e.g., awarding money or points for correct answers and removing them for incorrect ones). Social feedback has been found to have less of a positive impact for individuals on the autism spectrum, and the non-social feedback generally produces equivalent or nearly-equivalent performance in both ASD and typically-developing participants (e.g., Delmonte et al., 2012; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Lin, Rangel, & Adolphs, 2012; Sepeta et al., 2012).

**Overall Aims and Hypotheses of Doctoral Dissertation**

The MOT studies involving participants on the autism spectrum reviewed above have provided an important basis for this thesis, in which a three-dimensional MOT task was used to assess attentional abilities in individuals with high-functioning ASD while manipulating cognitive load (Manuscript I) and feedback (Manuscript II).

**Manuscript I (Load).** The major aim of Manuscript I was to address the effect of load on attention in individuals with ASD using a three-dimensional multiple object tracking (3D-MOT) task. In line with cognitive load theory, we expected performance in both groups to steadily decline as cognitive load (number of targets) increased. However, we also expected to find worse performance under higher levels of cognitive load in our ASD group as compared with our TD group. If this pattern were to be found, it could arguably be attributable to enhanced perceptual capacity in individuals with ASD; because they would process distractors on tasks
more than typically developing (TD) individuals, whose capacity would be exhausted. The same hypothesized outcome might also be interpreted within the context of the attentional resource theory of attention; in that poorer performance at higher loading levels might instead be the result of diminished attentional resource capacity in individuals with ASD.

**Manuscript II (Feedback).** The major aim of Manuscript II was to determine the role of feedback in 3D-MOT task performance for both neurotypicals and individuals with ASD in which task difficulty (cognitive load) was modified. The main impetus for this research was the need to account for the potential effects of adding feedback to a task that will eventually be used as an attentional training tool with special populations; including individuals on the autism spectrum. Building on previous research in our lab with typical adolescents and adults, we hypothesized that feedback may hinder performance over this single session for both the ASD and TD groups. However, given the type of our feedback (criterial, visual, computerized, and non-social in nature), we did not expect that our ASD sample’s performance would be markedly hindered compared to our TD sample’s; if at all.
CHAPTER 3: MANUSCRIPT I: ASSESSING THE EFFECT OF A COGNITIVE LOAD MANIPULATION ON VISUAL ATTENTION IN AUTISM USING A MULTIPLE OBJECT TRACKING TASK

This is an exact reproduction of the following article (in preparation for submission):

Assessing the Effect of a Cognitive Load Manipulation on Visual Attention in Autism Using a Multiple Object Tracking Task

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Abstract

Autism spectrum disorder (ASD) is characterized by differences in visuo-spatial perceptual and attentional abilities, with some evidence supporting enhanced perceptual capacity in individuals with ASD, and some supporting decreased attentional capacity in individuals with ASD. Multiple object tracking (MOT) paradigms are useful in assessing these abilities, as the task demands the use of sustained, selective, and distributed attention to dynamic visual information. One important factor that may underlie some of these differences and has yet to be assessed is the effect of cognitive load on multiple object tracking (MOT) task performance in individuals with ASD. We assessed dynamic visual attention in adolescents and adults with ASD \((n = 15)\) using a 3D-MOT paradigm with 4 cognitive loading levels (1, 2, 3, and 4 tracked items). In line with cognitive load theory, increasing the number of target items resulted in significantly worse performance on the 3D-MOT for both the ASD \((n = 15)\) and TD \((n = 15)\) groups as the number of tracked items increased. However, contrary to our hypothesis, performance at higher levels of cognitive loading was not relatively impaired for the ASD group. Thus, this result does not support the notion that individuals with ASD have a greater perceptual capacity or decreased attentional capacity as compared to neurotypicals. Though the TD group outperformed the ASD group at all loading levels, none of these differences was statistically detectable. This suggests that individuals with ASD are susceptible to load taxation in a dynamic visual attention task in ways that are comparable to neurotypicals.

Keywords: autism spectrum disorder, multiple object tracking (MOT), visual attention, cognitive load
Literature Review

Autism spectrum disorder (ASD) is a heterogeneous neurodevelopmental disorder that typically emerges in early childhood. A recent report from the Centers for Disease Control (2014) revealed that roughly 1.5% of individuals in the United States have a diagnosis of ASD, and that this rate is increasing. The DSM-5 diagnostic criteria for ASD include: (1) persistent deficits in social communication and social interactions across multiple contexts; and (2) restricted, repetitive patterns of behaviour, interests, or activities; currently and/or historically. These criteria are rated by severity, and the diagnosis specifies whether a language or intellectual impairment is present (American Psychiatric Association, 2013).

For decades, deficits in social cognition and communication have been the proverbial face of ASD. However, researchers have begun to recognize that atypicalities in visual perception and attention in ASD may be highly related to both social and non-social deficits (e.g., repetitive behaviours, preoccupations with routine or sameness) (e.g., Allen & Courchesne, 2001; Keehn et al., 2017; van Noordt et al., 2017). Many researchers have found superior performance in visual search tasks such as the Embedded Figures Test in children and adults with ASD (e.g., Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009; Kaldy, Kraper, Carter, & Blaser, 2011; Mottron, Belleville, & Ménard, 1999). The Embedded Figures Test (Witkin, 1971) requires the identification of visual elements that are hidden within larger fields. Frith’s (1989) Weak Central Coherence (WCC) theory maintains that individuals with ASD demonstrate a perceptual processing bias for featural or local information, and an inability to integrate this local information to obtain a more global picture (Happé & Frith, 2006). However, subsequent research showed that global processing difficulties may be overcome when tasks specifically demand global attention (e.g., Happé & Frith, 2006; Koldewyn, Weigelt, Kanwisher, & Jiang,
2013). Thus, over time, many researchers moved from labelling this difference in ASD a *deficit* in global processing (as in the WCC theory), to a *strength* in detail-focused processing (as in the Enhanced Perceptual Functioning model; e.g., Mottron, Dawson, Soulières, Hubert, & Burack, 2006).

Perception works in concert with attention; the latter of which is limited in capacity and acts as a type of perceptual funnel for the observer (Rensink, 2013). Attentional differences are among the earliest indicators of autism spectrum disorder to emerge (Powell, Wass, Erichsen, & Leekam, 2016). Unlike impaired social orienting (e.g., orienting to faces or social movement), which is generally not seen at very early stages of development, young children who are later diagnosed with ASD show impaired non-social attention at a very early age (Powell et al., 2016). Some researchers have found deficits in selective attention and higher distractibility among individuals with ASD during visuospatial tasks (Belmonte & Yurgelun-Todd, 2003; Burack, 1994; Ciesielski, Coursehne, & Elmasian, 1990). While some research has found typical distributed attention in ASD (e.g., Bogte, Flamma, Van Der Meere, & Van Engeland, 2009; Rutherford, Richards, Moldes, & Sekuler, 2007), others have found deficits (e.g., Althaus, De Sonneville, Minderaa, Hensen, & Til, 1996; Ciesielski, Knight, Prince, Harris, & Handmaker, 1995). Working memory in the visual domain is believed to depend greatly on sustained attentional capacity, and to be moderated by the ability to inhibit distractions (Cowan, 2001). On the Cambridge Neuropsychological Test Automated Battery, Chien and colleagues (2015) found impairment in visual memory and visual sustained attention in a sample of adolescents with ASD; which was moderated by age and IQ.

These discrepant findings (i.e., strengths in some areas of visual perception and attention, and weaknesses in others) may be resolved if we assume that individuals with ASD have a
higher load capacity than typically developing individuals (Adams & Jarrold, 2012; Remington, Swettenham, Campbell, & Coleman, 2009; Remington, Swettenham, & Lavie, 2012) or if we assume that they have a lower attentional resource limit than typically developing individuals (Koldewyn et al., 2013).

Lavie (1995, 2005) proposed the load theory of attention that states that when focusing attention on task-relevant stimuli at low load, spare processing capacity shifts involuntarily to the perception of irrelevant stimuli (late selection). However, when focusing on task-relevant stimuli at high load, processing capacity is reached and irrelevant stimuli are ignored. Put differently, the manner in which distractors are processed depends heavily on the level and type of load involved in the processing of goal-relevant information. If a task exhausts an individual’s perceptual capacity (i.e., when load is high), distractors will not be processed; but if full load capacity has not yet been met (i.e., when load is low), distractors will be processed. Since first proposed by Lavie (1995), myriad studies in the visual domain have lent support to the load theory of attention in typically developing individuals (e.g., Bahrami, Lavie, & Rees, 2007; Lavie, Beck, & Konstantinou, 2014; Wei, Kang, & Zhou, 2013). In most behavioural studies such as those cited above, load was manipulated either by varying the number of items in the display, varying the similarity of the target and non-target stimuli, or altering the task while keeping the display constant (Murphy, Groeger, & Greene, 2016).

Using a modified flanker task varying perceptual load, Remington and colleagues (2009) concluded that individuals with ASD required higher perceptual load to be able to ignore irrelevant distractors; suggesting that they may have enhanced perceptual capacity. Remington and colleagues (2012) replicated these findings using a similar task; confirming that, under higher levels of load, perceptual sensitivity was reduced in typical adults but not in adults with...
ASD. Subsequent studies have revealed similar performance between adults with ASD and neurotypicals under extremely high perceptual load; suggesting a limit to ASD superiority in visual search tasks (Hessels, Hooge, Snijders, & Kemner, 2014). Other studies have revealed greater susceptibility to inattentional blindness; both overall and as a function of perceptual load (interpreted as higher perceptual capacity) in ASD compared to neurotypicals (Swettenham et al., 2014). Furthermore, neurotypicals with above average scores on the Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) demonstrated greater distractor interference at high loading than those with below average AQ scores (Bayliss & Kritikos, 2011). These results provide additional support for the link between autism symptomology and individual differences in selective attention as a function of load.

Multiple object tracking (MOT) paradigms ask the participant to track a certain number of items in visual space over a certain time period while attempting to ignore distractor items. MOT paradigms in general (and our 3D-MOT task specifically) are accessible, adaptable, and accurate measures of selective, distributed, dynamic, and sustained attention: (1) selective attention to a target object or objects while ignoring distractor objects, (2) distributed attention by spreading attentional resources across multiple objects, (3) dynamic attention by tracking objects in 2D or 3D space, and (4) sustained attention over a period of time; both within and across trials (Pylyshyn & Storm, 1988; Scholl, 2009).

MOT tasks have recently been used to assess attentional abilities in individuals with ASD (Evers et al., 2014; Jiang, Capistrano, & Palm, 2014; Koldewyn et al., 2013; O’Hearn, Franconeri, Wright, Minshew, & Luna, 2013; Van der Hallen et al., 2015). In their study, Evers and colleagues (2014) found a reduced bias towards more global processing in the ASD group (i.e., reduced tracking performance when targets were grouped to distractors). O’Hearn and
colleagues (2013) used a similar modified MOT (Scholl, Pylyshyn, & Feldman, 2001). Their aim was to explore how differences in individuation might affect MOT performance. Individuation refers to the ability to attentionally capture a small number of items at the same time; it is also often referred to as subitizing. Contrary to Evers and colleagues’ (2014) findings, O’Hearn and colleagues (2013) found that ASD groups of various ages (9-12 years, 13-17 years, and 18-29 years) performed worse than their age-matched control groups overall, but did not find any effects of MOT condition (i.e., traditional vs. grouped). Van der Hallen and colleagues (2015) most recently used MOT to investigate the effect of object-based grouping in children with and without ASD and found that both showed adequate MOT performance (no group differences) and a similar amount of grouping interference. These studies provide support some support for the notion that grouping local components (i.e., targets linked to distractors) modifies attention to those separate components.

The other two published studies using MOT in an ASD sample focused on determining whether differences exist in their attentional capacity in a dynamic, sustained attention task. In a study by Jiang and colleagues (2014), though children (7-14 years) with ASD showed a lower tracking capacity overall on the MOT task than the typically-developing children, they showed greater deficit in a spatial working memory task than an MOT task; despite the latter placing heavier demands on sustained attention, location updating, and distractor inhibition. Koldewyn and colleagues (2013) found that 5- to 12-year-old children with ASD could track slightly fewer items than age-matched neurotypical children overall, but their performance was not particularly worse at higher speeds. The authors concluded that lower performance on the MOT task was not attributed to a specific deficit in dynamic attention, but rather a lower capacity to select and
maintain attention to multiple targets (selective, sustained, and distributed attention) (Koldewyn et al., 2013).

To reiterate, MOT paradigms have been used to assess both perceptual (local vs. global perception) and visuo-attentional (selective and sustained attention) abilities in ASD. Though Koldewyn and colleagues (2013) and Jiang and colleagues (2014) examined load capacity indirectly in children with ASD, no study has directly assessed the effects of cognitive load on visual attention in ASD using a 3D-MOT task. As outlined above, MOT paradigms are useful for targeting many types of visual attention (selective, distributed, dynamic, and sustained). They are also ideal for assessing the effect of visuospatial cognitive load manipulations, as task difficulty is increased with each additional item tracked. MOT tasks are nonverbal, which makes them more accessible to lower functioning individuals on the autism spectrum, and computerized tasks like ours tend to be better received by participants with ASD (DeThorne, Aparicio Betancourt, Karahalios, Halle, & Bogue, 2015; Moore & Calvert, 2000; Somogyi, Kapitány, Kenyeres, & Donauer, 2016). Our specific task offers the additional advantage of being three-dimensional (as is the world in which we live) and, thus, more applicable to real-world scenarios than traditional two-dimensional MOT tasks.

Given the mixed evidence from the two capacity-targeting MOT studies comparing children with ASD to neurotypical children, it is possible that adolescents and adults with autism have different attentional resource capacity than typically developing adolescents and adults. Again, Koldewyn and colleagues (2013) did not find a specific deficit in dynamic attention in their ASD sample, but argued that a deficit in selective attention was present. Jiang and colleagues (2014) found relatively spared sustained attention in their ASD sample, but overall worse performance on the MOT task as compared with neurotypicals. An alternative hypothesis
to the increased capacity theory would be that adolescents and adults might have a weaker ability to select and maintain attention to multiple targets (diminished attentional resource theory).

**Aims and Hypotheses.** We aimed to assess the effect of a cognitive load manipulation in adolescents and adults with ASD using a three-dimensional multiple object tracking task. In line with previous research (e.g., Tullo, Faubert, & Bertone, 2015), we expected to find significant differences between performance at all four levels of cognitive loading within groups; with each additional target item tracked increasing the difficulty of the task. In line with (1) the enhanced perceptual capacity, and (2) the decreased attentional resource theories we also hypothesized that the ASD group would show poorer performance at higher loading levels. According to the enhanced perceptual capacity theory, if this outcome were to be observed, it may be attributable to the over-processing of distractors by the ASD group as compared to the TD group (whose loading capacity may be exhausted). According to the decreased attentional resources theory, if this outcome were to be observed, it may be attributable to the ASD group having fewer attentional resources to allocate to targets as compared to the TD group. This is the first MOT study to test the enhanced load capacity hypothesis; which has historically been tested with dual-task paradigms; while the attentional resource theory has long been associated with MOT paradigms, specifically.

Secondary to our two main hypotheses, we expected that 3D-MOT performance would be positively correlated with Wechsler IQ scores as well as the Conners Continuous Performance Test (CPT); a standardized measure of attention (see Method section for descriptions). We administered the CPT to all participants as a way to screen for attentional difficulties, but also included a component measure, $d'$ (detectability) $t$-score, in our correlational analyses as we believed it to be the most relevant attentional analogue to our 3D-MOT task.
Method

Participants

**Autism spectrum disorder (ASD) group.** Twelve (12) males and 3 females on the autism spectrum were recruited through the *Clinique d’évaluation des troubles envahissants du développement (CETED)* at Rivière-des-Prairies Hospital, and the Summit Center for Education, Research, and Training (SCERT) at Summit School; both of which are located in Montreal, QC, Canada. Participants ranged in age from 15 to 30 years (*M* = 22.1, *SD* = 5.2). Individuals were excluded from participating if they (1) were taking medication that would affect their attention (i.e., stimulant or sedative medication), (2) had a diagnosis of attention deficit hyperactivity disorder (ADHD), (3) had a personal or family history of a seizure disorder (e.g., epilepsy), or (4) had an uncorrected vision problem. Only participants with verbal Wechsler IQ scores in the *Very Low* (formerly *Borderline*) range or higher (≤70) were included in this study, and the mean FSIQ was 102.1 (*SD* = 18.3). All ASD participants met diagnostic criteria for ASD based on the Autism Diagnosis Observation Schedule (ADOS; Lord et al., 2000) or a combination of the ADOS and the Autism Diagnosis Interview -- Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994). All participants were financially compensated for their time.

**Typically developing (TD) group.** Ten (10) male and 5 female neurotypical participants were recruited via online advertisements and tested at the main PNLab location at McGill University in Montreal, QC, Canada. Participants ranged in age from 19 to 30 years (*M* = 23.6, *SD* = 3.1). Individuals were excluded from participating if they (1) were taking medication that would affect their attention (i.e., stimulant or sedative medication), (2) had a diagnosis of attention deficit hyperactivity disorder (ADHD), (3) had a personal or family history of a seizure disorder (e.g., epilepsy), or (4) had an uncorrected vision problem. Only participants with verbal
Wechsler IQ scores in the Very Low range or higher (≤70) were included in this study, and the mean FSIQ was 107.7 (SD = 11.4). All TD participants were compensated for their participation.

The ASD and TD groups were matched on gender; chronological age; and Wechsler full-scale IQ (FSIQ), verbal comprehension ability (VCI), and perceptual reasoning ability (PRI). Table 1 shows a breakdown of demographic information for the ASD and TD groups.

Table 1

*Participant demographic information.*

<table>
<thead>
<tr>
<th></th>
<th>ASD (12 males, 3 females)</th>
<th>TD (10 males, 5 females)</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.1</td>
<td>5.2</td>
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<tr>
<td>FSIQ</td>
<td>102.1</td>
<td>18.3</td>
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<tr>
<td>VCI</td>
<td>101.8</td>
<td>22.6</td>
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<tr>
<td>PRI</td>
<td>103.3</td>
<td>19.9</td>
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*Note:* FSIQ = Full-Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index. Standard scores are reported for FSIQ, VCI and PRI.

**Procedure**

**3D-MOT task.**

*Apparatus.* Participants were fitted with a Sony HMZ-T1 wearable head-mounted display (HMD) for presentation of the 3D-MOT stimuli. The HMD had a display resolution of 1280 pixels by 720 pixels and a field of view of 45° visual angle. The HMD unit was lightweight (420 grams) and comfortable, but some participants wore glasses during the presentation of the stimuli and/or had large head circumferences, which rendered it impossible to fasten the straps of the HMD behind their heads. These participants held the apparatus with their hands and rested their elbows comfortably on a cushion on the table in front of them. The 3D-MOT program was launched from a 15.6” HP Elitebook 8570w Mobile Workstation laptop running Windows 7
Professional. The screen had a resolution of 1920 pixels by 1080 pixels. A real-time two-dimensional display of the three-dimensional display presented via HMD to the participant was visible on the laptop screen.

**Stimuli.** To ensure that participants were capable of completing the 3D-MOT task, practice trials tracking 1 sphere were administered before the actual trials began. To demonstrate their competence, participants needed to obtain correct responses on the first 2 of 3 trials. If unsuccessful, the instructions were restated to the participants and they were then required to obtain 2 correct responses on the next 3 trials in order to qualify for subsequent testing. All participants qualified for the study. Participants were then asked to track sequences of 1, 2, 3, and 4 target sphere trials in three-dimensional virtual space, over two blocks. Two blocks of trials for each loading level (number of targets) were presented in random, counterbalanced order (e.g., 2, 4, 1, 3, 3, 1, 2, 4) to each participant, with the number of trials presented at each loading level depending on the participant’s performance (range: 7 to 21). The experimenter controlled the presentation trials and trial blocks, and recorded participants’ verbal responses by entering them manually on the laptop’s numerical keypad. As presented in Figure 1., each trial was broken down into five stages.

(a) (b) (c) (d) (e)

**Figure 1.** Example of a 3D-MOT task trial comprised of 5 stages. (a) All 8 spheres are displayed in the visual field. (b) The target spheres (4, in this case) are highlighted orange. (c) Target spheres change back to yellow and all spheres move randomly throughout the visual field. (d) Numbers (1-8) appear on the spheres and the participant attempts to identify the target spheres. (e) Feedback is given to the participant by re-highlighting the target spheres in orange.
Trials began with a presentation of 8 yellow spheres randomly fixed across 3D virtual space (Figure 1a); in this case, a cube. The virtual size of the spheres varied between 20 and 55 cm, depending on their position in virtual space. Depending on the loading condition, 1, 2, 3, or 4 spheres then changed from yellow to orange for one second – these represented the spheres to track (targets). Figure 1b shows an example of a trial in which 4 spheres were to be tracked. The orange spheres then returned to their original colour and moved linearly and randomly throughout the 3D virtual space (Figure 1c). Just as physics would dictate in the real world, a sphere’s course was altered accordingly each time it bumped into another sphere or hit the outside boundaries of the virtual cube. After eight seconds of movement, the spheres stopped moving and an individual number from 1 to 8 appeared next to each for identification purposes. Participants then verbally identified the sphere(s) that they believed to be the target(s). Their selections were recorded manually by the experimenter on the numerical keypad, which “lit up” the chosen spheres (Figure 1d). Finally, feedback was provided to the participant by way of the target spheres once again changing to orange (Figure 1e). The next trial in the block would then begin automatically.

The speed of the spheres increased or decreased in subsequent trials depending on whether participants identified all tracked spheres correctly or not in the previous trial, respectively (1-up, 1-down staircase procedure; Kaernbach, 1991; Levitt, 2005). Initial sphere speed was set at 68 cm/second displacement, and speed increased or decreased by 0.05 log. Sphere movement speeds ranged from 27 cm/second to 544 cm/second. The 3D-MOT task ended once six inversions occurred (i.e., a correct answer followed by an incorrect answer, and vice-versa). The geometric mean speed of the last four inversions (i.e., the speed threshold) was calculated for each block of trials, and the average of the two blocks’ speed thresholds was used.
as our measure of 3D-MOT performance (Legault, Troje, & Faubert, 2012). The average of
speed thresholds from Blocks 1 and 2 of each loading level represented the measure of
performance on the 3D-MOT task for that loading level (e.g., for 3 target items, \( ST_{(3, \text{block1})} + ST_{(3, \text{block2})}/2 = ST_3 \)).

**Cognitive measure.** All TD participants and 9 ASD participants completed the Wechsler
Abbreviated Scale of Intelligence, 2nd Edition (WASI-II; Wechsler, 2011). The WASI-II is a
brief measure of cognitive ability for individuals aged 6 to 90 years. It includes four subtests that
factor into verbal comprehension (VCI) and perceptual reasoning (PRI) indices, as well as a full-
scale intelligence quotient (FSIQ). The remaining 6 ASD participants, recruited from the shared
CETED database at Rivière-des-Prairies Hospital, already had valid Wechsler IQ scores at time
of testing in the present study. These were obtained during their recent participation in other,
unrelated research studies. Thus, VCI, PRI, and FSIQ scores from related adult and child
comprehensive Weschler intelligence scales were used for those participants in place of WASI-II
scores. These tests included the Wechsler Adult Intelligence Scale, 4th Edition (WAIS-IV;
Wechsler, 2008), and the Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV;
Wechsler, 2003). The publisher of all three of the above-mentioned Wechsler tests maintains that
there are “strengthened connections between the WASI–II and the comprehensive Wechsler
intelligence scales [that] result in a stronger empirical foundation for using the instruments
together” (Wechsler, 2011).

**Attention measure.** All participants completed the Conners Continuous Performance
Test (CPT; Conners, 2000) on the same laptop used for the 3D-MOT task. This 14-minute-long
computerized test of attention is widely utilized by clinicians to assess attention-related
difficulties, and by researchers as a multifaceted measure of attention. These facets include
inattentiveness, impulsivity, sustained attention, and vigilance. In this test, participants must press the spacebar as soon as they see a letter appear on the screen in front of them, but must try to inhibit this response when that letter is an “X.” The inter-stimulus interval (ISI) time varies by block between 1, 2, and 4 seconds, and the test contains 360 trials over 6 blocks. Having been tested several months before the ASD group, an earlier edition of the test (CPT II) was administered to the TD group, while the most recent edition of the test (CPT 3; Conners, 2014) was administered to the ASD group. For the purposes of this study, CPT-II and CPT-3 data are comparable because the t-score scale and normative sample are identical (Conners, 2014). The clinical cutoff for the CPT (i.e., the level at which performance signals the presence of attentional problems) is at t-score of 60. The highest $d'$ t-score obtained in our sample was 60. $D'$ scores ranged from 31 to 57 in the ASD group, and between 43 and 60 in the TD group.

A measure of inattentiveness, the detectability ($d'$) t-score is a transformed signal detection statistic that demonstrates how well the participant can discriminate non-targets/noise (in this case, the letter “X”) from targets/signal (all other letters). The $d'$ t-score was determined to be the most useful score to compare with performance on the 3D-MOT task; as the 3D-MOT task demands an ability to detect the signal (target spheres) from the noise (non-target spheres). Scores other than $d'$ on the CPT were not available for the TD group. All CPT t-scores were correlated with 3D-MOT performance for the ASD group (see Results section). Gender-specific norms were used to evaluate CPT performance.

Table 2 shows the breakdown of the testing procedure and average amount time taken to complete each portion of the study for all participants.
Table 2

Breakdown of testing procedure

<table>
<thead>
<tr>
<th>Task</th>
<th>Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed Consent</td>
<td>5</td>
</tr>
<tr>
<td>3D-MOT</td>
<td>45-60</td>
</tr>
<tr>
<td>WASI-II*</td>
<td>30</td>
</tr>
<tr>
<td>CPT</td>
<td>15</td>
</tr>
<tr>
<td>Breaks as needed</td>
<td>5-15</td>
</tr>
<tr>
<td>Total time</td>
<td>100-125</td>
</tr>
</tbody>
</table>

Note: This step was omitted for participants with valid Wechsler IQ scores.

Results

All data were analyzed using the IBM SPSS 20 statistical software package for iOS operating systems (IBM Corp, 2012). As a first step, all data were inspected for outliers and any unusual distribution properties.

Cognitive Load

A 4 (1, 2, 3, and 4 target items) x 2 (ASD vs. TD) mixed model ANOVA did not find a significant interaction between loading level and diagnostic group, $F(3, 84) = 0.27, p = 0.61$; nor was there a significant difference in performance between diagnostic groups when speed threshold was collapsed across all loading levels ($t(28) = -1.93, p = 0.06$).

Two separate repeated measures ANOVAs revealed significant differences across all levels of cognitive load for both the ASD ($F(3, 42) = 263.47, p < 0.001$, partial $\eta^2 = 0.95$) and TD ($F(3, 42) = 171.19, p < 0.001$, partial $\eta^2 = 0.92$) groups. A Bonferroni correction was applied to the alpha level in pairwise comparisons cognitive loading levels for both groups (0.05/6 comparisons = adjusted alpha level of 0.008), and all comparisons were significant (ASD group: ST$_1$ vs. ST$_2$, $t(14) = 17.00, p < 0.001$; ST$_2$ vs. ST$_3$, $t(14) = 5.97, p < 0.001$; ST$_3$ vs ST$_4$, $t(13) = 5.06 p = 0.001$; TD...
group ST\textsubscript{1} vs. ST\textsubscript{2}, \(t_{(14)} = 13.33\ p < 0.001\); ST\textsubscript{2} vs. ST\textsubscript{3}, \(t_{(14)} = 4.97,\ p = 0.001\); ST\textsubscript{3} vs ST\textsubscript{4}, \(t_{(14)} = 5.29,\ p = 0.001\). Figure 2 shows the decrease in average speed threshold as a function of increased number of target items for the ASD group (Figure 2a) and TD (Figure 2b) groups.

**Figure 2.** Average 3D-MOT speed threshold scores by number of target items (cognitive loading level). Means and standard errors are shown. Higher average speed threshold scores reflect better performance on the 3D MOT task. Black bars show average speed threshold in cm/s for the ASD group tracking 1 (\(M = 253.55,\ SE = 6.26\)), 2 (\(M = 134.52,\ SE = 9.96\)), 3 (\(M = 92.72,\ SE = 8.92\)), and 4 (\(M = 64.52,\ SE = 8.92\)) spheres. White bars show average speed threshold in cm/s for the TD group tracking 1 (\(M = 275.79,\ SE = 13.21\)), 2 (\(M = 155.24,\ SE = 9.87\)), 3 (\(M = 116.03,\ SE = 7.43\)), and 4 (\(M = 77.86,\ SE = 6.72\)) spheres. *\(p < .01\).
3D-MOT Performance and Cognitive Ability

Performance on the 3D-MOT task was positively associated with cognitive ability in both groups. However, this association was found chiefly in the ASD group and was largely driven by perceptual reasoning ability (PRI). Significant correlations were found between PRI and ST2 ($r_{13} = 0.582, p = 0.023$), ST3 ($r_{13} = 0.599, p = 0.018$), and ST4 ($r_{13} = 0.696, p = 0.004$) for the ASD group, and with ST3 $r_{13} = 0.724, p = 0.002$) for the TD group. No significant correlations between 3D-MOT performance and VCI were found. This pattern of associations provides support for the notion that 3D-MOT task taps nonverbal, spatial cognitive abilities as measured by Wechsler intelligence tests; especially for individuals on the autism spectrum. Table 3 shows correlations between 3D-MOT performance and Wechsler IQ scores for the ASD and TD groups.
Table 3

Correlations between 3D-MOT performance and Wechsler IQ scores.

<table>
<thead>
<tr>
<th>Speed Threshold</th>
<th>FSIQ</th>
<th>VCI</th>
<th>PRI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ASD group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.402 (0.137)</td>
<td>0.319 (0.246)</td>
<td>0.385 (0.156)</td>
</tr>
<tr>
<td>2</td>
<td>0.321 (0.244)</td>
<td>0.060 (0.831)</td>
<td>0.582* (0.023)</td>
</tr>
<tr>
<td>3</td>
<td>0.560* (0.030)</td>
<td>0.395 (0.145)</td>
<td>0.599* (0.018)</td>
</tr>
<tr>
<td>4</td>
<td>0.665** (0.007)</td>
<td>0.501 (0.057)</td>
<td>0.555* (0.032)</td>
</tr>
<tr>
<td>Collapsed</td>
<td>0.577* (0.024)</td>
<td>0.368 (0.177)</td>
<td>0.682** (0.005)</td>
</tr>
<tr>
<td><strong>TD group</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.320 (0.245)</td>
<td>0.215 (0.441)</td>
<td>0.277 (0.317)</td>
</tr>
<tr>
<td>2</td>
<td>0.137 (0.626)</td>
<td>0.019 (0.945)</td>
<td>0.235 (0.399)</td>
</tr>
<tr>
<td>3</td>
<td>0.342 (0.212)</td>
<td>-0.081 (0.774)</td>
<td>0.724** (0.002)</td>
</tr>
<tr>
<td>4</td>
<td>0.412 (0.127)</td>
<td>0.220 (0.430)</td>
<td>0.414 (0.125)</td>
</tr>
<tr>
<td>Collapsed</td>
<td>0.348 (0.202)</td>
<td>0.125 (0.656)</td>
<td>0.453 (0.090)</td>
</tr>
</tbody>
</table>

Note: Two-tailed Pearson correlations and (p values) are shown. * p <0.05 ** p <0.01

3D-MOT Performance and the CPT

D’ scores differed significantly between groups, with the ASD group having a statistically and clinically better ability to distinguish targets from non-targets on the CPT than the TD group ($t_{(28)} = -3.572, p = 0.001$). The mean $d’$ score for the TD group ($M_{TD} = 51.67$) falls within the average range (indicating an average ability to distinguish targets from non-targets), while the mean $d’$ score for the ASD group ($M_{ASD} = 43.20$) falls within the low range (indicating a good ability to distinguish targets from non-targets).

Contrary to our hypothesis, however, $d’$ scores were not significantly associated with performance on the 3D-MOT task for the TD group ($ST_1 r_{(13)} = 0.372, p = 0.172$; $ST_2 r_{(13)} = 0.206, p = 0.462$; $ST_3 r_{(13)} = 0.087, p = 0.757$; $ST_4 r_{(13)} = -0.312, p = 0.257$), and only associated
with ST$_2$ in the ASD group ($ST_1 r_{(13)} = -0.225, p = 0.42; ST_2 r_{(13)} = -0.515, p = 0.050; ST_3 r_{(13)} = -0.293, p = 0.288; ST_4 r_{(13)} = -0.193, p = 0.490$).

Although other CPT measures were unavailable for the TD group, these were examined for the ASD group in relation to 3D-MOT performance. Significant negative associations were found between 3D-MOT performance at higher levels of cognitive loading and CPT $3^{rd}$ Perseverations scores in the ASD group ($ST_2 r_{(13)} = -0.566, p = 0.028; ST_3 r_{(13)} = -0.671, p = 0.006$). A measure of impulsivity, perseverations are random or anticipatory responses (button presses) made during the task. This association suggests that lower impulsivity may be related to heightened sustained attention (i.e., better performance) on the 3D-MOT task.

**Discussion**

The present study is the first to use a three- (as opposed to two-) dimensional multiple object tracking paradigm with an ASD population. We aimed to assess visual attention using a 3D-MOT task in individuals with autism. More specifically, we assessed the effect of cognitive load on 3D-MOT performance in individuals with ASD compared to typically developing individuals. This was accomplished by having participants track 1, 2, 3, and 4 target spheres of 8 total spheres in virtual space; calculating the average speed at which all targets could be correctly identified at each level of loading (performance outcome measure); and exploring within- and between-group differences in speed thresholds. The association between 3D-MOT performance and Wechsler IQ and CPT $t$-scores was also investigated.

In line with the cognitive load theory of attention, we hypothesized that task difficulty would increase as number of target items increased. As expected, increasing the number of target items resulted in significantly worse performance on the 3D-MOT (i.e., lower speed thresholds at higher loading levels). We also hypothesized that individuals with ASD have enhanced
perceptual capacity, or decreased attentional resources, and that this would manifest in weaker 3D-MOT performance specifically under higher levels of cognitive loading. Contrary to our hypothesis, however, speed thresholds at higher levels of cognitive loading were not relatively decreased for the ASD group. This result does not support the notion that individuals with ASD have a greater perceptual capacity or decreased attentional resources.

Although the TD group had, on average, higher speed thresholds at all levels of cognitive loading than the ASD group, their performance was not significantly better than the ASD group at any loading level. It is possible that increasing both tracked items and distractor items in our 3D-MOT task would lead to a significant difference between diagnostic groups. It is also possible that the trend we observed would become significant with an increased sample size. Our results were consistent with those of Koldewyn and colleagues (2013), who did not find deficits in selective attention in their ASD group on an MOT task. If differences in selective attention were at the root of diagnostic differences in MOT capacity in Koldewyn and colleagues’ (2013) study, they would have been seen at higher speeds; at which the risk of selection failure is greater (Franconeri, Lin, Pylyshyn, Fisher, & Enns, 2008; Franconeri, Jonathan, & Scimeca, 2010).

3D-MOT performance was linked to PRI primarily in the ASD group, suggesting that perceptual reasoning abilities are associated with visuo-spatial attention in ASD. As of this writing, only two studies have reported a link between attention task performance and perceptual reasoning ability specifically. Oksama and Hyönlä (2004) found that visuospatial-short-term memory and attention switching were associated with MOT performance, and recent work in our laboratory using the 3D-MOT task has yielded similar positive correlations between MOT performance and perceptual reasoning ability with typically-developing adults (Tullo et al., 2015). Though the specific relationship between PRI and MOT performance in ASD appears
unique, some researchers have found links between IQ and executive functioning ability in ASD populations (Keehn, Lincoln, Müller, & Townsend, 2010; Liss et al., 2001; Lopez, Lincoln, Ozonoff, & Lai, 2005). For instance, though a study by Keehn and colleagues (2010) did not reveal significant differences in executive control in ASD versus TD groups on an attention task, only the performance of the ASD group was significantly correlated with IQ. It is possible that a greater ability to parse a visual scene into its parts (an ability required by subtests making up the PRI such as Block Design and Matrix Reasoning) is associated with a lower likelihood of using holistic (global) strategies to reduce cognitive load when attentional resources are limited (Meinhardt-Injac, Persike, & Meinhardt, 2014; Mottron et al., 1999).

Though we expected performance on the 3D-MOT to be associated with our primary CPT measure ($d'$ – a measure of inattentiveness characterizing the ability to discriminate targets from non-targets), it was not. Interestingly, our TD group had significantly better CPT $t$-scores overall, but this did not translate into better performance on the 3D-MOT. Though we did not have the TD data available, good performance on the 3D-MOT was associated with greater impulse control in the ASD group. This result is consistent with a study by Gonzalez, Martin, Minshew, and Berhmann (2013), in which adults with ASD were better at inhibiting impulsive trigger responses in a decision task.

**Limitations**

Despite our attempts to control for as many participant and procedural factors as possible, we are aware of several limitations to our study. As most of our efforts were focused on obtaining a sample of participants with ASD with confirmed autism diagnoses from accessible professionals, and who did not have a co-occurring attention disorder, our sample size is smaller than we would have preferred. Our exclusionary criteria (e.g., no comorbid attention disorders)
limit our ability to generalize our findings to all other individuals with and without ASD, especially those with attention disorders. Given that many participants in our ASD group have been eager to participate in (and/or have participated in) research studies before, ours may not a representative sample of individuals with high functioning ASD, or individuals with ASD in general. 3D-MOT performance was linked to PRI in the ASD group only, suggesting that perceptual reasoning abilities are associated with visuo-spatial attention in ASD.

**Current and Future Directions**

An application of this technology and general line of inquiry that is currently being explored is the use of 3D-MOT as an attention training task. Thompson, Gabrieli, and Alvarez (2010) determined that MOT training could increase visual attention capacity as well as tracking speed in a group of typically-developing adults. Most recently, Chamoun and colleagues (2017) have observed improved tracking performance using our task over multiple sessions; and Tullo, Guy, Faubert and Bertone (2018) have found that multiple sessions using our 3D-MOT task with children with various special needs improved their attention and learning. Even without being solicited, many of our ASD participants expressed great enjoyment of the 3D-MOT task; and given the high comorbidity of ADHD in individuals with autism, an intervention to help improve attention (e.g., in the classroom) would likely be well-received by parents, teachers, and students with autism themselves.
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*Journal of Vision, 15, 463.*


CHAPTER 4: BRIDGING MANUSCRIPTS

The first manuscript aimed to assess the effect of load on 3D-MOT performance in adolescents and adults with ASD, and to determine if (and if so, how) performance differs from that of typically-developing individuals. We had hoped to find support for superior perceptual load capacity or decreased attentional resources in our ASD group but instead found no statistically significant differences in performance between the ASD and TD groups; though the TD group did show higher speed thresholds than the ASD group at all loading levels. We wished to use the same platform (our 3D-MOT task) in Manuscript II to address a different question; namely, if (and if so, how) the presence of absence of the feedback provided in our task affects performance in individuals with ASD.

Manuscript II will outline how feedback differentially affects both typically developing individuals and those with ASD; including how our specific task feedback has been shown to affect typically developing individuals. The main focus of Manuscript II is to assess the effect of the presence of feedback on 3D-MOT task performance, and if and how this differs when we manipulate an important moderating factor in feedback effectiveness – task difficulty. Here, task difficulty can be thought of as low when cognitive load (i.e., number of targets) is low; and high when cognitive load (i.e., number of targets) is high. The methodology used in Manuscript II is therefore similar to that used in Manuscript I.

Our 3D-MOT task is currently being implemented as an attentional training tool (both in our laboratory and outside of it), with widely varying populations; from children with intellectual disabilities (Tullo, Guy, Faubert, & Bertone, 2018) to top-tier professional athletes (Romeas et al., 2016). Our goal looking forward is to expand the use of the 3D-MOT paradigm as a training tool to individuals with ASD. Now that we have established a successful paradigm in which to
assess attention in an accurate, controlled, and real-world environment, we wished to continue to try to optimize the task for use with an ASD population. Ergo, in addition to exploring the effects of feedback on task performance, another impetus for conducting a second study using the 3D-MOT with an ASD population is to further optimize the task for use as an attentional training tool. For example, if we were to find that feedback is detrimental to task performance (and, in future studies, learning over the course of several sessions) for individuals with ASD, we may choose to omit it from the 3D-MOT paradigm.
CHAPTER 5: MANUSCRIPT II: THE ROLE OF FEEDBACK IN PERFORMANCE IN AUTISM SPECTRUM DISORDER: EVIDENCE FROM A 3D MULTIPLE OBJECT TRACKING TASK

This is an exact reproduction of the following article (in preparation for submission):

The Role of Feedback in Performance in Autism Spectrum Disorder: Evidence from a 3D Multiple Object Tracking Task

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Abstract

Compared to neurotypicals, individuals on the autism spectrum differ in their response to feedback under experimental and learning conditions. Multiple factors contribute to feedback’s differential effect on performance and learning for all individuals. One of these factors is task difficulty. Multiple object tracking (MOT) tasks are useful in assessing attention and can be modified to be more or less difficult as a function of how many targets participants are asked to track. We asked adolescents and adults with \((n = 27)\) and without \((n = 28)\) ASD to track 1 (low difficulty) and 4 (high difficulty) target spheres over two randomized blocks of 3D-MOT testing. Half of the participants received feedback on their performance, and half did not. A three-way interaction was found between diagnostic group, feedback, and task difficulty. Performance at tracking 4 targets was significantly impaired for all groups when compared with performance at tracking 1 target. Individuals with autism who received feedback performed better than their peers who did not receive feedback, but only when task difficulty was low. Feedback did not significantly affect the performance of typically developing individuals, though a trend towards feedback being detrimental to performance was found. When diagnostic groups were pooled, participants who received feedback demonstrated significantly larger gains from the first block of trials to the second; suggesting that feedback is useful to task learning, even over the course of one session. In sum, the type of feedback used in our study appears to impact individuals with ASD differently than neurotypicals; aiding the former group when task difficulty is manageable.

*Keywords*: autism spectrum disorder, feedback, task difficulty, cognitive load, multiple object tracking (MOT), visual attention
Literature Review

Feedback is defined as any type of information conveyed by a human or non-human mediator to an individual about their performance (Hattie & Timperley, 2007). On behavioural tasks, feedback is usually provided visually and/or audibly within the experimental task; for example, the appearance of “Right!” on the screen after a correct response or the sound of a buzzer after an incorrect response. Task performance can often be strengthened with the provision of feedback in typically developing adults (Liu, Dosher, & Lu, 2014), but feedback can also have a negative impact on performance depending on its properties and the circumstances under which it is provided. One of these factors is task difficulty. Task difficulty can be modified by placing lesser or greater load on cognitive resources needed for learning or successful task completion (Bayindir, Bolger, & Say, 2017).

Feedback can be both beneficial and detrimental to task performance; its efficacy moderated by factors such as feedback type, delivery method, timing, and task difficulty. Hattie and Timperley (2007) identify four levels at which feedback can impact performance: the task level, the process level, the self-regulation level, and the self level. Task level (or criterial) feedback provides information about whether an individual’s performance is correct or incorrect; process level feedback is linked to the information processing and learning required to successfully complete a task (including error correction); self-regulation level feedback relies on the individual’s self-monitoring, self-control, and self-discipline to continue and/or improve task performance; and self level feedback is person-focused and irrelevant to the task itself (i.e., praise) (Hattie & Timperley, 2007). Task and process level feedback have been shown to elicit the greatest positive effect (Hattie & Timperley, 2007; Kluger & DeNisi, 1996). Different types of feedback can also have differing impacts on learning and motivation. For instance, Wilbert,
Grosche, and Gerdes (2010) determined that criterial feedback, specifically (i.e., feedback focused on task completion; similar to Hattie and Timperley’s (2007) task level feedback), significantly increased the rate of learning for university students. Wilbert and colleagues (2010) maintain that the focus on task fulfillment elicited by criterial feedback (as opposed to social comparative feedback; similar to Hattie and Timperley’s (2007) self level feedback) activates the goal to complete the task; thus leading to higher task involvement and better participant performance.

Hattie and Timperley (2007) reviewed 74 meta-analyses of various feedback delivery modalities and determined that the most effective for classroom learners are of the video-, audio-, or computer-assisted instructional type. Computerizing the delivery of feedback ensures that it is delivered uniformly and reliably to all participants; thus reducing human error. Feedback presented in a human-computer can also prove to be more intuitive and thus more valuable to the participant (Howie, Sy, Ford, & Vicente, 2000). The timing of feedback provision on different types of tasks can also differentially impact its efficacy. Immediate feedback during task learning often results in faster rates of acquisition (Hattie & Timperley, 2007). However, during tasks in which automaticity is the goal, immediate feedback may actually hamper performance (Hattie & Timperley, 2007).

The attentional resources of the individual at the time that feedback is introduced, and how the individual allocates these resources, may also affect one’s ability to integrate feedback (Maddox, Bohil, & Ing, 2004; Zeithamova & Maddox, 2007). The mental resources or effort needed to complete a cognitive task are a function of the task’s difficulty (Sweller, 1994), and more difficult tasks demand lengthier processing time and more practice before feedback becomes beneficial (Hattie & Timperley, 2007; Perico, 2014). In a face perception task,
Meinhardt-Injac, Persike, and Meinhardt (2014) found that while young adults benefitted from feedback under both low and high attentional demands, older adults demonstrated better performance only when feedback was presented at low attentional demand, and performed worse than a “No Feedback” group under high attentional demands. The attentional resources of individuals with ASD as applied to our 3D-MOT task were investigated in a prior study (Levy, Tullo, Mottron, Faubert, & Bertone, 2017). Though other researchers using MOT paradigms found differences in the number of objects successfully tracked by individuals with ASD (e.g., Koldewyn, Weigelt, Kanwisher, & Jiang, 2013), Levy and colleagues (2017) found no differences between diagnostic groups in the tracking of 1, 2, 3, and 4 objects in a 3D-MOT task.

A growing body of research supports the notion that individuals on the autism spectrum process certain forms of feedback differently than neurotypicals, and that this differential processing may underlie the social deficits present in their phenotype. Deficits in social interactions among individuals with high-functioning autism are thought to be influenced by lower ability to process feedback and rewards (Larson, South, Krauskopf, Clawson, & Crowley, 2011; McPartland, Crowley, Perszyk, Muerkerji, & Naples, 2012; Sinha et al., 2014; van Noordt et al., 2017).

Individuals with ASD exhibit atypical activation of reward circuitry during the anticipation and processing of monetary incentives and social cues (Dichter et al., 2012; Panasiti, Puzzo, & Chakrabarti, 2015; Rademacher, Schulte-Ruther, Hanewald, & Lammertz, 2016), but there is also evidence that the ability to process external, concrete feedback appears to be intact in ASD; while internal, more abstract feedback is weaker than in typically developing individuals (Larson et al., 2011). An EEG study of children and young adults with ASD revealed that although they are as sensitive to the valence of reward feedback, comparable to their
neurotypical peers, they have reduced synchronization of medial frontal theta activity during feedback processing (van Noordt et al., 2017). The medial frontal cortex is sensitive to deviations from expected outcomes and are involved in updating expectations following prediction errors (van Noordt et al., 2017).

Whether feedback is positive or negative (feedback valence) appears to impact learning in autism differently than in neurotypicals. For example, negative auditory feedback (i.e., a “beep” sound for incorrect responses) on a visual search task did not help performance in a group of adults with ASD (Plaisted, O’Riordan, & Baron-Cohen, 1998). In another example, removing negative feedback on the Wisconsin Card Sorting Task brought performance for the ASD group to TD levels (Broadbent & Stokes, 2013). Finally, Groen and colleagues (2008) found that children with ASD may place greater significance on positive versus negative feedback stimuli.

The vast majority of studies examining the effect of feedback on performance in ASD do so by comparing performance when provided social feedback (e.g., smiling faces for correct answers; frowning faces for incorrect ones) versus non-social feedback (e.g., awarding money or points for correct answers and removing them for incorrect ones). Social feedback appears to have less of a positive impact for individuals with ASD, while non-social feedback generally produces equivalent or nearly-equivalent performance in both ASD and typically-developing participants (e.g., Delmonte et al., 2012; Demurie, Roeyers, Baeyens, & Sonuga-Barke, 2011; Kohls, Peltzer, Herpetz-Dahlmann, & Konrad, 2009).

One way in which we can manipulate task difficulty is by using a paradigm that taps attentional load, such as multiple object tracking (MOT) tasks. In the context of multiple object tracking, load capacity denotes the number of objects an individual can perceive before attention becomes overloaded. Our laboratory has been the first to investigate the role of feedback in a
multiple object tracking task. Over the course of four training sessions, the provision of trial-by-trial (immediate) visual feedback increased task performance – in this case measured by the learning that took place from the first to the fourth session – for on our 3D-MOT task for typically-developing adolescents and adults (Perico, 2014). However, feedback appeared to decrease task performance in typically-developing participants completing just one session of our 3D-MOT task (Tullo et al., 2015); possibly by taxing attentional resources (Wilbert et al., 2010; Zeitmahova & Maddox, 2007). Thus, the feedback specifically associated with our 3D-MOT task appears to facilitate task performance for typically developing individuals when presented over multiple sessions, but may impose additional demands on attention before a certain threshold is met.

Aims and Hypotheses. We aimed to assess the role of feedback using a three-dimensional multiple object tracking (MOT) task in which task difficulty (cognitive load) was modified. We hypothesized that the provision of feedback might contribute to weaker MOT performance over this single session for both the ASD and TD groups. However, given the type of our feedback (criterial, visual, computerized, and non-social in nature), we did not expect that the discrepancy between the Feedback vs. No Feedback ASD groups would be significantly greater than that between the Feedback vs. No Feedback TD groups.

Method

Participants

Autism spectrum disorder (ASD) groups. Twenty (20) males and 7 females on the autism spectrum were recruited through and tested at the Clinique d’Évaluation des Troubles Envahissants du Développement (CÉTED) at Rivière-des-Prairies Hospital; and the Summit Center for Education, Research, and Training (SCERT) at Summit School in Montreal, Canada.
Participants ranged in age from 15 to 30, with a mean age of 21.1 years. Exclusionary criteria included (1) taking medication that would affect attention (i.e., stimulant or sedative medication), (2) having a diagnosis of attention deficit hyperactivity disorder (ADHD), (3) having a personal or family history of a seizure disorder (e.g., epilepsy), or (4) having an uncorrected vision problem. Only participants with verbal Wechsler IQ scores in the Very Low range or higher (<70) were included in this study, and the average full-scale IQ of the ASD sample was 100.3. All ASD participants met diagnostic criteria for ASD based on the Autism Diagnosis Observation Schedule (ADOS; Lord et al., 2000) or a combination of the ADOS and the Autism Diagnosis Interview -- Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994). All participants were compensated for their participation. Participants in the ASD sample were assigned to either Feedback ($n = 15$) or No Feedback ($n = 12$) conditions.

**Typically developing (TD) groups.** Fifteen (15) male and 13 female typically developing (TD) participants were recruited via online advertisements and tested at McGill University in Montreal, Canada. Participants ranged in age from 18 and 30, with a mean age of 23.1 years. The same exclusionary criteria that applied to the ASD group was applied to the TD group. Again, only participants with verbal Wechsler IQ scores in the Very Low range or higher (<70) were included in this study, and the average full-scale IQ of the TD sample was 105.1. All participants were compensated for their participation. Participants in the TD sample were assigned to either Feedback ($n = 15$) or No Feedback ($n = 13$) conditions.

The ASD and TD samples were matched on gender, chronological age, and Wechsler FSIQ, verbal comprehension ability (VCI), and perceptual reasoning ability (PRI). Table 1 shows a breakdown of demographic information for the ASD and TD samples.
Table 1
Participant demographic information.

<table>
<thead>
<tr>
<th>Feedback</th>
<th>ASD (12 males, 3 females)</th>
<th>TD (10 males, 5 females)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Range</td>
</tr>
<tr>
<td>Age (years)</td>
<td>22.1</td>
<td>5.2</td>
<td>15-30</td>
</tr>
<tr>
<td>FSIQ</td>
<td>102.1</td>
<td>18.3</td>
<td>65-134</td>
</tr>
<tr>
<td>VCI</td>
<td>101.8</td>
<td>22.6</td>
<td>70-147</td>
</tr>
<tr>
<td>PRI</td>
<td>103.3</td>
<td>19.9</td>
<td>65-133</td>
</tr>
<tr>
<td>No Feedback</td>
<td>ASD (8 males, 4 females)</td>
<td>TD (5 males, 8 females)</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Range</td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.1</td>
<td>4.0</td>
<td>15-29</td>
</tr>
<tr>
<td>FSIQ</td>
<td>98.5</td>
<td>8.8</td>
<td>84-110</td>
</tr>
<tr>
<td>VCI</td>
<td>96.3</td>
<td>9.1</td>
<td>82-112</td>
</tr>
<tr>
<td>PRI</td>
<td>105.9</td>
<td>12.4</td>
<td>80-120</td>
</tr>
</tbody>
</table>

Note: FSIQ = Full-Scale Intelligence Quotient, VCI = Verbal Comprehension Index, PRI = Perceptual Reasoning Index. Mean standard scores are reported for FSIQ, VCI and PRI. Note: No differences (p’s all > 0.05) were found when comparing demographic information within diagnostic groups, either (i.e., ASD F vs. ASD NF; TD F vs. TD NF).

Procedure

3D-MOT task. 3D-MOT stimuli were presented on a Sony HMZ-T1 wearable head-mounted display (HMD). The HMD had a display resolution of 1280 pixels by 720 pixels and a field of view of 45° visual angle. The 3D-MOT program was launched from a 15.6” HP Elitebook 8570w Mobile Workstation laptop running Windows 7 Professional. A 2D display of the 3D display presented via HMD to the participant was visible on the laptop screen in real time.

To ensure that participants were capable of completing the 3D-MOT task, practice trials tracking 1 sphere were administered before the actual trials began. To demonstrate their competence, participants needed to obtain correct responses on the first 2 of 3 trials. If unsuccessful, the instructions were restated and participants were then required to obtain 2
correct responses on the next 3 trials in order to qualify for subsequent testing. All participants qualified for the study.

Participants were then asked to track two blocks each of 1 and 4 target spheres among 8 total spheres in three-dimensional virtual space; with presentation order counterbalanced. The number of trials per block depended on individual performance and ranged from 7 to 28. The experimenter controlled the presentation trials and trial blocks, and recorded participants’ verbal responses by entering them manually on the laptop’s numerical keypad. As presented in Figure 1., each trial was broken down into 5 stages for participants in the Feedback groups; with the 5th (feedback) stage omitted for the No Feedback groups.

![Figure 1](image.png)

**Figure 1.** Example of a 3D-MOT task trial with three target spheres. (a) All 8 spheres are displayed in the visual field. (b) The target spheres are highlighted orange. (c) Target spheres change back to yellow and all spheres move randomly throughout the visual field. (d) Numbers (1-8) appear on the spheres and the participant attempts to identify the target spheres. (e)* For participants in the Feedback groups only, feedback on performance is provided by way of highlighting original target spheres in orange once again.

Trials began with a presentation of 8 yellow spheres randomly dispersed in 3D virtual space (Figure 1a); in this case, a cube. The virtual size of the spheres varied with their position in virtual space and ranged between 20 and 55 cm. Depending on the trial block, the 1 or 4 target spheres then changed from yellow to orange for one second (Figure 1b). The orange spheres then changed back to their original colour and moved linearly and randomly throughout the 3D virtual space (Figure 1c). Spheres’ courses were altered accordingly when they collided with another
sphere or the outside boundaries of the virtual cube; and spheres often occluded other spheres as they moved in virtual space. After eight seconds of movement, the spheres stopped moving and an individual number from 1 to 8 appeared next to each for identification purposes. Participants then verbally identified the sphere(s) that they believed were the original targets. Their selections were recorded manually by the experimenter on the numerical keypad (Figure 1d). Finally, for the Feedback participants only, the target spheres turned orange again; providing participants with feedback on their performance (Figure 1e).

The speed of the spheres increased or decreased in subsequent trials depending on whether participants identified all tracked spheres correctly or not in the previous trial, respectively (1-up, 1-down staircase procedure; Levy et al., 2017). Initial sphere speed was set at 68 cm/second displacement, and speed increased or decreased by 0.05 log based on the previous trial’s speed. Sphere movement speeds ranged from 27 cm/second to 544 cm/second. Blocks ended once six inversions (i.e., a correct answer followed by an incorrect answer, and vice-versa) occurred. The geometric mean speed of the last four inversions (i.e., the speed threshold) was calculated for each block of trials, and the average of the two blocks’ speed thresholds was used as our measure of 3D-MOT performance (Legault, Troje, & Faubert, 2012).

Cognitive measure. Measures of crystallized intelligence, nonverbal fluid intelligence, and overall intelligence were obtained for all participants. All TD participants and 17 ASD participants completed the Wechsler Abbreviated Scale of Intelligence, 2nd Edition (WASI-II; Wechsler, 2011). The WASI-II is a brief measure of cognitive ability for individuals aged 6 to 90 years. It includes four subtests that factor into verbal comprehension (VCI) and perceptual reasoning (PRI) indices, as well as a full-scale intelligence quotient (FSIQ). Ten (10) ASD participants, recruited from the shared CÉTED database at Rivière-des-Prairies Hospital and
SCERT at Summit School, already had valid Wechsler IQ scores at time of testing in the present study. These were obtained during their recent participation in other, unrelated research studies. Thus, VCI, PRI, and FSIQ scores from related adult and child comprehensive Weschler intelligence scales were used for those participants in place of WASI-II scores. These tests included the Wechsler Adult Intelligence Scale, 4th Edition (WAIS-IV; Wechsler, 2008), and the Wechsler Intelligence Scale for Children, 4th Edition (WISC-IV; Wechsler, 2003). The publisher of all three Wechsler tests claims that there are “strengthened connections between the WASI–II and the comprehensive Wechsler intelligence scales [that] result in a stronger empirical foundation for using the instruments together” (Wechsler, 2011).

**Attention measure.** All participants completed the Conners Continuous Performance Test (CPT; Conners, 2000). This computerized test of attention is commonly used by clinicians to assess attention difficulties, and by researchers as a multidimensional measure of attention. These dimensions include inattentiveness, impulsivity, sustained attention, and vigilance. In this test, participants must press the spacebar as soon as they see a letter appear on the screen in front of them, but must try to inhibit this response when that letter is an “X.” The inter-stimulus interval (ISI) time varies by block between 1, 2, and 4 seconds, and the test contains 360 trials over 6 blocks. Having been tested several months before the ASD groups, an earlier edition of the test (CPT II) was administered to the TD group, while the most recent edition of the test (CPT 3; Conners, 2014) was administered to the ASD group. CPT-II and CPT-3 data are comparable for the purposes of this study, because the t-score scale and normative sample are identical (Conners, 2014).
Detectability ($d'$) is signal detection statistic that demonstrates how well the participant can discriminate non-targets/noise (in this case, the letter “X”) from targets/signal (all other letters). The detectability ($d'$) $t$-score was determined to be the most useful score to compare with performance on the 3D-MOT task; as the 3D-MOT task demands an ability to detect the signal (target spheres) from the noise (non-target spheres). $T$-scores other than $d'$ on the CPT were not available for the TD group. All CPT $t$-scores were correlated with 3D-MOT performance for the ASD group (see Results section). Gender specific norms were used to evaluate CPT performance. The clinical cutoff for CPT $t$-scores (i.e., the level at which performance signals the presence of attentional problems) is a 60. The highest $d'$ $t$-score obtained in our sample was 62; and scores ranged between 31 and 67 for the ASD sample, and between 31 and 62 for the TD sample.

Table 2 shows the breakdown of the testing procedure and average amount time taken to complete each portion of the study for all participants.

Table 2

<table>
<thead>
<tr>
<th>Task</th>
<th>Time (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed Consent</td>
<td>5</td>
</tr>
<tr>
<td>3D-MOT</td>
<td>20-30</td>
</tr>
<tr>
<td>WASI-II*</td>
<td>30</td>
</tr>
<tr>
<td>CPT</td>
<td>15</td>
</tr>
<tr>
<td>Breaks as needed</td>
<td>5-15</td>
</tr>
<tr>
<td>Total time</td>
<td>75-95</td>
</tr>
</tbody>
</table>

*Note: *This step was omitted for participants with valid Wechsler IQ scores.
Results

All data were analyzed using the IBM SPSS 20 statistical software package for iOS operating systems (IBM Corp, 2012). All data were inspected for outliers and any unusual distribution properties.

3D-MOT Performance and Task Difficulty

A 2 (difficulty level) X 2 (diagnostic group) mixed model ANOVA confirmed that performance on the 3D-MOT at low difficulty was significantly better than at high difficulty ($F_{(1, 53)} = 1108.97, p < 0.001$, partial $\eta^2 = 0.95$). A two-way interaction was also found, such that the TD_{(F+NF)} group outperformed the ASD_{(F+NF)} group on the 3D-MOT task at low difficulty (1 tracked item); but no significant difference was found between diagnostic groups at high difficulty (4 tracked items) ($F_{(1, 53)} = 9.60, p = 0.003$, partial $\eta^2 = 0.15$). Figure 2 shows the average 3D-MOT speed threshold (ST) scores by task difficulty for ASD_{(F+NF)} vs. TD_{(F+NF)} groups.
Figure 2. Average 3D-MOT speed threshold (ST) scores by task difficulty for ASD\(_{(F+NF)}\) vs. TD\(_{(F+NF)}\) groups. Means and standard errors are shown. Black bars show average STs for the ASD\(_{(F+NF)}\) group: ST\(_{\text{Low}}\) (M = 242.69, SE = 6.25) and ST\(_{\text{High}}\) (M = 69.53, SE = 5.78). White bars show average STs for the TD\(_{(F+NF)}\) group: ST\(_{\text{Low}}\) (M = 292.24, SE = 9.76) and ST\(_{\text{High}}\) (M = 83.56, SE = 5.17). *** p < 0.001.

3D-MOT Performance and Feedback

In addition to the significant two-way interaction found between task difficulty level and diagnostic group on task performance, a 2 (difficulty level) x 2 (diagnostic group) x 2 (feedback group) mixed model ANOVA revealed a significant three-way interaction between task difficulty, diagnostic group, and feedback group on task performance \((F(1, 51) = 7.20, p = 0.010, \text{partial } \eta^2 = 0.124)\). It should be noted, however, that in this overall model, the task difficulty*feedback group interaction was not significant \((p = 0.57)\). The subtleties of this three-way interaction are illustrated with the help of Figure 3, which depicts 3D-MOT performance at low and high task difficulty, and by feedback provision status within each diagnostic group. In addition to the effect of diagnostic group (Figure 2), the provision of feedback appeared to improve performance on the 3D-MOT when only when difficulty level was low, and only in our
ASD sample. No significant effect of feedback was observed at high difficulty within the ASD sample. Although the TD_{NF} group obtained higher average STs at low and high difficulty levels than the TD_{F} group, this difference was not significant.

Figure 3. Average 3D-MOT speed threshold scores (in cm/s) by number of target items for (a) ASD_{(F)} vs. ASD_{(NF)} and (b) TD_{(F)} vs. TD_{(NF)} groups. Means and standard errors are shown. (a) Black bars show average STs for the ASD_{(F)} group: ST_{Low} (M = 253.55, SE = 6.24) and ST_{High} (M = 64.52, SE = 8.62). White bars show average STs for the ASD_{(NF)} group: ST_{Low} (M = 229.11, SE = 11.80) and ST_{High} (M = 75.79, SE = 8.47). (b) Black bars show average STs for the TD_{(F)} group: ST_{Low} (M = 275.79, SE = 13.21) and ST_{High} (M = 77.86, SE = 6.72). White bars show average STs for the TD_{(NF)} group: ST_{Low} (M = 311.23, SE = 11.76) and ST_{High} (M = 90.13, SE = 7.41). * p < 0.05.

Another way in which we can assess the effect of feedback is by examining the ST gain from the first block of trials at each difficulty level to the second. When we do this, we find a significant difference between feedback groups collapsed across diagnostic groups when difficulty is low (indicated by enhanced performance in the feedback group), but no difference when difficulty is high (see Figure 4). Given the large standard errors in Figure 4, an alternative strategy for gaging whether feedback was beneficial to performance from Blocks 1 to 2 is to assess how many participants registered a positive versus negative ST difference. On average, more than two thirds (70\%) of participants who received feedback saw gains in performance
from Block 1 to 2 (ASD = 73.3%, TD = 66.7%); while only approximately half (48%) of participants who did not receive feedback did (ASD = 45.8%, TD = 50%).

**Figure 4.** Average 3D-MOT speed threshold gains from Block 1 to Block 2 by task difficulty. Means and standard errors are shown. (a) Low difficulty (1 target): ASD_F: $M = 21.33$, SE = 10.88; TD_F: $M = 30.33$, SE = 19.28; ASD_NF: $M = -42.12$, SE = 21.39; TD_NF: $M = -6.90$, SE = 20.65. (b) High difficulty (4 targets): ASD_F: $M = 13.37$, SE = 5.59; TD_F: $M = 15.46$, SE = 5.05; ASD_NF: $M = -3.21$, SE = 7.23; TD_NF: $M = 7.01$, SE = 9.72. *p < 0.05.

**3D-MOT Performance and the CPT**

$d'$ t-scores differed significantly between diagnostic groups, with the ASD_{F+NF} group having a statistically and clinically better ability to distinguish targets from non-targets on the CPT than the TD_{F+NF} group ($t_{(53)} = -2.865, p = 0.006$). The mean $d'$ t-score for the TD_{F+NF} group ($M = 51.11$) falls within the average range (indicating an average ability to distinguish targets from non-targets), while the mean $d'$ t-score for the ASD_{F+NF} group ($M = 44.70$) falls within the low range (indicating a good ability to distinguish targets from non-targets). $d'$ t-scores were not significantly associated with performance on the 3D-MOT task for either the
TD (F+NF) group (ST\textsubscript{Low} \(r\) = 0.070, \(p = 0.725\); ST\textsubscript{High} \(r\) = -0.175, \(p = 0.374\)), or the ASD (F+NF)
group (ST\textsubscript{Low} \(r\) = -0.166, \(p = 0.409\); ST\textsubscript{High} \(r\) = -0.222, \(p = 0.265\)).

**Discussion**

We aimed to assess the role of feedback using a three-dimensional multiple object
tracking (MOT) task in which we manipulated task difficulty (cognitive load; in this case). We
asked participants with ASD and neurotypicals to track 1 (low task difficulty) and 4 (high task
difficulty) target spheres over two randomized blocks of testing; with half of the participants
receiving feedback on their performance, and half not. Based on previous research using our 3D-
MOT paradigm with both neurotypicals (Perico, 2014; Tullo et al., 2015) and individuals with
ASD (Levy et al., 2017), we hypothesized that feedback would hinder performance for both the
ASD and TD groups over this one session. However, given the type of our feedback (criterial,
visual, computerized, and non-social in nature), we did not expect that the discrepancy between
the Feedback vs. No Feedback ASD groups would be significantly greater than that between the
Feedback vs. No Feedback TD groups.

Performance on our 3D-MOT task varied between diagnostic groups; with the typically-
developing group outperforming the ASD group when tracking 1 but not 4 target items when
collapsed across feedback groups. One potential explanation for this discrepancy is the notion
that individuals with ASD have a higher load capacity than neurotypicals. Lavie’s (2005) load
theory of attention stipulates that irrelevant distractors are perceived differently based on whether
the task depletes perceptual capacity or not (i.e., leaves some “spare” capacity that results in
irrelevant distractor processing). In line with this theory, in a task such as the MOT, individuals
with ASD may be processing distractor items along with target items more so than neurotypicals;
resulting in weaker performance (Remington, Swettenham, & Lavie, 2012). However, when
perceptual capacity is reached (in our case, when tracking the maximum number of target items), irrelevant distractor items are no longer processed and performance resembles that of the typically-developing group.

Performance also varied as a function of task difficulty and whether feedback was provided or not. As expected, we found that performance, as measured by speed threshold, was much lower at high task difficulty (4 targets) than at low task difficulty (1 target). This pattern held true for both diagnostic groups and both feedback groups. Our previous investigation of the effect of feedback using our 3D-MOT task has demonstrated that, at least for typically-developing adults, feedback can be beneficial to task performance (learning) over several sessions (Perico, 2014), but it was found to be detrimental to performance in a single session (Tullo et al., 2015). In the present study, feedback was beneficial only to the ASD group, and only when task difficulty was low. We did not find a statistically significant effect (positive or negative) of feedback in our TD sample, but a trend towards it being detrimental to overall performance was found. That said, when diagnostic groups were pooled, we did find that participants who received feedback had statistically significant larger gains between the first block of trials presented to them, and the second; suggesting that feedback may be useful to task learning even over the course of just one session.

As reviewed in the introduction, several factors can moderate the effectiveness or impact of feedback; for both neurotypicals and individuals with ASD. The type of feedback used in our 3D-MOT task most closely resembles a hybrid of task (criterial) and process level feedback; as it informs participants about the correctness of their performance on each trial, but it may also serve a more process-oriented purpose to aid in their mastery of the task. Positive impacts of feedback are found most consistently for these types of feedback. Feedback occurs immediately
after each trial (once the participant has made his or her selections); which has been associated with better performance in some studies in the long term but may impede performance in the short term. Our task, including the mode in which feedback is delivered, is entirely computerized; which is associated with positive task performance outcomes for individuals with ASD. Several studies have examined the impact of computerized feedback on individuals on the autism spectrum. Somogyi, Kapitány, Kenyeres, and Donauer (2016) determined that, when given visual feedback, children improved their postural control (which appears to be weaker in ASD). Moore and Calvert (2000) determined that children with ASD were more attentive, more motivated, and learned more vocabulary words in the computer version of a vocabulary drill than when the drills were given by teachers. In a syllable production intervention study, DeThorne, Aparicio Betancourt, Karahalios, Halle, and Bogue (2015) highlighted the benefits of immediate, computerized feedback for children on the autism spectrum. Examining the role of feedback in adults with ASD on a fake Windows pop-up identification task, Kelley and Collins McLaughlin (2012) found a main effect of feedback amount (with participants who received more feedback performing better), but also found that older adults with ASD benefited from increased feedback for fluid ability (working memory) cues but from decreased feedback for crystallized ability (grammar) cues.

Kana, Keller, Cherkassky, Minshew, and Just (2006) note that visual feedback is especially useful in intervention with children with autism, and cognitive training effects in ASD samples have been found to be stronger the earlier they are implemented (Powell, Wass, Erichsen, & Leekam, 2016). Training on a gaze-contingent visual sustained attention task showed learning transfer in children with ASD (Powell et al., 2016). Children and teens with Asperger syndrome and attention difficulties who participated in 6-month weekly attention game
training intervention saw significant pre-to-post-test improvements in selective, sustained, and distributed attention (Bravo-Álvarez & Frontera-Sancho, 2016).

**Future Directions**

Given this encouraging research, a future application of our 3D-MOT task and general line of inquiry that is currently being explored is the use of our task in an attention training intervention. We now have some indication that feedback will not hamper learning in an ASD population; and that, in fact, it may be beneficial to them at low levels of task difficulty. Thompson, Gabrieli, and Alvarez (2010) determined that MOT training (with 4 target items and trial-by-trial feedback provided) could increase visual attention capacity as well as tracking speed in a group of typically-developing adults. Tullo, Guy, Faubert, and Bertone (2018) trained children with various special needs on the 3D-MOT task and found that their attention and learning increased after multiple sessions.

**Limitations**

The limitations of our current study are similar to those of Levy and colleagues’ (2017). As most of our efforts were focused on obtaining a sample of participants with confirmed autism diagnoses from accessible professionals, and who did not have a co-occurring attention disorder, our sample size is smaller than we would have preferred. Given that many participants in our ASD sample have been keen to participate in research studies before, ours may not a representative sample of individuals with high functioning ASD, or individuals with ASD in general. Excluding participants with attention disorders also potentially limits our ability to generalize our findings to those with attention disorders. Measuring ERPs during probabilistic learning paradigm, Groen and colleagues (2008) found that non-medicated children with ADHD (but not children with ASD) were less able to monitor their error responses when learning via
performance feedback. However, this weakness diminished in children with ADHD treated with methylphenidate. It may be interesting to the current study’s ASD sample’s performance on our 3D-MOT task with that of a sample with comorbid ADHD (non-medicated vs. medicated).
References


A historical review, a meta-analysis, and a preliminary feedback intervention theory. 


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CHAPTER 6: GENERAL DISCUSSION

Cognitive Load

Manuscript I aimed to assess visual attention using a 3D-MOT task in individuals with autism. More specifically, the effect of cognitive load on 3D-MOT performance in individuals with ASD compared to typically developing individuals was investigated. This was accomplished by having participants track 1, 2, 3, and 4 target spheres of 8 total spheres in virtual space; calculating the average speed at which all targets could be correctly identified at each level of loading (speed threshold); and exploring within- and between-group differences in speed thresholds. Correlations between 3D-MOT performance and Wechsler IQ and CPT t-scores were also generated.

In line with the load theory of attention (Lavie, 1995), we hypothesized that 3D-MOT performance would decrease as number of target items increased. As expected, increasing the number of target items resulted in significantly worse performance on the 3D-MOT (i.e., lower speed thresholds at higher loading levels) for both the ASD and TD groups. Based on previous MOT (e.g., Koldewyn et al., 2013; Van der Hallen et al., 2015) and non-MOT (e.g., Adams & Jarrold, 2012; Remington et al., 2009) visual perception and attention studies, we also hypothesized that individuals with ASD might have enhanced perceptual capacity. We expected that, if this theory held true, we would see impaired 3D-MOT performance specifically under higher levels of cognitive loading, due to the persistence of distractor processing in the ASD group. Contrary to our hypothesis, however, speed thresholds at higher levels of cognitive loading were not relatively decreased for the ASD group in Manuscript I. In fact, no significant between-diagnostic group differences were found overall or at any loading level; though the TD group had higher speed thresholds overall. Thus, the notion that individuals with ASD have a greater perceptual capacity as per the load theory of attention was not supported in Manuscript I.
Despite Manuscript II’s focus on feedback, an interesting load-related finding emerged: a significant difference between ASD and TD performance on the 3D-MOT was found at low task difficulty (i.e., loading level of 1), but not at high task difficulty (i.e., loading level of 4) when diagnostic groups were collapsed across feedback groups. It is likely that, if we had had a larger sample size in Manuscript I, we would have observed a similar outcome (e.g., significant impairment in performance at 1, 2, and 3 tracked items; and no difference at 4 tracked items) in 3D-MOT performance. This finding in Manuscript II lends supports the hypothesis in Manuscript I that individuals with autism have a higher perceptual capacity than neurotypicals: If performance was impaired across all loading levels, it could speak to an attentional deficit in ASD; but because no impairment was found at 4 targets, it is possible that this loading level represented the point at which perceptual capacity was reached for the ASD group.

It is also possible that, despite our having labelled a loading level of 1 target as “low”, that the cognitive load on attention for even 1 target in our 3D-MOT task was high, and thus a loading level of 4 targets would be considered very high. In this case, cognitive load theory and the hypothesis that individuals with ASD have greater load capacity would dictate that the ASD group’s capacity would only be reached at “very high” load (i.e., 4 targets), but not yet at “high load” (i.e., 1 target). Thus, we would expect the TD group to outperform the ASD group at “high” load capacity, but perform equally well at “very high” load capacity (i.e., when both groups have reached their capacity limit).

Nevertheless, Manuscript I’s results were consistent with those of Koldewyn and colleagues (2013), who did not find deficits in selective attention in their ASD group on an MOT task. If differences in selective attention were at the root of diagnostic differences in MOT capacity in Koldewyn and colleagues’ (2013) study, they would have been seen at higher speeds;
at which the risk of selection failure is greater (Franconeri, Lin, Pylyshyn, Fisher, & Enns, 2008; Franconeri et al., 2010).

**Feedback**

Manuscript II aimed to assess the role of feedback on our 3D-MOT task. We manipulated task difficulty by asking participants with ASD and neurotypicals to track 1 and 4 target spheres over two randomized blocks of testing; with half of the participants receiving feedback on their performance, and half not. We wished to optimize feedback conditions for our ASD population to engage with our task at a level on par with our typically-developing participants while manipulating just one of the factors affecting feedback efficacy (task difficulty). Thus, we ensured that our feedback was corrective and non-social in nature, delivered via a computer interface, and provided immediately after each trial.

Performance on our 3D-MOT task varied between diagnostic groups; with the typically-developing group outperforming the ASD group when tracking 1 but not 4 target items when collapsed across feedback groups (as described above.).

Performance also varied as a function of task difficulty and whether feedback was provided or not. As expected, we found that performance, as measured by speed threshold, was much lower at high task difficulty (4 targets) than at low task difficulty (1 target). This pattern held true for both diagnostic groups and both feedback groups. Our laboratory’s prior investigation of the effect of feedback using our 3D-MOT task has demonstrated that, at least for typically-developing adults, feedback can be beneficial to task performance (learning) over several sessions (Perico, 2014), but it was found to be detrimental to performance in a single session (Tullo et al., 2015). In the present study, feedback was beneficial only to the ASD group, and only when task difficulty was low. We did not find a significant effect (positive or negative)
of feedback in our TD sample, but a trend towards it being detrimental to overall performance was found. That said, when diagnostic groups were pooled, we did find that participants who received feedback had significantly larger gains between the first block of trials presented to them, and the second; suggesting that feedback is useful to task learning, even between block presentation within a single session.

Computerized feedback has been shown to impact individuals on the autism spectrum in several domains. Somogyi, Kapitány, Kenyeres, and Donauer (2016) determined that, when visual feedback was given, children improved their postural control (which appears to be weaker in ASD). Moore and Calvert (2000) found that children with ASD were more attentive, more motivated, and learned more vocabulary words in the computer version of a vocabulary drill than when the drills were given by teachers. In a syllable production intervention study, DeThorne, Aparicio Betancourt, Karahalios, Halle, and Bogue (2015) highlighted the benefits of immediate, computerized feedback for children on the autism spectrum. Examining the role of feedback in adults with ASD on a fake Windows pop-up identification task, Kelley and Collins McLaughlin (2012) found a main effect of feedback amount (with participants who received more feedback performing better), but also found that older adults with ASD benefited from increased feedback for fluid ability (working memory) cues but from decreased feedback for crystallized ability (grammar) cues.

Kana, Keller, Cherkassky, Minshew, and Just (2006) found visual feedback to be especially useful in intervention with children with autism, and cognitive training effects in ASD samples have been found to be stronger the earlier they are implemented (Powell et al., 2016). Training on a gaze-contingent visual sustained attention task showed learning transfer in children with ASD (Powell et al., 2016). Children and adolescents with Asperger syndrome and attention
difficulties who participated in 6-month weekly attention game training intervention saw significant pre-to-post-test gains in selective, sustained, and distributed attention (Bravo-Álvarez & Frontera-Sancho, 2016).

**3D-MOT Performance and the CPT**

Though we expected performance on the 3D-MOT to be associated with our primary CPT measure ($d'$ $t$-score – a measure of inattentiveness characterizing the ability to discriminate targets from non-targets), it was not. Interestingly, our TD sample had significantly better average CPT $t$-scores overall, but this did not translate to better performance on the 3D-MOT. This may simply mean that our 3D-MOT task is not as strongly correlated with a measure of inattention (such as $d'$) as it may be with a measure of, say, sustained attention (such as measures like Hit Reaction Time on the CPT-3, for which we do not have data for our TD sample). Though we did not have the TD data available, good performance on the 3D-MOT was associated with greater impulse control in the ASD group. This result is consistent with a study by Gonzalez, Martin, Minshew, and Berhmann (2013), in which adults with ASD were better at inhibiting impulsive trigger responses in a decision task.

Chien, Gau, Shang, and Wu (2014) compared CPT performance of neurotypical children and adolescents ($n = 255$) with children and adolescents with ASD ($n = 354$) and found that the ASD group displayed more inattentive, hyperactive/impulsive, and oppositional symptoms than neurotypicals. We did not find an impairment in $d'$ CPT $t$-scores in our autism samples (in fact, in general they had better $d'$ $t$-scores than the TD group), but we were not able to compare their other CPT $t$-scores to the TD group’s due to our loss of CPT data for the TD group.
Considerations and Limitations

Several limitations of our studies, as well as important considerations of participant and task factors specific to our studies, are discussed next.

Participants.

Sample size and exclusionary criteria. As most of our efforts were focused on obtaining a sample of participants with confirmed autism diagnoses from accessible professionals, and who did not have a co-occurring attention disorder, our sample size is smaller than we would have preferred. Our exclusionary criteria (e.g., no comorbid attention disorders) limit our ability to generalize our findings to all other individuals with and without ASD. Though we consider having “clean” samples to be a strength of these studies, and though many studies of participants with ASD boast samples of similar size (e.g., 18 total ASD participants in Evers et al., 2014), increasing statistical power by testing more participants would be ideal. A future addendum to these studies that might solve both of these issues may involve adding a comorbid ASD/ADHD group, and covarying CPT $d'$-scores with 3D-MOT performance.

Attention disorders. Prior to the publication of the DSM-5 in 2013, individuals could not hold diagnoses of both ASD and attention deficit hyperactivity disorder (ADHD), but this is no longer the case. Stevens, Peng, and Barnard-Brak (2016) analyzed data from the 2011 Survey of Pathways to Diagnosis and Services; a nationally representative American survey conducted by the National Center for Health Statistics (NCHS), Centers of Disease Control, and Prevention (CDC). They determined that ADHD co-occurs in a majority (59%) of children with a diagnosis of autism spectrum disorder.

Christakou and colleagues (2013) asked whether there exist shared behavioural and/or cognitive abnormalities in ASD and ADHD, and, if so, if these are based on different underlying
pathophysiologies. The authors found that children with ADHD and ASD display both shared and diagnosis-based abnormalities in sustained attention brain function with increased cognitive load (Christakou et al., 2013). A study by Johnson and colleagues (2017) determined that fronto-parietal attentional networks and subcortical arousal systems are involved in performance on the Sustained Attention to Response Task in ADHD (as evidenced by variability in response time and a longer mean response time), whereas prefrontal cortex (executive control regions) are involved in sustained attention in high functioning ASD (as evidenced by more commission errors). Measuring ERPs during probabilistic learning paradigm, Groen and colleagues (2008) found that non-medicated children with ADHD (but not children with ASD) were less able to monitor their error responses when learning via performance feedback. However, this weakness diminished in children with ADHD treated with methylphenidate. Given the high comorbidity between, and the shared and unshared characteristics of, the two diagnoses, it is important to understand how perceptual and attentional differences may affect MOT performance in individuals with ADHD, or both ASD and ADHD.

It is also vital to consider how ADHD symptomatology manifests in the context of load theory. Forster and colleagues (2014) examined the effect of irrelevant distractors under perceptual load (letter search task) in a sample of adults with ADHD. They found that distractors led to a significantly higher interference effect on search reaction time for the ADHD group; but also that increasing perceptual load significantly curbed distractor interference for the ADHD group (Forster et al., 2014).

Our exclusionary criteria (e.g., no comorbid attention disorders) limit our ability to generalize our findings to all other individuals with and without ASD, especially those with
attention disorders. It may be interesting to the current study’s ASD sample’s performance on our 3D-MOT task with that of a sample with comorbid ADHD (non-medicated vs. medicated).

**Anxiety, stress, and motivation.** An alternative explanation for enhanced performance in the Feedback versus No Feedback conditions in the ASD group only is that the ASD group may have felt more pressure and/or anxiety to perform well on the basis of seeing when their responses were incorrect. A precedent for this idea comes from an experimental risk-taking study by South, Dana, White, and Crowley (2010), in which anxiety predicted risk-taking solely in adults with ASD; suggesting that task performance may have been motivated by fear of failure. Anecdotal evidence for this notion with regard to our specific study came from casual post-debriefing conversations with a number of participants in the ASD group. When asked if they thought they would have preferred to have seen whether their responses were correct or not, the majority of participants queried (approximately 5 out of 7) said that they would prefer not to know how they were performing during the task. Given this response, it might be useful to ask this question of all participants to see if their recorded responses are correlated with their group’s performance.

Some evidence for this exists in studies of neurotypicals as well. For example, Morelli and Burton (2009) found that stress-inducing photographs led to worse performance on an MOT task in typically developing adults compared with non-stressed controls. In an ERP study, Su and colleagues (2017) determined that negative emotion appeared to impair attention resource allocation during an MOT task in a neurotypical sample. These are examples of MOT studies that establish some precedent for the expectation of diminished performance under less-than-ideal conditions for individuals with autism spectrum disorder.
Given that many participants in our ASD group have been eager to participate in (and/or have participated in) research studies before, ours may not a representative sample of individuals with high functioning ASD, or individuals with ASD in general. The question of whether high (or low) motivation may affect performance on our 3D-MOT task has yet to be evaluated, but some research on the impact of stress and anxiety on task performance exists. Regardless of whether motivation, anxiety, and/or stress factored into performance in the present study, future behavioural research in ASD should take these factors into account, as they may impact vigilance and sustained task performance (Gonzalez, Best, Healy, Bourne, & Kole, 2010).

**Gender.** Autism spectrum disorder diagnoses are much more likely to be given to males than females; by a margin of 4.3 to 1 (Fombonne, 2005). Many studies presented herein were careful to balance their groups by gender, and the gender distribution between our groups was not significantly different. Given the nature of our task, we did not expect to find, nor did we find, differences in performance between males and females in our two studies. However, some sex differences have been found with regard to the processing of monetary versus social rewards on tasks (feedback); as discussed in the Feedback section of Chapter 2. For instance, Spreckelmeyer and colleagues (2009) found that anticipation of both monetary rewards and social approval activate the same neurological structures in both male and female brains, and that this activation is proportional to the level of anticipated reward. However, men reacted faster than women to cues signaling high levels of reward, and faster to these cues in the monetary reward task relative to the social reward task. It is possible that males with ASD may be even less motivated to receive social feedback than females with ASD, and given the higher preponderance of males with ASD, it may be even less optimal to include social (versus nonsocial) feedback on tasks aimed at training individuals with ASD.
ASD diagnosis. The defining characteristics of autism have been debated and tailored by experts a great deal over time. The most recent standardization of these criteria in the Diagnostic and Statistical Manual of Mental Disorders, 5th Edition (DSM-5; APA, 2013) include several changes. Firstly, the subcategories of autistic disorder, Asperger syndrome (AS), pervasive developmental disorder – not otherwise specified (PDD-NOS), and childhood disintegrative disorder are now part of the same broad category known as “autism spectrum disorder” (ASD). Secondly, in the DSM-IV-TR, symptoms comprised a triad of domains: social impairment; language/communication impairment; and restricted/repetitive behaviours, interests, and activities (RRBs). The DSM-5 criteria for ASD now covers two domains: (1) deficits in social communication and social interaction, and (2) RRBs. This change is significant, especially for individuals with Asperger syndrome; many of whom have no history of language delay or impairment. Finally, the DSM-5 added levels of severity to quantify the degree of impairment in the above-mentioned domains.

This collapsing of diagnostic categories may be important to bear in mind, because many of the studies cited in this dissertation were conducted before the publication of the DSM-5 in May 2013. As such, different authors may have been more or less restrictive with regard to diagnostic categories; for example, categorizing participants with an Asperger diagnosis differently than those with a PDD-NOS diagnosis. Even with the unification under one ASD diagnosis, it is clear that ASD is a heterogeneous disorder. For instance, despite similar symptom presentation at the time of childhood ASD diagnosis, around 30% of children with a similar symptom presentation at the time of ASD diagnosis in childhood remain nonverbal into adulthood; whereas around 30% demonstrate a reasonably normal verbal IQ (Jeste & Geschwind, 2014). Furthermore, growth curves in language skill attainment appear to be different in classic
autism versus PDD-NOS (Anderson et al., 2007; Thurm, Manwaring, Luckenbaugh, Lord, & Swedo, 2014).

Many of our participants were initially diagnosed before the publication of the DSM-5, so their precise course of symptomatology (e.g., presence of language deficits) may not have been as clear when recruiting participants for these studies. Though we were careful to include only high-functioning participants with a diagnosis of ASD, and did not expect prior diagnostic categorization to play a role in performance on our specific task, some of the older studies cited in the Literature Review (Chapter 2) did separate their groups by diagnostic categories (e.g., PDD-NOS vs. Asperger’s); with mixed findings in terms of statistically significant group differences. One of the advantages of using our 3D-MOT task is that it does not require much verbal input from the participant and could, in theory, be adapted such that the participant selects the suspected targets themselves instead of naming them out loud. Thus, it may be interesting to administer our task to lower-functioning individuals with ASD to see if group differences exist in processing cognitive load and feedback.

**Perceptual reasoning ability (PRI).** 3D-MOT performance was linked to PRI primarily in the ASD group, suggesting that perceptual reasoning abilities are associated with visuo-spatial attention in ASD. As of this writing, only two studies have reported a link between attention task performance and perceptual reasoning ability specifically. Oksama and Hyönä (2004) found that visuospatial-short-term memory and attention switching were associated with MOT performance, and recent work in our laboratory using the 3D-MOT task has yielded similar positive correlations between MOT performance and perceptual reasoning ability with typically-developing adults (Tullo et al., 2015). Though the specific relationship between PRI and MOT performance in ASD appears unique, some researchers have found links between IQ and
executive functioning ability in ADS populations (Keehn et al., 2010; Liss et al., 2001; Lopez et al., 2005). For instance, though a study by Keehn and colleagues (2010) did not reveal significant differences in executive control in ASD versus TD groups on an attention task, only the performance of the ASD group was significantly correlated with IQ. It is possible that a greater ability to parse a visual scene into its parts (an ability required by subtests making up the PRI such as Block Design and Matrix Reasoning) is associated with a lower likelihood holistic (global) strategies to reduce cognitive load when attentional resources are limited (Meinhardt-Injac et al., 2014; Mottron et al., 1999).

**Atypical inhibition.** Inhibition refers the ability to restrain or withhold certain urges or responses. In social settings, inhibition helps us to refrain from performing or saying inappropriate actions or utterances, respectively. Inhibition is an executive function that is typically impaired in ASD (Adams & Jarrold, 2012). Repetitive and stereotyped behaviours are likely examples of impaired inhibitory control. The CPT requires participants to inhibit their responses to non-targets. However, only 5 of our participants out of 27 had CPT t-scores over the clinical cutoff (> 60), which may make them an atypical sample.

**Task.**

**MOT: A measure of working memory?** A study by Zhang, Xuan, Fu, and Pylyshyn (2010) aimed to determine whether the same attentional resources are tapped for tracking objects in an MOT paradigm as they are when held in working memory. The authors measured dual-task interference between visual working memory tasks (either involving explicit, implicit, or no spatial processing) and an MOT task in a group of typically developing young adults (Zhang et al., 2010). Results suggested that resource competition with MOT exists only for visual working memory tasks that demand the encoding of spatial properties (Zhang et al., 2010). A few studies
(e.g., Allen, Baddeley, & Hitch, 2006; Cavanagh & Alvarez, 2005) have established a direct link between MOT tracking capacity and spatial working memory capacity in typically developing adults, and spatial working memory ability predicts much of the individual variability in MOT tracking capacity (Trick, Mutreja, & Hunt, 2012). Most relevant to our study, the NeuroTracker technology has been shown to be useful in improving both verbal and visual working memory span in members of the Canadian Armed Forces (Vartanian, Coady, & Blackler, 2016). These findings lend support to the notion that MOT is a form of working memory task.

Given this, another explanation for impaired ASD 3D-MOT performance compared with the TD group may be that they have lower spatial working memory abilities. Deficits in working memory have been found for static displays in some studies (Lopez et al. 2005; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; Poirier, Martin, Gaigg, & Bowler, 2011; Russo et al. 2007), but not others (Griffith, Pennington, Wehner, & Rogers, 1999). We did not assess working memory skills in our sample, but this theory can be tested in future studies by collecting a measure of working memory skills (e.g., administering the full Wechsler assessment, which contains a measure of working memory; instead of the WASI, which does not).

**Distractor items and performance measures.** In MOT, distractor effects on tracking performance have sometimes been explained in terms of recruiting attentional resources for their suppression (e.g., Flombaum, Scholl, & Pylyshyn, 2008; Pylyshyn & Annan, 2006; Pylyshyn, Haladjian, King, & Reilly, 2008), being the results of crowding (e.g., Franconeri, Alvarez, & Enns, 2007; Franconeri et al., 2010), or both (e.g., Bettencourt & Somers, 2009) (Störmer, Li, Heekeren, & Linderberger, 2011). Drew, Horowitz, and Vogel (2013) argue that while increasing the number of distractors appears to lead to confusing targets with distractors, increasing speed appears to lead to “dropping” target items. Furthermore, perceptual load
increases when set size and target-distractor similarity increase (Hessels et al., 2014). In our case, the set size remained constant (8 spheres), and targets were indistinguishable from distractors. Because we held the number of total spheres in our task presentation constant, as the number of targets spheres increased, the number of distractor spheres necessarily decreased (i.e., a loading level of 3 would have 3 targets and 5 distractors; a loading level of 1 would have 1 target and 7 distractors). In some studies, MOT performance has been shown to decrease as the number of distractor items increases (Bettencourt & Somers, 2009; Feria, 2012; Sears & Pylyshyn, 2000; Tombu & Seiffert, 2011). However, as discussed in Manuscripts I and II herein, a steady decrease in 3D-MOT performance was observed with each additional target (and, thus, with each removed distractor).

This discrepancy is likely due to the way that MOT performance is calculated in the above-mentioned studies versus ours. While our performance measure is speed threshold (the average speed at which participants could track all target items correctly per loading level); the measure of performance used in other studies is often a $K$ score that includes number of targets, distractors, and screen size (e.g., Bettencourt & Somers, 2009), or percentage of targets identified correctly (e.g., Feria, 2013). A future manipulation of our task might involve an adding or subtracting of distractor items in a way that does not keep the total set size constant, as we did in our studies. However, it is worth laying out the methodological advantages of using speed threshold over other measures of MOT performance. For one, unlike the number of tracked items, speed threshold values vary along a continuous ratio scale (Faubert & Sidebottom, 2012). The task is better able to adapt to the participant’s capacity over time; this makes measuring performance gains over time more precise and eliminates a potential ceiling effect.
Strengths, Contributions, and Clinical Applications

As discussed above, researchers are beginning to recognize the importance of attentional differences in ASD and how they relate to social and non-social deficits associated with ASD symptomatology and etiology. This dissertation attempted to add to growing evidence that individuals with autism have a greater perceptual capacity than typically developing individuals; thereby addressing a long-standing debate in perceptual and attention research in ASD. Individuals on the autism spectrum appear to have perceptual and attentional strengths (e.g., enhanced or at the very least intact local processing) and weaknesses (e.g., greater distractibility) compared to typically developing individuals, but the load theory of attention attempts to reconcile some of these seemingly inconsistent findings by assuming that individuals with ASD have a greater perceptual capacity than neurotypicals. Though our hypothesized results may also be interpreted by a deficit in attention (i.e., decreased attentional resources to split among the target items) rather than an advantage in perceptual capacity, it may be worth choosing to frame this difference in a more positive light until we are better able to tease apart the intricacies through replication and more targeted research. One way to do this might be for educators and other professionals to try to reduce distraction among their students/clients by increasing the perceptual load of their lessons (e.g., by using hand gestures or content-heavy slides) (Murphy et al., 2016). If these techniques for overwhelming load capacity were to work particularly well for individuals with ASD compared with neurotypicals, it would lend support for the enhanced perceptual capacity theory over the decreased attentional resource theory in ASD.

Some of unique contributions and strengths of using a 3D-MOT paradigm with an ASD population include: (1) the 3D-MOT paradigm represents the best trade-off between empirical and ecological measures of real-world object-based visual attention (selective, sustained,
distributed, and dynamic); (2) the 3D-MOT task is nonverbal and thus accessible to all participants irrespective of language ability; (3) Manuscripts I and II are the first of their kind to use a three-dimensional MOT task with an ASD population, and (4) Manuscript II represents the first study to assess the effect of feedback on performance in an MOT task with an ASD population.

**3D-MOT for cognitive/attentional training.** An application of our 3D-MOT task and general line of inquiry that is currently being explored is the use of our task in an attention training intervention. We now have some indication that feedback will not hamper learning in an ASD population; and that, in fact, it may be beneficial to them at low levels of task difficulty. Being able to control and direct one’s attention is crucial in being able to navigate one’s environment (both actual and academic) (Powell et al., 2016). Attention is thus essential to efficient learning. Several studies have pointed to the link between attentional control and early language development (e.g., Kannass & Oakes, 2008; Rose, Feldman, & Jankowski, 2009), to early learning (Rose, Feldman, & Jankowski, 2011; Steele, Karmiloff-Smith, Cornish, & Scerif, 2012; Welsch, Nix, Blair, Bierman, & Nelson, 2010), and even to math achievement (May, Rinehart, Wilding, & Cornish, 2013) in ASD. These transitions are purported to happen through the child’s improved ability to regulate and focus attention to highly stimulating sources (as opposed to being a passive recipient of the environmental stimuli) (Powell et al., 2016; Scerif, 2010). Based on these findings, the earlier that attentional training intervention, the more chance of it impacting their achievement and acquisition of knowledge in many areas (Karmiloff-Smith, 1992; Wass, Scerif, & Johnson, 2012).

**Training with 3D-MOT tasks.** There is evidence that MOT tasks and even videogame-based tasks play a role in honing certain attentional skills (Trick, Jaspers-Fayer, & Sethi, 2005);
our 3D-MOT task based in NeuroTracker technology is both. Over 10 sessions, typically
developing adult participants in Parsons and colleagues’ (2016) cognitive training study showed
improved 3D-MOT performance, attentional functioning, visual processing speed, and working
memory; as well as significant changes in resting-state EEG functioning. Thompson, Gabrieli,
and Alvarez (2010) determined that MOT training could increase visual attention capacity as
well as tracking speed in a group of typically-developing adults. Training on our 3D-MOT task
over several sessions led to enhanced attentional abilities (tracking more objects at higher speeds)
for high-level athletes (Faubert & Sidebottom, 2012; Romeas et al., 2016), older typically
developing participants (Legault et al., 2013), and recent research from our lab has found
increased performance on the 3D-MOT task following several training sessions (e.g., Perico,
2014).

Since the initial writing of this thesis, my colleagues completed a study that best
highlights important educational and clinical applications of using our 3D-MOT paradigm as a
training tool for individuals with ASD and other neurodevelopmental disorders (Tullo et al.,
2018). In a randomized-control-trial (RCT) study taking place over 5 weeks, they administered
15 sessions of the NeuroTracker task to a group of 6- to 18-year-olds with ASD, ADHD,
intellectual disability, language disorder, specific learning disability, or unspecified
neurodevelopmental disorder. Participants completed the CPT-3 (the same measure used in
Manuscripts I and II herein) as baseline and outcome measures of their attention. One hundred
twenty-nine (129) participants were assigned either to the treatment group (15 sessions of 3D-
MOT; \( n = 43 \)), an active control group (15 sessions of a puzzle-like math game, \( 2048; n = 43 \)), or
a treatment-as-usual group (\( n = 43 \)) (Tullo et al., 2018).
Tullo and colleagues (2018) found significant improvements on the CPT-3 for the treatment group only. The authors concluded that 3D-MOT training was useful in improving attentional abilities in children and teens with neurodevelopmental conditions, and that the 3D-MOT task and CPT-3 were ideal measures of performance and near-transfer, respectively; partially due to their accessibility to individuals with low or unmeasurable verbal abilities. No main effect of diagnosis was found.

Some of the differences between my colleagues’ study and the ones presented in this dissertation are that Tullo and colleagues (2018) used a fixed number of targets in their task (3 of 8 spheres), and all participants received feedback on their performance. Though the current studies took place over a single session, we were able to ascertain that (1) manipulating cognitive load has consequences for 3D-MOT performance in ASD and TD populations (Manuscripts I and II), and (2) exposure to the task in its standard form (i.e., including the provision of feedback) led to improved performance from Block 1 to Block 2 when task difficulty was low (Manuscript II). Lab-based studies such as those outlined in Manuscripts I and II have begun to inform and guide the optimization of training interventions for individuals with ASD such as the large-scale RCT described above by attempting to capture the effects of attentional subcomponents (in our case, cognitive load and feedback).

**3D-MOT as a measure of attention.** Although we did not find significant links between 3D-MOT performance and CPT $d'$-t-score, some significant correlations were found in the ASD group between 3D-MOT performance and measures of inattention and impulsivity. Although more thorough comparison to existing measures of attention is warranted, another potential use of the 3D-MOT task is as a standardized measure of attention; including, but not limited to, individuals with autism and nonverbal populations.
Concluding Remarks

This dissertation reflects an original contribution to the autism spectrum disorder literature. We used a highly adaptable, reliable, and ecologically valid three-dimensional multiple object tracking task to address two important research questions: how (1) cognitive load, and (2) feedback affect performance on such a task for adolescents and adults with ASD. We sought to investigate whether certain patterns of strengths and weaknesses in perception and attention in ASD would bear out in Manuscript I, and suggested the possibility that what might look like a deficit may actually be the result of an advantage (i.e., enhanced perceptual capacity) for individuals on the autism spectrum. In Manuscript II, we investigated whether feedback over the course of one session would be helpful or detrimental to our ASD group, and our results have been useful as, since the initial submission of this thesis, our 3D-MOT task has been used successfully as an attentional training tool for children with ASD and other neurodevelopmental conditions (Tullo et al., 2018).
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doi:10.1163/156856888X00122


doi:10.1016/j.cortex.2012.03.005


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Steele, A., Karmiloff-Smith, A., Cornish, K., & Scerif, G. (2012). The multiple subfunctions of


object-tracking (3D-MOT) paradigm improves attention in students with a neurodevelopmental condition: a randomized controlled trial. *Developmental Science, e12670*. doi: 10.1111/desc.12670


connectivity during facial emotion recognition in children with autism spectrum disorders.


Appendix A.1

Kijiji Advertisement

*The image above is not a current advertisement on Montreal Kijiji. It was made as a draft, was previewed, and then deleted.*
Appendix A.2

Craigslist and McGill Classified Script:

“We are studying the differences between individuals’ attentional abilities through the use of a computerized, 3-D multiple object tracking task.

You will receive $15 for participating in this study, which will last between 1.5 and 2 hours.

The study will take place at our lab at McGill University in the Education building (3700 rue McTavish).

Since the present study involves visual attention tasks, certain criteria must be met for participation. You may not qualify if:

1) You are currently taking medication for a pre-existing condition that would affect your attention (e.g., stimulants or sedatives).
2) You have a diagnosis of ADHD.
3) You have a personal or family history of seizure disorders.
4) You have any condition that affects your vision.

If you’re interested in participating, or for a full description of this study, please message us through this ad.”
Appendix A.3

Recruitment - Oral Script

Institution: Faculty of Education, McGill University

Title of Project: *Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task*

Project Leader: Bianca Levy, Ed.M., Ph.D. candidate
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Oral Script:

“Hello, my name is RECRUITMENT RESEARCH ASSISTANT’S NAME calling from the McGill University’s Perceptual Neuroscience Laboratory for Autism and Development, led by Dr. Armando Bertone. You were previously contacted for studies with Dr. Bertone and you agreed to be contacted about new studies. I am therefore calling to find out if your child is available and interested to participate in a new study entitled, “*Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task*”.

Response: “No”. Recruiter: I am sorry to hear that, but thank you for your time. Hopefully, we will speak to you again in the future. Take care.”

Response: “Yes”. Recruiter: “Excellent! The aim of this study is to better assess attentional abilities using a computerized task. This study will take place over one session, which will last between 1.5 and 2 hours. [Your/your child’s] cognitive and attentional skills will be assessed at the beginning of the study as a baseline performance measure. During the session, [you/your child] will be asked to follow a subset of moving spheres in 3-D space while using a head mounted visual display. Dr. Armando Bertone will be supervising all of the testing, which will take place in the Education Building and adjacent Coach House annex, both on the McGill University downtown campus.

“There is no direct benefit from participating in this study, other than contributing to the scientific advancement of knowledge with respect to the development of visual perception. Furthermore, there are no foreseeable risks or harm associated with [you/your child’s] participation in this study. To reduce the effects of fatigue, each testing session will include as many breaks as [you/your child] require(s).”

“It is important for you to know that you are free to abandon this study at any time. Are you still interested in participating?”

“‘You/your child will receive $15 for participating in this study, which will be handed out upon its completion.”

If the participant (and their parent(s), when applicable) is/are interested, verify that the participant meets certain inclusion criteria:

“I will have to ask you a few questions before confirming [your/your child’s] participation in the study. [Do you/does your child] have any problems with vision? If so, do [you/they] wear glasses or contact lenses to correct
these problems? [Are you/is your child] currently taking medication? If yes, what kind of medication? [Do you/does your child] have a diagnosed disorder of attention (ADHD) or seizures?”

If the participant conforms to the inclusion criteria:
“When are you available to participate in the study?”
Please fill out and print a participant form once the family has committed to participate. Please record the appointment date and time, and any other pertinent notes on the participant form. Record all appointments in the online calendar (only accessed by the applicants).

Additional Information
“Participants will be assessed individually under the supervision of Dr. Armando Bertone (Assistant Professor) at the Perceptual Neuroscience Laboratory for Autism and Development. (Education Building, 3700 McTavish Street). I will come to meet you in the foyer of the Education building at the arranged date and time.

“At the laboratory, I will explain and issue a consent form before testing begins.”

[For parents of child participants] “Once started, you will wait in the waiting room, adjacent to the child-friendly testing room, while your child participates in the study.”

“Do you have any questions? If you require any additional information or need to withdraw [your child] from the study, please contact, Armando Bertone, at 514-398-3448. Thank you.”
Appendix A.4

**Adult (18+) Consent Form**

**Institution:** Faculty of Education, McGill University

**Title of Project:** *Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task*

**Project Leader:** Bianca Levy, Ed.M., Ph.D. candidate  
School & Applied Child Psychology  
Department of Educational and Counselling Psychology  
Faculty of Education, McGill University

**Project Supervisor:** Armando Bertone, Ph.D.  
School & Applied Child Psychology  
Department of Educational and Counselling Psychology  
Faculty of Education, McGill University

**Introduction:** We are interested in improving our knowledge of how attentional capacities differ between individuals with and without autism spectrum disorder. More specifically, we are interested in assessing how increasing the cognitive load and feedback on our task affects participants’ ability to pay attention. We will assess these abilities by asking you to track multiple spheres in 3-D space.

The study will be carried out in the Faculty of Education at McGill University. Although the research findings will be disseminated at scholarly conferences and in the writing of scientific articles, results from individual participants will remain strictly confidential (i.e., your name, individual participation measures, and any other identifying information will never be used).

**Procedures:** The study will take between 1.5 and 2 hours to complete. You will be asked to sit comfortably while wearing special goggles (known as a virtual head mounted display, or HMD) while you complete a computerized multiple object tracking (MOT) task. The task will involve looking, tracking and reporting on a number of moving spheres in the visual display. These tasks are very simple, but are sensitive enough to help us understand your attentional processing. You will also partake in a series of short cognitive assessments targeting attentional, concentration, and problem-solving skills to provide us with a baseline measure of your abilities.

**Advantages of the proposed study:** There is no other direct advantage from your participation in the present study other than your contribution to the advancement of scientific knowledge regarding how attentional abilities develop during typical development. Although the results obtained from the multiple object tracking tasks have no diagnostic value, a better understanding of how attentional abilities develop will be able to guide the development of efficient age-specific learning approaches, methods, and tailored materials.

**Disadvantages of the proposed study:** There are no known side effects associated with the previously described visual and/or cognitive tasks.

**Confidentiality:** All the information will be kept confidential, except as required or permitted by law. You will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. The principal researcher can only perform the decoding of the data or an individual authorized by the former. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study is published or presented at scientific meetings, personal identity will never be revealed. All of the information will be kept confidential, except as required or permitted by law. Data obtained from this study will be stored until the completion of the principal investigator’s thesis defense, after which it will be rendered completely anonymous through the deletion of any identifiers that would allow for the participant to be retraced.
Participation: Participation is voluntary. You may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

Incidental Findings: Although your cognitive and behavioural findings are clinically non-interpretable (i.e., not used for diagnosis), any questions regarding your performance will be explained to you, upon your request.

Compensation: You will be compensated $15 for your participation upon completion of the study.

Contact Numbers: If you have any questions about the research, please contact Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any questions or concerns regarding your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831 or lynda.mcneil@mcgill.ca.

Declaration of the participant:

In signing this consent form, I recognize that all aspects of the study have been explained to me, and that I understand the study. I also agree that I have had the opportunity to ask questions about the study, and that all my questions have been answered satisfactorily.

I, __________________, have read the above description with one of the investigators, __________________. I fully understand the procedures, the advantages, and the disadvantages of the study, all of which have been explained to me. I freely and voluntarily give my consent to participate in this study.

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<tr>
<th>Name of Participant</th>
<th>Signature of Participant</th>
<th>Date</th>
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<tr>
<td>Name of Examiner</td>
<td>Signature of Examiner</td>
<td>Date</td>
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Appendix A.5

Parental Consent Form

Institution: Faculty of Education, McGill University

Title of Project: Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task

Project Leader: Bianca Levy, Ed.M., Ph.D. candidate
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Introduction: We are interested in improving our knowledge of how attentional capacities differ between individuals with and without autism spectrum disorder. More specifically, we are interested in assessing how increasing the cognitive load and feedback on our task affects participants’ ability to pay attention. We will assess these abilities by asking you to track multiple spheres in 3-D space.

The study will be carried out in the Faculty of Education at McGill University. Although the research findings will be disseminated at scholarly conferences and in the writing of scientific articles, results from individual participants will remain strictly confidential (i.e., your child’s name, individual participation measures, and any other identifying information will never be used).

Procedures: The study will take between 1.5 and 2 hours to complete. Your child will be asked to sit comfortably while wearing special goggles (known as a virtual head mounted display, or HMD) while they complete a computerized multiple object tracking (MOT) task. The task will involve looking, tracking and reporting on a number of moving spheres in the visual display. These tasks are very simple, but are sensitive enough to help us understand your attentional processing. Your child will also partake in a series of short cognitive assessments targeting attentional, concentration, and problem-solving skills to provide us with a baseline measure of their abilities.

Advantages of the proposed study: There is no other direct advantage from your and your child’s participation in the present study other than your contribution to the advancement of scientific knowledge regarding how attentional abilities develop during typical development. Although the results obtained from the multiple object tracking tasks have no diagnostic value, a better understanding of how attentional abilities develop will be able to guide the development of efficient age-specific learning approaches, methods, and tailored materials.

Disadvantages of the proposed study: There are no known side effects associated with the previously described visual and/or cognitive tasks.

Confidentiality: All the information will be kept confidential, except as required or permitted by law. Your child will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. The principal researcher can only perform the decoding of the data or an individual authorized by the former. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study is published or presented at scientific meetings, personal identity will never be revealed. All of the information will be kept confidential, except as required or permitted by law. Data obtained from this study will be stored until the completion of the principal investigator’s thesis defense, after which it will be rendered completely anonymous through the deletion of any identifiers that would allow for the participant to be retraced.
**Participation**: Participation is voluntary. You or your child may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

**Incidental Findings**: Although your child’s cognitive and behavioural findings are clinically non-interpretable (i.e., not used for diagnosis), any questions regarding their performance will be explained to you, upon your request.

**Compensation**: Your child will be compensated $15 for their participation upon completion of the study.

**Contact Numbers**: If you have any questions about the research, please contact Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any questions or concerns regarding your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831 or lynda.mcneill@mcgill.ca.

**Declaration of the participant:**

In signing this consent form, I recognize that all aspects of the study have been explained to me, and that I understand the study. I also agree that I have had the opportunity to ask questions about the study, and that all my questions have been answered satisfactorily.

I, __________________, have read the above description with one of the investigators, __________________. I fully understand the procedures, the advantages, and the disadvantages of the study, all of which have been explained to me. I freely and voluntarily consent to have my child participate in this study.

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<th>Name of Parent/Legal Guardian</th>
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Appendix A.6

Assent Form (14- to 17-year-olds)

Institution: Faculty of Education, McGill University

Title of Project: Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task

Project Leader: Bianca Levy, Ed.M., Ph.D. candidate
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Why are we doing these tests on the computer?
We are doing these tasks to better understand how well teenagers can pay attention to a set of specific objects in a group of other objects. Our goal is to determine if attention can improve using these tasks and whether it can affect how well you perform on other tasks. This study will look at your ability to follow multiple objects at the same time.

What will happen during my time here at the lab?
I will be asking you to do a couple of activities with me today. You might find some of the activities very easy, and some of them hard – that’s completely normal! We just want you to always try your best.

For the main activity, you are going to be following a set of moving spheres within a larger group of spheres while wearing a comfortable special goggles, so it’ll look like the spheres are moving in 3-D space. After a certain amount time, I am going to ask you to tell me where the spheres moved. For another, shorter activity, I’ll ask you to push a button when you see certain letters come up on the screen, and try not to push it when other letters come up. These activities will test your attention and focus. Lastly, we will also do an activity that will measure your different thinking abilities. Specifically, you will build a puzzle using blocks, give me the definition of certain words, solve some puzzles, and describe the similarities between two different words.

Once we’re done, you will receive $15 for your participation.

Can I decide if I want to do these tests?
Your parents gave their permission to have you participate in this research project. However, you do not have to participate if you do not want to. If you do want to participate, you do not have to answer any of the questions and we can stop at any time.

Who will know what I did during these activities?
All of the responses given throughout these activities are kept confidential. This means that only myself and other researchers working with me on this project will see your answers. The answers from all of the teenagers who participated in this project may be presented at meetings or written in articles, but your name will not be used and no one will know that you participated in this study.

Do you have any questions?

Do you want to take part in the study?
Assent of Participant [Adolescent – Minor]

Participant’s name: ____________________________________

“I fully understand the procedure, the advantages, and the disadvantages of participating in this study: all of which have been explained to me. I freely and voluntarily give my assent to participate in this study.”

Participant’s signature ______________________________   Date ________________

Name of Examiner ______________________________   Signature of Examiner ________________   Date ________________
Appendix B.1

Canevas téléphonique pour le recrutement des sujets

« Bonjour, je m’appelle (nom de l’assistant(e)), je suis assistante de recherche au laboratoire de recherche du Dr Bertone à l’hôpital Rivière-des-Prairies du CIUSS de Nord-de-l’Île-de-Montréal. Je vous appelle afin de vous demander si vous seriez intéressé(e) et disponible pour participer à une étude. Le titre de l’étude est : **Rétroaction et charge cognitive chez les autistes : Preuves d’un suivi d’objets multiples tridimensionnel.**

« Votre participation consistera de faire un suivi visuel de différentes nombres de sphères qui bougent dans un espace virtuel tridimensionnel. Vous porteriez un visiocasque personnel 3-D confortable lors de cette tâche. Vous devriez aussi compléter quelques mesures standardisées cognitives et attentionnels.

Vous n’avez aucun avantage direct à participer à cette étude à part le fait de faire avancer les connaissances scientifiques sur l’autisme. Il n’existe pas de risques prévisibles liés à votre participation, mis à part le temps que cela vous prendra pour effectuer les tâches et votre déplacement.

La compensation pour l’étude est de 15$. Il vous est possible d’abandonner l’étude à tout moment.»

*Si la personne est intéressée, vérifier si elle répond aux critères d’inclusion :*

« J’aurais quelques questions à vous poser avant de confirmer votre participation à l’étude. Avez-vous des problèmes spécifiques de vision? Portez-vous des lunettes ou des verres de contact qui corrigent ces problèmes de vision? Êtes-vous atteint(e) d’un trouble de déficit de l’attention? Prenez-vous actuellement des médicaments? Si oui, quel type? »

*Si la personne répond aux critères :*

« Quand seriez-vous disponibles pour participer à l’étude? »

**Fixer le rendez-vous.**

« Parfait, je viendrai vous chercher à l’accueil de l’Hôpital Rivière des Prairies, à l’heure et au jour fixé, je vous laisse le numéro où me joindre d’ici là. Le formulaire de consentement sera expliqué et signée sur place.

S’il vous plaît, il est important de ne consommer ni alcool ni drogues non-prescrites dans les jours qui précèdent le rendez-vous. Avez-vous des questions? Si vous souhaitez me rejoindre, vous pouvez me contacter au (numéro de téléphone). Merci beaucoup.»
Appendix B.2

FORMULAIRE D’INFORMATION ET DE CONSENTEMENT
(Participants majeurs)

1. Titre du projet, nom des chercheurs et affiliation

   Titre
   Rétroaction et charge cognitive chez les autistes : Preuves d’un suivi d’objets multiples tridimensionnel

   Chercheur principal
   Armando Bertone, Ph.D., Université McGill

   Co-chercheuse
   Bianca Levy, Ed.M.
   Candidate au doctorat (Ph.D.), Université McGill

2. Description du projet
   Cette étude aborde les effets de charge cognitive et rétroaction sur l'attention chez les individus atteints d’un trouble du spectre autistique (TSA) en utilisant un suivi d’objets multiples informatisé (« multiple object tracking task », ou MOT). Ceci sera évalué en comparant la performance d’individus atteints d’un TSA à un groupe de participants non-autiste.

3. Procédures de l’étude
   Je participerai à une session d’environ 1.5 à 2 heures, dépendant du groupe dans lequel je serai placé(e). La tâche primaire sera un suivi d’objets multiples tridimensionnel (3D-MOT), dans lequel je porterai un visiocasque personnel 3-D et suivrai des sphères sur un écran. Je compléterai aussi des mesures standardisées informatisées et non-informatisées afin de déterminer mon profil cognitif et attentionnel. Je compléterai ces tâches au Laboratoire de Neuroscience en Perception pour l’autisme et les conditions du développement, à l’Hôpital Rivière-des-Prairies, du CIUSS du Nord-de-l’Île-de-Montréal.

4. Avantages et bénéfices pour le sujet
   Il n’y a aucun avantage découlant de ma participation à cette étude, outre le fait de contribuer à l’avancement des connaissances scientifiques dans ce domaine de recherche.

5. Indemnité compensatoire
   Suite à cette expérience, une indemnité compensatoire de 15$ me sera remise.

6. Inconvénients et risques
   Un inconvénient est le temps pris pour me rendre à l’Hôpital Rivière-des-Prairies, où l’étude s’effectue, ainsi que le temps que je vais mettre pour compléter les tâches. Aucun risque connu n’est relié aux expériences auxquelles je vais participer. Des mesures seront prises afin de pallier aux éventuels inconvénients qui peuvent être entraînés par la répétition de stimuli soit la fatigue, l’inconfort relié à l’immobilité et à l’attention soutenue. En effet, la présentation des stimuli sera régulièrement interrompue, me permettant ainsi de relaxer légèrement.

7. Modalités prévues en matière de confidentialité
   Les informations qui me concernent dans le cadre de ce projet demeureront confidentielles. Un code chiffré sera utilisé pour remplacer mon nom de sorte qu’aucun membre de l’équipe autre que les chercheurs impliqués dans l’étude (mentionnés plus haut), ne puisse m’identifier. Les données obtenues au cours de ce projet seront donc codées, mais non anonymes. Un code sera utilisé lors de la publication de l’étude et dans aucun cas mon nom ne sera divulgué. Les données nominatives ne seront pas conservées. Seules les données brutes le seront. Ces données seront conservées pour une période de dix ans, car elles sont nécessaires aux vérifications suite à la publication. Mes informations personnelles contenues dans la base de données de la Clinique de l’autisme de l’Hôpital Rivière-des-Prairies pourront être consultés dans le cadre de cette recherche, et les résultats de la présente recherche pourront y
8. Clause de responsabilité
S’il survient un incident suite à ma participation à cette étude, je pourrai faire valoir tous les recours légaux garantis par les lois en vigueur au Québec, sans que cela n’affecte les soins qui me sont prodigués. Ma participation ne libère ni les chercheurs ni l’établissement de leurs responsabilités civiles et professionnelles.

9. Liberté de participation et droit de retrait
Ma participation à cette étude est tout à fait volontaire. Ainsi, je suis libre d’accepter ou de refuser d’y participer. Mon refus ne va pas nuire à mes relations avec mon médecin ou avec les autres intervenants si je suis un patient à l’Hôpital Rivière-des-Prairies. Je suis également libre de me retirer de cette étude en tout temps. Toute nouvelle connaissance acquise au cours du processus d’expérimentation pouvant affecter ma décision d’y participer me sera communiquée dans les plus brefs délais. Mes données seront détruites au cas où je déciderais de ne pas compléter les tâches.

10. Nom des personnes-ressources
Pour de plus amples renseignements au sujet de ce projet de recherche ou pour aviser de mon retrait, je pourrai contacter le chercheur principal, Armando Bertone, au 514-323-7260, poste 4571. Pour formuler une plainte, des commentaires ou pour des questions concernant mes droits en tant que participant, je pourrai communiquer avec la Commissaire locale aux plaintes et à la qualité des services de l’Hôpital Rivière-des-Prairies, Mme Caroline Roy, au 514-338-2259.

11. Formule d’adhésion et signatures
J’ai lu et compris le contenu du présent formulaire. Je certifie que le contenu de ce formulaire m’a également été expliqué verbalement. J’ai eu l’occasion de poser toutes mes questions et on y a répondu de façon satisfaisante. Je sais que je suis libre de participer au projet et que je demeure libre de m’en retirer en tout temps, par avis verbal, sans que cela n’affecte la qualité de mes traitements, de mes soins futurs et des rapports avec mon médecin ou avec le centre hospitalier si je suis patient de l’Hôpital Rivière-des-Prairies. Je certifie que l’on m’a laissé le temps voulu pour prendre ma décision et j’ai pris cette décision sans contrainte ni pression de qui que ce soit. Je comprends que je recevrai une copie du présent formulaire. Je consens à participer à ce projet de recherche.

____________________  ___________________  __________________
Nom du participant en majuscules     Signature du participant     Date

12. Formule d’engagement du chercheur
Je certifie avoir expliqué au signataire les termes du présent formulaire de consentement et avoir répondu à ses questions. Je certifie également lui avoir clairement indiqué qu’il est libre de mettre un terme à l’expérimentation à tout moment et que je lui remettrais une copie signée et datée du présent formulaire de consentement.

____________________  ___________________  __________________
Nom du chercheur     Signature du chercheur     Date

13. Informations de type administratif
Le formulaire original sera inséré à mon dossier médical (s’il y a lieu). Une copie sera insérée dans le dossier de recherche et une autre copie me sera remise. Le projet de recherche et le présent formulaire de consentement ont été approuvés par le comité d’éthique de la recherche de l’Hôpital Rivière-des-Prairies.
Appendix B.3

FORMULAIRE D’INFORMATION ET DE CONSENTEMENT
(Participants mineurs)

1. Titre du projet, nom des chercheurs et affiliation

   Titre
   Rétroaction et charge cognitive chez les autistes : Preuves d’un suivi d’objets multiples tridimensionnel

   Chercheur principal
   Armando Bertone, Ph.D., Université McGill

   Co-chercheuse
   Bianca Levy, Ed.M.
   Candidate au doctorat (Ph.D.), Université McGill

2. Description du projet
Cette étude aborde les effets de charge cognitive et rétroaction sur l’attention chez les individus atteints d’un trouble du spectre autistique (TSA) en utilisant un suivi d’objets multiples informatisé (« multiple object tracking task », ou MOT). Ceci sera évalué en comparant la performance d’individus atteints d’un TSA à un groupe de participants non-autiste.

3. Procédures de l’étude
Mon enfant participera à une session d’environ 1.5 à 2 heures, dépendant du groupe dans lequel il/elle sera placé(e). La tâche primaire sera un suivi d’objets multiples tridimensionnel (3D-MOT), dans lequel je porterai un visiocasque personnel 3-D et suivrai des sphères sur un écran. Mon enfant complétera aussi des mesures standardisées informatisées et non-informatisées afin de déterminer son profil cognitif et attentionnel. Mon enfant complétera ces tâches au Laboratoire de Neuroscience en Perception pour l’autisme et les conditions du développement, à l’Hôpital Rivièrendes-Prairies, du CIUSS du Nord-de-l’Île-de-Montréal.

4. Avantages et bénéfices pour le sujet
Il n’y a aucun avantage découlant de sa participation à cette étude, outre le fait de contribuer à l’avancement des connaissances scientifiques dans ce domaine de recherche.

5. Indemnité compensatoire
Suite à cette expérience, une indemnité compensatoire de 15$ sera remise à mon enfant.

6. Inconvénients et risques
Un inconvénient est le temps pris pour me rendre à l’Hôpital Rivièrendes-Prairies avec mon enfant, où l’étude s’effectue, ainsi que le temps mis par mon enfant pour compléter les tâches. Aucun risque connu n’est relié aux expériences auxquelles mon enfant va participer. Des mesures seront prises afin de pallier aux éventuels inconvénients qui peuvent être entraînés par la répétition de stimuli soit la fatigue, l’inconfort relié à l’immobilité et à l’attention soutenue. En effet, la présentation des stimuli sera régulièrement interrompue, permettant ainsi à mon enfant de relaxer légèrement.

7. Modalités prévues en matière de confidentialité
Les informations qui concernent mon enfant dans le cadre de ce projet demeureront confidentielles. Un code chiffré sera utilisé pour remplacer son nom de sorte qu’aucun membre de l’équipe autre que les chercheurs impliqués dans l’étude (mentionnés plus haut), ne puisse l’identifier. Les données obtenues au cours de ce projet seront donc codées, mais non anonymes. Un code sera utilisé lors de la publication de l’étude et dans aucun cas son nom ne sera divulgué. Les données nominatives ne seront pas conservées. Seules les données brutes le seront. Ces données seront conservées pour une période de dix ans, car elles sont nécessaires aux vérifications suite à la publication. Les informations personnelles de mon enfant contenues dans la base de données de la Clinique de l’autisme de l’Hôpital
Rivièrdes-Prairies pourront être consultés dans le cadre de cette recherche, et les résultats de la présente recherche pourront y être transférés. Il est possible que les chercheurs doivent permettre l’accès aux dossiers de recherche au comité d’éthique de la recherche de HRDP et aux organismes subventionnaires de la recherche à des fins de vérification ou de gestion de la recherche. Tous adhèrent à une politique de stricte confidentialité.

8. Clause de responsabilité
S’il survient un incident suite à la participation de mon enfant à cette étude, je pourrai faire valoir tous les recours légaux garantis par les lois en vigueur au Québec, sans que cela n’affecte les soins qui lui sont prodigués. Sa participation ne libère ni les chercheurs ni l’établissement de leurs responsabilités civiles et professionnelles.

9. Liberté de participation et droit de retrait
La participation de mon enfant à cette étude est tout à fait volontaire. Ainsi, il est libre d’accepter ou de refuser d’y participer. Le refus de mon enfant ne va pas nuire à ses relations avec son médecin ou avec les autres intervenants s’il est un patient à l’Hôpital Rivière-des-Prairies. Il est libre de se retirer de cette étude en tout temps. Je suis également libre d’accepter ou de refuser que mon enfant participe à cette étude et je peux l’en retirer en tout temps, aux mêmes conditions. Toute nouvelle connaissance acquise au cours du processus d’expérimentation pouvant affecter sa décision d’y participer me sera communiquée dans les plus brefs délais. Les données de mon enfant seront détruites au cas où il déciderait de ne pas compléter les tâches.

10. Nom des personnes-ressources
Pour de plus amples renseignements au sujet de ce projet de recherche où pour aviser de mon retrait, je pourrai contacter le chercheur principal, Armando Bertone, au 514-323-7260, poste 4571. Pour formuler une plainte, des commentaires ou pour des questions concernant mes droits en tant que participant, je pourrai communiquer avec la Commission locale aux plaintes et à la qualité des services de l’Hôtel Rivière-des-Prairies, Mme Caroline Roy, au 514-338-2259.

11. Formule d'adhésion et signatures
J’ai lu et compris le contenu du présent formulaire. Je certifie que le contenu de ce formulaire m’a également été expliqué verbalement. J’ai eu l’occasion de poser toutes mes questions et on y a répondu de façon satisfaisante. Je sais que mon enfant est libre de participer au projet et qu’il demeure libre de s’en retirer en tout temps, par avis verbal, sans que cela n’affecte la qualité de ses traitements, de ses soins futurs et des rapports avec son médecin ou avec le centre hospitalier, si mon enfant est un patient de l’Hôpital Rivière-des-Prairies. Je demeure aussi libre de l’en retirer à tout moment aux mêmes conditions. Je certifie que j’ai eu suffisamment de temps pour prendre la décision et que j’ai pris cette décision sans contrainte ni pression de qui que ce soit. Je certifie que le projet a été expliqué à mon enfant dans la mesure du possible et qu’il accepte d’y participer sans contrainte ni pression. Je comprends que je recevrai une copie du présent formulaire. Je consens à ce que mon enfant participe à ce projet de recherche.

Assentiment du mineur

Nom du représentant légal  Signature du représentant légal  Date

Nom du participant  Signature du participant  Date

12. Formule d’engagement du chercheur
Je certifie avoir expliqué aux signataires les termes du présent formulaire de consentement et avoir répondu à leurs questions. Je certifie également leur avoir clairement indiqué qu’ils sont libres de mettre un terme à l’expérimentation à tout moment et que je leur remettrai une copie signée et datée du présent formulaire de consentement.

Nom du chercheur  Signature du chercheur  Date
13. Informations de type administratif
Le formulaire original sera inséré au dossier médical de mon enfant (s’il y a lieu). Une copie sera insérée dans le dossier de recherche et une autre copie me sera remise. Le projet de recherche et le présent formulaire de consentement ont été approuvés par le comité d’éthique de la recherche de l’Hôpital Rivière-des-Prairies.
Appendix C.1

**Summit**  
**Consent Form for Parent/Legal Tutor**

**Institution:** Faculty of Education, McGill University

**Title of Project:** *Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task*

**Project Leader:** Bianca Levy, Ed.M., Ph.D. candidate  
School & Applied Child Psychology  
Department of Educational and Counselling Psychology  
Faculty of Education, McGill University

**Project Supervisor:** Armando Bertone, Ph.D.  
School & Applied Child Psychology  
Department of Educational and Counselling Psychology  
Faculty of Education, McGill University

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Hello,

Your child is invited to participate in a research study. It is important that you read over and understand the information presented in this consent form. It is possible that this form contains words or expressions with which you are unfamiliar or require clarification. If this is the case, please do not hesitate to let us know. Take all the time you need to decide if you would like your child to participate.

**Introduction:** We are interested in improving our knowledge of how attentional capacities differ between individuals with and without autism spectrum disorder. More specifically, we are interested in assessing how increasing the cognitive load and feedback on our task affects participants’ ability to pay attention. We will assess these abilities by asking you to track multiple spheres in 3-D space. The study will be carried out at Summit is supported by an NSERC grant awarded to Dr. Armando Bertone. Although the research findings will be shared at scholarly conferences and in the writing of scientific articles, results from individual participants will remain strictly confidential (i.e., your child’s name, individual participation measures, and any other identifying information will never be used).

**Procedures:** The study will take between 1.5 and 2 hours to complete. Your child will be asked to sit comfortably while wearing special goggles (known as a virtual head mounted display, or HMD) while he/she completes a computerized multiple object tracking (MOT) task. The task will involve looking, tracking and reporting on a number of moving spheres in the visual display. Your child will also complete a series of short cognitive assessments targeting attention, concentration, and problem-solving skills to provide us with a baseline measure of his/her abilities.

**Advantages of the proposed study:** There is no other direct advantage from your child’s participation in the present study other than their contribution to the advancement of scientific knowledge in the domain of attention and autism.

**Disadvantages of the proposed study:** There are no known side effects associated with the previously described visual and/or cognitive tasks.

**Confidentiality:** All the information will be kept confidential. Your child will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. Only the principal researcher or an individual authorized by them can decode this information. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study are published or presented at scientific meetings, personal identities will never be revealed. All of the information will be kept confidential. Data obtained from this
study will be coded (i.e., all identifying information will be removed, making it impossible to retrace the participant), stored electronically on a password-protected computer, and destroyed after 10 years by the lab director, Dr. Armando Bertone. The original participant list containing participants’ personal information (e.g., name, gender, contact information) will be kept in a locked box within a locked cabinet and will only be accessible by the primary investigator (Bianca Levy) and her research assistants. This list will be destroyed after the completion of the principal investigator’s thesis defense and any manuscripts associated with this study are published; whichever comes last.

**Participation:** Participation is voluntary. You or your child may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

**Incidental Findings:** Although your child’s cognitive and behavioural findings are clinically non-interpretative (i.e., not used for diagnosis), any questions regarding your performance will be explained to you, upon your request.

**Compensation:** Your child will be compensated $25 for participation upon completion of the study.

**Contact Numbers:** If you have any questions about the research, please contact Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any questions or concerns regarding your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831 or lynda.mcneil@mcgill.ca.

To ensure the study is being conducted properly, authorized individuals such as a member of the Research Ethics Board, may have access to your child’s information. By signing this consent form, you are allowing such access. Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

**Declaration of the participant’s parent or legal tutor (if applicable):**

I, ___________, have read the above description with one of the investigators, ____________, and I consent to have my child participate in this study.

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<th>Signature of Parent/Legal Tutor</th>
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Appendix C.2

Summit
Assent Form (14- to 17-year-olds)

Institution: Faculty of Education, McGill University

Title of Project: Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task

Project Leader: Bianca Levy, Ed.M., Ph.D. candidate
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Hello,
You are invited to participate in a research study. It is important that you read over and understand the information presented in this consent form. It is possible that this form contains words or expressions with which you are unfamiliar or require clarification. If this is the case, please do not hesitate to let us know. Take all the time you need to decide if you would like to participate.

Why are we doing these tests on the computer?
We are doing these tasks to better understand how well teenagers can pay attention to a set of specific objects in a group of other objects. Our goal is to determine if attention can improve using these tasks and whether it can affect how well you perform on other tasks. This study will look at your ability to follow multiple objects at the same time.

What will happen during my time here at the lab?
I will be asking you to do a couple of activities with me today. You might find some of the activities very easy, and some of them hard – that’s completely normal! We just want you to always try your best.
For the main activity, you are going to be following a set of moving spheres within a larger group of spheres while wearing a comfortable special goggles, so it’ll look like the spheres are moving in 3-D space. After a certain amount of time, I am going to ask you to tell me where the spheres moved. For another, shorter activity, I’ll ask you to push a button when you see certain letters come up on the screen, and try not to push it when other letters come up. These activities will test your attention and focus. Lastly, we will also do an activity that will measure your different thinking abilities. Specifically, you will build a puzzle using blocks, give me the definition of certain words, solve some puzzles, and describe the similarities between two different words.
Once we’re done, you will receive $25 for your participation.

Can I decide if I want to do these tests?
Your parents gave their permission to have you participate in this research project. However, you do not have to participate if you do not want to. If you do want to participate, you do not have to answer any of the questions and we can stop at any time.

Who will know what I did during these activities?
All of the responses given throughout these activities are kept confidential. This means that only myself and other researchers working with me on this project will see your answers. The answers from all of the teenagers who participated in this project may be presented at meetings or written in articles, but your name will not be used and no one will know that you participated in this study.

Do you have any questions?
Do you want to take part in the study?

**Assent of Participant [Adolescent – Minor]**

Participant’s name: ____________________________________

“I fully understand the procedure, the advantages, and the disadvantages of participating in this study; all of which have been explained to me. I freely and voluntarily give my assent to participate in this study.”

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Appendix C.3

Consent Form for Summit TECC
18+ Participants and Parents/Legal Tutors

Institution: Faculty of Education, McGill University

Title of Project: Cognitive load and feedback in autism: Evidence from a 3-D multiple object tracking task

Project Leader: Bianca Levy, Ed.M., Ph.D. candidate
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Project Supervisor: Armando Bertone, Ph.D.
School & Applied Child Psychology
Department of Educational and Counselling Psychology
Faculty of Education, McGill University

Hello,
You are invited to participate in a research study. It is important that you read over and understand the information presented in this consent form. It is possible that this form contains words or expressions with which you are unfamiliar or require clarification. If this is the case, please do not hesitate to let us know. Take all the time you need to decide if you would like to participate.

Introduction: We are interested in improving our knowledge of how attentional capacities differ between individuals with and without autism spectrum disorder. More specifically, we are interested in assessing how increasing the cognitive load and feedback on our task affects participants’ ability to pay attention. We will assess these abilities by asking you to track multiple spheres in 3-D space. The study will be carried out at Summit TECC (1819 Boulevard René-Lévesque O, Montréal, QC H3H 2P5) and is supported by an NSERC grant awarded to Dr. Armando Bertone. Although the research findings will be shared at scholarly conferences and in the writing of scientific articles, results from individual participants will remain strictly confidential (i.e., your name, individual participation measures, and any other identifying information will never be used).

Procedures: The study will take between 1.5 and 2 hours to complete. You will be asked to sit comfortably while wearing special goggles (known as a virtual head mounted display, or HMD) while you complete a computerized multiple object tracking (MOT) task. The task will involve looking, tracking and reporting on a number of moving spheres in the visual display. You will also complete a series of short cognitive assessments targeting attentional, concentration, and problem-solving skills to provide us with a baseline measure of your abilities.

Advantages of the proposed study: There is no other direct advantage from your participation in the present study other than your contribution to the advancement of scientific knowledge in the domain of attention and autism.

Disadvantages of the proposed study: There are no known side effects associated with the previously described visual and/or cognitive tasks.

Confidentiality: All the information will be kept confidential. You will be assigned a study number and the information will be filed using this unique identifier code. Only this code will link the participant to the sample. The principal researcher can only perform the decoding of the data or an individual authorized by the former. Therefore, apart from Dr. Bertone and the principal investigator, only members of regulatory agencies or members of the Research Ethics Board may have access to the data. If data from this study is published or presented at scientific
meetings, personal identity will never be revealed. All of the information will be kept confidential. Data obtained from this study will be coded (i.e., all identifying information will be removed, making it impossible to retrace the participant), stored electronically on a password-protected computer, and destroyed after 10 years by the lab director, Dr. Armando Bertone. The original participant list containing participants’ personal information (e.g., name, gender, contact information) will be kept in a locked box within a locked cabinet and will only be accessible by the primary investigator (Bianca Levy) and her research assistants. This list will be destroyed after the completion of the principal investigator’s thesis defense and any manuscripts associated with this study are published; whichever comes last.

**Participation:** Participation is voluntary. You may refuse to participate or withdraw from the study at any time without any prejudice to your future involvement with McGill University. In the case that you do withdraw from the study, all previous data collected will be destroyed.

**Incidental Findings:** Although your cognitive and behavioural findings are clinically non- interpretable (i.e., not used for diagnosis), any questions regarding your performance will be explained to you, upon your request.

**Compensation:** You will be compensated $25 for your participation upon completion of the study.

**Contact Numbers:** If you have any questions about the research, please contact Dr. Armando Bertone at the Faculty of Education at (514) 398-3448 or armando.bertone@mcgill.ca. If you have any questions or concerns regarding your rights or welfare as a participant in this research study, please contact the McGill Ethics Officer at 514-398-6831 or lynda.mcneill@mcgill.ca.

To ensure the study is being conducted properly, authorized individuals such as a member of the Research Ethics Board, may have access to (your/your child’s) information. By signing this consent form, you are allowing such access. Please sign below if you have read the above information and consent to participate in this study. Agreeing to participate in this study does not waive any of your rights or release the researchers from their responsibilities. A copy of this consent form will be given to you and the researcher will keep a copy.

**Declaration of the participant:**

I, __________________, have read the above description with one of the investigators, __________________, and I give my consent to participate in this study.

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<th>Name of Participant</th>
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**Declaration of the participant’s parent or legal tutor (if applicable):**

I, __________________, have read the above description with one of the investigators, __________________, and I consent to have my child participate in this study.

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