

Investigating learning, working memory, and attention:
can 3D multiple object tracking (3D-MOT) tasks address the need for dynamic assessments?

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ABSTRACT

Multiple Object Tracking (MOT) paradigms are designed to measure one's ability to focus on and track a subset of moving objects over an extended period of time. Performance on MOT tasks has been interpreted as reflecting real-world dynamic attention and working memory. As well, MOT tasks have been used as cognitive training paradigms to objectively assess and enhance attentional abilities. While it is known that MOT training improves attention, there is little understanding about the effect of feedback during learning on a three-dimensional MOT (3D-MOT) task, as well as the potential for transferability of attentional capacities from MOT to similar cognitive tasks. As well, while working memory is found to play a key role in MOT performance, the extent to which MOT tasks could be used to assess working memory has yet to be systematically explored. This dissertation includes two manuscripts that aim to explain factors that can improve 3D-MOT as an attention and learning training paradigm, and to assess 3D-MOT as a potential assessment tool for working memory, with prospective implications for clinical screening tools. The goal of the first study in the thesis (Manuscript 1) was to determine whether the presence of feedback positively affected performance on 3D-MOT across testing sessions; as well, this manuscript sought to determine whether improved performance on 3D-MOT would transfer to other validated measures of attention, and whether these transfers would be affected by the presence of feedback during learning. Results showed that feedback significantly impacted learning during a 3D-MOT task, and may have an important role for the transferability of cognitive abilities. The second study (Manuscript 2) examined whether 3D-MOT tasks could be used as a non-verbal tool to assess attention and working memory while taking into consideration the role of development. Results revealed that similar performance was observed on 3D-MOT across adolescents and adults, as compared to validated

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neuropsychological methods, suggesting that 3D-MOT tasks have the potential to be used as an assessment instrument for working memory, addressing the need for non-verbal dynamic assessment tools that can be easily tailored for clinical populations, and for individuals of different ages and cognitive functioning.

RÉSUMÉ

Les paradigmes de suivi d'objets multiples (MOT) mesurent la capacité de concentration d'un individu et sa capacité à suivre un sous-ensemble d'objets en mouvement pendant une longue période de temps. La performance aux tâches de MOT a été interprétée comme reflétant l'attention dynamique dans le monde réel et la mémoire de travail. De plus, les tâches de MOT ont été utilisées comme paradigmes de remédiation cognitive pour évaluer objectivement l'amélioration des capacités attentionnelles. Il a été démontré que l'entraînement en MOT améliore l'attention. En revanche, l'effet de la rétroaction sur l'apprentissage dans une tâche de MOT tridimensionnelle (MOT-3D), ainsi que le potentiel de transférabilité des capacités attentionnelles de la MOT à des tâches cognitives similaires, sont moins connus. D'autre part, la mémoire de travail joue un rôle important dans la performance au MOT, mais la possible utilisation des tâches de MOT pour évaluer la mémoire de travail n'a pas encore été systématiquement explorée. La présente thèse contient deux manuscrits qui visent à expliquer les facteurs qui peuvent améliorer le MOT-3D en tant que paradigme d'entraînement de l'attention et d'apprentissage. Cette thèse vise aussi à évaluer le MOT-3D comme un outil d'évaluation potentiel pour la mémoire de travail, avec des implications prospectives comme outil de dépistage clinique. L'objectif de la première étude de la thèse (Manuscrit 1) était de déterminer si la présence de la rétroaction avait une incidence positive sur le MOT-3D durant les séances d'essai. De plus, ce manuscrit cherchait à déterminer si une amélioration de la performance au MOT-3D transférerait vers d'autres mesures d'attention déjà validées, et si ces transferts seraient affectés par la présence de la rétroaction lors de l'apprentissage. Les résultats démontrent que la rétroaction a eu une incidence importante sur l'apprentissage au cours d'une tâche de MOT-3D et qu'elle peut avoir un rôle important pour la transférabilité des capacités cognitives. La deuxième

étude (Manuscrit 2) a examiné si les tâches de MOT-3D pouvaient être utilisées comme outil non verbal pour évaluer l'attention et la mémoire de travail tout en prenant en compte le rôle du développement. Les résultats démontrent que les adolescents et les adultes ont des performances similaires aux tâches de MOT-3D en comparaison avec des méthodes neuropsychologiques déjà validées, ce qui suggère que les tâches de MOT-3D ont le potentiel d'être utilisées comme outil d'évaluation pour la mémoire de travail. Ceci répond au besoin de développer des outils d'évaluation dynamique non-verbaux qui peuvent être facilement adaptés aux populations cliniques, aux personnes de tout âge, et avec divers fonctionnements cognitifs.

CONTRIBUTION OF AUTHORS

This dissertation is comprised of two manuscripts. The first project was conceptualized and prepared by Dr. Armando Bertone, Dr. Jocelyn Faubert and myself. I completed all data collection and received assistance with the planning and execution of the statistical analyses. I wrote the manuscript and received editorial input from Drs. Armando Bertone and Jocelyn Faubert. The second manuscript was conceptualized and planned by Dr. Armando Bertone and myself; with guidance from Dr. Bertone, I chose the assessment tools and planned the testing methodology. I completed all data collection and wrote the manuscript, with editorial assistance from Dr. Armando Bertone. Michael Frisby assisted with the planning and execution of the statistical analyses and provided edits for the results section in the manuscript. Co-authorship on this thesis is in accordance with McGill's Graduate and Postdoctoral Studies Thesis Guidelines. The first manuscript is currently under review in *Neuropsychologia*, and the second manuscript is in preparation for publication submission to the *Journal of Neuropsychology*.

CHAPTER I: INTRODUCTION

During each day, an individual is expected to attend to an extraordinary amount of visual information. Typically, real world visual scenes are complex in nature, involving multiple elements, both moving and stationary. To successfully navigate through such environments, the ability to track multiple objects at once is an extremely important asset. The ability to simultaneously attend to multiple salient aspects of a visual scene is referred to as multiple object tracking (MOT) (Pylyshyn, 2001). One's ability to track multiple objects is founded on the concurrent ability to inhibit non-salient stimuli, prioritizing relevant components (Scholl, 2009). The process of tracking salient objects as well as the ability to inhibit distractors requires selective and sustained attention, with the demand for attentional resources increasing with increased complexity of a visual scene (Doran & Hoffman, 2010; Drew, McCollough, Horowitz, & Vogel, 2009; Feria, 2012; Howe, Drew, Pinto, & Horowitz, 2011; Scholl, 2009; Tombu & Seiffert, 2008). Considering the importance of MOT in everyday life, it is necessary to find ways to measure one's attentional ability through methods that mimic real world scenarios. Thus, tasks were developed to determine one's attentional propensity based on the ability to track a subset of moving objects within a dynamic visual scene. Characteristically of real world visual scenes, MOT involves selective and sustained attention to multiple objects, requiring varied attentional demands based on the number of additional factors affecting the individual (e.g., fatigue, stress) or the presented scene itself (e.g., increased number of objects). The increase in complexity and resource requirements for task completion, further solicit working memory. Working memory, selective, and sustained attention often work together in MOT tasks, either consequently or in parallel (Allen, McGeorge, Pearson, & Milne, 2006; Cavanagh & Alvarez, 2005; Howe et al., 2011; Jiang, Vázquez & Makovski, 2008).

The main goal of this dissertation research was to explore facets of attention and working memory in MOT that were closely related to my program of study, thus related to knowledge regarding cognitive functioning, learning and development. These interests evolved through the research process from a primary interest in what can improve MOT as an attention and learning training paradigm, and to introduce MOT tasks as an assessment tool for working memory, with prospective implications for clinical screening tools. This primary research interest evolved with increased clinical practice which pointed to the need for dynamic assessment tools, specifically for individuals with limited or no verbal ability. This thesis used a three-dimensional MOT task (3D-MOT) as a tool to actualize these goals.

The dissertation is comprised of seven chapters, including the present introductory section (Chapter I). In Chapter II, a comprehensive overview of MOT is presented, highlighting areas pertinent to the areas addressed in this thesis. Chapter III provides a bridging section between the literature review (Chapter II) and the first manuscript, presented in Chapter IV. Manuscript 1 is an exact reproduction of an article submitted to the journal *Neuropsychologia* (2017), authored by Perico, Faubert, and Bertone. This article is entitled *Feedback facilitates learning on a 3D Multiple Object Tracking (MOT) task: considerations for attention and transferability*, focused on the role of feedback on perceptual learning with 3D-MOT tasks. As well, it provided further support for the use of MOT paradigms for attentional training. The primary objectives for this study were to i) determine whether the presence of feedback during 3D-MOT would improve performance across testing sessions, ii) address whether improved performance on 3D-MOT would transfer to other validated measures of attentional ability and iii) whether these transfers would be affected by the presence of feedback during training.

A bridging section (Chapter V) is included between Chapters IV and VI to address and clarify the link between manuscripts. Manuscript 1 evaluates the potential of 3D-MOT as a tool to facilitate learning and improve attention emphasizing the use of feedback, whereas Manuscript 2 focuses on using 3D-MOT as a tool to assess dynamic attention and working memory. In Chapter VI, Manuscript 2 is presented. Authored by Perico, Faubert, and Bertone (2017), it is entitled *Three-dimensional MOT task as an assessment tool for attention and working memory: a comparison with traditional measures*, and is in preparation for submission to the *Journal of Neuropsychology*. This manuscript focuses on the potential for 3D-MOT paradigms to be used as an assessment tool for dynamic attention and working memory, to complement existing neuropsychology measures. While MOT has been consistently linked to attention and working memory abilities (Allen et al., 2006; Cavanagh & Alvarez, 2005; Howe et al., 2011; Jiang et al., 2008) it has yet to be compared to existing assessment measures. The primary objectives of this manuscript were therefore to i) determine whether performance across increasingly taxing working memory conditions would be comparable across 3D-MOT and traditional assessment measures, ii) address the role of development by examining performance across adolescents and adults. In conclusion, Chapter VII summarizes findings from the previous two manuscripts and further depicts their implications for research and clinical practice.

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CHAPTER II: LITERATURE REVIEW

How are multiple objects tracked simultaneously?

Pylyshyn (1989) offered the first explanation of how multiple objects are tracked simultaneously by proposing a theory of visual indexing. Prior to this, it was generally accepted that attention could only be directed to a single region in the visual field at once (i.e., attentional spotlight) (Treisman & Gelade, 1980), and that tracking moving objects occurred as a consequence of a rapid rate of attention movement (Pylyshyn & Strom, 1988). However, moving objects cannot be tracked by focal attention using a single stored description of each feature, because for visually identical targets, the only separating feature would be location. The problem is that the location of a moving object is constantly changing and can often overlap with other objects, failing to explain successful multiple object tracking (Pylyshyn, 2001). As a result, Pylyshyn (1989) proposed that the visual system has a pre-attentive mechanism that individuates features, and indexes their locations in a scene, allowing an individual to locate these features when necessary for further analysis. This system is referred to as FINSTs (FINgers of INSTantiation) and is thought to provide a reference point for determining a target's location (Pylyshyn, 1989). FINSTs can be attached to four to five targets in typical adults, which can be tracked independently and in parallel, maintaining their distinctive identity but without explicitly encoding their locations or recognizing their features; they are essentially a reference point in case further processing is needed (Pylyshyn, 1989).

Pylyshyn's (1989) theory was supported by subsequent research indicating that if a target shape changed it was more easily recognized than if a distractor shape changed, demonstrating that the elements that were indexed were kept in better focus (Sears & Pylyshyn, 2000). Interestingly, Pylyshyn and Strom (1988) found that even when all objects were visually

identical, subjects could track the targets as long as they were identified at the beginning of the task.

Furthermore, Pylyshyn (2001) proposed that it is not the location of the target that is primary in the indexing process but rather the object itself, leading to the concept of object-based attention (Cavanagh & Alvarez, 2005; Doran & Hoffman, 2010; Pylyshyn, 2001; Scholl, 2009; Viswanathan & Mingolla, 2002). Objects seem to maintain individuality and separate spatiotemporal properties through motion, remaining indexed and thus being distinguishable in tracking tasks (Pylyshyn, 2001). Furthermore, Saiki (2003) specified that two separate processes may exist within Pylyshyn's understanding of visual indexes; namely, a more superficial location binding process that allows for efficient tracking and a more in depth attentional allocation process to retrieve a more integrated representation of an object when required (Saiki, 2003).

Tracking demands

Despite the fact that target tracking is believed to occur pre-attentively, factors such as increased speed and distractor proximity and/or similarity increase a tasks' attentional demands by requiring more attentional resources for target/distractor differentiation (Doran & Hoffman, 2010; Feria, 2012; Papenmeier, Meyerhoff, Jahn & Huff, 2014; Tombu & Seiffert, 2008). An object tracking task requires a participant to continuously track a subset of moving objects for an extended period of time (Allen et al., 2006; Cavanagh & Alvarez, 2005; Pylyshyn & Storm, 1988) (see next section for detailed description of MOT task). Tracking tasks are generally characterized by two separate phases; the acquisition phase and the object maintenance phase (Allen et al., 2006). During the acquisition phase, targets are indexed and separated from the distractors, whereas during the maintenance phase, objects are kept in focus by continually updating their location to maintain visual continuity of motion (Allen et al., 2006).

Speed is crucial when conceptualizing tracking difficulty, as this factor is found to produce the same level of interference that a dual-task produces (a paradigm wherein an individual is required to perform two tasks simultaneously) (Papenmeier et al., 2014; Tombu & Seiffert, 2008). Faster object motion increases the difficulty for target/distractor differentiation; it also challenges one's ability for continuous tracking throughout the task (Tombu & Seiffert, 2008). Faubert and Sidebottom (2012) emphasized the effect of speed on task dynamics, namely that the faster the movement, the larger the interaction (i.e., object collisions and crossovers) between objects in the task. The increase of these events renders the tracking task more difficult to complete, by enhancing the amount of cognitive resources required. Furthermore, Faubert and Sidebottom (2012) also found that when the speed threshold at which the objects were moving exceeded an individual's threshold, the movement was perceived as faster than it actually was, indicating difficulty in allocating cognitive resources beyond one's capacity.

Distractor characteristics, such as proximity and similarity to targets, decrease one's ability to successfully inhibit distractors and maintain focus on targets (Doran & Hoffman, 2010; Feria, 2012; Tombu & Seiffert, 2008). More specifically, proximity makes it more difficult to recognize boundaries between target objects and distractors, a key stage for object identification (Tombu & Seiffert, 2008). Similarly, physical salience of a distractor, or the degree of similarity to the target, will affect how well an individual will be able to differentiate it from a target object. Feria (2012) determined that tracking tasks, which included distractors that held more features in common with targets, resulted in lower overall performance as opposed to tasks with more distinctive distractors. The increase in sheer number of distractors, regardless of their features, was also found to decrease tracking performance (Feria, 2012; Pylyshyn & Storm, 1988; Zhang, Xuan, Fu & Pylyshyn, 2010).

These findings point to the influence that factors such as speed and target/distractor characteristics (e.g. number of targets and distractors, similarity, proximity, etc.) have on the allocation of attention and overall use of cognitive resources (Doran & Hoffman, 2010; Feria, 2012; Tombu & Seiffert, 2008). Given the large number of factors that influence one's tracking performance, MOT paradigms can be used to provide an objective method to assess and control how each factor affects individual outcomes.

Multiple Object Tracking paradigms: real-world object based attention

In a typical MOT task, the items displayed are identical and targets are only briefly identified (or indexed) at the beginning of a trial by signaling (i.e., lighting up or cueing) the subset of items to be tracked (Scholl, 2009). The tracking task requires participants to follow the subset of items within a dynamic scene over an extended period of time wherein the items move amongst each other within a defined physical space, in either two or three dimensions (i.e., 3D-MOT). In mimicking real world object tracking, items can become momentarily occluded, when they disappear behind other objects. Since objects are expected to follow motion trajectories, participants can nonetheless maintain tracking despite momentary occlusion (Pylyshyn, 2001). In fact, Viswanathan and Mingolla (2002) found that when three-dimensional depth cues were present, thus showing a closer representation of a real-world visual scene, MOT performance increased. Without depth cues, tracking of multiple objects was found to be more difficult, suggesting that depth cues allow for a quicker interpretation of whether objects moved in front or behind other objects, thus enhancing the understanding of motion continuation (Viswanathan & Mingolla, 2002) and increasing our ability to track target objects.

Since MOT tasks may seem simplistic in their effort to mimic real-world object based attention, Wolfe and colleagues (2007) considered two potential concerns, namely: (i) in real-

world tracking, items are not always indexed and constant across the length of the tracking (e.g. when driving down the road, the tracked items might change); (ii) real world tracking is more likely to need to be sustained over a longer period of time than the sub-minute length trials utilized in most MOT tasks (Wolfe et al., 2007). To tackle these concerns and determine whether MOT tasks are in fact valid measures of real-world tracking, they investigated the differences of *fixed* tracking (four items over eight for the length of the trial), *add* tracking (wherein objects were randomly added to the tracked subset) and *dynamic* tracking (wherein objects were added AND subtracted during the trial). As well, they examined MOT tracking ability over sustained efforts of ten minutes in length (Wolfe et al., 2007). What they discovered is that there were no significant differences in accuracy among different tracking modalities, and that participants were consistently able to track the same number of objects regardless of the tracking type, thus indicating that standard MOT tasks retain their ecological validity. Moreover, results from the 10-minute trials indicated that while participants can track objects for extended time periods, they could only sustain tracking with the presence of feedback (Wolfe et al., 2007). The feedback employed in these studies consisted in probing of the tracked objects, giving participants a chance to change their strategies for tracking through the task completion. Without the presence of feedback, they saw a steady decline in performance or a marked reduction in the number of objects tracked over time (Wolfe et al., 2007).

While concerns are often posed as to the simplicity of the MOT task, Horowitz, Birnkrant, Fencsik, Tran, and Wolfe (2005) indicated that in fact, these tasks could be more complex than real-world scenarios because object identities are not unique, but rather, are identical. Physical differences presented in real-world scenarios can function as feedback and allow for the maintenance of tracking with reduced effort. These studies support MOT paradigms

as valuable assessments of real-world object-based dynamic attention. In fact, it is apparent from the task's inherent demands that multiple facets of attention are responsible for adequate performance.

MOT and Attention

Multiple Object Tracking (MOT) paradigms require the use of various aspects of attention, where individuals must (i) divide their attention among the targets, (ii) select targets from non-targets, and (iii) maintain the tracked objects across spatial and temporal changes (Makovski, Vázquez, & Jiang, 2008). Scholl (2009) described the role of attention during MOT tasks in terms of three principal aspects: *selectivity*, *capacity* and *effort*. Scholl (2009) described the concept of *selectivity* as the manner with which certain stimuli are more easily processed than others. Recent models of attention have emphasized the role of object-based attention, such as that used for MOT tasks, wherein the main unit of selection is not a single feature but rather the entire object (Doran & Hoffman, 2010; Pylyshyn, 2003). These models have highlighted that there are characteristics of objects that render them more easily distinguishable as an entity rather than a set of composing features; having closed boundaries is one such factor (Doran & Hoffman, 2010). Scholl (2009) explained the concept of object-based attention, affirming that boundary cohesion allows for better tracking and easier flow of attention, by relegating focus on a wider object surface rather than to a single point.

The second attentional concept of MOT is *capacity*, which refers to the limitation in amount of simultaneous processing that can occur. Previous research showed that one can concurrently keep track of 4-5 individual moving objects in a visual field (Allen et al., 2006; Pylyshyn, 2001; Viswanathan & Mingolla, 2002). However, as previously mentioned, there are several factors that affect one's capacity for object-based attention, such as the proximity and

similarity of distractors.

The third attentional concept defined by Scholl (2009) is *effort*, which relates to the amount of cognitive fatigue that is produced following sustained tracking of multiple objects. Through the course of a MOT task, sustained attention is allocated to the indexes to prevent decay as a result of fatigue, in addition to being used for error recovery to ensure that objects are not lost while in motion (e.g., when being occluded). Factors such as increased duration, higher speed, increased number of targets and the individual's current state have been shown to increase subjects' fatigue, leading to a decrease in overall performance (Scholl, 2009). Interestingly, Scholl (2009) found a large amount of individual differences in relation to each of the above stated factors and how they impact subjects' performance.

The amount of effort needed to complete a MOT task is in direct relation to the task's perceived difficulty. Doran and Hoffman (2010) highlighted that perceived task difficulty will significantly affect how attention will be allocated. For a tracking task with low difficulty (e.g., tracking two objects among a set of differently shaped/coloured distractors), selective attention may not be required, as the tracking process may remain pre-attentive. However, with the increase of tracking difficulty, and thus increased effort (i.e., more objects among similar or equal distractors), selective attention will be required to separate targets from distractors (Doran & Hoffman, 2010). In conclusion, Scholl (2009) suggested that MOT could be both pre-attentive and intentional, depending on both the task difficulty and the individual's cognitive state.

The role of attention in MOT tasks has also been studied with the use of electrophysiological measures. For example, Drew et al. (2009) examined individuals' electrophysiological responses to a target, a distractor or an extraneous object that was part of the background, during the course of a MOT task. Results demonstrated that targets elicited the

greatest electrophysiological response, followed by distractors and lastly by background objects. Drew et al. (2009) suggest that the differential neural response was the result of a greater attentional engagement allocated to targets during the tracking task, separating them from distractors or extraneous stimuli. They further suggest that attention is distributed in correspondence to the salience of the object, explaining the greatest response for targets, followed by distractors, as they interacted with targets and needed to be attended to in order to discriminate them (Drew et al., 2009). These studies clearly elucidate the attentional requirements posed during MOT tasks and the strong role of attention in MOT proficiency.

MOT and Working Memory

Working memory is defined as the amount of information that an individual can maintain in memory in order to process it and produce a response (Trick, Jaspers-Fayer & Sethi, 2005). Following Baddeley's tri-component theory (Baddeley & Hitch, 1974), working memory is posited to have three main components: the phonological loop, the visual-spatial sketchpad and the executive (Baddeley & Hitch, 1974). The phonological loop is used to store and manipulate verbal information; the visual-spatial sketchpad is used to store and manipulate visuo-spatial information; lastly, the executive is thought to be responsible for switching attention and coordinating the activity of the other two stores (Baddeley & Hitch, 1974; Trick et al., 2005; Trick, Mutreja, & Hunt, 2012). Within the context of MOT, the visual-spatial sketchpad and the executive are thought to be concurrently involved. The visuo-spatial sketchpad is implicated due to the nature of the MOT task, whereas the executive is thought to oversee the balance between attention and working memory capacity required for effective completion (Trick et al., 2012). Working memory affects MOT performance as it controls the amount of information (i.e.

objects) that an individual can maintain in memory at once, and supports an individual's ability to filter irrelevant (i.e. distractors) and relevant (i.e. targets) information (Cowan et al., 2009).

Dual-task paradigms are often administered to assess whether working memory processes are contributing to MOT performance. Such paradigms require participants to perform the target task concurrently with a task that is representative of the cognitive resources required for the first task (Allen et al., 2006; Zhang et al., 2010). Dual-task interference is then estimated as the difference in performance between dual-tasks assessments and single-task baselines (Zhang et al., 2010). If performance is unaffected, then different cognitive resources are tapped for each task; on the other hand, if performance deteriorates, the same cognitive resources are thought to be used, causing the decline in performance because of having reached capacity limits (Allen et al., 2006; Zhang et al., 2010). Furthermore, dual-task interference is thought to occur because of the creation of competition within processes controlled by executive working memory; some of these include the ability to maintain and select objects in the face of distractions, updating and monitoring, multitasking and task switching. These processes weigh on one's ability to displace cognitive resources efficiently (Trick et al., 2012).

Increasing the number of targets in MOT tasks consistently leads to a decrease in performance, and is one example wherein dual-task paradigms were used to assess working memory involvement (Allen et al., 2006; Trick et al., 2012; Zhang et al., 2010). The decline in performance following an increase in items (targets and/or distractors) was represented as a marked decrease in the ability to discriminate targets from distractors, as well as a significant decrease in reaction time. The deterioration of performance was also correlated to the dual-task's difficulty; with more cognitive resources required for a second task, the decrease in performance was magnified (Allen et al., 2006, Zhang et al., 2010). The impact on performance however,

seems to be modality specific; if the dual-task used to assess MOT performance is targeting visuo-spatial working memory processes, performance is more affected than if targeting verbal working memory (Allen et al., 2006). In fact, MOT shows the highest levels of interference when using spatial working memory tasks as opposed to non-spatial counterparts (e.g. verbal recall) (Zhang et al., 2010).

While visual working memory is thought to depend on an attention-based rehearsal mechanism, it often becomes challenging to separate when working memory and attention are required respectively, and if they can be separated at all. Fougne and Marois (2006) examined the effect of interference of working memory tasks of varied difficulty on MOT performance. The results showed that MOT tasks impaired the completion of an interfering visual working memory task when the MOT task difficulty (determined by the number of objects to be tracked and speed of motion) increased. Fougne & Marois (2006) therefore proposed that the higher the MOT task difficulty, the lower the working memory capacity. However, these authors also suggested that the interference is difficulty-dependent since with low MOT difficulty the interference was reduced. Consequently, MOT tasks are more attention based during low difficulty conditions, but increasingly solicit working memory under high difficulty conditions (Fougne & Marois, 2006). This seems to support the dual influence of attention and working memory in MOT tasks (Fougne & Marois, 2006; Zhang et al., 2010). Furthermore, Zhang and colleagues (2010) proposed that MOT tasks show a heavier attentional basis in the search phase of the task, but require visuo-spatial working memory ability for the identification and localization of objects. In sum, these studies confirm the need for both attention and working memory during MOT, albeit under different conditions. As well, they introduced the concept of

working memory *capacity*, another factor that may impact one's performance on tasks requiring increased utilization of working memory skills.

MOT and Working Memory capacity

Working memory capacity during MOT tasks is quickly reached and is severely limited (Allen et al., 2006; Fougne & Marois, 2006; Trick et al., 2005). In fact, it is expected that by adulthood one can track a maximum of 4 to 5 objects for an extended period of time (Allen et al., 2006; Fougne & Marois, 2006; Trick et al., 2005). These constraints are thought to represent visual working memory's and attention's maximum capacity for tracking moving objects. While it was originally believed that only a fixed number of objects could be tracked, the proposal of a Resource Availability theory (Alvarez & Franconeri, 2007) is believed to be more accurate. This theory holds that there is a maximum amount of resources available for tracking, and that dependent on task demands, they may be used more, or less, quickly. It is suggested that the number of objects that could be tracked is inversely related to the resources required to track each object (Alvarez & Franconeri, 2007). For example, for each item that is added to a tracked subset the speed at which it can be successfully tracked decreases. Similarly, the number of objects and the speed of motion that can be effectively tracked are reduced if the space between targets and distractors is reduced, as differentiation requires increased resources (Alvarez & Franconeri, 2007; Doran & Hoffman, 2010; Scholl, 2009). It is however unclear whether MOT tasks reveal capacity limits that are corroborated by existing, standardized assessments of working memory ability.

The role of working memory has also been studied beyond the ability to recall the target objects and has extended to the role of object trajectories during motion (Ogawa, Watanabe &

Yagi, 2009). Ogawa and colleagues (2009) discussed the visual system's sensitivity to regularities (e.g. repetition of movements) and observed the role of repeated object trajectories and their effect on performance during MOT tasks. They concluded that repeated trajectories are implicitly learned as contextual cues that enhance MOT performance without any conscious awareness. To examine the role of learned trajectories further, target trajectories learned within a practice trial were switched and used for distractors. Performance was impaired during this condition likely resulting from the difficulty of inhibiting learned patterns. Thus, they conjectured that target trajectories are learned and aid performance through a facilitatory effect, but distractor trajectories, while also implicitly learned, exhibit an inhibitory effect during MOT tasks (Ogawa et al., 2009). This study further attests to the role of working memory in MOT, and highlights that working memory capacity is not solely defined by the quantity of items that can be processed, but also by the inherent task difficulty and the amount of cognitive resources it demands.

In conclusion, the role of working memory in MOT is supported by tasks examining dual-task interference and by the impairments in performance that result from reaching working memory's maximum capacity. The understanding that there are maximum working memory and attentional capacities, lends to the importance of considering factors that positively enhance performance on both attention and working memory tasks; one such factor is learning.

MOT and Learning

Attention and learning are highly intertwined, as attention is posited to focus the learning process while learning is expected to decrease the amount of attention required for the successful completion of a task (Doshier, Han, & Lu, 2010). There are two fundamental notions that symbolize the relationship between attention and learning. First, attention improves perceptual

learning and it is expected that when attentional resources are allocated during a task, learning will occur at a faster rate, and vice versa (Doshier et al., 2010). Second, learning attained through continuous practice is expected to reduce the limitations that result from the confines of attentional capacity. Attentional capacity is reduced for tasks in which multiple elements must be followed at once. However, following repeated practice, the ease of performance increases as the need for attentional allocation decreases, suggesting that learning how to perform a task reduces the need for attentional resources (Doshier et al., 2010). Roelfsema et al. (2010) proposed that learning suppresses the attention allocated to irrelevant features of a task, allowing the key features to become more salient. In fact, perceptual learning is thought to occur through a process termed attention weighing, where more attention is posed to salient elements in a task, and less attention is given to distractor items. This allows more emphasis to be placed on the target objects and the tracking activity, while less importance is given to peripheral or task-irrelevant elements (Doshier et al., 2010).

Learning paradigms typically involve repetition and multiple training trials to determine whether performance improves as a function of learned patterns; such is the case for MOT tasks, showing improved performance as a function of consistent training (Faubert, 2013; Parsons et al., 2015). It has been demonstrated that training on the MOT task leads to a significantly increased ability to track a larger number of objects, moving at greater speeds, and with increased performance interpreted as reflecting increasingly efficient attentional abilities (Faubert & Sidebottom, 2012). For example, Faubert & Sidebottom, (2012) demonstrated that athletes who trained consistently on a MOT task improved up to 300% on baseline MOT speed thresholds. As well, it has been established that learning attained through continuous practice can reduce the limitations that result from limits of attentional capacity and enhance performance on

a cognitive task (Doshier et al., 2010).

Jiang, Vázquez, and Makovski (2008) examined the relationship between attention and learning using a MOT task. They were interested in finding out what participants learned from the task, and whether the learning process was related to the targets' trajectories during motion. Target trajectories were defined as the different directions that the objects were most likely to move; they posited that throughout training participants would learn some of the potential trajectories, thus increasing their readiness for tracking. Additionally, they were interested in determining whether learning was associated to temporal predictions, or rather the prediction of future target movements, hypothesizing that better prediction led to more successful tracking (Jiang et al., 2008). Results indicated that learning during an MOT task (as defined by increased performance over trials), does not result from an increased understanding of the objects' motion trajectories, but rather from learning targets' trajectories in relation to one another (Jiang et al., 2008). They also suggested that temporal prediction is not a key component of attentive tracking, but rather, that individuals may be learning repeated motion trajectories within trials, and that successful performance in attentive tracking is a direct result of selective attention. These results further indicate the intricate relationship between attention and learning, particularly within MOT paradigms.

An added factor associated with learning that was previously discussed when conceptualizing the role of working memory in MOT, is perceived task difficulty. Task difficulty affects the learner by imposing a certain level of resource exertion to fulfill the task demands (Paas & Merriënboer, 1994). There are two main factors that affect the perceived difficulty of a task, namely the characteristics of the task itself, and the cognitive abilities of the individual. A task of higher perceived difficulty is associated with higher mental effort, and at least initially,

with lower performance. In fact, tasks that have high difficulty levels are often negatively associated with learning, because most of the available resources are allocated to performing the task and not enough resources can be allotted to building meaningful connections to facilitate learning (Paas & Merriënboer, 1994).

The review thus far has discussed how MOT performance can be used to assess various spheres of cognitive functions, including attention, working memory and learning. For the most part, what we presently know and understand about these relationships (including theories) have originated from research involving typically-developing adult participants. One factor that affects individual ability, and thus performance differences across these areas of cognitive functioning is developmental stage. The literature surrounding MOT and typical development is a burgeoning field, identifying important differences in performance dependent on age and associated cognitive and executive functioning. As well, MOT has been increasingly used with atypically developing (e.g. neurodevelopmental conditions) and clinical populations (e.g., anxiety and depressive disorders) to determine its role as a tool for assessing general attentional abilities (Norton et al., 2016; Kelemen et al., 2007; Becker & Leininger, 2011; Morelli & Burton, 2004). The role of MOT in relation to attentional/cognitive abilities, typical and atypical development will be discussed in the following sections.

MOT and typical development

The continuous interchange between attention and working memory within MOT tasks is particularly noted when taking into consideration developmental level. Significant differences are present across periods of development in working memory capacity, for example. In fact, with regard to MOT performance, working memory capacity and attentional propensity are thought to be the driving force of the performance differences across development (Kharitonova

et al., 2015; Cowan et al., 2009). In particular, the ability to filter information to keep only relevant material in working memory seems to be at the root of improved performance by adulthood and is thought to depend on the accurate use of executive resources (such as controlled attention, and inhibition). These processes are known to improve with age and are believed to result from a growing ability to individuate objects, maintain them in memory, and ignore distractors (Alloway, Gathercole, & Pickering, 2006; Ryokai et al., 2013; Trick, 2005).

The literature on MOT and development is riddled with different accounts detailing the specific ages wherein tracking performance improves. It is generally understood that dependent on task difficulty, as well as task appeal (how child friendly it is), performance will slightly vary. In a study conducted by Trick and colleagues (2005) the number of objects that could be tracked across ages of 6, 8, 10, 12, and 19 years was examined. They identified 6 year olds as having the lowest level of MOT accuracy, since they could track only one object reliably. This number increased to two objects by age 8, three objects at age 10 and 12, finally up to four objects reliably tracked at 19 years of age (Trick et al., 2005). Trick and colleagues (2005) hypothesized that the lower performance among 6 year olds may be due to their inability to concentrate for an extended period of time, rather than an inability to maintain more than one object in memory (Trick et al., 2005).

Slightly different results were found in a study conducted by Ryokai and colleagues (2013). They examined the use of a child friendly MOT task (*TrackFX*), that was administered with an iPad to improve the engagement of children as young as three years old, and allow them to respond independently and within their ability (motor versus verbal) by touching the targets at the end of a trial. Within this study they compared children's performance to that of adults. Children's ability to track multiple moving objects was found to improve significantly between

the ages of 3 and 6 years (Ryokai et al., 2013), with adult-like performance appearing between ages of 11 and 13 years, dependent on task difficulty (Trick et al., 2005). When compared to adults, children's performance was found to deteriorate between three and four objects. It was additionally noted that both children's and adults' performance decreased linearly with each added object (Ryokai et al., 2013). Ryokai and colleagues (2013) further noted that children showed the largest differences to adults when additional distractors were included in the task, reflective of attentional inhibition challenges; the negative consequences of increased numbers of distractors were not as relevant across adults (Ryokai et al., 2013). It was posited that adults had better attentional allocation strategies than children, in addition to an improved ability to inhibit distractors; these are both processes that are expected to ameliorate over the course of development (Ryokai et al., 2013).

Neurological research has also found differences in performance across developmental stages (Kharitonova et al., 2015). While it was originally believed that the main explanation for the age-based differences in performance was structural immaturity, studies have revealed that the efficiency with which the required brain areas are activated plays a significant role (Kharitonova et al., 2015). In fact, Kharitonova and colleagues (2015) found that while with adults there is a clear increase in brain activation with more challenging working memory loads, children's patterns are consistent only up to a certain point, beyond which brain activation no longer changes. It was thus hypothesized that the amount of brain activation is reflective of the working memory capacity, explaining why children's brain activity deteriorated beyond a certain task difficulty. This was corroborated by looking at performance within the limits of working memory capacity of children, wherein brain activation in children was comparable to that of adults (Kharitonova et al., 2015).

In summary, these results indicate that performance on MOT tasks is affected by one's developmental level, specifically regarding an individual's ability to (i) concentrate for extended time segments, (ii) inhibit distractors while successfully allocating attentional resources to targets, and (iii) engage the required brain structures with sufficient activation.

While these studies shed light on the use of MOT to assess performance among typically developing populations, MOT tasks have additionally been shown to provide relevant clinical distinctions among atypically developing populations. Specifically, several studies have focused on the use of MOT to examine visuospatial and dynamic attention in clinical populations.

MOT and atypical development / neurodevelopmental conditions

In previous sections, an explanation of the role of attention, working memory, learning and development within the realm of MOT was provided. With that in mind, MOT tasks have been further utilized to determine whether differences exist among clinical populations, such as William's syndrome and Down's syndrome wherein difficulties in the skills MOT requires for successful performance are generally present (e.g., visuo-spatial processing, working memory abilities).

Clinical studies have been conducted with individuals with William's Syndrome (WS), to examine the effect of deficits in visuo-spatial ability on MOT performance (O'Hearn et al., 2009). An atypical pattern of performance is present among children with WS compared to typically developing individuals. Children with WS show stronger performance than comparable three to four year olds, when recalling multiple *static* objects; on the other hand, they perform significantly worse when having to track multiple *moving* objects (O'Hearn et al., 2009). These findings reflect unique insight into the cognitive processes required to track multiple objects

within the confines of WS; in addition, they corroborate clinical research by providing further evidence of visuo-spatial challenges in this population (O'Hearn et al., 2009).

Research was also conducted with individuals with Down's syndrome (DS), a population wherein, in contrast to WS, visual-spatial abilities are considered a relative strength (Brodeur et al., 2013). Brodeur and colleagues (2013) found that individuals with DS showed impairments in MOT performance compared to typically developing children. It was concluded that participants with DS, were not able to track multiple objects concurrently; they would instead track one object, and conjecture as to the position of the remaining target objects (Brodeur et al., 2013). It was also posited that performance among those with DS resulted from potential difficulties with attentional inhibition and executive working memory. Similarly, visual attention challenges often observed in individuals falling on the Autism Spectrum, have revealed challenges with MOT performance, specifically related to attention allocation and maintenance, rather than to object speed (Evers et al., 2014; Koldewyn, Weigelt, Kanwisher & Jiang, 2014) While it is difficult to speculate as to the exact areas of deficits since MOT is a task involving multiple brain areas, this research brings forth important information regarding the functioning of clinical populations (Brodeur et al., 2013).

Overall, research among atypically-developing populations has emphasized important differences in MOT performance; these differences can serve as an early indicator of developmental concerns. Accordingly, using MOT tasks to determine individual variations from the timelines/milestones of typical development of object tracking ability is a route that should be considered (Ryokai et al., 2013). Obtaining this type of information can highlight situations that suggest atypical development and can allow parents, teachers and clinicians to assess delays at earlier stages, leading to higher likelihood of successful prevention or early intervention.

MOT tasks appear to be sensitive enough to highlight important differences between typically developing and clinically relevant populations, emphasizing the importance of maximizing its use (Brodeur et al., 2013; O'Hearn et al., 2009; Ryokai et al., 2013). Despite this evidence highlighting that MOT tasks may be useful assessment tools for both preventative measures and for addressing present functioning, studies have yet to look at its role in comparison to existing measures to assess its potential to become a normed (non-verbal) assessment tool measuring different facets of executive functioning, specifically attention and working memory. Given the potential implications of having such a tool in clinical practice, this became the motivation for the second study included in this dissertation research.

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CHAPTER III. BRIDGING MANUSCRIPTS - LITERATURE REVIEW TO

MANUSCRIPT 1

A thorough review of MOT, learning and attention was provided in Chapter II. As explained, attentional and learning abilities play a significant role in one's ability to perform on MOT tasks. Concurrently, training on MOT tasks is thought to improve one's attentional ability and learning propensity. In Chapter IV, Manuscript 1 is presented. The study focuses on the effect of feedback on learning using an MOT task and on the potential for transferability of learned attentional abilities. While learning is thought to occur with and without feedback, it is suggested that feedback plays a significant role in the efficiency and quality of learning (Hattie & Timperley, 2007; Kelley & McLaughlin, 2012; Roelfsema, van Ooyen, & Watanabe, 2010). In fact, feedback is proposed to affect performance through both affective (i.e., by increasing motivation, justifying effort, and enhancing engagement in a task) and cognitive processes (by confirming correct or incorrect responses, restructuring understanding, and providing higher levels of self-awareness) (Hattie & Timperley, 2007). In sum, feedback allows one to recognize how to gear their responses to attain correct task-dependent performance. However, while the performance enhancing effect of feedback has been widely studied, it is often overlooked and seldom tested as a variable of interest within the realm of cognitive learning. It is thus unclear whether the presence of feedback can facilitate the improvement of attention and learning and positively affect MOT performance.

In contrast to the well-known positive nature of feedback on task performance, transferability of learned attentional abilities is a field that has yet to be thoroughly explored. Evidence of transferability requires ability to empirically measure whether a training task improves performance not only on the specific task being rehearsed, but also on all tasks that

require similar cognitive skills (Jeter, Doshier, Petrov, & Lu, 2009). It was therefore deemed important to determine whether learning on a MOT task could influence the transferability of attentional capacities to other similar cognitive tasks. Previous research identified factors such as task difficulty (Ahissar & Hochstein, 1997), task precision/similarity (Jeter et al., 2009) and practice (Paas & Merriënboer, 1994) that significantly affect the likelihood of transferability, and were considered within the realm of MOT paradigms.

Chapter IV is the exact reproduction of a study whose aims are to assess (i) whether the presence of feedback during MOT differentially improved performance, (ii) whether improved performance on MOT acquired during training sessions would transfer to other more traditional measures of attentional ability (i.e., the Continuous Performance Test, CPT-II (Conners, 2000), (iii) whether the presence of feedback during the MOT training task would differentially affect the extent of transferability to the traditional, CPT-II task (i.e., the transfer task).

CHAPTER IV. MANUSCRIPT 1.

This chapter is an exact reproduction of the following manuscript currently under review in
Neuropsychologia

Feedback facilitates learning on a 3D Multiple Object Tracking (MOT) task:
considerations for attention and transferability.

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ABSTRACT

Attentional processes play an integral role in learning, affecting performance on most cognitive tasks. Feedback can additionally impact the efficiency and quality of learning. Multiple Object Tracking (MOT) tasks have been used to objectively assess real-world attention, and as cognitive training paradigms geared at its improvement. MOT training improves attention, but little is known about the transferability of attentional capacities from MOT to similar cognitive tasks, or whether feedback during learning affects transfer. This study's goal was to assess whether improved performance on 3D-MOT is transferrable to other measures of attention, while addressing the role of feedback. Forty adults participated in four sessions on consecutive days. Baseline measures of MOT, intellectual and attentional abilities were obtained. Participants were randomly assigned to two groups with or without feedback. Following training, participants were re-assessed to determine improvements relative to baseline. Day 4 MOT performance was significantly higher for the feedback group, as defined by increased speed threshold for tracking items. Improved MOT performance transferred to other attention tasks to a greater extent than the no-feedback group. The results indicate that feedback significantly impacts learning during a high-level dynamic attention task, and may have an important role for the transferability of cognitive abilities.

Keywords: multiple object tracking, feedback, attention, learning, transfer

INTRODUCTION

Real world visual scenes are complex in nature involving multiple elements, both moving and stationary. To successfully navigate through such environments, the ability to track multiple objects at once is an extremely important asset. Simultaneously attending to multiple salient aspects of a visual scene is referred to as multiple object tracking (MOT) and is founded on the ability to inhibit non-salient stimuli while prioritizing relevant components (Pylyshyn, 1989; Scholl, 2009). The process of tracking salient objects as well as the ability to inhibit distractors requires selective and sustained attention, with greater attentional resources needed with increased complexity of a visual scene (Doran & Hoffman, 2010; Drew, McCollough, Horowitz, & Vogel, 2009; Feria, 2012; Howe, Drew, Pinto, & Horowitz, 2011; Scholl, 2009; Tombu & Seiffert, 2008). Multiple object tracking paradigms were thus developed to examine and potentially enhance one's attentional ability.

Multiple Object Tracking (MOT) paradigms are designed to assess participants' ability to focus on and track a subset of moving objects with attention, over an extended period of time. This task is often considered the best empirical measure of real-world object-based visual attention (Scholl, 2009). In MOT tasks the items displayed are identical, and targets are only briefly identified at the beginning of a trial (i.e., lighting up or cueing subset of target items). The tracking task requires participants to follow the subset of items within a dynamic scene wherein the items move among each other within a defined physical space, in either two or three dimensions. In mimicking real world object tracking, items can become momentarily occluded when they disappear behind other objects; however, since objects are expected to follow motion, participants can maintain tracking despite momentary occlusion (Pylyshyn, 2001).

Multiple Object Tracking (MOT) paradigms require the use of various aspects of

attention, where individuals must (i) divide their attention among the targets, (ii) select targets from non-targets, and (iii) maintain the tracked objects across spatial and temporal changes (Makovski, Vázquez, & Jiang, 2008). Accordingly, studies have determined ways to improve attentional ability with the use of this task. It was discovered that consistently training on the MOT task (repeating the task over several sessions) significantly improves one's ability to track an increasing amount of objects, moving at greater speeds, with increased performance interpreted as reflecting more efficient attentional abilities (Faubert & Sidebottom, 2012). The impact of this training was demonstrated to be associated with, and be predictive of performance in sports (Faubert, 2013; Mangine et al., 2014; Romeas et al., 2016). Furthermore, significant positive changes of this training on other metrics such as neuroelectric brain activity, neuropsychological assessments of attention, working memory and executive function have been shown (Parsons et al., 2015). The method proposed in the studies mentioned above used the 3D-MOT paradigm (Faubert & Sidebottom, 2012; Faubert, 2013). It was demonstrated that stereoscopy is critical for attending to dynamic objects that are occluded during the animation as represented by greatly increased speed thresholds of up to a factor of three (Faubert & Allard, 2015).

Considering the improvements in attentional ability associated with training on MOT tasks, it is important to address the factors that positively affect performance. One such factor, thought to enhance one's attentional abilities, is learning. Attention and learning are highly intertwined, as attention is posited to focus the learning process, while learning is expected to decrease the amount of attention required for a task (Doshier, Han, & Lu, 2010). Two fundamental notions symbolize the relationship between attention and learning. First, attention improves perceptual learning and it is expected that when attentional resources are allocated

during a task, learning will occur at a faster rate (Doshier et al., 2010). Second, learning attained through continuous practice is expected to reduce the limitations that result from the confines of attentional capacity. Generally, attentional capacity is reduced for tasks in which multiple elements must be followed at once; however, following repeated practice, the ease of performance increases and the need for attentional allocation decreases, suggesting that learning how to perform a task reduces the need for attentional resources (Doshier et al., 2010).

A specific factor of interest within the realm of attentional ability and learning is feedback. Learning is thought to occur with and without feedback. However, it is suggested that feedback plays a significant role in the efficiency and quality of learning, by providing the necessary information that can aid one's performance on a specific task (Hattie & Timperley, 2007; Kelley & McLaughlin, 2012; Roelfsema, van Ooyen, & Watanabe, 2010). Feedback is defined as immediate knowledge of one's performance (whether a response was correct or not) provided after individual trials or following task completion (Hattie & Timperley, 2007). Studies have indicated that the provision of correct feedback leads to significant improvements in task performance and positively affects the rate of learning, delineated by faster performance improvements over time (Hattie & Timperley, 2007).

Regardless of how feedback is used to improve learning on a specific task, it is believed that once learning occurs, it can last for extended periods of time, such as months or even years (Roelfsema et al., 2010). However, there are contradicting accounts as to whether the effects of learning on one task are specific to the learned task (Roelfsema et al., 2010), or whether such beneficial effects can be re-allocated or transferred to tasks that involve similar cognitive functions. Considering the effects of learning and attention on task performance, and the fact that many cognitive tasks use similar underlying cognitive processes relying on both attention and

learning, it is important to empirically measure whether a training task improves performance not only on the specific task being rehearsed, but also on tasks that require similar cognitive skills (Jeter, Doshier, Petrov, & Lu, 2009).

With the use of MOT to assess attentional ability, it is increasingly important to determine what factors can be implemented to further strengthen one's attentional capacity. Feedback is a factor that is often overlooked and seldom tested within the realm of cognitive training, although it is universally understood to be beneficial to performance. As well, considering that attention is required for a variety of different cognitive tasks, understanding how improved performance using MOT tasks can affect other spheres of cognitive functioning is paramount. The present study thus had three main objectives. First, we aimed to determine whether the presence of feedback during the course of a MOT paradigm differentially improved performance. Second, we aimed to assess whether improved performance on a MOT task acquired during training sessions would transfer to another more traditional measure of attentional ability (i.e., the Continuous Performance Test, CPT-II (Conners, 2000)). Lastly, we wanted to understand whether the presence of feedback during the MOT training task would differentially affect the extent of transferability to the traditional, CPT-II task (i.e. the transfer task).

METHODS

Participants

Forty adults, between the ages of 18 and 30 years, participated in the present study ($M = 23.3$ $SD = 3.36$). Of these 40 participants, 13 were male and 27 female. There were 6 male and 14 female participants in the Feedback group and 7 male and 13 female participants in the No Feedback group. Based on an intake interview participants were excluded from the study if they

were taking stimulants or sedatives that would affect their attention; had a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD); history of seizure disorders; or conditions affecting their vision. In order to confirm general typical cognitive status the Wechsler Abbreviated Scale of Intelligence (Wechsler, 2011) was administered to all participants on the first day of testing. Participants were then randomly assigned to either Feedback or No Feedback groups. The Feedback group had a mean age of 23.15 years of age ($SD = 3.17$) and a mean WASI FSIQ of 112.1 ($SD = 17.9$). The no Feedback group had a mean age of 23.3 years of age ($SD = 3.62$) and a mean WASI FSIQ of 112.1 ($SD = 17.9$). Of the 40 participants, the data of two participants were omitted from analysis since they scored as extreme outliers (see Data Analysis section). However, each participant completed all four days of testing.

Apparatus

Sony HMZ-T1 Wearable Head-mounted display (HMD).

Since previous research found that self-motion can interfere with performance on the MOT task (Thomas & Seiffert, 2010), the present experiment immersed participants in a virtual reality representation of the task, covering their entire visual field. A 3D Multiple Object Tracking task based on the NeuroTracker platform (www.neurotracker.net) was used. The task was controlled using a laptop and Sony HMZ-T1 Wearable Head-mounted display (HMD). The HMD had a 3D display (increasing ecological validity) with 1280 x 720 display resolution and a field of view of 45 degrees, producing virtual image sizes of 150" at 12 feet distance. The virtual size of the spheres was between 20 and 55 mm (larger when they were in front of the virtual cube) and followed a linear trajectory in the 3D virtual space (see Figure 1). The HMD also has headphones to reduce surrounding distractions. The unit is extremely light, weighing only 420 grams, which minimized any discomfort.

Stimuli

3D Multiple Object Tracking task.

As shown in Figure 1, participants were shown 8 spheres moving in a virtual volumetric space in different directions, and were asked to track 4 spheres during a 15 second trial. The spheres moved in a virtual cube with transparent virtual light blue walls. Each trial started with the presentation of 8 spheres positioned randomly in the 3D space (Figure 1-a). Four spheres then changed color, representing those that must be tracked for the length of the trial (Figure 1-b) and were then set in motion (Figure 1-c). Once stopped, the participant verbally indicated which of the spheres (now numbered and all the same color) were tracked, and those spheres were subsequently lit-up (Figure 1-d). Finally, feedback was provided to the participant by “lighting-up” the correct spheres (Figure 1-e) after the participant’s response, thereby assisting participants in determining whether they correctly tracked the items. During the first MOT administration (baseline), and for the no-feedback groups during testing, feedback was not provided. If participants correctly tracked the target spheres for three consecutive trials, the speed of the moving spheres increased; they decreased if responses were incorrect. The initial speed of the spheres was set at 68cm/s and depending on previous trial performance, item speed increased or decreased by 0.05 log. Possible speeds therefore ranged from 0.68 cm/s to 544 cm/s. The *maximum average speed threshold* at which participants were able to track four of the eight items with 100% accuracy, over the course of a session was used to define MOT performance. The entire task lasted approximately 15 minutes.

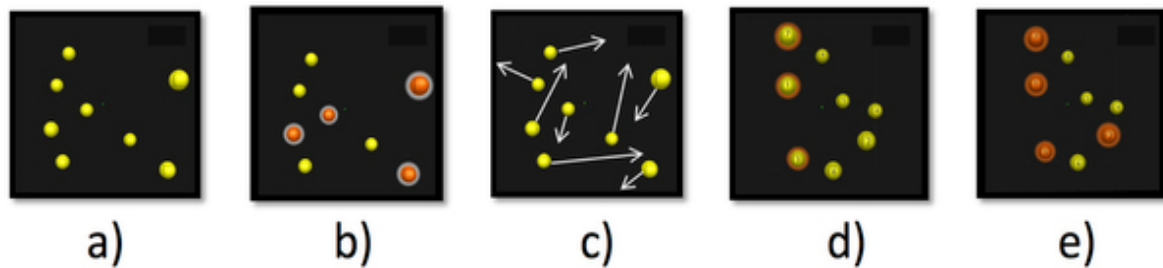


Figure 1. Progression of a Multiple Object Tracking trial with Feedback (e)

Assessment Materials

Wechsler Abbreviated Scale of Intelligence (WASI).

A baseline cognitive profile (i.e., IQ) was measured using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), to ensure participants had cognitive abilities that fell within the average range for their age. The WASI is a brief measure of intelligence that can be administered to participants between 6-89 years of age, and takes approximately 30 minutes to complete. It consists of four subtests assessing verbal crystallized abilities (Vocabulary and Similarities) and non-verbal fluid abilities (Block Design and Matrix reasoning). The composite results of these subtests are calculated into scores of Performance IQ, Verbal IQ, and Full Scale IQ (FSIQ) (Canivez, Konold, Collins, & Wilson, 2009).

Conners Continuous Performance Test II.

The Conners' Continuous Performance Test (CPT II) (Conners, 2000) version 5 for Windows is a computer-based assessment of attention used to assess participants' baseline levels of attention and post-test scores. The task requires participants to press the space bar every time a letter appears, except for the letter "X". Overall, the task is 14 minutes long and is preceded by a short practice (70 seconds) to make sure that participants understand the instructions prior to commencing the test. The instructions appear on the screen informing the participants to press the space bar as quickly as possible for every letter that appears on the screen except for the letter

“X”. The inter-stimulus intervals (ISIs) are 1, 2, and 4 seconds with a display time of 250 ms. The task is divided in 6 blocks and 3 sub-blocks, each containing 20 trials (i.e., letter presentations). The presentation order of the different ISIs varies between blocks.

The CPT-II computer program provides a varied amount of data highlighting different facets of attention. These include measures of omissions (failure to respond), commissions (number of times participant pressed the space bar when the letter “X” was on the screen), hit reaction time (mean response time), attentiveness (defined as detectability or d' , indicating the ability to discriminate between targets and non-targets), standard error, etc. (Conners, 2000). For the present study, only measures of detectability, omission, and standard error will be considered, as they should be most affected by improved attentiveness. This task was chosen as the transfer task as it provides accurate and detailed information about different facets of attention (e.g., reaction time, error rate, sustained attention across blocks, etc.) and is widely used in research as an assessment of attention.

Procedure

The experiment was conducted in a testing room of the Perceptual Neuroscience Laboratory for Autism and Development (PNLab) at McGill University. Upon arrival at the PNLab, all participants were given a consent form, describing the scope of the research (see Appendix A for sample consent form). Once the consent form was explained, read, and signed, cognitive assessment and training commenced. All participants took part in four testing sessions on four consecutive days: Baseline (Day 1 (D1), Day 2 (D2) & Day 3 (D3) (training sessions) and Day 4 (D4) (final training session and post-training assessment). The experiment was conducted over four days to assess the effect of training by solidifying MOT performance enough to be able to determine whether improved ability would affect transfer tasks; as well,

four days would give participants enough time for pre to post-test assessments. During D1, a cognitive profile was defined for all participants based on measures of (i) general intelligence using the Wechsler Abbreviate Scale of Intelligence (WASI) (Wechsler, 1999) and (ii) attention using the Continuous Performance Test II (Conners, 2000). Following cognitive assessment, a baseline measure of MOT performance was obtained without the presence of feedback, for all participants. For D1, the cognitive assessments, and baseline MOT tasks combined took approximately one hour to complete. For subsequent training phases (D2 - D4), participants were randomly assigned ($n = 20$) to either: (i) the MOT training group receiving feedback after trials or (ii) the MOT training group receiving no feedback. Both groups trained for two consecutive days on the MOT task (D2 & D3). The MOT task lasted approximately 15 minutes. After these two days of training, they were re-assessed on the MOT task (D4) and the CPT-II, in order to evaluate the effect of cognitive training, and the possible differential effect of feedback on performance. Participants were compensated for their participation at the completion of the study.

RESULTS

The dependent variable used in statistical analysis was the *speed threshold*, which reflected MOT task performance. Speed thresholds were calculated using a one up one down adaptive staircase procedure (Levitt, 1971). After a correct response (i.e., correctly identifying the 4 target spheres moving at a specific speed level), sphere speed displacement was increased by 0.05 log units and decreased by the same proportion after each incorrect response, resulting in a threshold criterion of 50%. The staircase ended after eight inversions and the maximum average speed threshold was estimated by the geometric mean speed of the last four inversions. The *speed threshold* was therefore the maximum speed of the spheres at which participants could

perform correctly over the course of a testing session. The data of two participants were omitted from analysis since they scored as extreme outliers, with scores deviating more than 3 standard deviations from the mean. The final number of participants used in analysis was therefore $n = 38$, with $n = 19$ for Feedback Group, and $n = 19$ in No Feedback group. To determine whether participants improved in MOT performance following four days of training, a pre-post comparison of speed threshold was conducted; a percent increase in performance was calculated to determine the change in performance from D1 to D4.

Change in MOT Performance: Feedback vs. No Feedback Groups

Speed Threshold.

An independent samples *t*-test was conducted to determine if a significant difference was present between Feedback and No Feedback groups following four days of training. A *t*-test, $t(36) = 2.34$, $p = .025$, revealed that the Feedback group had a significantly higher percent increase in speed threshold ($M = 39.8\%$) from pre-test to post-test as opposed to the No Feedback group ($M = 8.4\%$) (See Figure 2). Paired *t*-tests looking at each group individually, showed that the Feedback group significantly improved from pre-test to post-test, $t(18) = 4.03$, $p < .001$, whereas the No Feedback group did not, $t(18) = 0.61$, $p = .55$.

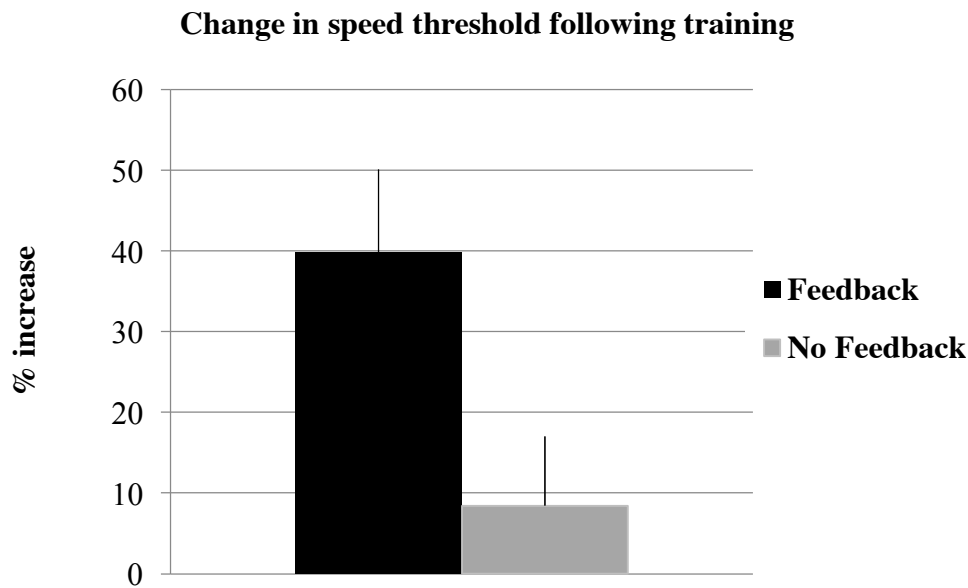


Figure 2. Mean percent change in MOT Speed Threshold Following Training for Feedback and No Feedback groups. Error bars represent the standard error of the mean.

MOT: Change in performance over training sessions

Although *Change in performance* was measured by calculating a percent increase in speed score for both groups between D1 and D4, we were also interested in the *rate* of change in performance across the four days of training, as it would indicate the differential process of learning based on group differences. Within this context, learning was defined as the change in performance during D2, 3, and 4 of training, relative to D1. If both groups increased in performance across training sessions, then learning would be equally occurring among groups. However, a different pattern of performance relative to baseline would show the effect of feedback on MOT performance. In order to decrease inter-subject variable performance was *normalized* relative to D1 scores. This would render the rate of learning more clearly comparable between groups.

Rate of learning.

A Mixed Design ANOVA was conducted to test whether speed threshold across four

days of training differed among groups. The between subjects factor was group, either Feedback ($n = 19$) or No Feedback ($n = 19$). The within subjects factor was the day of training, with three levels according to the day of testing relative to baseline (Day 2, Day 3 and Day 4). The dependent variable was the improvement (i.e. % increase) in speed threshold relative to baseline.

Results from the repeated measures ANOVA (see Table 1) indicated a significant main effect of group, $F(1, 36) = 5.73$, $p = 0.022$, $\eta^2 = .644$. The Feedback group showed a higher percentage of performance improvement relative to baseline ($M = 37.91\%$, $SE = 9.07$) compared to the No Feedback group ($M = 7.2$, $SE = 9.07$). It can thus be inferred that Feedback had a positive effect on rate of relative performance from baseline to post-test. The repeated measures ANOVA did not show significant main effects of Day ($F(2, 72) = 1.107$, $p = .336$, $\eta^2 = .03$) or an interaction effect ($F(2, 72) = .852$, $p = 0.431$, $\eta^2 = .023$) between group and day (see Figure 3). The means of performance improvement relative to baseline for both groups on each training day are represented in Figure 3.

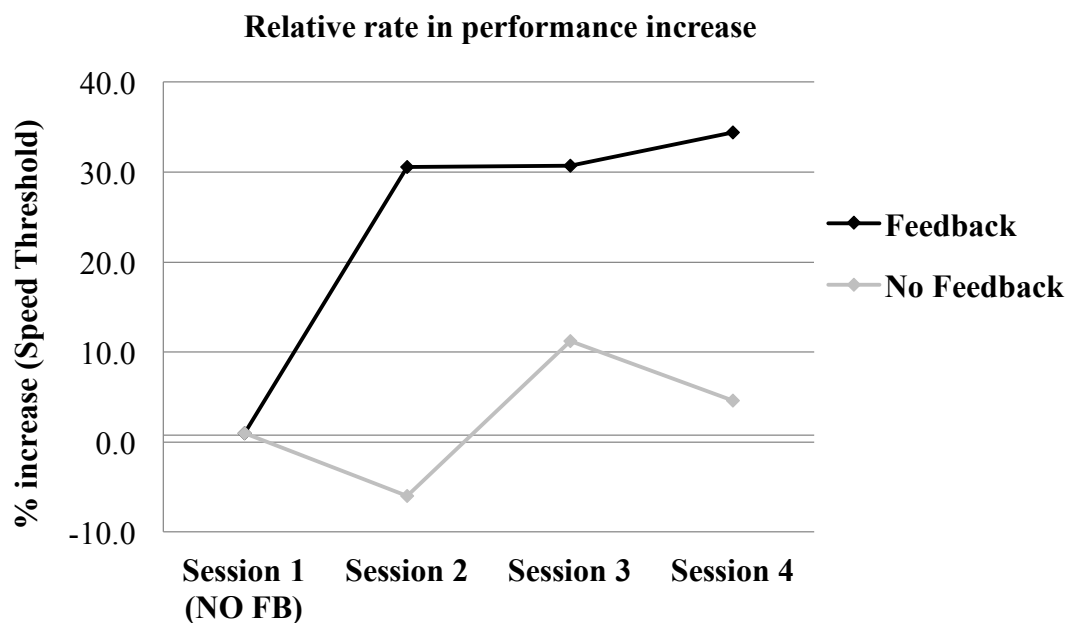


Figure 3. MOT performance increase (Mean percent change in MOT Speed Threshold) for each

session relative to baseline for Feedback and No Feedback groups.

CPT performance

Prior to analyzing whether transferability of cognitive abilities occurred between the MOT performance and CPT, the change in CPT performance was assessed with pre- versus post-test comparisons. All CPT data scores were analyzed as T-scores, which represent the score of the individual taking the test compared to the population average, or the normative group (Conners, 2000); T-scores were used over raw scores as they provide information consistent with the age of the participants.

Detectability scores were significantly different from pre-test to post-test for both Feedback, $t(18) = -2.12, p = .047$, ($M_{pre} = 48.80$; $M_{post} = 44.19$), and No Feedback, $t(18) = -2.17, p = .043$, ($M_{pre} = 49.32$; $M_{post} = 43.77$) groups. However, the groups did not significantly differ from one another in terms of percent increase from pre- to post-test, $t(36) = 0.373, p = .71$. Omission errors were not significantly different from pre-test to post-test for both Feedback, $t(19) = -1.4, p = .176$ and No Feedback groups, $t(19) = .88, p = .386$. As well, the groups did not significantly differ from one another, $t(36) = 1.19, p = .24$. Error rate was significantly different from pre-test to post-test for the Feedback group, $t(19) = -2.18, p = .042$ ($M_{pre} = 43.54$; $M_{post} = 40.39$) but not for the No Feedback group, $t(19) = .616, p = .545$ ($M_{pre} = 44.44$; $M_{post} = 46.24$). The two groups did not differ significantly from one another in terms of percent difference from pre- to post-test, $t(36) = 1.85, p = .07$. However, the Feedback group showed a decrease in the percentage of error rate from pre-test to post-test ($M = -6.83\%$) as compared to the No Feedback group whose error rate increased ($M = 5.81\%$), as shown in Figure 4.

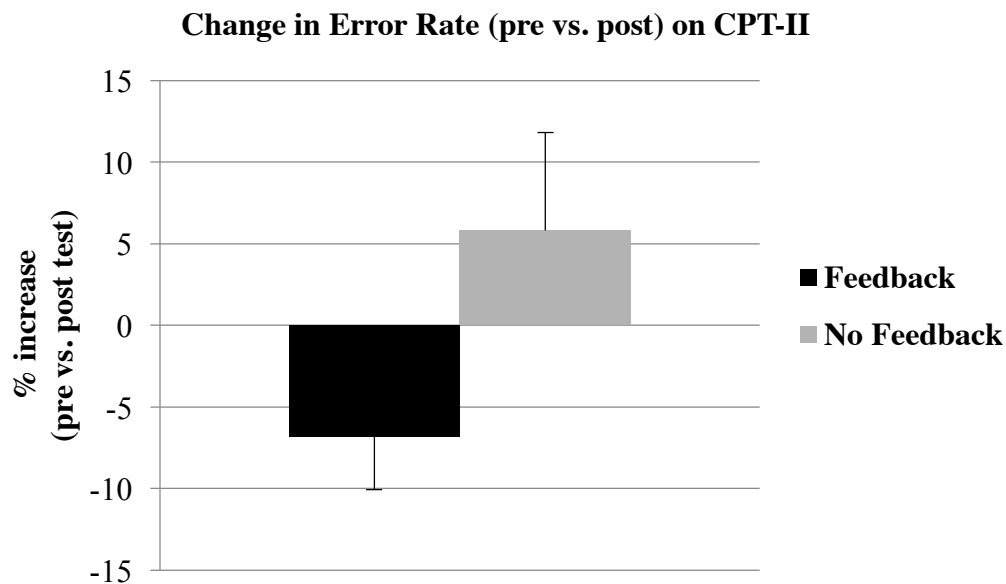


Figure 4. Percent Increase in Error from Baseline to Post-test on the CPT Task for both Feedback and No Feedback groups

Transferability

To assess transferability, three multiple regressions were conducted to determine whether MOT performance significantly predicted improvements on CPT measures of detectability, omissions, and error rate. For the present study, only these three measures of CPT performance were chosen as they are expected to be primarily affected by improved attentiveness. For each of the standard multiple linear regressions, the independent variables were group, percent increase on the MOT, and percent increase on the MOT by group. Furthermore, groups were treated as categorical variables and were dummy coded as 0 = Feedback and 1 = No Feedback.

Detectability (d').

A standard multiple regression was run to evaluate how well MOT performance predicted the improvement in detectability on the CPT measure, following four days of training. Results indicated that the overall model only accounted for 17% of the variance, which was not

significant ($R^2 = .029$, $F(3,37) = .338$, $p = .738$). Based on these results, MOT performance did not significantly predict participants' improvement in detectability after MOT training.

Omissions.

A standard multiple regression analysis was used to test if MOT performance predicted improvements in omission scores on the CPT task following four days of training. Results indicated that the predictors only accounted for 20% of the variance, which was not significant ($R^2 = .039$, $F(3,37) = .462$, $p = .711$). Based on these results, MOT performance did not significantly predict changes in omission scores on the CPT task.

Error rate.

A standard multiple regression was conducted to understand whether MOT performance predicted the percent increase in error rate on the CPT task, following four days of training. Results indicated that the predictors accounted for 46.6% of the variance, which was statistically significant ($R^2 = .217$, $F(3,37) = 3.144$, $p = .038$). The prediction was statistically significant for the independent variable of percent increase in MOT by group ($B = .342$, $t = 2.081$, $p = .045$). However, the individual predictors of group and MOT performance were not significant. As presented in the previous section on CPT performance pre vs. post-test for both groups, it was evidenced that the Feedback group decreased in error rate, whereas the No Feedback group increased in error rate, thus corroborating these results.

Based on the results obtained transferability seems to be occurring, however not across all measures of CPT performance.

DISCUSSION

The present study investigated the role of feedback during a MOT task to determine its effect on improving individuals' attentional abilities. We also sought to determine whether the

improvement in performance gained from training on a MOT task over four days, would reflect on other tasks requiring similar cognitive abilities (CPT). Finally, assuming that feedback would affect performance, we wanted to determine whether feedback could also affect the transferability from the MOT task to the CPT task.

The primary objective was to determine if performance on the MOT task would be affected by the presence of feedback. Results revealed that feedback significantly affected performance, with the Feedback group showing a significant improvement in performance on the MOT, as defined by *speed threshold*, over the course of four days. Groups significantly differed in regards to *speed threshold* with higher thresholds reached by the Feedback group. Speed has a significant impact on a task's cognitive load, with the rise in speed increasing the amount of effort required for completion (Doran & Hoffman, 2010; Paas & Merriënboer, 1994). Based on these results, it could be suggested that feedback has an impact on learning, and thus decreasing the amount of effort (i.e., cognitive load) needed to focus on moving objects at increasing speeds (Doran & Hoffman, 2010; Paas & Merriënboer, 1994).

The two groups showed a significantly different trend in relative rate of performance increase (i.e., learning), with the Feedback group showing consistently higher improvements on all three days relative to baseline scores. Considering the effect of feedback on performance, it could be suggested that feedback leads participants to engage in self-regulated learning (Butler & Winne, 1995). It is likely that each participant applied specific strategies to complete the task, and feedback is an opportunity to monitor whether these are working. With continuous monitoring and updating of the current strategies, one becomes more competent at the completion of the task, thus improving overall performance (Butler & Winne, 1995; Hattie & Timperley, 2007). This is consistent with research examining the relationship between feedback,

self-regulated learning and cognitive processing, further establishing the importance of feedback in task engagement, regardless of specific task characteristics (Butler & Winne, 1995). As well, our results confirm that trial by trial feedback is an effective method of providing feedback (Herzog & Fahle, 1997).

While looking at the relative rate of learning for both groups, it is evident that the Feedback group showed consistently higher performance improvement over the three days following baseline. Doshier et al. (2010) suggested that the relationship between attention and learning is reciprocal, with attention focusing the learning process and learning decreasing the need for selective attention. It can thus be suggested that feedback increased participants' ability to focus on the learning process, resulting in faster learning, indicated by higher performance improvements for the Feedback group over training sessions. Parsing whether this is more related to attention, learning or feedback is difficult to say, but it confirms the importance of considering each factor in relation to one another.

The present study clearly established that perceptual learning occurred, determined by improved performance following repeated practice on the MOT task. However, the transferability of cognitive abilities from a training task to a similar cognitive task was not as clearly defined. Results suggest that MOT performance predicted error rate on the CPT task following four days of training. In fact, further analyses indicated that the Feedback group decreased in error rate following four days of MOT training as opposed to the No Feedback group whose error rate actually increased. An increase in MOT performance was found to predict a decrease in error rate on a similar cognitive task (CPT). In a study conducted by Phye (1991), the effects of feedback during task performance, as well as its role in transferring performance improvements to a separate task, were analyzed. Supporting the present results,

Phye (1991) suggested that corrective feedback facilitates transfer by requiring participants to place increasing effort to develop a strategy that will overlap between training and transfer tasks. The increased effort on the training task renders participants better able to devise a strategy for correct completion, strengthening the learning process; this would ultimately free attentional resources that could be allocated on solving a transfer task (Phye, 1991). Thus, this would explain why in our study the Feedback Group performed better on post-test CPT assessment. As well, pre-post test CPT comparisons indicated that participants in the Feedback group showed improved attention scores over training, as demonstrated by increase in detectability (d') of targets and decrease in error rate, corroborating previous research that evidenced the role of MOT in improving attentional ability and endorsing the effect of feedback on performance (Faubert & Sidebottom, 2012; Hattie & Timperley, 2007; Makovski et al., 2008). Thus, improved performance on the MOT, as a result of learning and lessened cognitive load, is posited to have improved participants' ability to allocate a higher amount of effort to the transfer task, specifically to warding off errors.

Nevertheless, transferability did not seem to occur for all measures of CPT performance, namely detectability or omissions. It could be suggested that the four days of training on the MOT were not sufficient for transferability to occur in all realms (Paas & Merriënboer, 1994). Despite being enough training to show performance improvements, it may not be sufficient to solidify the attentional abilities enough to transfer to other cognitive tasks. Further studies should investigate longer MOT sessions, and/or training for increased number of days to determine whether practice played a role in the amount of possible transfer. Another reason that could have deterred successful transfer is the difference between tasks. Even though both the MOT task and the CPT task are aimed at assessing attentional ability, Jeter et al. (2009) suggested that task

precision affects the transfer of perceptual learning. They argued that task precision, or rather the match between tasks, will affect transferability. The CPT task may not be similar enough to the MOT task to show transferability under all domains. The MOT task is more interactive and engaging; as well, participants get small breaks between trials. In contrast, the CPT task is a continuous 14-minute task, wherein participants must remain focused. The lack of feedback on the CPT task could have also affected performance, increasing the difference between tasks.

CONCLUSION

The present study has highlighted the importance of feedback during the completion of an attentional task (i.e., 3D-MOT) with regards to both (i) learning (significantly improved 3D-MOT performance over three days) and (ii) transferability (significantly affected transfer of improved 3D-MOT performance on another attentional task). These results suggest that feedback, an often-overlooked variable during cognitive assessment and training tasks, has significant implications for learning and attention.

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Author Contributions Statement

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Competing financial interests:

The authors declare no competing financial interests

Ethical approval and informed consent:

All experimental protocols were reviewed and approved by the McGill University Research Ethics Board. The methods carried out by this study were in agreement to the guidelines and regulations set forth by the research ethics board and are suited to comply with provincial, national and international requirements. Lastly, informed consent was obtained from all participants who took part in this study.

CHAPTER V. BRIDGING MANUSCRIPTS - MANUSCRIPT 1 TO MANUSCRIPT 2

In Chapter IV, a 3D-MOT task was used to (i) investigate learning as a function of feedback and (ii) address the potential for transferability of attentional abilities following a 3D-MOT learning regimen. New evidence was provided on the role of feedback in 3D-MOT tasks, revealing that feedback significantly impacts rate of learning and transfer of attentional abilities. Following four days of training participants receiving feedback significantly outperformed those not receiving feedback. As well, feedback was found to enhance participants' learning rate across training days as compared to those not receiving feedback. Lastly, some evidence of transfer was revealed indicating that the improvement in performance on the 3D-MOT task, resulted in fewer errors on an attention task requiring similar cognitive resources.

The results presented in Chapter IV, further corroborated the existing literature linking learning and attention and their seemingly joint influence on performance (see chapter II) using a 3D-MOT task. Study 1 revealed that attentional and cognitive ability appear closely connected in 3D-MOT performance, and it is clear that improvements in attentional performance on 3D-MOT tasks, may transfer to other tasks requiring similar cognitive resources.

As discussed in the Introduction (Chapter II), in addition to assessing dynamic visual attention, 3D-MOT tasks have also been used to examine working memory. Previous studies have highlighted that working memory and attention have a dual influence on MOT performance, and the amount of effort that is required for task completion appears to be the primary factor in the recruitment of working memory capacity (Fougnie & Marois, 2006; Zhang et al., 2010). Working memory has been shown to be consistently implicated in MOT when task demands intensify such as through an increase in either the number of objects to track, or the length of the tracking trial (Allen, McGeorge, Pearson, & Milne, 2006). In fact, existing

literature on MOT tasks reports a decline in performance when increasing the length of tracking trials (Pylyshyn, 2004; Allen, McGeorge, Pearson, & Milne, 2006). The negative impact on performance as a function of increased trial length is posited to result from an increased demand on working memory. Taken together, it is understood that working memory is implicated in MOT and that trial length is one such indicator of working memory exertion, as it directly impacts MOT performance (Allen et al., 2006; Fougne & Marois, 2006; Trick et al., 2005). However, the assumption that increasing trial length reflects higher working memory recruitment has never been validated or compared to other tasks measuring working memory ability. Thus, Study 2 (Chapter VI) provides the first attempt to look at whether manipulating MOT task difficulty by increasing the length of the tracking trial, affects MOT task performance similarly to increasingly difficult conditions on another validated working memory assessment tool, such as the Paced Auditory Serial Addition Task (PASAT). If found to be similar, the findings from this study will serve as a foundation for future research investigating the potential for 3D-MOT to be used as an assessment tool to complement existing neuropsychological batteries to assess various cognitive abilities, including working memory. The use of 3D-MOT as an assessment tool would be particularly relevant as it could be used for non-verbal populations, a widely-underserved group.

The aim of Study 2 is to (1) determine whether performance on a visual-attentional 3D MOT task is associated with working memory as measured by traditional assessment tools (i.e., PASAT); (2) determine whether attentional ability significantly impacts working memory performance across MOT and traditional measures; and (3) to assess how such capacities occur at different periods of development (adolescents, adults).

CHAPTER VI. MANUSCRIPT 2.

This chapter is an exact reproduction of the following article currently in preparation for submission to the Journal of Neuropsychology

Three-dimensional MOT task as an assessment tool for attention and working memory:
a comparison with traditional measures.

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ABSTRACT

Performance on three-dimensional multiple object tracking (3D-MOT) tasks has been interpreted as reflecting real-world dynamic attention and working memory, with MOT performance consistent with developmental expectations. However, performance on MOT tasks has yet to be compared to more traditional assessment methods to establish the feasibility of using them to complement neuropsychological assessments. The aim of this study is to assess whether 3D-MOT tasks can be used as a tool to assess attention and working memory as compared to more traditional and validated neuropsychological methods. Fifty-two participants, placed in adolescent (n=21) and adult (n=31) groups, were assessed on a 3D-MOT task where 3 out of 8 items were tracked over increasingly extended time periods (5, 8, 11, & 15 seconds), increasing working memory load. In addition, all participants also completed the Paced Auditory Serial Addition Test (PASAT) working memory task, and the Conners' Continuous Performance Test (CPT-III) of attention. Results indicated that all groups showed a reduction in 3D-MOT performance (defined as the average speed at which target spheres were successfully tracked) with increasing working memory load. Importantly, performance on the 3D-MOT and the PASAT working memory task declined in a similar rate with increasing working memory load for adolescents and adults, showing similar patterns of performance. Of note, results were significantly affected by individual scores on perceptual reasoning indices on the Wechsler Abbreviated Scale of Intelligence-II (WASI-2). These results suggest that individuals with higher PRI scores may be predisposed to stronger working memory abilities in dynamic tasks. Overall, these findings suggest that 3D-MOT tasks have the potential to be used as an assessment tool for working memory, addressing the need for non-verbal dynamic assessment tools that can be

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easily tailored for clinical populations and individuals of different ages and cognitive functioning.

Keywords: multiple object tracking, working memory, attention, assessment, cognitive functioning, development, perceptual reasoning

INTRODUCTION

Multiple object tracking (MOT) refers to an individual's ability to reliably track a subset of moving objects over an extended period of time. During a MOT task, participants are required to follow a subset of items within a dynamic scene wherein the items move amongst each other within a defined physical space, in either two or three dimensions. In mimicking real world object tracking, items can become momentarily occluded, when they disappear behind other objects. Since objects are expected to follow motion trajectories, participants can nonetheless maintain tracking despite momentary occlusion (Pylyshyn, 2001). A significant body of research has suggested that performance on MOT tasks is related to one's attentional and working memory ability (Allen, McGeorge, Pearson, & Milne, 2006; Cavanagh & Alvarez, 2005; Howe, Drew, Pinto, & Horowitz, 2011; Jiang, Vázquez, & Makovski, 2008). For these reasons, this task is often considered the best empirical measure of real-world object-based visual attention (Scholl, 2009). It is generally well accepted that MOT paradigms require the use of various aspects of attention, where individuals must (i) divide their attention among the targets, (ii) select targets from non-targets, and (iii) maintain the tracked objects across spatial and temporal changes (Makovski, Vázquez, & Jiang, 2008).

Scholl (2009) described the role of attention during MOT tasks in terms of three principal aspects: selectivity, capacity, and effort. Selectivity was described as the ease with which certain stimuli can be processed, exemplified by the finding that closed object boundaries are more easily attended to than single points. Capacity, instead, refers to the limitation in amount of simultaneous processing that can occur, restricting tracking ability to a small number of items (Allen et al., 2006; Pylyshyn, 2001; Viswanathan & Mingolla, 2002). In addition to these, there are many factors that affect one's capacity for object-based attention, namely speed of motion,

object characteristics, number of distractors and object proximity (Allen et al., 2006; Cavanagh & Alvarez, 2005; Doran & Hoffman, 2010; Faubert & Sidebottom, 2012; Feria, 2012; Pylyshyn & Strom, 1988; Tombu & Seiffert, 2008; Zhang, Xuan, Fu & Pylyshyn, 2010). Finally, the amount of effort that an individual must exert to complete a task, affects the role that attention plays in its execution. Effort is related to the amount of resources that must be recruited for task completion, and is thus indicative of task difficulty, with increasingly challenging tasks requiring higher levels of effort, or resource recruitment.

Previous studies have highlighted that working memory and attention have a dual influence on MOT performance, and the amount of effort that is required for task completion appears to be the primary factor in the recruitment of working memory capacity (Fougnie & Marois, 2006; Zhang et al., 2010). In fact, working memory is consistently implicated in MOT when task demands intensify, such as through an increase in either the number of objects to track, or the length of the tracking trial (Allen et al., 2006). In addition, a finite amount of resources are thought to be available for tracking and, dependent on task demands, these may be used more, or less quickly (Alvarez & Franconeri, 2007). With that said, most assessments targeted at measuring working memory ability entail a progressive increase in task difficulty in order to determine when performance deteriorates; a significant decline in performance assumes that working memory capacity has been reached (Allen et al., 2006). It remains to be understood whether manipulating MOT task effort (e.g., increasing trial length) may reveal similar performance disruptions as is observed on traditional working memory assessments.

While working memory and attention are known to have maximum capacities, these are differentially reached depending on one's developmental stage (i.e., chronological age reflective of expected cognitive ability), particularly when both attentional and working memory abilities

are still developing. In fact, working memory capacity and attentional propensity are thought to be the driving force of the performance differences across development (Kharitonova et al., 2015; Cowan, Morey, AuBuchon, Zwilling & Gilchrist, 2009). Additional hypotheses have been made, explaining improved performance among adults because of attentional allocation strategies and an improved ability to inhibit distractors (Cowan et al., 2009; Ryokai, Farzin, Kaltman & Niemeyer, 2013; Stormer, Li, Heerkeren & Linderberger, 2013; Trick, 2005).

It is generally understood that dependent on task difficulty, task appeal (how child friendly it is), and modifications for effective completion (e.g., touch screen versus verbal response), performance on MOT tasks will slightly vary. Children's ability to track multiple moving objects was found to improve significantly between the ages of 3 and 6 years (Ryokai et al., 2013), with adult-like performance appearing between ages of 11 and 13 years, dependent on task difficulty (Trick et al., 2005). When compared to adults, children's performance was found to deteriorate between three and four objects. It was additionally noted that both children's and adults' performance decreased linearly with each added object (Ryokai et al., 2013). Ryokai and colleagues (2013) further noted that children showed the largest differences relative to adults when additional distractors were included in the task, reflective of attentional inhibition challenges, as the negative consequences of increasing distractors were not as relevant in adults (Ryokai et al., 2013).

In addition to research focusing on MOT performance among typically developing individuals, several studies have begun to investigate how MOT performance varied among clinical populations characterized by atypical development, or neurodevelopmental concerns (O'Hearn, Hoffman, & Landau, 2009; Ryokai et al., 2013; Brodeur et al., 2013). These studies have revealed diagnostically relevant differences in MOT performance, suggesting that MOT

tasks are sensitive enough to highlight key aspects differentiating typically developing and clinical populations (Brodeur et al., 2013; O'Hearn et al., 2009; Ryokai et al., 2013); Performance differences among clinical populations can serve as an early indicator to developmental concerns. Accordingly, using MOT tasks to determine individual variations from the timelines of typical development of object tracking ability is a route that should be effectively considered (Ryokai et al., 2013). Notably, the majority of these studies have interpreted reduced MOT performance as evidence for decreased visual attention.

As previously discussed, MOT tasks can be used not only to assess visual attention, but also to measure different aspects of cognition, including working memory. By increasing trial length, working memory is progressively recruited, increasing task difficulty and thus impacting MOT performance. However, it remains unknown whether performance on MOT tasks is comparable to that of more traditional assessments of attention and working memory. The aim of the present study was thus to determine whether MOT tasks can be used as an assessment tool for attention, and in particular, working memory, to complement more traditional measures. For this study, we chose to use the Paced Auditory Serial Addition task (PASAT) as a comparison tool to measure working memory ability. Both PASAT and MOT tasks showed similar neural activations that were reflective of attention and working memory resource recruitment; these included the fronto-parietal areas (responsible for attention and working memory), intraparietal sulcus, and the frontal eye fields (Culham et al., 1998; Drew & Vogel, 2008; Lockwood, Linn, Szymanski, Coad & Wack, 2004; Tüdös, Hok, Hrdina & Hluštík, 2014). In addition, the PASAT measures working memory performance with four conditions of increasing difficulty, thus comparable in structure to our MOT paradigm. PASAT conditions differ in terms of item presentation, with faster presentation being reflective of higher difficulty; MOT conditions differ

by trial length, with increasingly longer trials reflecting higher difficulty. Given the similar structures and corresponding neural activations, comparison between tasks was deemed both feasible and valuable to address the potential for MOT tasks to assess working memory ability. If MOT tasks were in fact able to assess working memory, it would provide a dynamic and engaging tool that could be used across the lifespan. Most importantly, MOT would allow for the assessment of non-verbal populations across a wide variety of ages and clinical presentations.

The main objectives of the following study were to (1) determine whether performance on a 3D-MOT task is associated with working memory as measured by a traditional assessment tool (i.e., PASAT); (2) determine whether attentional ability significantly impacts working memory performance across MOT and traditional measures; and (3) to assess how such capacities occur at different periods of development (adolescents, adults). It was hypothesized that MOT performance across working memory conditions would be comparable to performance on traditional assessment tools of working memory. It was further expected that overall attentional ability (measured with the Continuous Performance Test, CPT-III (Conners, 2004)) would influence performance across working memory conditions, displaying better performance with higher attentional ability. Lastly, it was expected that performance would be affected by developmental level, showing better performance with increasing age.

METHODS

Participants

Thirty-one adults and 21 adolescents participated in the present study. Based on an intake interview, participants were excluded from the study if they were taking stimulants or sedatives that would affect their attention, had a diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), a history of seizure disorders or traumatic brain injury, or conditions affecting their

visual or auditory abilities as these are fundamental requirements in the completion of the tasks. In order to confirm typical general cognitive and attentional functioning, the Wechsler Abbreviated Scale of Intelligence, 2nd edition (Wechsler, 2011) and the CPT-III (Conners, 2004) was administered to all participants (see Table 1 for descriptive statistics).

Table 1.

Descriptive statistics for each participant group, including age, Wechsler's Intelligence Scale IQ (Full-Scale (FSIQ), performance (PIQ) and verbal (VIQ) scores, and CPT-III d' score.

	Adolescents (13 M, 8 F)			Adults (7 M, 24 F)		
	Mean	SD	Range	Mean	SD	Range
Age (years)	15.20	1.63	13-17	23.30	3.33	18-30
WASI FSIQ	103.31	9.60	75-118	107.19	15.50	78-136
WASI VCI	94.75	7.18	81-105	104.10	18.37	72-147
WASI PRI	112.19	15.54	70-134	108.32	16.41	63-142
CPT-III (d')	47.33	7.71	36-64	49.10	6.91	36-65
scores						

Note. $p < .05^*$; $p < .01^{**}$

Participants were recruited both through an already-existing participant list of the Perceptual Neuroscience Laboratory of Autism and Development, and through advertisement on McGill University classifieds, Kijiji, and Craigslist. Prior to testing, all participants (or their parents if they were under the age of 18) signed assent and/or consent forms approved by the ethics committee at McGill University, consistent with the guidelines and tenets of the Declaration of Helsinki. Participants were compensated for their participation at the completion of the study.

Procedure

The experiment was conducted in a testing room of the Perceptual Neuroscience Laboratory for Autism and Development (PNLab) at McGill University. Upon arrival at the PNLab, all participants and their legal guardians were given a consent form, describing the scope of the research. The consent form was explained, read, and signed, prior to starting the study. Of

note, adolescents were required to have parental consent to participate; they also signed an assent form prior to beginning the study. During testing sessions, the following measures were gathered for all participants (see below for description of tasks): (i) general intelligence measure using the Wechsler Abbreviated Scale of Intelligence-II (WASI-II) (Wechsler, 2001); (ii) attention and concentration measure using the Continuous Performance Test III (Conners, 2004); (iii) working memory measure using the Chi/Paced Auditory Serial Addition Test (PASAT) (Gronwall, 1977); and (iv) performance on a 3D-MOT. Administration of MOT and PASAT tasks (see below for description) were counterbalanced to account for practice effects. Several breaks were included within testing sessions to account for fatigue. As well, MOT and PASAT conditions were counterbalanced in order, for the same reason and to prevent practice effects. The assessment was conducted over one session; duration ranged from 1.5 hours for returning participants for whom cognitive assessments had been previously conducted, to approximately 2 hours for new participants.

Assessment Materials

Wechsler Abbreviated Scale of Intelligence – 2nd edition (WASI-II).

For each participant, a baseline cognitive profile (i.e., IQ) was measured using the WASI-II. The WASI-II is an individually administered, standardized test and was used to ensure participants cognitive abilities fell within the average range for their age. The WASI-II is a short and reliable measure of intelligence for use in clinical, psycho-educational, and research settings; it can be administered to participants between 6-89 years of age. The WASI-II is comprised of four subtests (Vocabulary, Block Design, Similarities, and Matrix Reasoning); resulting scores include a Full Scale IQ measure (FISQ-4), a Perceptual Reasoning Index (i.e., Block Design and Matrix Reasoning) and a Verbal Comprehension Index (i.e., Vocabulary and Similarities).

Overall, administration of the WASI-II lasted approximately 30 minutes (Canivez, Konold, Collins, & Wilson, 2009; Wechsler, 1999).

Conners Continuous Performance Test III.

The Conners' Continuous Performance Test (CPT III) for Windows is a computer-based assessment of attention used to measure participants' baseline attentional ability. CPT-III performance was measured to screen participants with significant attentional difficulties, and to assess how attentional level may relate to performance on increasingly difficult MOT conditions. The task required participants to press the space bar every time a letter appears, except for the letter "X". The speed at which the letters appeared on the screen varied throughout the task. The task was 14 minutes long and was preceded by a short practice set (70 seconds) to make sure that participants understood the instructions prior to commencing the test. The instructions appeared on the screen informing the participants to press the space bar as quickly as possible for every letter that appeared on the screen except for the letter "X". The CPT-III computer program provides data highlighting different facets of attention. These include measures of omissions (failure to respond), commissions (number of times participant pressed the space bar when the letter "X" was on the screen), error rate, hit reaction time (mean response time), attentiveness (defined as d' , or the ability to discriminate between targets and non-targets), impulsivity, sustained attention and vigilance. The test is aimed at individuals eight years and older (Conners, 2004). For the present study, a measure of attentiveness (d') was used to account for the effect of attentional ability on working memory performance.

Computerized Paced Auditory Serial Addition Test (PASAT/CHIPASAT).

The PASAT (adult version, 16-54 years) and CHIPASAT (child/adolescent version 8-15 years) is a serial-addition task used to examine the role of working memory, sustained and

divided attention, with auditory stimuli. During the task, a random series of 61 single digits from 1 to 9 (for adults) or 1 to 5 (for children/adolescents) are enumerated every 2.4, 2.0, 1.6 or 1.2 seconds depending on condition. The participants are required to add each digit to the one presented immediately prior to it. The response must be given prior to the presentation of the next digit to count as correct (see Figure 2). While the task is produced, and scored, through a computer software, the experimenter must record the answers manually. The primary difference between the child and adult versions are the maximum sums that can be reached, 18 for adults and 10 for children. The task lasts 10 to 15 minutes on average (Tombaugh, 2006).

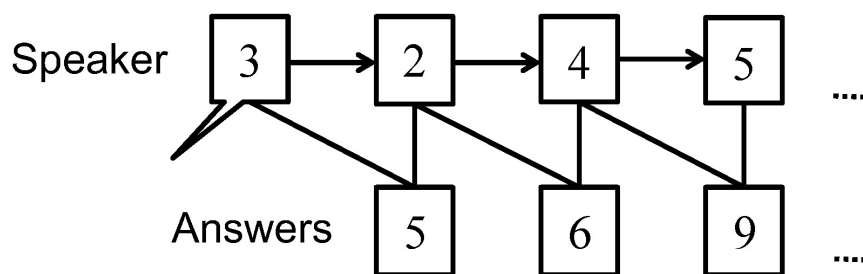


Figure 1. Sample PASAT trial of the 2.0s condition. Numbers are presented every two seconds, within which time participants must provide the resulting addition. This process continues until all 60 numbers are presented.

While the computerized PASAT and CHIPASAT have not been formally normed, studies have indicated that this computerized version and Gronwall's audiocassette version produced equivalent results to Stuss et al.'s (1988) normative data. Wingenfeld, Holdwick, Davis, and Hunter (1999) tested 168 college students on the computerized version of the PASAT and their performance did not differ significantly from published normative data for audiocassette versions. The software thus follows the original normative data for the PASAT (Stuss et al., 1988) and for the CHIPASAT (Johnson, Roethig-Johnston, & Middleton, 1988).

3D Multiple Object Tracking task.

Since previous research found that self-motion can interfere with performance on the

MOT task (Thomas & Seiffert, 2010), the present experiment immersed participants in a virtual reality representation of the task, covering most of the visual field. The 3D-MOT task used is based on the NeuroTracker platform (www.neurotracker.net). The task was controlled using a laptop and presented using a Sony HMZ-T1 Wearable Head-mounted display (HMD). The HMD had a 3D display (increasing ecological validity) with 1280 x 720 display resolution and a field of view of 45 degrees, producing virtual image sizes of 150" at 12 feet distance. The virtual size of the spheres was between 20 and 55 mm (larger when they were in front of the virtual cube) and followed a linear trajectory in the 3D virtual space (see Figure 1). The HMD also has headphones to reduce surrounding distractions. The unit is light, weighing only 420 grams, which minimized any discomfort.

As shown in Figure 1, participants were shown 8 spheres moving in a virtual volumetric space in different directions, and were asked to track 3 target spheres (of eight) moving in a virtual cube for trials of either 8, 10, 12, or 15 seconds. Each trial started with the presentation of 8 spheres positioned randomly in the 3D space (Figure 1-a). Unlike Figure 1, for this study three spheres then changed color (or become indexed), representing those that must be tracked for the length of the trial (Figure 1-b) and were then set in motion (Figure 1-c). Once stopped, all the spheres stopped and were numbered (1 through 8), after which the participant was asked to verbally identify the target spheres indexed at the beginning of the trial, which were entered using a keypad by the experimenter and highlighted (Figure 1-d). Finally, feedback was provided to the participant whereby the originally indexed spheres were "lit up" in red (Figure 1-e) before the next trial was initiated.

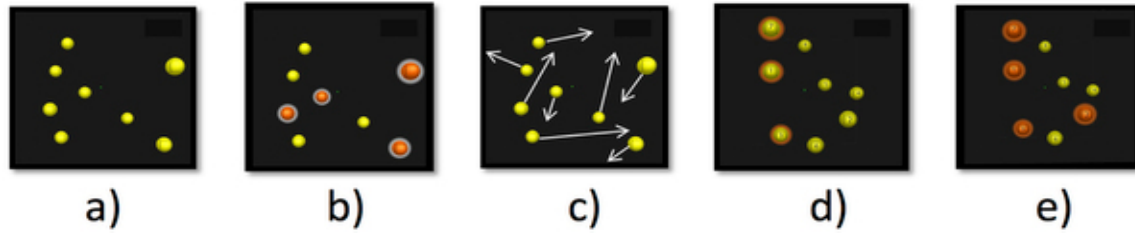


Figure 2. Progression of the 3D-MOT trial used in the present study.

A successful trial was defined by a participant correctly tracking all three of the target spheres. After a correct response (i.e., correctly identifying the 3 target spheres moving at a specific speed level), sphere speed displacement was increased by 0.05 log units and decreased by the same proportion after each incorrect response, resulting in a threshold criterion of 50%. The initial speed of the spheres was set at 68cm/s and depending on performance, item speed increased or decreased by 0.05 log across trials, generated using a one up one down staircase procedure (Levitt, 1971). Adaptive staircase designs allow for participants to constantly perform at a challenging level, while maintaining a level of perceived feasibility (Thompson et al., 2013). The staircase ended after eight inversions and the maximum average speed threshold was estimated by the geometric mean speed of the last four inversions. Possible speeds therefore ranged from 0.68 cm/s to 544 cm/s. 3D-MOT performance was defined by the *maximum average speed threshold* at which participants could track three of the eight items over the course of a session.

For the purpose of the present study, 3D-MOT performance was assessed over four conditions varying in difficulty level, defined as the length of the tracking trial (i.e., 5s, 8s, 11s, 15s); the longer the trial, the more difficult the tracking task. Depending on the number of trials needed to obtain a threshold (typically between 10 and 25 trials), the entire task lasted approximately 45 minutes; within this time two maximum speed thresholds were gathered for each of the four conditions; the average of the two thresholds was used as the dependent

variable.

RESULTS

Task performance across difficulty levels for PASAT and 3D-MOT

Performance on each test at different working memory difficulty levels was assessed. Task difficulty was defined as the increase requirement of working memory resources. In other words, the more difficult the task, the more working memory resources were required for successful task completion. It is generally accepted that capacity is reached when performance begins to decrease, as resources for best performance are no longer available (Fougnie & Marois, 2006; Allen et al., 2006). For the purpose of clarity, different working memory conditions will be referred to under the category of *time*; *task* will refer to MOT and PASAT/CHIPASAT; and *age* will include adult and adolescent groups. Lastly, PASAT will be used to refer to both PASAT and CHIPASAT tasks.

3D-MOT performance across working memory conditions

The 3D-MOT task encompassed four conditions (i.e., 5s, 8s, 11s, or 15s) of increasing difficulty. Task difficulty was defined as the length of the trial, with longer trials requiring increasing working memory resources; it was hypothesized that performance would decrease with increased trial length.

The dependent variable used in statistical analyses, indicative of MOT performance, was the *average maximum speed threshold* for each condition; the *speed threshold* was the maximum average speed at which participants could reliably track 3 out of 8 spheres. Of note, two speed thresholds were gathered and averaged for each condition, to provide a more reliable estimate of 3D-MOT performance. The *average maximum speed threshold* for each condition resulted as follows:

Table 2.

Average maximum speed thresholds on 3D-MOT across conditions

Group	Condition			
	5s	8s	11s	15s
Adults	1.86 (0.48)	1.62 (0.46)	1.52 (0.37)	1.27 (0.36)
Adolescents	1.92 (0.39)	1.52 (0.42)	1.35 (0.48)	1.10 (0.33)

A two-way mixed analysis of variance (ANOVA) was conducted to examine the effect of *age* and *time* on 3D-MOT performance. A significant main effect of time was revealed, $F(3,150) = 54.163$, $p = 0.000$, indicating that performance significantly changed between the 5s condition ($M = 1.88$; $SD = .44$) and the 15s condition ($M = 1.21$; $SD = .36$). Post-hoc pairwise comparisons of the main effect of time revealed that significant differences are present between all levels ($p = .000$) except for 8s to 11s ($p = .082$). Mean differences between conditions are shown in Table 2. Mauchly's test of sphericity for repeated measures was not violated, thus conforming with ANOVA assumptions, $W = .895$, $\chi^2(5) = 5.38$, $p = .372$.

Table 3.

Mean differences across MOT conditions

Time	Mean Difference			
	5s	8s	11s	15s
5s	-	.316*	.448*	.694*
8s	-.316*	-	.132(ns)	.378*
11s	-.448*	-.132 (ns)	-	.246*
15s	-.694*	-.378*	-.246*	-

Note. *significant at $p < 0.05$

No significant main effect was found for age group, $F(1,50) = 0.976$, $p = .328$. As well, there was no significant interaction between age group and time, $F(3,150) = 2.325$, $p = .077$.

These results support the hypothesis that MOT performance decreases with increasingly difficult working memory conditions. However, it does not support expected performance differences across age groups. Results are shown in Figure 1.

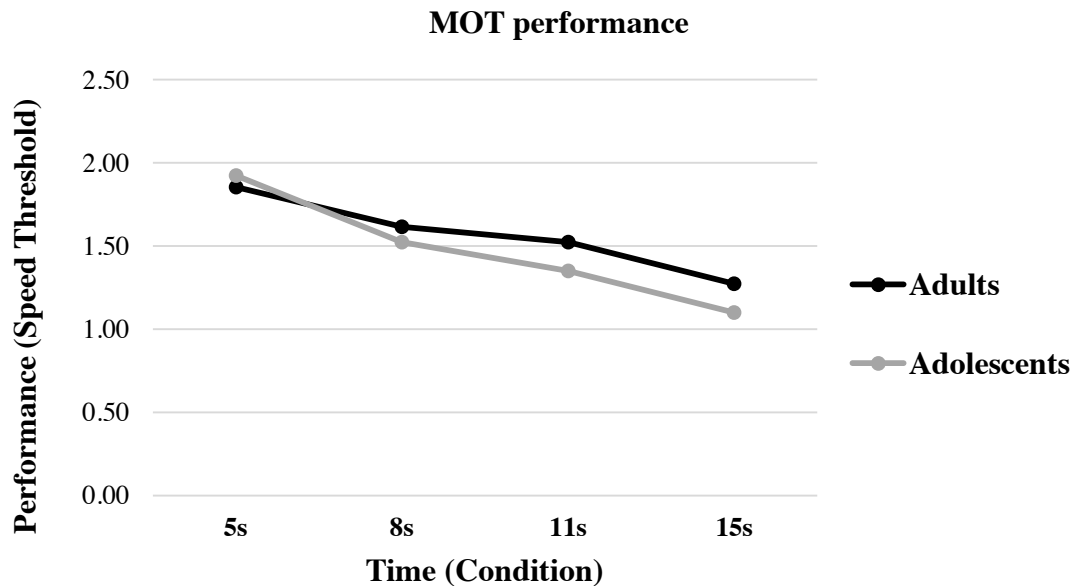


Figure 3. MOT performance, as measured by average speed threshold, for adolescents and adults across WM conditions. Similar performance is observed between groups across conditions.

PASAT performance across conditions

The PASAT entailed four conditions differentiated by the speed at which numbers were presented (i.e. 2.4s, 2.2s, 1.6s, 1.2s). Task difficulty was defined as the speed of presentation, with faster rates leading to worse performance. The dependent variable (PASAT performance) was the *number of correct additions* across each condition; the maximum possible score was 60 correct additions. Results for groups, across conditions, are shown in Table 3.

Table 4.

Average number of correct additions across PASAT conditions

Group	Condition			
	2.4s	2.2s	1.6s	1.2s
Adults	44.16 (10.19)	38.32 (9.97)	32.16 (9.37)	23.39 (7.27)
Adolescents	42.43 (10.73)	35.95 (9.63)	31.29 (7.89)	25.38 (6.09)

Mauchly's test of sphericity for repeated measures was violated, $W = .664$, $\chi^2(5) = 19.925$, $p = .001$; thus, degrees of freedom were corrected using Greenhouse Geisser estimates of sphericity. A two-way mixed design analysis of variance (ANOVA) was conducted to examine the effect of age and time on PASAT performance. A significant main effect of time was revealed, $F(2.324, 116.197) = 155.223$, $p = 0.000$, indicating that performance significantly changed between the 2.4s ($M = 43.46$; $SD = 10.73$) and 1.2s conditions ($M = 24.19$; $SD = 6.83$). Post-hoc pairwise comparisons of the main effect of time revealed that significant differences were present between all levels ($p = .000$). Mean differences between conditions are shown in Table 4.

Table 5.

Mean differences across PASAT conditions

Time	Mean Difference			
	2.4s	2.2s	1.6s	1.2s
2.4s	-	6.157*	11.571*	18.911*
2.2s	-6.157*	-	5.414*	12.753*
1.6s	-11.571*	-5.414*	-	7.339*
1.2s	-18.911*	-12.753*	-7.339	-

Note. *significant at $p < 0.05$

No significant main effect was found for age group, $F(1,50) = .105$, $p = 0.748$. As well, there was no significant interaction between age group and time, $F(2.324,116.197) = 2.229$, $p = 0.104$. These results confirmed expectations that PASAT performance deteriorates with increasingly difficult WM conditions. Given the PASAT is a normed task standardized across age groups, performance differences between adolescents and adults were not expected. Results are shown in Figure 4.

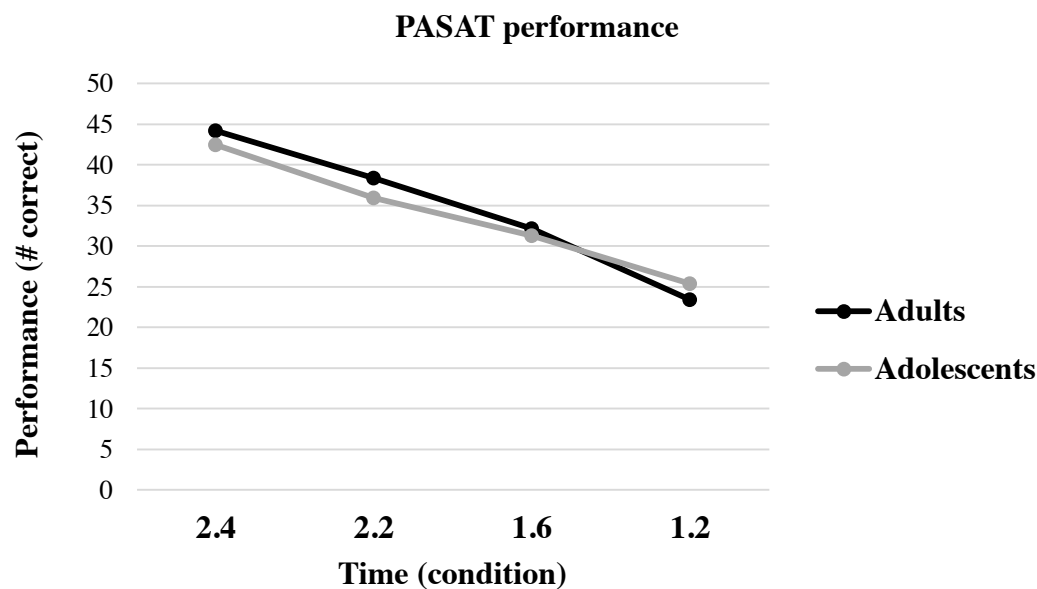


Figure 4. PASAT performance, measured as the number of correct additions, for adolescents and adults across WM conditions. Similar performance is observed between adults and adolescents across conditions.

Comparison of MOT to PASAT performance, across conditions and age groups

Since different performance scores were used within each task, the scores were transformed into standardized z-scores to facilitate comparison (Zheng et al., 2012). The results are represented as a distance from the mean of zero; the easiest condition is likely to be positively removed from the mean, in standard deviation units, as performance is above average, whereas the most difficult condition would be negatively removed from the mean.

Data were analyzed using a linear mixed model treating subjects as the random effect to track the within-subjects' correlations. The model was fit using restricted maximum likelihood (REML) estimation and a variance components structure on the covariance matrix of the random effects. The goal was to achieve a parsimonious final model that included all significant fixed effects and hypothesis-driven interactions. The fixed effects included age group (i.e. adult, adolescent), task (i.e. MOT, PASAT/CHIPASAT), time (i.e. working memory condition, four conditions per task), IQ (i.e. WASI-II Perceptual Reasoning Index) and attentional ability (i.e. CPT III d' score, measure of detectability and indicator of general attention). The latter two fixed effects were used as covariates to control for participant's baseline attention and perceptual cognitive ability.

The WASI-II Perceptual Reasoning Index was chosen as a covariate to control for the effect of IQ on performance. The PRI performance accounts for an individual's aptitude in visual perception, visual-motor integration, visuospatial processing and coordination as well as efficiency during task completion (Dowell & Mahone, 2011). These skills are highly consistent with MOT task demands and thus appear most relevant in these analyses. Furthermore, correlations between MOT performance and IQ scores revealed that PRI is more strongly correlated to performance than VCI [VCI ($r(376) = .173, p = 0.001$) and PRI ($r(376) = .230, p = 0.000$)].

Results of the linear mixed model revealed no significant main effect of age (adult and adolescent), $F(1,43) = 2.868, p = 0.098$, and no significant main effect of time, $F(1,324) = 3.443, p = 0.064$. Furthermore, no significant main effect of attentional ability (CPT d') was found, $F(1, 43) = 1.946, p = 0.170$. Lastly, no significant interaction was shown between task (MOT and PASAT/CHIPASAT) and time, $F(1, 324) = 2.718, p = 0.100$, suggesting both tasks displayed a

similar performance trend across conditions. Performance trends across WM conditions in adults and adolescents are shown in Figure 5 and 6. These results support the hypothesis that increasing MOT trial length renders the task more difficult, challenging working memory capacity and negatively impacting performance. Furthermore, this decline in performance is comparable to that observed with the PASAT, as hypothesized. However, contrary to our hypothesis, no significant developmental differences were observed between adolescents and adults.

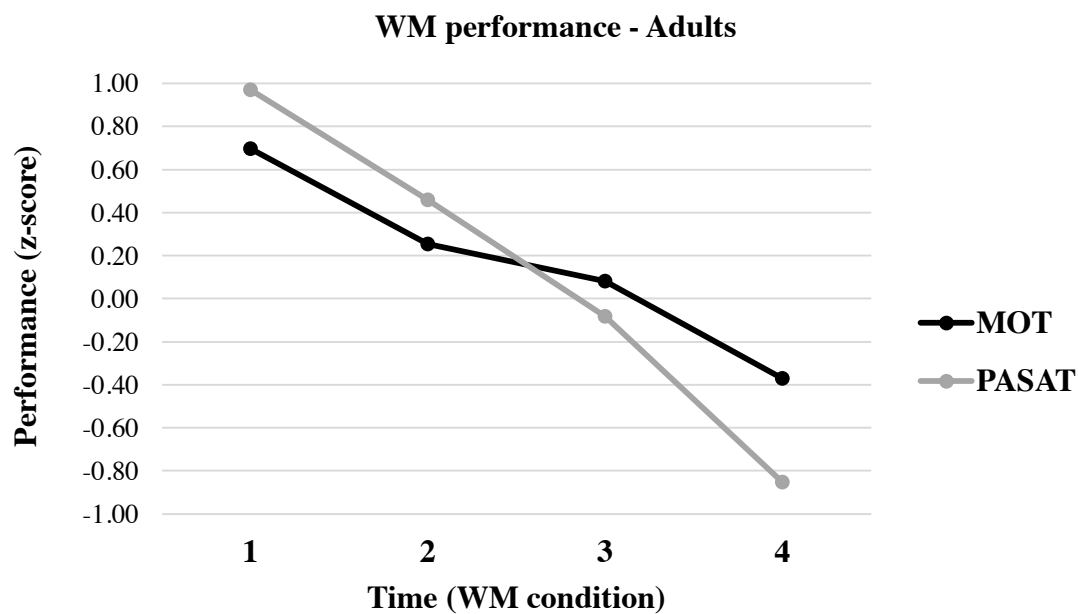


Figure 5: Adult performance on MOT (black line) and PASAT (gray line) is represented in terms of z-scores, across working memory conditions. Conditions are presented from easiest (1) to hardest (4). A similar decline in performance across increasingly more difficult conditions is shown for both MOT and PASAT.

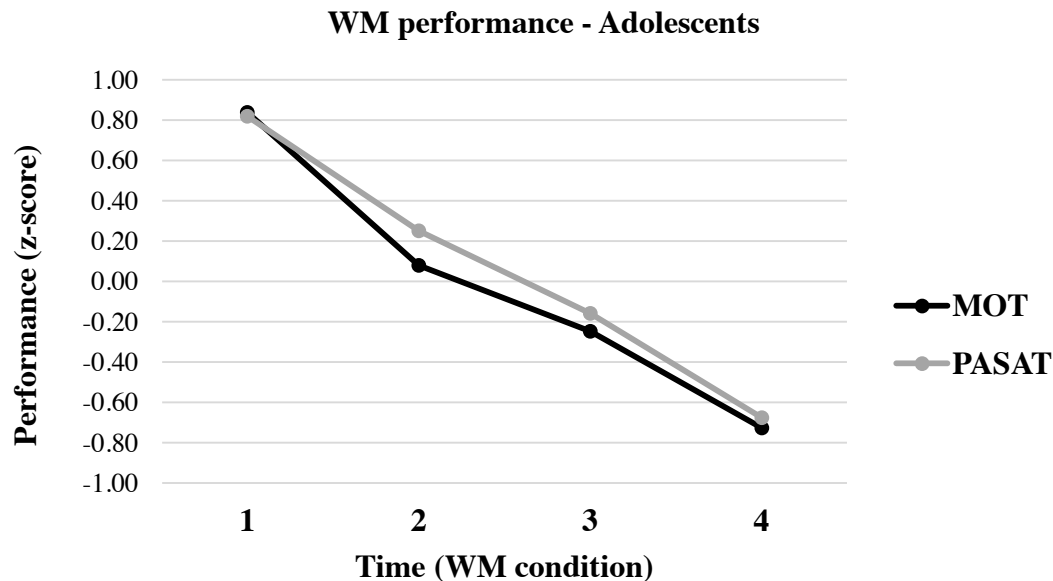


Figure 6: Adolescent performance on MOT (black line) and PASAT (gray line) is represented in terms of z-scores, across working memory conditions. Conditions are presented from easiest (1) to hardest (4). A similar decline in performance across increasingly more difficult conditions is shown for both MOT and PASAT.

Results revealed a significant main effect of task, $F(1, 324) = 6.113$, $p = 0.014$ and of IQ (PRI), $F(1, 152.784) = 6.971$, $p = 0.009$. From preliminary models, a significant interaction was found between task and time; however, it appeared that other factors may be impacting the interaction term. For this reason, IQ PRI was added to the interaction term, which resulted in a significant three way interaction between task, time, and IQ(PRI), $F(2, 324) = 4.167$, $p = 0.016$; this interaction suggests that the mean difference between MOT and PASAT performance is moderated by perceptual IQ. The estimate for the variance of the random effect is 0.183 with a standard error of 0.0497. Coefficients for the model can be found in Table 6. These results suggest that while both tasks displayed a similar decline in performance across increasingly difficult working memory conditions, it appears that perceptual IQ affected the mean difference between MOT and PASAT performance.

Table 6.

Estimates of Fixed Effects for GLM

Parameter	Estimates of fixed effects			
	Estimate	SE	p-value	CI
Intercept	.182	.865	.834	-1.54 – 1.90
Age: Adult	.251	.148	.098	-0.480 - .55
Age: Adolescent	0 ²	0 ²	-	-
Task: MOT	-.384	.155	.014	-.689 - -.078
Task: PASAT	0 ²	0 ²	-	-
IQ PRI	.016	.006	.009	.004 - .028
Time	-.221	.209	.293	-.632 - .191
CPT d1	-.014	.009	.170	-.033 - .006
Task (MOT) x time	-.273	.165	.100	-.598 - .053
Task (PASAT) x time	0 ²	0 ²	-	-
Task (MOT) x IQpri x time	.0009	.002	.616	-.003 - .005
Task (PASAT)x IQpri x time	-.003	.002	.104	-.007 - .001

Note 1. Dependent variable: z score

Note 2. This parameter is set to zero because it is redundant

In summary, results revealed that consistent with our hypotheses, (i) increasing trial length on MOT increased task difficulty, impacting working memory capacity and decreasing performance; (ii) performance on MOT across increasingly difficult working memory conditions was comparable to PASAT performance. In contrast and, unlike what was hypothesized, no significant developmental differences in performance were present between adolescents and adults for MOT.

DISCUSSION

The present study compared 3D-MOT task performance to that of a traditional, standardized working memory assessment tool, the PASAT. The main objectives were to (1) determine whether performance on a visual-attentional 3D-MOT task is associated with working memory as measured by PASAT performance; (2) determine whether attentional ability

significantly impacts working memory performance across MOT and traditional measures; and (3) assess how such capacities occur at different periods of development (adolescents, adults).

Results revealed that both 3D-MOT and PASAT tasks displayed a similar decline in performance across increasingly difficult working memory conditions. Two important considerations can thus be made. First, task difficulty for each condition, and the increase in difficulty across conditions, was comparable for MOT and PASAT. Second, the *impact* of each condition's difficulty on performance was similar across tasks, displaying a comparable decline in the ability to sustain working memory performance. For MOT tasks, each working memory condition differed by trial length, thus the primary goal was to sustain tracking for a longer time. The results obtained in this study confirmed that increasing trial length significantly impacted working memory capacity, thereby causing a deterioration in performance. In contrast, PASAT conditions were differentiated by a reduction in the presentation time; the primary goal was then to process number additions, and provide a response more quickly. Notably, the working memory conditions for MOT and PASAT were increasingly difficult for each task but for different reasons. For the MOT task, the increase of trial length required higher levels of effort to be expended for reliable tracking. Working memory is thought to have a time limit, thus longer trials would increase the likelihood of working memory decay and consequently the potential loss of cued items (i.e., worse performance) (Cowan, 1995). For PASAT, the working memory conditions were differentiated by the ability to generate information (simple calculations), with faster paced trials making maintenance and recall more challenging, leading to worse performance. Barrouillet, Bernardin, and Camos (2004) proposed that working memory ability does not only depend on the duration of the task but also on the demands placed on cognitive resources (e.g., faster speed). It is likely that MOT and PASAT, despite stimulating working

memory in different ways, were subject to similar interference, and thus comparable cognitive resource expenditure. For example, PASAT trials required participants to inhibit previously presented numbers, whereas MOT trials required participants to inhibit distractor items. Each task then added cognitive demands by either increasing speed or length of tracking. The increase in difficulty of each condition (within both MOT and PASAT) revealed a similar decline in performance. Thus, it seems that the amount of cognitive resources required for each condition's specific difficulty level were comparable across 3D-MOT and PASAT conditions. For these reasons, it appears that 3D-MOT can be compared to a traditional and standardized neuropsychological assessment of working memory, and may be used to provide relevant information regarding one's ability to sustain working memory among increasingly challenging conditions.

Results also demonstrated that perceptual reasoning ability as measured by PRI had a positive effect on MOT task performance, while it did not seem to significantly impact PASAT performance across both adolescent and adult groups. The moderating effect of PRI on MOT performance is not unexpected since perceptual IQ embodies skills such as visual-spatial reasoning and visuo-motor coordination (Dowell & Mahone, 2011); these abilities are most consistent with a dynamic task such as MOT. It may be the case that, while both tasks assessed working memory, different facets of working memory were being addressed. A study conducted by Thompson et al. (2013), looked at the potential for working memory training to affect – as a means of transfer – cognition or intelligence. Their research study used MOT as a control training task involving perceptual skill learning, but additionally conceptualized it as training of visual spatial working memory. Within their study, they found that while MOT performance did

not correlate with complex working memory tasks, it improved performance on visual spatial tasks such as the matrix reasoning subtest of the WASI (Thompson et al., 2013).

It is also noteworthy to consider that while PRI positively affected MOT performance, the relationship between working memory performance and IQ may have been mediated by the number of items that participants could maintain in working memory, or their inherent capacity (Fukuda, Vogel, & Awh, 2010). It is possible that their PRI may be higher because their working capacity was also higher, which would affect MOT performance twofold: first, it would allow for easier tracking of multiple items; second, by allowing extra working memory resources to be used for increasingly difficult conditions. It may be interesting to obtain baseline working memory score, using either the Wechsler Intelligence Scale for Children or the Wechsler Adult Intelligence Scale (depending by the age) to correlate performance on MOT and PASAT (Wechsler, D., 2008; Wechsler, D., 2014). These measures assess both visual and auditory working memory and would provide a better understanding as to each participant's inherent ability, thus potentially allowing for further acknowledgement of how working memory capacity can affect both PRI and ultimately performance on MOT.

The second objective of this study was to understand how overall attentional ability would impact MOT performance. The attentional ability of all participants was measured with the CPT-III d' score, an indicator of detectability also used as a reliable marker of general attention. This attention score was used as a covariate to determine whether attentional ability moderated the participants' task performance. Interestingly, attentional ability was not found to significantly affect performance across tasks for either adolescents or adults, seemingly suggesting that working memory may have played a larger role in task completion, consistent with the task demands. Visual attention and working memory often work together in learning

tasks, wherein visual attention typically plays a role in the consolidation of perceptual information into visual working memory (Schmidt, Vogel, Woodman, & Luck, 2002); as well, it is generally believed that the act of maintaining target items in working memory requires sustained attention to protect from the interference of distractor items (Matsukura et al., 2007). For these reasons, it was originally expected that attentional ability would be related to performance. However, more recent research has in fact determined that while visual working memory and attention interact, often in a supportive fashion, it appears that once target items have been attended to by cueing, they persist in working memory storage without the need for sustained attention (Hollingsworth & Maxcey-Richard, 2013). Thus, this may explain why detectability did not influence overall performance on either task. It would be interesting to determine whether a participant's detectability score influenced their ability to commence MOT tasks; for example, it would be noteworthy to examine whether a higher detectability score lends to better initial performance on MOT tasks, reflective of attention playing a larger role in the initial stages of MOT (i.e. cueing of target items).

The third objective for this study was to determine whether performance on MOT and PASAT across working memory conditions would significantly differ as a result of developmental stage (i.e. adolescents versus adults). Results revealed adolescents (13-17 years) and adults (18-30 years) performed in a comparable manner across MOT conditions, thus contrary to our original hypothesis. In a study conducted by Trick et al. (2005), they identified how many objects could be tracked simultaneously across different age groups (6, 8, 10, 12, and 19). While younger children (6 years old) could only track one object at a time, by 10-12 years old, individuals could reliably track up to three objects. As well, Trick and colleagues (2005) hypothesized that the lower performance among younger participants may have been a result of

their inability to concentrate for an extended period of time, rather than an inability to maintain more than one object in memory (Trick et al., 2005). In fact, it is generally expected that by four years of age, working memory faculties are developed (Alloway, Gathercole & Pickering, 2006), however the efficiency with which they can be used, and the amount of effort that must be exerted, differs. Further studies identified that youth may reach adult-like performance between the ages of 11 and 13 years, dependent on task difficulty. When compared to adults, youth's performance was found to deteriorate between three and four objects (Trick et al., 2005). It is likely that the results that were obtained in the present study are reflective of what was noted in Trick et al. (2005); given our chosen age range (13-17 years) it appears that their performance was in fact like that of adults. It could also be suggested that adolescents seemed to exert similar levels of effort on task completion thus potentially challenging the notion that performance efficiency, as well as the ability to concentrate, is not fully developed until adulthood (Alloway et al., 2006). Also notable is that we chose three objects rather than four to account for the longer trial lengths. It would thus be interesting to determine performance scores with younger age groups, as well as performance across children, adolescents, and adults, while maintaining four objects during the tracking task.

Overall, the present study focused on the potential to use MOT within neuropsychological and psychoeducational testing batteries to provide further information on an individual's cognitive, memory, and learning abilities. At present, further investigation is being conducted with younger age groups to determine whether significant developmental differences may be present in school-aged children. Along with suggestions made in previous sections, this may provide a clearer understanding of the data obtained from performance on MOT across age groups, and their meaning with reference to working memory ability. Future research should also

expand on existing literature attempting to determine the brain dynamics of attention and working memory. Specifically, electrophysiological approaches have been used to investigate working memory utilization (particularly regarding individuation of targets) within MOT tasks. Two primary event-related potentials have been identified in target selection and quantity of targets to be tracked (N2pc – N2 posterior contralateral, and CDA – contralateral Delay Activity, respectively) (Luck & Vogel, 2013; Ma, Husain & Bays, 2014; Pagano, Lombardi & Mazza, 2014). Further attending to how these may change and develop across the lifespan would be of interest to clarify the role of development and MOT task performance.

In addition, several studies examining MOT in clinical populations have determined that this task is sensitive to atypical functional brain activation related to spatial attention and vigilance (Beaton et al., 2010). Furthermore, it was also found to be sensitive to deficits in tracking ability in individuals with amblyopia (Secen, Cullham, Ho & Giaschi, 2011; Ho et al., 2006). The results from the present study lend support to the feasibility of using MOT as an assessment tool for working memory across typically developing populations. Moving forward, similar studies should investigate the differences in working memory performance across clinical populations to determine whether results could be corroborated. It would be interesting to note whether conditions in which working memory ability is typically reduced (e.g. ADHD), would display poorer performance on both 3D-MOT and PASAT tasks with comparable trends – as observed in this study. It appears that there are multiple ways to use MOT as an assessment tool, displaying its multifaceted qualities and the value of using it for both research and clinical practice.

Lastly, it is noteworthy to consider some potential limitations of the present study along with areas that may require further analysis moving forward. It is well-known that 3D-MOT

requires the use of working memory as well as aptitude with visual-spatial skills. It may thus be the case that MOT would in fact be most related to visual-spatial working memory rather than a broader working memory tool. For these reasons, it would be beneficial to compare MOT performance to an existing, and more specific, visual-spatial working memory assessment, such as the Corsi block-tapping test, or the CANTAB spatial span task (Kessels et al., 2010; Fray, Robbins & Sahakian, 1996). As well, to further investigate the effect of PRI on performance, it may be interesting for future studies to use a visual PASAT to assess whether results would differ. The present study used the auditory version of the PASAT, as it is deemed most sensitive in assessing working memory abilities. With that said, PRI may be more correlated to performance on a PASAT task that requires visual recognition of stimuli (Thombaugh, 2006), thus rendering MOT and PASAT tasks more comparable. Finally, results of MOT performance revealed that between conditions 2 and 3 (8s and 11s trials), participants did not show significantly worsened scores, as would be expected by the increase in trial length. It will be interesting to further address the reason why those two trial lengths did not impact performance as significantly as other trial times. Obtaining electrophysiological data could elucidate whether those trial lengths require similar cognitive effort, and thus do not impact performance differently. As well, it may be interesting to look at different trial lengths to determine whether working memory decrements occur within ranges, so that 8-11 seconds may be one range, 12-14 another, and so on.

CONCLUSION

The present study investigated the potential for 3D-MOT tasks to be used as a complementary neuropsychological tool for assessing working memory across different populations (e.g., non-verbal) and developmental stages. Using a validated working memory

assessment tool, the PASAT, allowed for the comparison of working memory abilities as measured by 3D-MOT. Our results display similar performance trends across both tasks, among increasingly difficult working memory conditions, thus suggesting that both tasks may similarly address working memory functions.

This study has highlighted important factors that can affect one's ability to successfully perform on MOT tasks across increasingly difficult working memory conditions, including perceptual reasoning skills, attentional ability, and developmental stage. With that, it has identified the importance of further investigating MOT performance in comparison to more specific tasks, such as those geared at visual-spatial working memory. These results have provided further support to research findings distinguishing the use of attention and working memory in separate stages of tracking and highlighted how effort expenditure affects performance over differently demanding MOT conditions. Lastly, this study revealed that adolescents of ages 13 to 17, displayed no significant differences in MOT performance as compared to adults, possibly suggesting that working memory abilities may be fully developed by early teenage years.

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CHAPTER VII: GENERAL DISCUSSION

Summary of Findings and Original Contributions to Knowledge

The aim of this dissertation research was to explore areas of attention and working memory in MOT and provide improved understanding of its ties to cognitive functioning, learning and development. Within that conceptualization, the specific goals were twofold. First, we sought to better understand learning and attention within the context of MOT to identify factors, like feedback, that can enhance one's potential to learn task specific, and generalizable skills. Second, we aimed to introduce 3D-MOT as an assessment tool for attention and working memory, with prospective implications for clinical screening tools. Results from the presented manuscripts sought to both extend previous work on attention training and learning in MOT and introduce a new conceptualization of 3D-MOT tasks as an assessment tool.

In Manuscript 1, the effect of feedback on learning and attention training were examined within the context of MOT. While previous studies had examined the role of feedback in task performance (Hattie & Timperely, 2007), it had yet to be determined whether feedback may affect MOT-specific performance. Findings from this study revealed that the presence of feedback significantly impacted learning across testing sessions, supporting the use of feedback to enhance performance on MOT tasks. In addition to MOT performance, feedback also impacted participants' rate of learning, showing a faster, more pronounced improvement across training days. These research findings added to the existing literature of attention training in MOT (Faubert, 2013; Faubert & Sidebottom, 2012) by identifying trial-by-trial feedback as a key factor for optimizing learning and attention training using 3D-MOT. Lastly, Manuscript 1 aimed to identify whether improvements in performance on MOT as a result of training, would transfer to tasks requiring similar attentional skills. Findings revealed that individuals receiving

feedback through training, displayed a reduced amount of errors on a CPT attention task, as compared to pre-training scores. However, not all facets of CPT performance were affected by improved MOT results, suggesting there may be factors that impact transfer, such as task similarity, insufficient exposure or practice, or different cognitive demands (Jeter et al., 2009; Paas & Merriënboer, 1994; Phye, 1991).

Following the results obtained from Manuscript 1 and with increasing consideration of the potential impact of MOT in clinical practice, Manuscript 2 focused on the possibility of using 3D-MOT to assess working memory by comparing to existing neuropsychological assessment tools for working memory. Findings revealed that performance on 3D-MOT across increasingly difficult working memory conditions were comparable to those on a traditional working memory assessment tool, the PASAT. Interestingly, when performance across 3D-MOT and PASAT was compared, it was noted that the participants' perceptual reasoning seemed to mediate performance on tasks, albeit in a different way for each. Despite research existing on the link between MOT and perceptual reasoning and the inherent role that spatial reasoning has on task completion (Dowell & Mahone, 2011; Thompson et al., 2013), the present findings highlight a differential role of perceptual reasoning abilities in the comparison among assessment tools, suggesting that MOT may be more suited as a subtype of working memory assessments, namely spatial working memory. The knowledge of this relationship will allow future studies to further examine MOT performance in relation to other tasks. Another important finding depicted in Manuscript 2, was the absence of a developmentally driven performance discrepancy between adults and adolescents. While there are a series of different accounts detailing various age ranges and their expected performance on MOT, research studies have suggested that by ages 13-17 working memory faculties may be fully developed, and functioning as those of adults (Trick et

al., 2005; Alloway, Gathercole & Pickering, 2006). However, different from adults is youth's ability to concentrate for extended periods of time, or track an increasingly large number of objects (Trick et al., 2005; Ryokay, 2013). This study thus contributes to the literature supporting adult-like performance across adolescents 13-17 years of age suggesting that by adolescence working memory may be fully developed, as depicted by their working memory performance on 3D-MOT tasks. The results from Manuscript 2 provide an introductory look at MOT as an assessment tool for attention and working memory while highlighting its strong potential to complement existing neuropsychological tools and depicting the feasibility of using it in clinical settings.

Clinical Implications and Future directions

The results from this dissertation cover several areas impacting clinical work, including how to enhance learning and attention, as well as how to broaden the scope of traditional working memory assessments to include a dynamic, ecologically valid, tool. These findings can have significant implications for prevention, assessment and intervention.

3D-MOT as a screening tool.

Performance on MOT tasks was found to be mediated by one's perceptual reasoning. As explained in Manuscript 2, perceptual reasoning accounts for an individual's aptitude in visual perceptual, visual-motor integration, visuospatial processing and coordination, as well as efficiency during task completion (Dowell & Mahone, 2011). There are several clinical conditions that significantly impact one's ability in these areas. In fact, as explained in Chapter 2, research has examined performance on MOT in clinical populations for whom these faculties are impaired and found confirmatory results; some of these conditions included Turner's syndrome (Beaton & Stoddard, 2010), Amblyopia (Ho et al., 2006; Secen, Culham, & Giaschi, 2011),

Down's Syndrome (Brodeur et al., 2013), and William's Syndrome (O'Hearn et al., 2009). Results from MOT performance could thus function as a screening tool for these conditions, facilitating access to services and further diagnostic assessments.

In addition to perceptual reasoning skills, the results from this dissertation research highlight how MOT could be used to not only to determine one's working memory abilities but also to recognize deviations from typical performance. Working memory is believed to be a core deficit in children with dyscalculia, due to its role in successful completion of calculation and problem solving exercises (Passolunghi, 2006; Passolunghi & Siegel, 2001); as well, deficits in executive functions, which include working memory, are observed in conditions such as Attention Deficit Hyperactivity Disorder (ADHD) (Klingberg et al., 2005; Mezzacappa & Buckner, 2010) and Autism Spectrum Disorder (Kenworthy, Yerys, Anthony & Wallace, 2008). In addition to clinical populations, but retaining clinical implications, MOT has been used with elder populations to assess at-risk older drivers (Bowers et al., 2013), revealing that performance on MOT was reflective of driving performance. Having a clear understanding of how MOT performance is impacted across these conditions could allow for early recognition of individuals who deviate from typical performance and could thus benefit from more preventive efforts or remediation services.

In contrast to many current assessments of attention and working memory, MOT has an engaging quality that allows for its use in children as young as three years of age, with limited or no verbal abilities, or with poor English-language comprehension skills (Cacchione et al., 2014; Ryokai et al., 2013). Furthermore, its limited length allows for wide ranging use across developmental groups and clinical populations alike. These considerations are significant for two primary reasons: firstly, task engagement allows for more accurate performance assessments

(Matthews et al., 2002; Skinner, Kindermann & Furrer, 2009); secondly, short assessments allow for prevention efforts to be more feasible as they would be easily implemented across a variety of settings. Part of the ease of MOT implementation across settings is asserted by the fact that its administration does not necessarily require an individual with specific qualifications. For example, if implemented within the school system, teachers could administer the MOT task and provide the results to the school psychologist who would use it as a screening tool to determine who may require further attention. It is often challenging for teachers to recognize specific difficulties (e.g. working memory, attention or learning challenges) among children within large classrooms, until these issues become blatant, at which point remediation may need to be more significant; concurrently, it is at times difficult to differentiate ability from performance impacted by socio-emotional factors. The use of MOT as a screening tool could provide important information regarding not only early identification of challenges, but also insight into differentiating ability versus behavioral challenges. In addition, early identification can provide school psychologists with supplementary information regarding which children may need immediate attention, and the areas wherein they may require increased remediation. This approach could prevent worsening of symptoms, or performance, before services are rendered to the child or adolescent in need.

While further research is necessary to solidify our results, and validate 3D-MOT as a screening tool, the present dissertation provided a significant step forward in understanding its potential as a clinical tool.

3D-MOT as an assessment tool.

The literature review (see Chapter 2) provided a thorough conceptualization of MOT and specifically highlighted that MOT tasks are often deemed to be the best empirical measure of

real-world object-based visual attention (Scholl, 2009). The task's ecological validity lends itself to be a valuable medium to assess individuals' functioning in select areas. The findings from this dissertation research revealed a range of possibilities for the use of 3D-MOT tasks as an assessment tool for working memory, attention and learning.

As described at length in Chapter 2, working memory and attention are highly intertwined, and typically co-facilitate effective task performance. It is widely understood that individuals with attention deficits (e.g. ADHD) have concurrent challenges across areas of attention and working memory (Barkley, 1997). The findings from the present body of research reflect the potential for 3D-MOT tasks to be implemented as an assessment tool, for both attention and working memory providing a non-verbal dynamic tool to formally assess individuals with suspected challenges in these areas. Not only would it add to existing assessments but it would focus on specific areas of attention that are most related to real-world scenes, thus providing relevant information about the individual's functioning in everyday tasks. As well, reflective of what was discussed in the previous section, 3D-MOT tasks would help to assess individuals whose attention difficulties render the assessment process particularly challenging; MOT is both engaging and interactive, stimulating the examinee to their full potential. Clinical tools are always changing in the direction of being more engaging, to recruit implicit motivation and allow for a measurement of true potential (Matthews et al., 2002; Skinner et al., 2009), an element which 3D-MOT would certainly be able to provide, thus emphasizing the clinical implications of its use.

With regard to learning, in Manuscript 1 participants underwent a training regimen wherein they completed MOT training over four days. While the study focused on feedback as the primary factor of interest, compelling results were displayed in terms of learning rate with a

steep learning curve between baseline and post-test assessments. Further research in the area would be warranted to determine whether learning ability could be evaluated using this task. Many existing assessments of learning ability rely on either verbal competency or, when assessing visual-spatial learning, rely on static tasks (e.g. Test of Memory and Learning; California Verbal Learning Test) (Delis, Freeland & Kaplan, 1988; Reynolds & Bigler, 1994). Thus, MOT could serve as a tool to assess learning ability in a non-verbal manner, while also attending to learning needs within real-world visual-spatial tasks. Moreover, it could be a tool that has reduced dependence on one's crystallized, verbal intelligence. It is often assumed that non-verbal tasks are free of verbal bias; however, research analyzing the impact of verbal knowledge and educational background, informs otherwise, indicating that these factors will affect nonverbal performance on standard neuropsychological assessments, such as design fluency, visual search, or complex figure tests (Rey-Osterreith Complex Figure) (Rosselli & Ardila, 2003). Whether MOT would reflect these results, remains to be seen.

Lastly, it is increasingly important to develop assessment tools that are culturally sensitive and that can be used in a cross-cultural fashion. Existing literature using non-verbal assessments, such as Design Fluency or Visual Search tests, across culturally diverse individuals depicted significant differences in performance between cultures (Rosselli & Ardila, 2003). These results address the need of finding tools that would reveal lower cultural interference. However, at present, these areas have yet to be explored within the context of MOT. These research efforts would allow for 3D-MOT tasks to retain not only ecological validity, but also be used across the lifespan and among diverse populations.

3D-MOT as an intervention tool.

Training on MOT tasks over several sessions has shown significant enhancements of attentional abilities, thus suggesting that MOT paradigms can be recognized as attention training tools (Drew, McCollough, Horowitz & Vogel, 2009; Faubert, 2013; Faubert & Sidebottom, 2012). The present research highlighted important factors that can impact the likelihood of effective improvements of performance on MOT tasks, such as the use of feedback, rendering MOT an increasingly more powerful tool in eliciting successful attentional training. Feedback is a significant factor in the efficiency and quality of learning (Hattie & Timperley, 2007) and is deemed to have a proactive role, by eliciting internal motivation to boost performance (Nicol & Macfarlane-Dick, 2007). Furthermore, clinical interventions are typically affected by difficulties with eliciting and maintaining motivation. Given MOT's inherent interactive and engaging qualities, paired with the motivational boost of feedback provided within a game-like construct, this tool is likely to provide significant benefits within treatment settings. As highlighted in Chapter 2, MOT is malleable and flexible to different developmental groups and ability levels. Future considerations stemming from this body of research, within the context of treatment, should look more specifically at clinical populations with attention deficits and their likelihood of displaying improved attentional performance following a MOT training regimen. In addition, focus should be placed on determining the ideal length of training programs and whether different levels of impairment (i.e., severity of attention deficit) would benefit differently from such training.

There are numerous clinical conditions that are characterized by significant difficulties in attentional abilities, including concentration and maintenance of attention (e.g., ADHD). Research supports that individuals with ADHD typically learn better when engaging in

stimulating activities, including multiple dimensions (e.g., auditory and visual, visual and motor, etc.) (Haghshenas, Hosseini, & Aminjan, 2014; Imhof, 2004). Many treatment approaches for ADHD are geared at improving executive functioning including both facets of selective and sustained attention, as well as working memory abilities; these are areas that 3D-MOT targets (Tran & Hoffman, 2016, Scholl, 2009; Allen et al., 2004; Fougner & Marois, 2006). Existing programs use MOT paradigms as part of their training regimens, such as the COGMED program, a computer-based program geared at improving attention and working memory (Chacko et al., 2013). As well, our lab has used 3D-MOT to determine the efficacy of training attention with students diagnosed with a neurodevelopmental condition (Tullo, Guy, Faubert, & Bertone, 2017-in revision). Using a randomized control trial, students aged 6-18 years, were trained on either 3D-MOT, an active control task, or a treatment as usual group, within their own school environment. Post-training assessments revealed that students trained using 3D-MOT showed increased attentional abilities following a 15-session intervention. These results suggest that 3D-MOT is not only effective in training attention, but also an accessible and adaptable tool for atypically developing students with ranging levels of cognitive functioning. Lastly, this study suggests that 3D-MOT is easily implemented in the school setting, and is an ideal approach to provide specialized services to students with a neurodevelopmental condition (Tullo et al., 2017).

With that said, while enhancement of attentional abilities using 3D-MOT have provided positive results (Faubert, 2013; Faubert & Sidebottom, 2012; Tullo et al., 2017), working memory training has yet to be explored with this paradigm. It would be interesting to determine whether similar results could be attained with working memory, given the inconsistent results present in the literature, revealing both supportive findings (Morrison & Chain, 2011; Klingberg, 2010) and concerns with the large variation in results across studies (Shipstead et al., 2010).

Comparing performance on 3D-MOT training to existing working memory and attention programs, may provide further understanding of the role of 3D-MOT as a working memory training tool. It may additionally address some of the limitations discussed in Manuscript 2, namely whether 3D-MOT would be most valuable at assessing a subset of working memory (e.g. visual-spatial working memory).

In conclusion, this dissertation research contributed to the conceptualization of (i) using 3D-MOT as a screening tool across areas of attention, working memory and learning; (ii) its use as a dynamic, non-verbal assessment tool that could be used with a widely-underserved population; and (iii) using 3D-MOT as a treatment tool geared at improving attentional and working memory abilities. These results provide a starting point on which to build further investigation of the potential for MOT to be used in a series of clinical, research and educational settings. MOT has the potential of being a useful, efficient, and engaging tool with which to advance assessment practices, educational services, and future research in the field.

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