Fundamental Movement Skills and Motor Planning Abilities among Children with Autism Spectrum Disorders

Kerri L. Staples

Department of Kinesiology and Physical Education

McGill University

A thesis submitted to McGill University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Kinesiology and Physical Education

Abstract

Behaviours of children with autism spectrum disorders (ASD) are developmental in nature, where movement skill differences can be accounted for in terms of either *delays* or *deficits*. This dissertation includes three manuscripts that collectively delineate differences in planning and execution of fundamental movement skills by children with ASD in terms of delays and deficits. The first manuscript compares performance of twenty-five children with ASD to three typically developing comparison groups individually-matched on chronological age (CA), movement skill (DEV), and mental age equivalence (MA) on the *Test of Gross Motor Development* (*TGMD-2*). Performance of children with ASD was poor compared to the CA group on locomotor and object control subtests of the *TGMD-2,* suggesting a delay in development. Children with ASD were strategically matched to the DEV group on raw score from the locomotor portion of the *TGMD*-2. This group was approximately half the age of the children with ASD, demonstrating the extent of this delay. Comparisons to the MA group showed that differences in movement skill cannot be accounted for entirely in terms of cognition as the children with ASD performed significantly worse on both subtests. The second manuscript describes the initial development and validation of an obstacle course to explore movement planning to better understand the differences in performance of fundamental movement skills found in the first study. The psychometric properties were sufficient to warrant further use. The third manuscript examined movement planning based on performance of children with ASD on the obstacle course compared to the same three groups of typically developing children. Motor planning was inferred from frequency of acts of hesitation and hesitation time during the obstacle course, while movement execution was inferred from execution time, movement pattern, and success. Despite demonstrating similar movement patterns as the younger DEV group, when compared to all three comparison groups, the children with ASD took significantly longer to plan and execute their movements. Collectively, findings from both tasks suggest that children with ASD are delayed in the planning and execution of movement skills and may also develop these skills differently than their typically developing peers, which supports a deficit position.

Résumé

Les comportements des enfants autistes sont de nature développementale; les différences des habiletés de mouvement peuvent être expliquées comme des différences de délais ou de déficits. Cette thèse est composée de trois articles scientifiques, qui collectivement expliquent les différences de la planification et de l'exécution des mouvements fondamentaux des enfants autistes, en ce qui a trait aux délais et déficits. Le premier article compare la performance de vingt-cinq enfants autistes à trois groupes d'enfants avec un développement typique. Les enfants étaient jumelés individuellement par l'âge chronologique (AC), l'habileté de mouvement (HM), et l'équivalence de l'âge mentale (AM) mesuré avec le « *Test of Gross Motor Development (TGMD-2).* La performance des enfants autistes était faible en comparaison avec le groupe AC sur les sous-tests de control du mouvement et control des objets du TGMD-2, suggérant un délai de développement. Les enfants autistes étaient jumelés au groupe HM par leur résultat brut au sous test du control du mouvement du TGMD-2.Les enfants de ce groupe étaient deux fois plus jeune que les enfants autistes, ce qui démontre l'ampleur du délai. Des comparaisons au groupe HM, démontrent que les différences d'habiletés de mouvement ne peut être complètement expliqué par la cognition étant donné que les enfants autistes performaient moins bien aux deux sous-tests, et ce, de façon significative. Le deuxième article décrit le développement et la validation d'une course à obstacles pour' explorer la planification des mouvements afin de mieux comprendre les différences de l'exécution des mouvements fondamentaux trouvées lors de la première étude.

Les propriétés psychométriques étaient suffisantes pour justifier l'usage davantage. Le troisième article examine la planification du mouvement basée sur la performance des enfants autistes à la course à 'obstacle. La performance des enfants autistes était comparée aux performances des trois mêmes groupes d'enfants de développement typique. La planification du mouvement était indiquée par la fréquence des actes d'hésitation et le temps d'hésitation lors de la course à obstacles, alors que l'exécution du mouvement était indiqué par le temps pris pour réalisé le mouvement, le patron du mouvement et la réussite. Malgré des patrons de mouvement similaires au group HM plus jeune, les enfants autistes prenaient significativement plus de temps pour planifier et exécuter leurs mouvements en comparaison aux trois groupes d'enfants de développement typique. Ensemble, les résultats suggèrent que les enfants autistes ont un délai de développement aux niveaux de la planification et de l'exécution des habiletés de mouvements. De plus, les enfants autistes ne développent pas ces habiletés de la même façon que les enfants ayant un développement typique, ce qui appuie une position de déficit.

Acknowledgements

My family has been there every step of this seemingly never ending journey – not only did they listen to me talk incessantly about my research and even more about my kids, but they supported every decision I have made along the way and their belief in me has never faltered.

I was also very fortunate to have met some influential people during my undergrad years. Dr. Bell instilled confidence in me each and every time I walked into his office and was always quick to give me a proverbial kick in the a$$ whenever I began to second guess myself. Next came Donna who conveniently moved into Dr. Bell’s old office and helped me realize that I could build a career doing exactly what I loved. Then I was off to Montreal where Billy and Andrea helped me to realize that research was just as rewarding and almost as enjoyable as teaching. And all of a sudden I found myself in grad school - at times I know I did not choose the easiest path to go down (and may have been a bit stubborn when it came time to change directions), but in doing so I have learned so much more about myself these past six years than I ever imagined possible and I am truly grateful for all the support I received along the way.

I appreciate the feedback I received from my supervisor and committee in order to bring my ideas together and create this dissertation. Greg you gave me several opportunities to develop as a researcher and have provided both support and encouragement while I pursued my ideas and interests. Bob you have always been quick to answer questions and your sense of humour has helped me to see the light at the end of the tunnel more times than I care to count. Paul you have provided me with specific feedback that I know will help me throughout the years as my research continues to develop and evolve.

I was fortunate to have been a part of ART, which played an integral role in my understanding of ASD and my development as a researcher and also SSHRC, Special Olympics, and McGill University for providing funding support. And of course, this dissertation would never have been possible without the amazing students and teachers at Summit and Mountainview schools. I must also acknowledge my research assistants, who over the years endured many early mornings and long days in order for me to maintain my nearly unrealistic timelines. Not only were you wonderful RAs, but many of you also became close friends throughout my time at McGill…thank-you!

On a more personal note, I am indebted to the Cognition and Instruction cohort who included me as one of them throughout this journey and I am beyond grateful to my friends who tolerated my commitment to school over the past 12 years. I know there have been many times when months passed without a word spoken between us, but whenever I was in need of a chat to take my mind off school, a pep talk to get my mind back on school, or a fresh set of eyes to read through the final draft of a paper, you have always been there. And finally, these last few months have been more challenging than I ever anticipated and I am thankful that I didn't have to go through them alone…from preparing for interviews, then revisions, final edits, and finally photocopying…Nancy I could never have done this without you!

Contributions of Authors

The three manuscripts included are based on research conducted as part of my doctoral dissertation. As a doctoral student, I was responsible for all aspects of the research process including writing the manuscripts. Greg Reid, my supervisor, helped me to refine my initial ideas and facilitated my progress throughout the research process, including assistance with editing the final manuscripts. Throughout the dissertation I assumed increasing levels of responsibility, especially with respect to preparation of the manuscripts.

Table of Contents

List of Figures and Tables

Chapter 2

Fundamental Movement Skills and Autism Spectrum Disorders

Chapter 3
Development and Validation of a Movement Planning Task for Children with Autism Spectrum Disorders

Chapter 4
How Do Children with Autism Spectrum Disorders Plan Movement Skills

List of Appendices

Introduction

Estimates of autism vary considerably although the prevalence is seemingly on the rise. While Kanner originally estimated the prevalence to be 2 to 4 children per 10,000 (Kanner, 1943), this rose to 11 per 10,000 in the 1990's (Fombonne, 2003), with conservative estimates of 13 per 10,000 less than five years later (Fombonne, 2005a). Although prevalence rates have increased exponentially, their significance is difficult to gauge given that most epidemiological studies have not been adequately designed to examine trends over time, nor have they controlled for changes in diagnostic definitions, or age of diagnosis. More recent estimates of approximately 60 per 10,000 (Fombonne, 2005b) now reflect prevalence of autism spectrum disorders (ASD) rather than just autism itself. Regardless of the reasons behind these dramatic increases in ASD, it represents an increased number of children who may require unique service provisions and instructional considerations.

Three disorders (autistic disorder, Asperger's disorder, and pervasive developmental disorder not otherwise specified), with similar phenotypes are referred to collectively as ASD. A diagnosis of ASD is based on characteristic behaviours relative to typical development and developmental level. These behaviours reflect a triad of impairments in social reciprocity and communication in addition to restricted or repetitive interests and/or behaviours (American Psychiatric Association, 2000). Given these behaviours often present themselves in a wide variety of combinations and in varying degrees of severity, it is no surprise that unique behavioural profiles are found among individuals with

ASD. Increasing development and maturation leads to further changes in levels of functioning as these behaviours continue to change and evolve over time.

The nature of ASD is complex, with nearly all aspects of behaviour being implicated and a vast range of abilities evident both within and across individuals. While not all of these behaviours are unique to ASD (e.g., Ozonoff & Jensen, 1999), it is the pattern, severity, and pervasiveness of these impairments that characterizes the disorder. Perhaps the most puzzling (and yet remarkable) feature among individuals with ASD would be their characteristic patterns of strengths and weaknesses and demonstrable performance discrepancy between structured systematic tasks and interactions in somewhat unpredictable naturalistic social settings (e.g., Baron-Cohen, 2006). Given the enormous range of behaviour and heterogeneity in terms of symptom severity, intelligence, and adaptive functioning among individuals with ASD, it seems most probable that ASD is a result of interplay among multiple contributing factors rather than a single causal one. Although advances have been made across multiple disciplines, the cause of ASD is still speculative at this point.

From an early age, children with ASD have a marked inability (or disinterest) to engage in imaginative or pretend play. These early experiences, however, are fundamental in shaping behaviours (Piaget, 1962) and developing the brain. Structural findings show that children with ASD seem to have “too much brain” in some regions (i.e., frontal cortex), and yet “too little brain” in others (for review see Cody, Pelphrey, & Piven, 2002). Similarly, “experience-expectant” neural development would suggest these early experiences also strengthen efficient and functional neural connectivity (Greenough, Black, & Wallace, 1987). Functional MRI shows poor connectivity between brain regions (Just, Cherkassky, Keller, Kana, & Minshew, 2007), but overwhelming heightened connectivity at the local level (for review see Courchesne & Pierce, 2005). Advances in MRI-based methods have provided strong inclination towards this neurodevelopment account of ASD.

The results of twin and familial studies demonstrate that genetics are also implicated in ASD (Le Couteur, et al., 1996). However, differences in cognitive level, as well as unique patterns and severity of symptoms between monozygotic twins, suggest the role of genetics is not a straightforward one (Bolton, et al., 1994). While genetic influences seem obvious, the mode of transmission is not clear (i.e., not dominant, recessive, or x-linked). It may be that different genes (in some individuals) are simply more susceptible to ASD, rather than being causal in nature. Multiplex families (i.e., families with more than one child with ASD) have been fundamental to this line of research (Szatmari, et al., 2007). The behaviours observed among individuals with ASD would also suggest that functioning of the central nervous system is somehow altered (see Minshew, Sweeney, Bauman, & Webb, 2005). While a review of this research is beyond the scope of this dissertation, it is important to point out that a wide range of neurotransmitter and neuroendocrine systems have also been examined (see Anderson & Hoshino, 2005). Although no conclusive findings have been reached, improved techniques should allow a more comprehensive understanding of their role.

Nonetheless, these recent technological and theoretical advances have both broadened and yet further complicated our understanding of ASD. While each perspective provides a plausible account targeting specific behavioural aspects of ASD, none are able (yet) to account for the full range of behaviours or explain the diversity in developmental trajectories. Perhaps it is unrealistic to believe that a “one size fits all” theory actually exists. However, three theories at a cognitive psychological level (theory of mind, weak central coherence, executive functioning) have provided reasonable and empirically-driven accounts that have advanced our knowledge of the core behaviours of ASD. Research examining imitation has also greatly contributed to the understanding of the movement skills and motor planning abilities among children and adolescents with ASD. As such, the following is a brief synopsis of this literature relative to typically developing comparison groups with highlights to the major areas implicated in the movement domain.

Theoretical Perspectives

Theory of mind. In 1978, Premack and Woodruff described theory of mind (ToM) as the ability to attribute the mental states of others and to understand that beliefs and intentions can be different from their own. In typical development the understanding of mental states depends on an underlying cognitive mechanism that is assumed to be innate (Frith, 2000); this theoretical perspective assumes that individuals with ASD have a specific impairment in the development of a ToM (Baron-Cohen, Leslie, & Frith, 1985). Tasks designed to measure ToM abilities include measures of simple and increasingly complex abilities, which are known as first- and second-order beliefs. In belief tasks, children are asked to make inferences about what other people know, believe, and intend to do in certain situations.

First-order beliefs are based on the ability to understand another person's thoughts, intentions, or feelings (Baron-Cohen, et al., 1985). The Sally-Ann task requires children to observe a series of pictures that depict a specific scenario where Sally places a marble in a basket and then leaves the room. While Sally is out of the room, Ann hides that same marble in a box. Children are then asked where Sally will look for the marble when she returns. In order to answer correctly, the child must understand that Sally has a belief that is different from their own (i.e., Sally does not know what they know). While most typically developing 3 and 4 year old children are successful on tasks of this nature (Perner, Frith, Leslie, & Leekam, 1989), approximately 70 to 80% of children and adolescents with autism are not (Baron-Cohen, et al., 1985; Wimmer & Perner, 1983). On the other hand, this means that 20 to 30% of children and adolescents with autism are able to pass such tasks (Baron-Cohen, 1989; Baron-Cohen, et al., 1985; Leslie & Frith, 1988), which suggests that some children and adolescents with autism are able to develop ToM abilities at the most fundamental level.

Baron-Cohen (1989) also examined the second-order beliefs of children and adolescents with autism who were able to pass the Sally-Ann task. Similar to first-order belief tasks, a specific scenario is presented and followed by a question such as "Where does Mary think John has gone to buy ice cream?"

Second-order beliefs take into account the interaction of two people instead of just one person as in the first-order task. Although the majority of typically developing 7 year olds are able to pass second-order belief tasks (Perner & Wimmer, 1985), very few (if any) children and adolescents with autism were successful in this more complex task (Baron-Cohen, 1989). This suggests that even those children and adolescents with autism who have developed a ToM at the first-order level may still be delayed in the acquisition of a more complex ToM, requiring them to predict another person's thoughts about another person's thoughts. While some longitudinal studies have found that many children with ASD do show significant progressions in ToM development with increasing age (e.g., Steele, Joseph, & Tager-Flusberg, 2003), others have found little evidence of performance improvement, especially with second-order tasks (e.g., Ozonoff & McEvoy, 1994). Many of the adolescents who eventually passed these ToM tasks still experienced great difficulty interacting and communicating in social situations.

The ability to understand and take into account the perspective of another person is fundamental to meaningful social interactions. As such, ToM provides a plausible explanation for many of the deficits in social interaction and communication among individuals with ASD. The quality of their interactions is different – often slow and deliberate, seemingly effortful, during social situations. Individuals with ASD also lack insight and are particularly challenged when they have to consider what another person thinks or feels about something. Although some individuals with ASD are able to recognize basic emotions such as happy and sad, they have frequently learned these via deliberate practice rather than acquired through social interactions. As a result, they are still quite inept when it comes to understanding increasingly complex emotions. This limited appreciation of the range of emotions demonstrated by others contributes to lack of empathy, which plays an important role in social communication, another area of particular difficulty for individuals with ASD. The ToM perspective does address the social and communicative deficits among individuals with ASD; however, it is not able to address the full range of symptoms found among individuals with ASD. Beyond the performance of team sports which inevitably includes interaction with teammates, this perspective provides a limited account for impaired performance of movement skills and is rather silent with regard to the third ASD diagnostic domain of restricted and/or repetitive behaviours.

Weak central coherence. Central coherence is the process of bringing information together in order to construct a higher-level meaning that is influenced by the intended context (Frith & Happé, 1994). This coherent approach to information processing is relatively automatic and allows information to be integrated into coherent patterns and interpreted in order to make general sense and meaning, often at the expense of remembering the specific details (Frith & Happé, 1994; Happé, 1999). Based on this perspective, the core deficits in ASD are hypothesized to be specific weaknesses in the processing, integration, and contextual interpretation of information (Frith & Happé, 1994), or rather a processing bias towards local detail (Happé & Booth, 2008) . The weak central coherence (WCC) theory suggests that children with ASD process information differently, seeming to perceive and interpret the specific (local) details or pieces of information often at the expense of seeing the object or idea as a (global) whole (Frith, 1989). As a result, specific details are not integrated or contextualized for meaningful understanding and retention.

The WCC theory stems primarily from research demonstrating that children with ASD show superior performance on the Block Design subtest from the *Wechsler Intelligence Scale for Children* (Wechsler, 1991), which uses individual blocks to reconstruct a design from separate parts. Typically developing children have greater difficulty breaking up the whole design into its' constituent parts than do children with ASD, who are able to complete this task quickly and with few errors (Shah & Frith, 1983). The performance advantage appears to be in their ability to look at the pieces of the design, rather than the whole, and therefore to mentally segment the design. When a pre-segmented design was implemented, a significant performance increase was observed among the typically developing children, but not the children with ASD (Shah & Frith, 1993). This suggests the children with ASD already saw the design in terms of its' individual pieces and had no reason to benefit from having a pre-segmented design.

Additional research supporting the WCC theory and the apparent inability to see and make sense of the "big picture" has utilized other tasks such as the Embedded Figures Test (e.g., Shah & Frith, 1983) or visual illusions (e.g., Happé, 1996). When compared to their typically developing peers, children with ASD are able to find simple parts (or shapes) within a more complex whole (picture) faster and with fewer errors on the embedded figures test (Shah & Frith, 1983). Similarly, when asked to replicate a simple picture, children with ASD were more likely to include specific details in their drawings, but also to begin their drawings with the details and to create the overall picture in a piecemeal fashion (Booth, Charlton, Hughes, & Happé, 2003). Children with ASD also appear less susceptible to visual illusions compared to younger, typically developing children of similar verbal mental age (Happé, 1996). Visual illusions are based on perception – seeing the illusion as a whole, integrating the individual elements of the figure into the surrounding context. Children with ASD apparently focus on the individual details more so than the whole figure and as a result are able to make more accurate judgments on 2-dimensional illusions. Many children with ASD may experience great difficulty trying to put the pieces together to make a sense of a whole picture. It may be overly taxing when they are faced with having to connect multiple sources of information or a series of events in order to make meaning of a social situation.

The drive for coherence to organize and make meaning of information seems almost automatic among typically developing individuals. If this drive for coherence is different (or impaired) among individuals with ASD, it makes sense that they may be more detail-oriented or focused on individual pieces of information rather than trying to collectively understand the “big picture”. This WCC theory can account for the social and communicative deficits among individuals with ASD and does provide a unique perspective with respect to understanding some of the strengths and abilities that are also seen among individuals with ASD. However, WCC theory has more recently been described as being a preference towards local stimuli rather than an inability or deficit in seeing the global whole (Happé, 1999). Local and global processing can be understood along a continuum. Individuals with ASD show a greater propensity towards local detail, but this does not mean they cannot focus their attention at the global level. In fact, individuals with ASD are able to integrate information and understand at the global level following explicit instructions or when asked specific questions about the meaning of a picture (Happé & Frith, 2006). This suggested preference for local processing has been examined using the Navon task (Navon, 1977), a classic perceptual task where a larger letter is made up of smaller letters. For example, a large S is made up of smaller O’s. Based on WCC, it was hypothesized that children with ASD would report the local letters more often and/or more quickly than the control group providing support for a deficit in global processing. However, individuals with ASD are able to focus at the global level on a variety of tasks (e.g., Mottron, Dawson, Soulières, Hubert, & Burack, 2006) which suggests that local and global processing is not an either or phenomena.

Similarly, many children and adolescents with ASD may focus their attention on specific components (Klin, Jones, Schultz, Volkmar, & Cohen, 2002) of a particular movement or aspect of the environment rather than the seeing the entire movement skill (Reid, O'Connor, & Lloyd, 2003). For example, many children with ASD will watch the ball bounce during a basketball drill, but will not see how their instructor is absorbing the force of the ball to maintain control and therefore will demonstrate difficulty with this aspect of the skill. Many children and adolescents with ASD can look at other components of the movement if explicitly directed to do so, yet they frequently have difficulty integrating all of the components into a fluid movement. Tasks and environments have to be structured appropriately to encourage individuals with ASD to integrate details and information. However, attending to, and perceiving, both local detail and global understanding simultaneously, in addition to shifting attention between the two, clearly implicates the importance of executive control.

Executive functioning. The term 'executive function' in and of itself is a simplified term used to refer to a complex construct (Hughes, 2002). Executive functions refer to a wide range of underlying cognitive processes responsible for purposeful, goal-directed, and problem-solving behaviour (Gioia, Isquith, Guy, & Kentworthy, 2000). Typical development of executive functions has been explored extensively and is fairly well understood – they emerge early in life and continue to develop into young adulthood with important changes occurring between approximately 2 and 5 years of age (Zelazo & Müller, 2004). Adult-like performance is reached on some tasks by mid-adolescence whereas performance on increasingly complex tasks continues to develop until adulthood.

Executive functioning (EF) is another of the primary theoretical explanations of ASD; it describes the diagnostic and characteristic features of ASD in terms of an underlying executive processing impairment (Pennington, Rogers, Bennetto, Griffith, Reed, & Shyu, 1997). These cognitive processes appear to be primarily controlled in the prefrontal cortex (Bradshaw, 2003) and are fundamentally integrated in order to complete increasingly complex tasks. Logically, more complex and novel tasks require greater executive demand and involve more complex processing (Gioia, et al., 2000). However, conclusions have not been consistent when examining the different EF components, although it seems that children and adolescents with ASD demonstrate greater impairment when they are required to integrate multiple sources of information or attend to multiple cues in order complete a task. The development of EF processes commonly referred to in the literature on ASD, include cognitive flexibility, inhibition, planning, and working memory (Pennington & Ozonoff, 1996; Welsch & Pennington, 1988). Working memory is involved to some degree in the performance of most, if not all, EF tasks, and is difficult to measure directly. It seems more plausible to consider working memory as a necessary aspect for successful EF task performance, rather than as a separate domain.

Cognitive flexibility is the ability to shift thoughts and actions relative to the changing demands of a task or situation (Bennetto & Pennington, 2003). Measures of cognitive flexibility include the ability to shift from an ineffective strategy to a more appropriate one in order to complete the task while perseverative responses are thought to indicate impairments in cognitive flexibility. Very young children with ASD do not demonstrate impairment on spatial reversal tasks designed to assess cognitive flexibility when compared to younger, typically developing (TD) children of comparable MA (Rutherford & Rogers, 2003; Yerys, Hepburn, Pennington, & Rogers, 2007). However, children with ASD begin to show impairments on delayed response and spatial reversal tasks at approximately 5 years of age (McEvoy, Rogers, & Pennington, 1993). These performance differences persist with increasing age on the performance of the Wisconsin Card Sorting Task compared to TD children matched on either MA or CA (Prior & Hoffman, 1990; Shu, Lung, Tien, & Chen, 2001), even when MA or FSIQ are accounted for.

Inhibition is the ability to resist a previously reinforced or well-practiced response in order to respond otherwise (Brian, Tipper, Weaver, & Bryson, 2003). In order to tease apart inhibition from other EF abilities, simple tasks that involve attending to or selecting one stimulus over another (e.g., Stroop task) are commonly used, although with increasing age it is imperative to use more complex tasks in order to match the task to the developmental level of the child or adolescent. With one exception (Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006), individuals with ASD have not consistently demonstrated inhibition impairments relative to TD comparison groups (e.g., Ozonoff & Jensen, 1999).

Planning is the ability to set task goals and develop the appropriate steps or subtasks necessary to attain those goals (Gioia, et al., 2000). As such, planning includes being able to strategically determine the most effective steps necessary to reach an overall goal – the ability to think ahead and anticipate future subtasks. Multi-sequence tasks (i.e., tower tasks) are commonly used to measure planning abilities because they require the individual to develop a series of subtasks in order to complete them. With one exception (Ozonoff, Strayer, McMahon, & Filloux, 1994), impaired planning abilities have been found in all studies that have explored the planning abilities of children and adolescents with ASD relative to TD comparison groups (e.g., Ozonoff & Jensen, 1999; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2005). However, these tower tasks may be too difficult for young children as well as children and adolescents with low-functioning autism. Ozonoff et al. (1994) did not find differences in performance on the Stockings of Cambridge between 6 to 12 year old children with ASD relative to a comparison group of TD children matched on age and FSIQ. It is possible that this planning task proved to be difficult (i.e., possible floor effects) for even some of the younger typically developing children, thereby resulting in no performance differences between the groups. It is therefore difficult to make inferences regarding the development of planning abilities because children under the age of six have not been included. Nonetheless, it is clear that with increasing age children and adolescents with ASD do demonstrate deficits in planning.

For the most part, children and adolescents with ASD do demonstrate consistent impairment in the performance of EF tasks, specifically tasks designed to measure cognitive flexibility (e.g., McEvoy, et al., 1993) and planning (e.g., Hughes, 1996). Impairment in EF poses significant challenges to children and adolescents with ASD in their day to day life and movement skills in particular, especially with increasingly complex tasks, or when environments are not highly structured. In terms of movement, (motor) planning is a specific EF that plays an integral role in the development and performance of efficient movements and can be defined as the conceiving and organizing of a movement sequence (Hughes, Russell, & Robbins, 1994). Like all executive functions, motor planning is an underlying process that cannot be observed directly and therefore must be inferred from the performance of the task.

Imitation

Although not considered a primary theoretical perspective to account for the “core” behaviours among individuals with ASD, imitation contributes to overall development since much of early communication and (adaptive) learning among children occurs naturally through imitation. Imitation involves copying or reproducing the actions of another person and involves the ability to learn socially by observing others and integrating these observed behaviours into the repertoire of existing behaviours. In many ways imitation is a learning strategy through which infants and young children acquire, refine, and master new behaviours (Piaget, 1962). Given the role that imitation plays in social and communicative development and given the demonstrable impairment in these domains, it should come as no surprise that majority of individuals with ASD demonstrate particular difficulty imitating the actions of others (Smith & Bryson, 1994; Williams, Whiten, & Singh, 2004).

Impaired imitation among children and adolescents with ASD was first demonstrated nearly forty years ago (DeMyer, et al., 1972). Since this early investigation, the imitative abilities among individuals with ASD has received increasing attention and despite varied methodologies, majority of research has provided evidence of a specific impairment (for review see Rogers & Williams, 2006). One of the earliest accounts of this impairment suggested that difficulties with imitation reflected difficulties with coordination of movement skills (Damasio & Maurer, 1978). Of course, the ability to organize and execute a movement will play some role in imitation because successful performance is relative to both the perception of another's behaviour and the production of the appropriate action. While the results of one study demonstrated that majority of adolescents with ASD were able to imitate simple goal-directed actions, they still demonstrated particular difficulty with the more subtle aspects of the style, or how the movements were performed (Hobson & Lee, 1999). Similarly, another study found that children with autism had great difficulty imitating bimanual movements, and in some tasks seemed literally unable to coordinate their limbs (Jones & Prior, 1985). Collectively, these studies suggest the complexity and sequential nature of movements required for some tasks may contribute to the imitation impairment among many children and adolescents with ASD and children with ASD may not (independently) perceive the "style" of the action as being an essential aspect of the task.

Imitation also requires perception of an observed action as well as a plan to perform that action; successful performance needs to take into account both the means and the end goal of that action. Imitation implies goal-orientation, a specific action or actions directed towards achieving a particular goal. Emulation, on the other hand, focuses on achieving (what is perceived to be) the end goal and not necessarily the same actions, per se. Based on performance on the failed intentions task (Meltzoff, 1995), the majority children with ASD were able to "imitate" the end goal of a goal-directed task (i.e., emulate), but not necessarily the movements or behaviours to get there (Aldridge, Stone, Sweeney, & Bower, 2000; Carpenter, Pennington, & Rogers, 2001).

Children with ASD have a tendency to imitate according to their own perspective instead of another's (Hobson & Lee, 1999; Smith & Bryson, 1998). They also find imitation of nonmeaningful or novel actions more challenging than imitation of meaningful or familiar actions (Stone, Ousley, & Littleford, 1997). For example, children with ASD are more likely to imitate waving goodbye than they would be to extend their arms and hands in an unfamiliar posture (Rogers, Bennetto, McEvoy, & Pennington, 1996). This finding regarding the meaning of the task highlights the importance of imitating actions with a specific purpose or function. Greater impairment is also demonstrated when performing tasks that involve imitation of body movements and gestures compared to imitation of actions with objects (DeMyer, et al., 1972; Stone, et al., 1997). Although it is plausible that such difficulties reflect a social impairment in that many children and adolescents with ASD do not pay much attention to the actions of others, it is also likely they realize the affordances of certain objects and are therefore better able to imitate those actions. Affordances are the functional properties of an object or relationships between objects that may contribute to performance of actions with objects (Warren, 1984). A recent study examined the contribution of objects to imitation performance and included unconventional actions on objects that were not directly related to the affordances of the object itself (Rogers, Hepburn, Stackhouse, & Wehner, 2003). For example, instead of rolling a car across the table, the task included turning the car upside down and patting it or when asked to drink from a toy teapot (rather than a tea cup). This study found that children with ASD were impaired on imitation tasks involving actions on objects when the task requires actions that were contradictory to the affordances of the object or when the affordances were not as clear. Imitation impairments are relatively pervasive among individuals with ASD, although they are not necessarily universal. Imitation is complex and performance differences across tasks likely reflect a variety of factors, including multiple cognitive and neural processes.

Mirror neurons. One possible neural explanation is based on the discovery of a mirror neuron system in macaque monkeys (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). These mirror neurons are thought to be a critical link between observation (perception) and action because they are activated during both the performance of a goal-directed action and the observation of that action performed by another individual. There is increasing evidence to suggest that such a system functions similarly in humans (Rizzolatti, Fadiga, Gallese, & Fogassi, 1996) and may provide a neural basis that contributes to social understanding of others' actions and intentions, both of which are essential aspects of social and communicative development, including imitation.

This mirror neuron system has become a probable explanation for the demonstrable imitation impairments among individuals with ASD (Williams, Whiten, Suddendorf, & Perrett, 2001). Consistent differences in patterns of brain activation have been found among individuals with ASD in the areas of the brain believed to be associated with mirror neurons. Based on EEG, typically developing individuals demonstrate reduced mu frequency in the sensorimotor cortex when they either execute or observe the same actions. However, this mu suppression was not found among individuals with ASD when they observed videos of another person's hand movement (Oberman, Hubbard, McCleery, Altschuler, Ramachandran, & Pineda, 2005). Additional studies have used functional MRI to examine brain activity among high-functioning children with ASD during imitation and observation of different facial expressions portraying five different emotions (Dapretto, et al., 2006). Children with ASD were able to imitate each of the facial expressions, but did so with robust pattern of brain activity that was very different than the activation seen in their typically developing peers. Similarly, less extensive brain activation in areas associated with mirror neuron functioning were found among adolescents with ASD during a task involving execution and observation of simple hand movements (Williams, Waiter, Gilchrist, Perrett, Murray, & Whiten, 2006). Overall differences in patterns of activation and integration across brain regions were also found.

Collectively, research examining mirror neuron functioning in ASD suggests that activation patterns and perhaps neural strategies used to execute tasks are quite different and remarkably absent during the observation of these tasks being performed by others. However, the implications of this mirror neuron system with respect to imitative behaviour among individuals with ASD are not so straightforward. First, nothing is known about the development of this mirror neuron system and second, a single brain structure or system cannot account for the full range and complexity of imitation. It is more plausible that, like most behaviours, imitation is the result of an integrated network of brain structures and corresponding cognitive systems.

Neurological Development

Brain development among children and adolescents with ASD may best be described as having disrupted connectivity across neural regions where multiple networks throughout the brain are impacted (Just, et al., 2007; Just, Cherkassky, Keller, & Minshew, 2004; Koshino, Carpenter, Minshew, Cherkassky, Keller, & Just, 2005). Of the five main brain structures that are fundamentally involved in motor control and coordination of movements: a) spinal cord, b) brainstem, c) cerebellum, d) basal ganglia, and e) cerebral cortex (Magill, 1998; Shumway-Cook & Woollacott, 2007), all but the spinal cord has been associated in terms of structural and/or functional abnormalities among children and adolescents with ASD.

A cross-sectional study examined changes in the structure of the brainstem and cerebellum among individuals with ASD from the age of 6 months to 20 years compared to a typically developing comparison group comprised of similar sex and age matched individuals (Hashimoto, et al., 1995). This study is one of the first to consider changes that may exist across the lifespan, although it was limited to a cross-sectional design. However, it did report that the brainstem and cerebellum did increase in size with age in both groups, suggesting a similar pattern of development among children and adolescents with and without ASD. However, both the brainstem and cerebellum were found to be smaller in the young adults with ASD (Hashimoto, et al., 1995), although hyperplasia of the cerebellum has been found in other studies (e.g., Carper & Courchesne, 2000; Sparks, et al., 2002). In addition to integrating sensory information and coordinating movements, the brainstem and cerebellum also have vast neural connections with other parts of the brain (see Courchesne, 1989) including the limbic system, another area that has been implicated in ASD (e.g., Bauman & Kemper, 2005). While research examining the basal ganglia is limited, one study did report enlarged caudate nuclei (Sears, Vest, Mohamed, Bailey, Ranson, & Piven, 1999), although the increase in size was proportional the size of other brain structures.

The majority of research has been related to abnormalities in the cerebral cortex. More specifically, the brain size among children later diagnosed with ASD appears to be normal at birth (Courchesne, Carper, & Akshoomoff, 2003; Lainhart, Piven, Landa, Santangelo, Coon, & Folstein, 1997), by 12 months of age young children with ASD show an increased rate of head circumference growth (Hazlett, et al., 2005) and by approximately 2 years of age MRI scans show increased brain volume (Carper, Moses, Tigue, & Courchesne, 2002), including generalized enlargement of gray and white matter (Hazlett, et al., 2005) compared to typically developing peers of the same age. Similarly, boys with ASD ages 2 to 4 years were found to have significantly greater white matter volume in the frontal and parietal lobes and gray matter in the frontal and temporal lobes (Carper, et al., 2002). While overall volume of the cerebral cortex was not found to be enlarged among 5 to 11 year old boys with ASD (Herbert, et al., 2003), there was significantly increased white matter found in all four lobes of the brain with the most significant differences located in the frontal lobes (Herbert, et al., 2004), suggesting that even once the size normalizes the composition of white and gray matter and the quality of the connectivity within and between brain structures may still be very different.

There is also evidence to suggest increased local within and decreased distant connectivity between brain structures (Just, et al., 2007; Koshino, et al., 2005) as well as decreased corpus callosum size (Piven, Bailey, Ranson, & Arndt, 1997), which would impact the performance of skills that require integration across hemispheres. Given that the experiences of young children with ASD are altered early in development and brain connectivity is strengthened based on early experiences, these findings related to functional connectivity among different regions of the brain should not be unexpected. Longitudinal studies that track structural and functional changes are needed in order to understand how developmental changes in the brain are related to changes in (movement) behaviour across the lifespan.

Motor Control

Motor planning is implicitly based on a model of closed-loop control where the goal of the movement is determined, the appropriate response is selected, and the programming of that response is initiated (Kawato, Furukawa, & Suzuki, 1987). In a closed-loop model, the modification and continued execution of a movement is then reliant on information from the environment and sensory feedback (Magill, 1998; Schmidt & Lee, 2005). Essentially the central nervous system receives (sensory) input, decides which information is important and then attends to it, and then it organizes or integrates it into a meaningful perception from which a motor response is generated. This cycle continues until the goal of the movement is completed; however, if the most pertinent information is not paid attention to or the input is not organized or interpreted accurately in the first place, an abnormal movement response will occur.

Sensory information can be obtained from all senses, in particular the peripheral receptors or from the vestibular and visual systems. Body and limb orientation are determined by the various muscle and joint receptors in the body (Schmidt & Lee, 2005). The vestibular system also provides information with respect to head orientation and movements. The central nervous system integrates the proprioceptive information obtained from these muscle and joint receptors about position of the body and limbs with additional sensory information regarding the movement, location in space, velocity, and muscle activation via afferent neural pathways (Magill, 1998).

The visual information provided may include feedback about the errors made during the movement as well as predictive information about the environment in order to anticipate and avoid future errors (Schmidt & Lee, 2005). In order to successfully move through environments, especially those requiring the negotiation of obstacles or uneven terrain, both types of visual information are necessary to accurately plan and control movements. Visual information provides a relatively continuous evaluation of the movement with respect to the environment in order to update the motor command for the ongoing movement

(DeRugy, Taga, Montagne, Buekers, & Laurent, 2002). This continuous evaluation shows that the planning of movements is ongoing and allows adjustments of movement to be made several steps in advance. Patla and Vickers (1997) found that during obstacle avoidance, participants tended to fixate on a stationary obstacle at least one step prior (i.e., planning), but not while stepping over (i.e., executing) it. The results of this study support the differentiation between the planning and execution components of movement (Patla & Vickers, 1997).

Obstacle avoidance. Pryde, Roy, and Patla (1997) grouped typically developing children and adolescents (aged 5 to 16 years) according to age and stage of motor development and compared their performance on tasks consisting of walking on either a straight or winding path. The two youngest groups (5 to 7 vs 8 to 10 years) had similar movement times in both tasks, suggesting that the addition of an environmental constraint (i.e., the winding path) and the extra steering required does not involve greater motor control and/or information processing demands to further challenge the locomotor system. Furthermore, neither of the younger groups committed any errors (i.e., stepping outside of the path) on either condition, suggesting that children as young as five years of age are able to distinguish between the different types of visual information required for negotiating a winding path (Pryde, et al., 1997). Although mature patterns for locomotion are present by 5 to 7 years, strategies for obstacle avoidance do not begin until later (Grasso, Assaiante, Prévost, & Berthoz, 1998; McFadyen, Malouin, & Dumas, 2001; Patla, Prentice, & Gobbi, 1996; Pryde, et al., 1997).

The control and execution of basic locomotor skills requires significant interaction and coordination between the central and peripheral nervous systems and the environment (Taga, 1995). As such, running on an uneven soccer pitch or negotiating obstacles would therefore require even greater amounts of control. While it has been suggested that children aged 4 to 6 years are able to organize their movements with respect to only themselves and their own body positions, it is not until 7 to 8 years of age when children are able to organize their body positions and movements relative to stable and fixed patterns of their surrounding environments (Grasso, et al., 1998). Therefore, it would be expected that the development of an ability to negotiate stationary obstacles would be beginning in a typically developing 7 year old (McFadyen & Carnahan, 1997).

As discussed earlier, when the locomotor performance of typically developing children was compared on a walking task there was little difference in performance (Pryde, et al., 1997). However, with the addition of obstacles to the winding condition (i.e., addition of a task and an environmental constraint), a significant difference in errors committed was found between the two youngest groups. While the youngest group (5 to 7 years) was able to maintain their movement time, they did so at the expense of accuracy (i.e., speed-accuracy tradeoff) suggesting they are not yet able to plan their movements relative to the stationary obstacles in which they encountered. On the other hand, the 8 to 10 year olds were able to maintain both their speed and accuracy while negotiating the obstacles, which suggests early development of planning abilities (Pryde, et al., 1997). However, these obstacle avoidance strategies are continually practiced and refined in order to become adaptive to everyday situations and reach adult-like efficiency during adolescence (Ledebt, Bril, & Brenière, 1998; Patla, et al., 1996). While research supports the basic understanding of how these locomotor skills are planned and controlled among typically developing children, there is limited support to contend that the obstacle avoidance strategies of children with ASD follows a similar pattern of development and happens in the same way.

Cognitive Development

Majority of children and adolescents with ASD have associated cognitive impairments (National Research Council, 2001, p. 84). Based primarily on timing, it has been suggested that cognitive and motor development may be closely related. For example, the development of executive functions or underlying cognitive processes (see Zelazo & Müller, 2004, p. for review) follows similar patterns as to significant periods of motor development in early childhood (2 to 5 years) and again in adolescence when milestones and fundamental movement skills are practiced and attained, respectively. The frontal lobes are the regions of the brain that take the longest to mature. Similarly, the development of both higher order cognitive and refinement of movement skills continues into early adulthood, both of which involve the frontal lobes. Furthermore, there appears to be common brain structures (i.e., cerebellum, basal ganglia, and frontal cortex) that are implicated specifically in the performance of both cognitive and processes and movement skills (Diamond, 2000). While the precise association remains unclear, there does seem to be parallel development of specific cognitive (i.e., executive functions) and motor functions among typically developing children ages 5 to 6 years (Wassenberg, et al., 2005); this relationship has not yet been systematically investigated among children with ASD. However, executive functions play important roles in the development of efficient movement and planning has been identified as a deficit among children with ASD (Hughes, 1996).

Movement Behaviour

Movement has implications in each of the core diagnostic areas, yet few systematic investigations have examined the development or performance of movement skills among children with ASD. Furthermore, the majority of research examining the movement behaviour of children and adolescents with ASD has been based on early motor development and motor abilities. For the most part, there is general consensus that early motor development (i.e., age at which developmental milestones are attained) is delayed among young children with ASD when compared to typically developing children of the same age (e.g., Ornitz, Guthrie, & Farley, 1977; Provost, Lopez, & Heimerl, 2007; Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998). Motor abilities refer to the underlying capacities (i.e., balance or hand-eye coordination) that contribute to the performance of movement skills (Magill, 1998). While much of the research examining motor abilities suggests that impairments are common among children and adolescents with ASD (e.g., Ghaziuddin & Butler, 1998; Green, Baird, Barnett, Henderson, Huber, & Henderson, 2002; Miyahara, Tsujii, Hori, Nakanishi, Kageyama, & Sugiyama, 1997), these impairments do not appear to be universal (e.g., Dewey, Cantell, & Crawford, 2007; Manjiviona & Prior, 1995). Although informative, these studies have provided limited insight regarding the performance of fundamental movement skills among children with ASD, which is the focus of this dissertation.

Fundamental movement skills. The (goal-directed) locomotor and object control skills that emerge following the ability to walk (Burton & Miller, 1998) and are assumed to be the basis of more advanced, or sport-specific skills are known as fundamental movement skills. Movement skills can be evaluated in terms of the final outcome (i.e., how fast, how far, how accurate) or the movement pattern used (i.e., over or under, specific performance criteria). The *Test of Gross Motor Development* (*TGMD-2*) provides a developmental framework for examining the performance of fundamental movement skills in terms of the movement patterns used (Ulrich, 2000). It is standardized for children aged 3 to 10 years and normative data would suggest that by 10 years of age, majority of typically developing children are able to demonstrate mature movement patterns, meeting specific performance criteria, when they perform these skills. The *TGMD-2* includes specific performance criteria for each of 12 fundamental movement skills divided evenly into locomotor (run, gallop, hop, leap, jump, and slide) and object control (strike, dribble, catch, kick, throw, and roll) subtests. These are the movement skills that will be considered as fundamental throughout this dissertation.

Although there is considerable variability and impaired performance of movement skills cannot be considered universal, there is increasing recognition that the movement skills of children and adolescents with ASD are poorly developed compared to their typically developing peers (Baranek, 2002; National Research Council, 2001). Immature catching and throwing patterns have been observed among many children and adolescents with ASD (DeMyer, 1976; Reid, Collier, & Morin, 1983), with many children with ASD having particular difficulty controlling the direction and force of the ball when throwing (Manjiviona & Prior, 1995). Based on *TGMD-2* performance, one study found that 70% and 30% of 6 to 8 year old boys with ASD demonstrated delays in the performance of locomotor and object control skills, respectively when compared to normative data (Berkeley, Zittel, Pitney, & Nichols, 2001). Based on observations across a variety of fundamental movement skills, many children with ASD experience difficulty performing multi-sequence movements (Bauman, 1992) and show difficulty with the overall timing and coordination of movements that may involve two or more limbs, or both sides of the body, at the same time (Ghaziuddin & Butler, 1998; Jones & Prior, 1985; Morin & Reid, 1985; Reid, et al., 1983). While research examining the performance of movement skills among children and adolescents with ASD has been limited, results have consistently associated ASD with poor movement skills compared to their peers without ASD. The results of these studies have provided a great deal of insight into the performance of fundamental movement skills among children and adolescents with ASD, but there is still much to learn about the observable (and quantifiable) differences that exist, particularly when it comes to the performance of locomotor skills.

Movement behaviour includes all aspects of performance - the observable movements and the underlying processes that are inevitably required to produce them. Since it has been suggested that the movement difficulties observed among children and adolescents with ASD may be a result of an underlying deficit in executive functioning (Rogers, et al., 1996), this was the theoretical perspective adopted for this research. In the realm of executive functioning, planning is a general term that refers to the wide range of underlying cognitive processes that are responsible for purposeful, goal-directed, and problem-solving behaviours (Gioia, et al., 2000). For purposes of this dissertation, motor planning was defined as the conceiving and organizing of a movement sequence (Hughes, et al., 1994), which requires the ability to set task goals and develop the appropriate steps necessary to execute that movement sequence (McEvoy, et al., 1993). However, these underlying processes cannot be directly seen and therefore must be inferred from various aspects of the movement performance itself (e.g., Hughes, 1996).

Motor planning. The majority of studies that have examined planning among children and adolescents with ASD have used goal-directed reaching or aiming tasks (Hughes, 1996; Hughes & Russell, 1993; Mari, Castiello, Marks, Marraffa, & Prior, 2003; Rinehart, Bellgrove, Tonge, Brereton, Howells-Rankin, & Bradshaw, 2006; Rinehart, Bradshaw, Brereton, & Tonge, 2001) and planning has been inferred based on observed movement patterns, reaction time, or movement time. Based on observed movement patterns in a reach, grasp, and place task children with ASD had difficulty completing trials that required advanced planning and did not change their approach to the task, even following repeated trials (Hughes, 1996). Another study found that children with ASD were less likely to retrieve an object when they had to coordinate two movements together in order to do so (Hughes & Russell, 1993). Reaching and grasping movements also seemed independent of each other, with the grasping movement beginning after the reaching movement was finished instead of the movements being coordinated together (Mari, et al., 2003). While adolescents with ASD can execute movements required for goal-directed aiming tasks, they take significantly longer to prepare and perform the movements (Rinehart, et al., 2006; Rinehart, et al., 2001), suggesting that they are able to plan their movements, but do so differently and perhaps not as efficiently as their typically developing peers.

These tasks generally consist of multiple trials of discrete movements (e.g., reach-and-grasp) where specific task constraints, such as the size or distance of a target, were manipulated to examine how movements are adapted accordingly (e.g., Mari, et al., 2003). While these studies have contributed to our understanding of how discrete reaching and aiming movements are planned and performed, movement (especially during play) isn't always a discrete task that can be performed and measured in a laboratory. In fact, majority of skills performed in play and physical education are open skills that require consideration of the environment that they are performed in. As such, the task used in this dissertation is directed at understanding how children with ASD plan and perform their movements in an obstacle avoidance task (e.g., Pryde, et al., 1997) that includes everyday locomotor skills in a familiar environment (i.e., school gymnasium).

Overall, this dissertation aims to provide a better understanding of the how children with ASD plan and perform fundamental movements skills compared to three comparison groups of typically developing peers, each matched on a different developmental variable to ascertain differences in performance. A delay in development would suggest that performance reflects younger individuals, whereby skill progressions would occur in the same order as in typical development, but at a slower rate. If performance of movement skills among children with ASD simply reflects a delay in the development of such skills, performance should be comparable to children of similar developmental level (i.e., cognitive ability). On the other hand, a deficit would imply a distinct pattern of development that is not accounted for by cognitive level alone and differs from the order seen in typical development. This dissertation research includes three studies that build on previous work by using an executive functioning perspective to understand movement behaviour in terms of underlying cognitive deficits and through the notion of delays and deficits in development.

Research Questions

Four main research questions will be investigated to examine the development of movement skills and motor planning abilities among children with ASD. Do children and adolescents with ASD execute movements differently than their typically developing peers? Are these movement skill differences characterized by delays or deficits? What is the relationship between the performance of movement skills and cognitive ability? What is the relationship between planning and executing fundamental movement skills and is this relationship the same among all participants?

This doctoral dissertation is divided into four chapters. The first three chapters are research manuscripts, each providing a unique perspective examining development of fundamental movement skills and motor planning abilities among children with ASD. Collectively, these manuscripts address the overall research questions. The first manuscript examines fundamental movement skills among children with ASD based on performance on the *Test of Gross Motor* Development (Ulrich, 2000). Performance is compared to three typically developing comparison groups, strategically matched on developmental variables to examine the development of these skills relative to potential delays and deficits. The second manuscript continues development and validation of an obstacle course initially conceptualized as part of my Master's thesis (Staples, 2006) to assess motor planning abilities among children with ASD. The third manuscript brings together movement skill and motor planning among children with ASD. Following the suggestion of Sigman and Ruskin (1999), if these groups are matched closely on a control variables (e.g., movement skill), then any group differences on the target task (obstacle course) should be attributed to underlying differences (in motor planning). Overall, examining movement skills and motor planning abilities together affords more logical inferences to be made regarding the relationship between planning and executing fundamental movement skills. Since the majority of children and adolescents with ASD included in my dissertation research also have a cognitive impairment, this third manuscript will also examine the relationship between the performance of movement skills and cognition. Finally, this dissertation will conclude with a chapter summarizing the relevant findings and suggestions for future direction.

References

Aldridge, M. A., Stone, K. R., Sweeney, M. H., & Bower, T. G. R. (2000). Preverbal children with autism understand the intentions of others. *Developmental Science, 3*, 294-301.

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders*. (4th ed. - Text Revision). Washington, DC: Author.

Anderson, G. M., & Hoshino, Y. (2005). Neurochemical studies of autism. In F. R. Volkmar, R. Paul, A. Klin & D. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders* (Vol. 1: Diagnosis, development, neurobiology, and behavior, pp. 453-472). Hoboken, NJ: John Wiley & Sons.

Baranek, G. T. (2002). Efficacy of sensory and motor interventions for children with autism. *Journal of Autism and Developmental Disorders, 32*, 397-422.

Baron-Cohen, S. (1989). The autistic child's theory of mind: A case of specific developmental delay. *Journal of Child Psychology and Psychiatry, 30*, 285-297.

Baron-Cohen, S. (2006). Two new theories of autism: Hyper-systemising and assortive mating. *Archives of Disease in Childhood, 91*, 2-5.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition, 21*, 37-46.

Bauman, M., & Kemper, T. L. (2005). Neuroanatomic observations of the brain in autism: A review and future directions. *International Journal of Developmental Neuroscience, 23*, 183-187.

Bauman, M. L. (1992). Motor dysfunction in autism. In A. B. Joseph & R. R. Young (Eds.), *Movement disorders in neurology and neuropsychiatry* (pp. 660-663). Cambridge, MA: Blackwell Scientific Publications.

Bennetto, L., & Pennington, B. F. (2003). Executive functioning in normal and abnormal development. In S. J. Segalowitz & I. Rapin (Eds.), *Handbook of neuropsychology* (Vol. 8(2), pp. 785-802). Amsterdam: Elsevier Sciences.

Berkeley, S. L., Zittel, L. L., Pitney, L. V., & Nichols, S. E. (2001). Locomotor and object control skills of children diagnosed with autism. *Adapted Physical Activity Quarterly, 18*, 405-416.

Bolton, P., Macdonald, H., Pickles, A., Rios, P., Goode, S., Crowson, M., et al. (1994). A case-control family history study of autism. *Journal of Child Psychology and Psychiatry, 35*, 877-900.

Booth, R., Charlton, R., Hughes, C., & Happé, F. (2003). Disentangling weak coherence and executive dysfunction: Planning drawing in autism and attention-deficit/hyperactivity disorder. *Philosophical Transactions: Biological Sciences, 358*, 387-392.

Bradshaw, J. L. (2003). Developmental disorders of the frontostriatal system: Neuropsychological, neuropsychiatric, and evolutionary perspectives. *Archives of Clinical Neuropsychology, 18*, 215-217.

Brian, J. A., Tipper, S. P., Weaver, B., & Bryson, S. E. (2003). Inhibitory mechanisms in autism spectrum disorders: Typical selective inhibition of location versus facilitated perceptual processing. *Journal of Child Psychology and Psychiatry, 44*, 552-560.

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Champaign, IL: Human Kinetics.

Carpenter, M., Pennington, B. F., & Rogers, S. J. (2001). Understanding of others' intentions in children with autism. *Journal of Autism and Developmental Disorders, 31*, 589-599.

Carper, R. A., & Courchesne, E. (2000). Inverse correlation between frontal lobe and cerebellum sizes in children with autism. *Brain, 123*, 836-844.

Carper, R. A., Moses, P., Tigue, Z. D., & Courchesne, E. (2002). Cerebral lobes in autism: Early hyperplasia and abnormal age effects. *NeuroImage, 16*, 1038-1051.

Cody, H., Pelphrey, K., & Piven, J. (2002). Structural and functional magnetic resonance imaging of autism. *International Journal of Developmental Neuroscience, 20*, 421-438.

Courchesne, E. (1989). Neuroanatomical systems involved in infantile autism: The implications of cerebellar abnormalities. In G. Dawson (Ed.), *Autism: Nature, diagnosis, and treatment* (pp. 119-143). New York, NY: The Guilford Press.

Courchesne, E., Carper, R., & Akshoomoff, N. (2003). Evidence of brain overgrowth in the first year of life in autism. *JAMA, 290*, 337-344.

Courchesne, E., & Pierce, K. (2005). Why the frontal cortex in autism might be talking only to itself: Local over-connectivity but long-distance disconnection. *Current Opinion in Neurobiology, 15*, 225-230.

Damasio, A. R., & Maurer, R. G. (1978). A neurological model for childhood autism. *Archives of Neurology, 35*, 777-786.

Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., et al. (2006). Understanding emotions in others: Mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience, 9*(11), 28-30.

DeMyer, M. K. (1976). Motor, perceptual-motor, intellectual disabilities of autistic children. In L. Wing (Ed.), *Early Childhood Autism* (pp. 169-193). New York: Pergamon Press.

DeMyer, M. K., Alpern, G. D., Barton, S., DeMyer, W. E., Churchill, D. W., Hingtgen, J. N., et al. (1972). Imitation in autistic, early schizophrenic, and non-psychotic subnormal children. *Journal of Autism and Childhood Schizophrenia, 2*, 264-287.

DeRugy, A., Taga, G., Montagne, G., Buekers, M. J., & Laurent, M. (2002). Perception-action coupling model for human locomotor pointing. *Biological Cybernetics, 87*, 141-150.

Dewey, D., Cantell, M., & Crawford, S. G. (2007). Motor and gestural performance in children with autism spectrum disorders, developmental coordination disorder, and/or attention deficit hyperactivity disorder. *Journal of the International Neuropsychological Society, 13*, 246-256.

di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research, 91*, 176-180.

Diamond, A. (2000). Close interrelation of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development, 71*, 44-56.

Fombonne, E. (2003). Epidemiological surveys of autism and other pervasive developmental disorders: An update. *Journal of Autism and Developmental Disorders, 33*, 365-382.

Fombonne, E. (2005a). The changing epidemiology of autism. *Journal of Applied Research in Intellectual Disabilities, 18*, 281-294.

Fombonne, E. (2005b). Epidemiology of autistic disorder and other pervasive developmental disorders. *Journal of Clinical Psychiatry, suppl. 10*, 3-10.

Frith, U. (1989). *Autism: Explaining the enigma*. Oxford, UK: Blackwell Publishing.

Frith, U. (2000). Cognitive explanations of autism. In K. Lee (Ed.), *Childhood cognitive development. The essential readings* (pp. 324-337). Oxford: Blackwell.

Frith, U., & Happé, F. (1994). Autism: Beyond "theory of mind". *Cognition, 50*, 115-132.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119*, 593-609.

Ghaziuddin, M., & Butler, E. (1998). Clumsiness in autism and Asperger syndrome: A further report. *Journal of Intellectual Disability Research, 42*, 43-48.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kentworthy, L. (2000). *Behavior Rating Inventory of Executive Function*. Lutz, FL: Psychological Assessment Resources.

Grasso, R., Assaiante, C., Prévost, P., & Berthoz, A. (1998). Development of anticipatory orienting strategies during locomotor tasks in children. *Neuroscience and Biobehavioral Reviews, 22*, 533-539.

Green, D., Baird, G., Barnett, A. L., Henderson, L., Huber, J., & Henderson, S. E. (2002). The severity and nature of motor impairment in Asperger's syndrome: A comparison with specific developmental disorder of motor function. *Journal of Child Psychology and Psychiatry, 43*(5), 1-14.

Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and brain development. *Child Development, 58*, 539-559.

Happé, F. (1996). Studying weak central coherence at low levels: Children with autism do not succumb to visual illusions: A research note. *Journal of Child Psychology and Psychiatry, 37*, 873-877.

Happé, F. (1999). Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Sciences, 3*, 216-222.

Happé, F., & Booth, R. (2008). The power of the positive: Revisiting weak coherence in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology, 61*, 50-63.

Happé, F., & Frith, U. (2006). The weak coherence account: Detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders, 36*, 5-25.

Hashimoto, T., Tayama, M., Murakawa, K., Yoshimoto, T., Miyazaki, M., Harada, M., et al. (1995). Development of brainstem and cerebellum in autistic patients. *Journal of Autism and Developmental Disorders, 25*, 1-18.

Hazlett, H. C., Poe, M., Gerig, G., Gimpel Smith, R., Provenzale, J., Ross, A., et al. (2005). Magnetic resonance imaging and head circumference study of brain size in autism. *Archives of General Psychiatry, 62*, 1366-1376.

Herbert, M. R., Ziegler, D. A., Deutsch, C. K., O'Brien, L. M., Lange, N., Bakardjiev, A., et al. (2003). Dissociations of cerebral cortex, subcortical and cerebral white matter volumes in autistic boys. *Brain, 126*, 1182-1192.

Herbert, M. R., Ziegler, D. A., Makris, N., Filipek, P. A., Kemper, T. L., Normandin, J. J., et al. (2004). Localization of white matter volume increase in autism and developmental language disorder. *Annals of Neurology, 55*, 530-540.

Hobson, R. P., & Lee, A. (1999). Imitation and identification in autism. *Journal of Child Psychology and Psychiatry, 40*, 649-659.

Hughes, C. (1996). Brief report: Planning problems in autism at the level of motor control. *Journal of Autism and Developmental Disorders, 26*, 99-107.

Hughes, C. (2002). Executive functions and development: Why the interest? *Infant and Child Development, 11*, 69-71.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: It's implications for theories of autism. *Developmental Psychology, 29*, 498-510.

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*, 477-492.

Jones, V., & Prior, M. P. (1985). Motor imitation abilities and neurological signs in autistic children. *Journal of Autism and Developmental Disorders, 15*, 37-46.

Just, M. A., Cherkassky, V. L., Keller, T. A., Kana, R. K., & Minshew, N. J. (2007). Functional and anatomical cortical underconnectivity in autism: Evidence from an fMRI study of an executive function task and corpus callosum morphometry. *Cerebral Cortex, 17*, 951-961.

Just, M. A., Cherkassky, V. L., Keller, T. A., & Minshew, N. J. (2004). Cortical activation and synchronization during sentence comprehension in high-functioning autism: Evidence of underconnectivity. *Brain, 127*, 1811-1821.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child, 2*, 217-250.

Kawato, M., Furukawa, K., & Suzuki, R. (1987). A hierarchical neural-network model for control and learning of voluntary movement. *Biological Cybernetics, 57*, 169-185.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry, 59*, 809-816.

Koshino, H., Carpenter, P. A., Minshew, N. J., Cherkassky, V. L., Keller, T. A., & Just, M. A. (2005). Functional connectivity in an fMRI working memory task in high-functioning autism, *NeuroImage,* pp. 810-821.

Lainhart, J. E., Piven, J. W., M., Landa, R., Santangelo, S. I., Coon, H., & Folstein, S. E. (1997). Macrocephaly in children and adults with autism. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 282-290.

Le Couteur, A., Bailey, A., Goode, S., Pickles, A., Gottesman, I., Robertson, S., et al. (1996). A broader phenotype of autism: The clinical spectrum in twins. *Journal of Child Psychology and Psychiatry, 37*, 785-801.

Ledebt, A., Bril, B., & Brenière, Y. (1998). The build-up of anticipatory behaviour: An analysis of the development of gait initiation in children. *Experimental Brain Research, 120*, 9-17.

Leslie, A. M., & Frith, U. (1988). Autistic children's understanding of seeing, knowing and believing. *British Journal of Developmental Psychology, 6*, 315-324.

Magill, R. A. (1998). *Motor learning: Concepts and applications* (5th ed.). Boston: McGraw-Hill.

Manjiviona, J., & Prior, M. (1995). Comparison of Asperger syndrome and high-functioning autistic children on a test of motor impairment. *Journal of Autism and Developmental Disorders, 25*, 23-39.

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical*

Transactions of the Royal Society of London - Series B: Biological Sciences, 358, 393-403.

McEvoy, R. E., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology and Psychiatry, 34*, 563-578.

McFadyen, B. J., & Carnahan, H. (1997). Anticipatory locomotor adjustments for accommodating versus avoiding level changes in humans. *Experimental Brain Research, 114*, 500-506.

McFadyen, B. J., Malouin, F., & Dumas, F. (2001). Anticipatory locomotor control for obstacle avoidance in mid-childhood aged children. *Gait and Posture, 13*, 7-16.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31*, 838-850.

Minshew, N. J., Sweeney, J. A., Bauman, M. L., & Webb, S. J. (2005). Neurologic aspects of autism. In F. R. Volkmar, R. Paul, A. Klin & D. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders* (Vol. 1: Diagnosis, development, neurobiology, and behavior, pp. 473-514). Hoboken, NJ: John Wiley & Sons.

Miyahara, M., Tsujii, M., Hori, M., Nakanishi, K., Kageyama, H., & Sugiyama, T. (1997). Brief report: Motor incoordination in children with Asperger syndrome and learning disabilities. *Journal of Autism and Developmental Disorders, 27*, 595-603.

Morin, B., & Reid, G. (1985). A quantitative and qualitative assessment of autistic individuals on selected motor tasks. *Adapted Physical Activity Quarterly, 2*, 43-55.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. A. (2006). Enhanced perceptual functioning in autism: An update, and eight principles of autistic perception. *Journal of Autism and Developmental Disorders, 36*, 27-43.

National Research Council. (2001). *Educating children with autism: Report of the committee on educational interventions in children with autism*. Washington, DC: National Academy Press.

Navon, D. (1977). Forest before trees: The precedence of global features in visual perception. *Cognitive Psychology, 9*, 353-383.

Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altschuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG evidence for mirror neuron dysfunction in autism spectrum disorders. *Cognitive Brain Research, 24*, 190-198.

Ornitz, E. M., Guthrie, D., & Farley, A. J. (1977). The early development of autistic children. *Journal of Autism and Childhood Schizophrenia, 7*, 207-229.

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*, 171-177.

Ozonoff, S., & McEvoy, R. E. (1994). A longitudinal study of executive function and theory of mind development in autism. *Development and Psychopathology, 6*, 415-431.

Ozonoff, S., Strayer, D. L., McMahon, W. M., & Filloux, F. (1994). Executive function abilities in autism and Tourette's syndrome: An information processing approach. *Journal of Child Psychology and Psychiatry, 35*, 1015-1032.

Patla, A. E., Prentice, S. D., & Gobbi, L. T. (1996). Visual control of obstacle avoidance during locomotion: Strategies in young children, young and older adults. In A. M. Ferrandez & N. Teasdale (Eds.), *Changes in sensory motor behaviour in aging* (pp. 257-277). Amsterdam: Elsevier Science.

Patla, A. E., & Vickers, J. N. (1997). Where and when do we look as we approach and step over an obstacle in the travel path? *NeuroReport, 8*, 3661-3665.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 37*, 51-87.

Pennington, B. F., Rogers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity tests of the executive dysfunction hypothesis of autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 143-178). Oxford, UK: Oxford University Press.

Perner, J., Frith, U., Leslie, A. M., & Leekam, S. R. (1989). Exploration of the autistic child's theory of mind: Knowledge, belief and communication. *Child Development, 60*, 689-700.

Perner, J., & Wimmer, H. (1985). Attribution of second-order beliefs by 5-10 year old children. *Journal of Experimental Child Psychology, 39*, 437-471.

Piaget, J. (1962). *Play, dreams, and imitation in childhood*. New York, NY: Norton.

Piven, J., Bailey, J., Ranson, B. J., & Arndt, S. (1997). An MRI study of the corpus callosum in autism. *American Journal of Psychiatry, 154*, 1051-1056.

Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences, 1*, 515-526.

Prior, M. R., & Hoffman, W. (1990). Brief report: Neuropsychological testing of autistic children through an exploration with frontal lobe tests. *Journal of Autism and Developmental Disorders, 20*, 581-590.

Provost, B., Lopez, B. R., & Heimerl, S. (2007). A comparison of motor delays in young children: Autism spectrum disorder, developmental delay, and developmental concerns. *Journal of Autism and Developmental Disorders, 37*, 321-328.

Pryde, K. M., Roy, E. A., & Patla, A. E. (1997). Age-related trends in locomotor ability and obstacle avoidance. *Human Movement Science, 16*, 507-516.

Reid, G., Collier, D., & Morin, B. (1983). The motor performance of autistic individuals. In R. Eason, T. Smith & F. Caron (Eds.), *Adapted physical activity* (pp. 201-218). Champaign, IL: Human Kinetics.

Reid, G., O'Connor, J., & Lloyd, M. (2003). The autism spectrum disorders: Physical activity instruction. *Palaestra, 19*(2), 20-26, 47-48.

Rinehart, N. J., Bellgrove, M. A., Tonge, B. J., Brereton, A. V., Howells-Rankin, D., & Bradshaw, J. L. (2006). An examination of movement kinematics in young people with high-functioning autism and Asperger's disorder: Further evidence for a motor planning deficit. *Journal of Autism and Developmental Disorders, 36*, 757-767.

Rinehart, N. J., Bradshaw, J. L., Brereton, A. V., & Tonge, B. J. (2001). Movement preparation in high-functioning autism and Asperger disorder: A serial choice reaction task involving motor reprogramming. *Journal of Autism and Developmental Disorders, 31*, 79-88.

Rizzolatti, G., Fadiga, L., Gallese, V., & Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research, 3*, 131-141.

Rogers, S. J., Bennetto, L., McEvoy, R., & Pennington, B. F. (1996). Imitation and pantomime in high-functioning adolescents with autism spectrum disorders. *Child Development, 67*, 2060-2073.

Rogers, S. J., Hepburn, S. L., Stackhouse, T., & Wehner, E. (2003). Imitation performance in toddlers with autism and those with other developmental disorders. *Journal of Child Psychology and Psychiatry, 44*, 763-781.

Rogers, S. J., & Williams, J. H. G. (2006). Imitation in autism: Findings and controversies. In S. J. Rogers & J. H. G. Williams (Eds.), *Imitation and the social mind: Autism and typical development*. New York, NY: The Guilford Press.

Rutherford, M. D., & Rogers, S. J. (2003). Cognitive underpinnings of pretend play in autism. *Journal of Autism and Developmental Disorders, 33*, 289-302.

Schmidt, R. A., & Lee, T. D. (2005). *Motor control and learning: A behavioural emphasis* (4th ed.). Champaign, IL: Human Kinetics.

Sears, L. L., Vest, C., Mohamed, S., Bailey, J., Ranson, B. J., & Piven, J. (1999). An MRI study of the basal ganglia in autism. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 23*, 613-624.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: A research note. *Journal of Child Psychology and Psychiatry, 24*, 613-620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the Block Design task? *Journal of Child Psychology and Psychiatr, 34*, 1351-1364.

Shu, B. C., Lung, F. W., Tien, A. Y., & Chen, B. C. (2001). Executive function deficits in non-retarded autistic children. *Autism: The International Journal of Research and Practice, 5*, 165-174.

Shumway-Cook, A., & Woollacott, M. H. (2007). *Motor control: Translating research into clinical practice*. Philadephia, PA: Lippincott, Williams, & Wilkins.

Sigman, M., & Ruskin, E. (1999). Continuity and change in the social competence of children with autism, down syndrome, and developmental delays. *Monographs of the Society for Research in Child Development, 64*, 1-139.

Smith, I. M., & Bryson, S. E. (1994). Imitation and action in autism: A critical review. *Psychological Bulletin, 116*, 259-273.

Smith, I. M., & Bryson, S. E. (1998). Gesture imitation in autism. I: Nonsymbolic postures and sequences. *Cognitive Neuropsychology, 15*, 747-770.

Sparks, B. F., Friedman, S. D., Shaw, D. W., Aylward, E. H., Echelard, D., Artru, A. A., et al. (2002). Brain structural abnormalities in young children with autism spectrum disorder. *Neurology, 59*, 184-192.

Staples, K. (2006). *Development of a gross motor task to assess motor planning of children with autism spectrum disorders*. McGill University, Montreal, QC.

Steele, S., Joseph, R. M., & Tager-Flusberg, H. (2003). Brief report: Developmental change in theory of mind abilities in children with autism. *Journal of Autism and Developmental Disorders, 33*, 461-467.

Stone, W. L., Ousley, O. Y., & Littleford, C. D. (1997). Motor imitation in young children with autism: What's the object? *Journal of Abnormal Child Psychology, 25*, 475-485.

Szatmari, P., Paterson, A. D., Zwaigenbaum, L., Roberts, W., Brian, J., Liu, X.-Q., et al. (2007). Mapping autism risk loci using genetic linkage and chromosomal rearrangements. *Nature Genetics, 39*(3), 319-328.

Taga, G. (1995). A model of the neuro-musculo-skeletal system for human locomotion. I. Emergence of basic gait. *Biological Cybernetics, 73*, 97-111.

Teitelbaum, P., Teitelbaum, O., Nye, J., Fryman, J., & Maurer, R. G. (1998). Movement analysis in infancy may be useful diagnosis of autism. *Proceedings of the National Academy of Sciences, 95*, 13982-13987.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.). Austin, TX: Pro-Ed.

Verté, S., Geurts, H. M., Roeyers, H., Oosterlaan, J., & Sergeant, J. A. (2005). Executive functioning in children with autism and Tourette syndrome. *Development and Psychopathology, 17*, 415-445.

Verté, S., Geurts, H. M., Roeyers, H., Oosterlaan, J., & Sergeant, J. A. (2006). Executive functioning in children with an autism spectrum disorder: Can we differentiate within the spectrum? *Journal of Autism and Developmental Disorders, 36*, 351-372.

Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 683-703.

Wassenberg, R., Feron, F. J. M., Kessels, A. G. H., Hendriksen, J. G. M., Kalff, A. C., Kroes, M., et al. (2005). Relation between cognitive and motor performance in 5- to 6-year-old children: Results from a large-scale cross-sectional study. *Child Development, 76*, 1092-1103.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children* (3rd ed.). San Antonio, TX: Psychological Corporation.

Welsch, M. V., & Pennington, B. F. (1988). Assessing frontal lobe functioning in children: Views from developmental psychology. *Developmental Neuropsychology, 4*, 199-230.

Williams, J. H. G., Waiter, G. D., Gilchrist, A., Perrett, D. I., Murray, A. D., & Whiten, A. (2006). Neural mechanisms of imitation and 'mirror neuron' functioning in autistic spectrum disorder. *Neuropsychologia, 44*, 610-621.

Williams, J. H. G., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders, 34*, 285-299.

Williams, J. H. G., Whiten, A., Suddendorf, T., & Perrett, D. I. (2001). Imitation, mirror neurons and autism. *Neuroscience and Biobehavioral Reviews, 25*, 287-295.

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in children's understanding of deception. *Cognition, 13*, 103-128.

Yerys, B. E., Hepburn, S. L., Pennington, B. F., & Rogers, S. J. (2007). Executive function in preschoolers with autism: Evidence consistent with a secondary deficit. *Journal of Autism and Developmental Disorders, 37*, 1068-1079.

Zelazo, P. D., & Müller, U. (2004). Executive function in typical and atypical development. In U. Goswami (Ed.), *Blackwell Handbook of Childhood Cognitive Development* (pp. 445-469). Malden, MA: Blackwell Publishing.

Chapter Two

Fundamental Movement Skills and Autism Spectrum Disorders

Kerri Staples & Greg Reid

Note: This paper is in press (Journal of Autism and Developmental Disorders)

Abstract

Delays and deficits may both contribute to atypical development of movement skills by children with ASD. Fundamental movement skills of 25 children with ASD (ages 9 to 12 years) were compared to three typically developing groups using the *Test of Gross Motor Development* (*TGMD-2*). The group matched on chronological age performed significantly better on the *TGMD-2*. Another comparison group matched on movement skill demonstrated children with ASD perform similarly to children approximately half their age. Comparisons to a third group matched on mental age equivalence revealed the movement skills of children with ASD are more impaired than would be expected given their cognitive level. Collectively, these results suggest the movement skills of children with ASD reflect deficits in addition to delays.

Key words: autism spectrum disorders, movement, development, gross motor

Fundamental Movement Skills and Autism Spectrum Disorders

In his seminal work, Kanner described performance of movement skills by children with *autistic disturbances* as being essentially “normal” (1943). At the same time, Asperger observed the organization and performance of movements by children with *autistic psychopathy*, later termed Asperger syndrome, to be rather clumsy and ill-coordinated (1944; 1991). Since those early descriptions a variety of disciplines have examined movement behaviour among individuals with autism spectrum disorders (ASD). The purpose of this study was to examine the performance of fundamental movement skills among children with ASD who span the entire spectrum in terms of sex, subtype, and level of functioning.

In terms of understanding movement behaviour, a distinction between movement and motor is essential. Movement skills consist of goal-directed movements such as throwing a ball, which can be described according to the final outcome (i.e., 5 of 10 successful throws) or movement pattern used (i.e., over- or under-hand). Fundamental movement skills are the locomotor and object control skills that emerge following the ability to walk, between the ages of 1 and 7 years. These skills are considered “fundamental” in that they span ages and cultures and are assumed to be the basis of more advanced, or sport-specific skills (Burton & Miller, 1998). Motor abilities, on the other hand, refer to underlying capacities that contribute to performance of movement skills (Magill, 1998). Motor abilities are not directly observable and must be inferred from the performance of movement skills; scoring is based on a general ability such as balance or hand-eye coordination instead of the movement pattern used. For example, in the *Bruininks-Oseretsky Test of Motor Proficiency* (*BOTMP*) balance is inferred from walking heel to toe along a line (Bruininks & Bruininks, 2005).

Despite the importance of movement skills to overall development, much of the discussion and majority of research examining the movement behaviour of individuals with ASD has been based on motor abilities. For example, Provost, Heimerl, and Lopez (2007) found that pre-school aged children with ASD performed gross and fine motor skills similar to chronological and mental age-matched children with developmental delays on the *Peabody Developmental Motor Scales* (Folio & Fewell, 2000). Similarly, children and adolescents with ASD demonstrated impaired motor abilities on the *BOTMP* relative to normative data (e.g., Ghaziuddin & Butler, 1998) and typically developing children of similar age and IQ (e.g., Dewey, Cantell, & Crawford, 2007). Majority of children and adolescents with HFA or Asperger syndrome were also impaired relative to normative comparisons (e.g., Green, Baird, Barnett, Henderson, Huber, & Henderson, 2002) on the *Movement Assessment Battery for Children* (Henderson, Sugden, & Barnett, 2007). Although informative, these studies have provided limited insight regarding the actual performance of movement skills among children and adolescents with ASD.

Research examining the performance of movement skills among children and adolescents with ASD has been limited, but results have consistently associated ASD with poor movement skills compared to peers without ASD. In terms of locomotor skills, the performance of 15 children (10 boys, 5 girls) with high-functioning autism (HFA) was compared to normative data and approximately 80% scored in the poor or very poor range (Berkeley, Zittel, Pitney, & Nichols, 2001). However, many of the children seemed to focus on the function of the task instead of the process or form used to perform the actual skill. For example, their children walked or ran between the cones even when they were asked to gallop or leap. It may be that children with HFA interpreted the goal of the task as moving from point A to point B, rather than the actual movement pattern used to get there. Morin and Reid (1985) reported that poorly coordinated arm movements and a lack of opposition between arms and legs was characteristic of both running and jumping performance for adolescent males with ASD compared to a clinical control group matched on age and IQ.

In terms of object control skills, Berkeley and colleagues (2001) reported that only 53% of the children with HFA scored in the poor to very poor range, suggesting that object control skills were not as impaired as locomotor. Although greater performance variance was observed as some of the boys with HFA did not demonstrate any impairment in the performance of object control skills. In other research, majority of boys (DeMyer, 1976) and adolescent males (Morin & Reid, 1985; Reid, Collier, & Morin, 1983) with ASD demonstrated immature throwing and catching patterns.

Although these findings regarding locomotor and object control skills provided initial support regarding impaired movement skills among children and adolescents with ASD, these studies had several methodological limitations. For example, the findings from Berkeley and colleagues (2001) reflected only the movement skill performance of children with HFA. However, a high incidence of cognitive impairment is associated among children with ASD (National Research Council, 2001, p. 82), and investigating only those children whose IQ scores fall in average ranges means that ASD as a whole is no longer being studied (Jarrold & Brock, 2004). This study included children who represented the full range of ASD. Similarly, other studies (Morin & Reid, 1985; Reid et al., 1983) included only boys in their sample of children and adolescents with ASD. We ensured that girls with ASD were also included to provide approximately a 5:1 ratio of boys to girls, again representative of ASD. These studies also included both children and adolescents with ASD spanning across several years in age; however, important developmental changes with the onset of puberty which may confound interpretation of results. We constrained the children with ASD in our study to a narrow age range (9 to 12 years) and prior to puberty to facilitate interpretation of the results regarding movement skill development.

With one exception (Berkeley et al., 2001), limited number of movement skills were examined, which constrains the inferences that can be made. The twelve movement skills we examined were based on the skills being taught in physical education and were therefore deemed to be skills that would afford children with ASD to participate in additional physical activity pursuits.

In terms of comparison groups, two studies relied on normative data (Berkeley et al., 2001; Reid et al., 1983), while the other two compared performance to a group comprised of children and adolescents with intellectual impairment spanning a variety of diagnoses (DeMyer, 1976; Morin & Reid, 1985).

However, comparisons to clinical groups limit generalization of any findings beyond the specific groups being compared due to the heterogeneous composition of each group (Burack, Iarocci, Bowler, & Mottron, 2002). While there is no single “best” approach for matching, developmental level does provide a specific context to compare of levels of performance (Burack et al., 2002). This study included three typically developing comparison groups to provide a more detailed understanding of the complexity of movement behaviours demonstrated by children with ASD.

Planned comparisons also facilitate the exploration of delays and deviances in development (Jarrold & Brock, 2004). A delay in development would suggest that performance reflects younger individuals; skill progressions would occur in the same order as typically developing children, but at a slower rate. On the other hand, a deficit (or deviancy) would imply a distinct pattern of development that differs from the norm. In this study we compared the performance of fundamental movement skills by children with ASD to three typically developing comparison groups who were individually-matched on specific developmental variables: chronological age, movement skill development, and cognitive development.

Method

Participants

Twenty-five children with ASD were compared to three typically developing comparison groups[1], each individually matched on different developmental variables: (a) chronological age, (b) movement skill performance, and (c) mental age (see Table 1). The children with ASD were ages 9.1 to 12.8 years (*M* = 11.15 years) and reflected the full range of ASD[2] in terms of sex (21 boys, 4 girls), diagnosis (11 autistic disorder, 12 PDDNOS, 2 Asperger disorder), and cognitive functioning (full scale IQ (FSIQ) ranging from 34 to 104; *M* = 63). The age range of the children ensured that majority of children with ASD and the comparison groups would be able to perform the 12 fundamental movement skills of interest, but prior to puberty where maturation may confound interpretation of results. The *Leiter-R* (Roid & Miller, 1997) was administered to 21 of 25 children to provide a measure of FSIQ and mental age (MA) equivalence, which ranged from 3.9 to 10.7 years (*M* = 7.36 years).

[place Table 1 about here]

Children with ASD attended a school for students with developmental disabilities; school records indicated previous clinical diagnosis of ASD made by a psychiatrist based on *DSM-IV-R* criteria (American Psychiatric Association, 2000). The *Autism Diagnostic Observation Schedule* (*ADOS*; Lord, Rutter, DiLavore, & Risi, 2002) or the *Social Responsiveness Scale* (*SRS*; Constantino & Gruber, 2005) was used in conjunction with this diagnostic information to support ASD diagnosis for each participant. The *ADOS* was administered by a graduate student trained in administration and scoring to 21 of the 25 children with ASD, the parents of 3 participants completed the *SRS*, while the final participant had recently received a clinical diagnosis using the *ADOS* at an autism clinic.

The first comparison group was matched on sex and chronological age (CA; +/- 3 months), ranging from 9.2 to 12.6 years (*M* = 11.11 years). This group provides a comparison to typical development and a baseline from which to examine performance differences from same age peers.

The second comparison group was comprised of younger, typically developing children matched on movement skill performance based on the raw score of the locomotor subtest of the *Test of Gross Motor Development* (*TGMD-2*; +/- 3). Given the observable nature of movement skills, and since scoring is based on mastering the performance of each skill, it was possible to match these groups closely to ascertain the extent of delay. The locomotor raw score of three children with ASD was too low to be matched to a school-aged comparison sample; therefore, this developmentally-matched (DEV) group consisted of 22 children aged 4.9 to 6.9 years (*M* = 5.87 years) -- approximately half the age of the ASD group (see Table 1). Although these groups will inevitably differ on factors relevant to maturation and life experience (Burack et al., 2002), locomotor skills are universally present among school-age children. All children perform these skills on a daily basis which may not be the case with object control skills.

The third comparison group was matched on sex and MA equivalence (+/- 3 months) as determined by the *Leiter-R*. Based on confirmation of typical development by school records and teachers, the CA and MA of the children included in this third comparison group were deemed comparable. Two of the 21 children with ASD who were administered the *Leiter-R* had MA equivalence scores too low to be matched to school-aged comparison sample and were removed from further analysis. Therefore, this group was comprised of 19 typically developing children ranged from 4.9 to 10.7 years (*M* = 7.75 years). If movement skills are related to cognitive level, it would be expected that the ASD and MA groups would perform similarly.

Measures

Autism Diagnostic Observation Schedule. The *ADOS* is a semi-structured, standardized assessment used across ages, developmental levels, and language abilities. It consists of activities intended to facilitate direct observation of social and communication behaviours related to the diagnosis of ASD. In order to assess such a wide range of abilities the *ADOS* consists of four modules. The module is determined by the examiner relative to the individual's expressive language level and chronological age. Since the expressive language of the children included in this study ranged from nonverbal to fluent, all four modules were used. The *ADOS* was administered by a graduate student who received formal training in its' administration, scoring, and interpretation.

Social Responsiveness Scale. Impairment in social interaction or reciprocity is a diagnostic domain for ASD; the *SRS* is a 65-item questionnaire designed to assess these behaviours among school-aged children and adolescents with ASD in natural social settings. The parents completed the *SRS* by rating frequency of behaviours, reflecting a variety of areas of social impairment: (a) social awareness, (b) social information processing, (c) capacity for reciprocal social communication, (d) social anxiety or avoidance, and (e) autistic traits. Social impairment is measured on a quantitative scale across a range of severity, from mild to severe. The total score, reflecting social deficits in ASD, was used in this study.

Leiter-R. The *Leiter-R* is a nonverbal measure that consists of two assessment batteries (a) visualization and reasoning and (b) attention and memory, and has been standardized for use with individuals aged 2 to 21 years. Since the *Leiter-R* is a nonverbal measure, FSIQ scores may have been (slightly) underestimated for participants who were verbal. The *Leiter-R* was administered by a trained graduate student.

Test of Gross Motor Development. The primary dependent variables were based on performance results from the *TGMD-2* (Ulrich, 2000), a standardized assessment that measures components of a movement skill sequence for twelve fundamental movement skills divided evenly into locomotor (run, gallop, hop, leap, jump, and slide) and object control subtests (strike, dribble, catch, kick, throw, and roll). The *TGMD-2* is preferred over other assessment instruments because scoring is based on specific qualitative performance criteria representing the mature pattern of each skill rather than the outcome of performance such as distance thrown or accuracy. It provides a developmental framework to examine movement skill performance; test items are familiar to the children with ASD by using common functional skills, typical playground equipment and assessment occurring in a familiar gymnasium. Each skill includes 3 to 5 performance criteria. Multiple performance criteria afford children to receive credit for any aspect of the movement skill they are able to perform, which provides more detailed understanding of the movement patterns children used. Scoring is based on the presence (1) or absence (0) of each performance criteria. Two trials of each skill are scored. The sum of these scores for the 6 skills in each subtest is the raw score, which ranges from 0 to 48 for each subtest with a higher score indicating greater proficiency.

The reliability of the *TGMD-2* for use with children with ASD has not been investigated empirically; the *TGMD-2* was standardized and normative data established on a sample of typically developing children aged 3 to 10 years (Ulrich, 2000). Test-retest reliability and average alpha coefficients for the locomotor subtest were $r = .88$ and $\alpha = .85$. and for the object control subtest $r = .93$ and $\alpha = .88$, respectively. Construct validation was demonstrated across ages and comparisons between typically developing children and children with Down syndrome.

The chronological age of 52% of the children with ASD, and their chronological age-matched comparisons did exceed the age of the normative sample; while the children with ASD were nine years and older, their performance on the *TGMD-2* was not expected to reach a ceiling. However, many of the comparison children scored within the highest standard score on the *TGMD-2*, suggesting ceiling effects. Furthermore, 44% of the children with ASD scored within the lowest standard score on the *TGMD-2* suggesting floor effects. As a result, standard scores, age equivalents, and the overall gross motor development quotients were inappropriate for comparison purposes (Mervis & Klein-Tasman, 2004); the sum of the raw scores from the *TGMD-2* was used as the dependent variables.

Procedure

All procedures were carried out under IRB approval at McGill University. Data were collected at two schools: (a) a private school for students with developmental disabilities, and (b) an elementary school. Approval was obtained from the respective school boards, parent committees, and school principals. Prior to participation, informed consent was obtained from parents who also explained procedures to their son or daughter in a level appropriate to their understanding to obtain written assent.

In order to ensure that all children understood each movement skill, the primary researcher provided individualized instructions for each child with ASD as necessary. Administration protocol for the *TGMD-2* requires verbal instructions and a demonstration followed by a practice trial; a second demonstration is provided if the child does not understand the task following the practice trial. By definition, the goal of the demonstration and practice trial is to ensure the child understands the task (Roid & Miller, 1997). Some children also required hand-over-hand manipulation during the second demonstration. For example, it was difficult for some children with ASD to differentiate between throwing and rolling a ball. For two children, in order to make the task more meaningful, they threw or kicked the ball to the researcher instead of at the wall. For other children, the researcher performed the skill alongside them for motivation and one other child performed locomotor skills when moving throughout the gymnasium (i.e., in a game of tag with the researcher) instead of between the cones. Although these modifications were not specified in the

TGMD-2 manual, similar standardized assessments such as the *ADOS* and the *Leiter-R* do provide guidelines to ensure understanding of the task and both state that flexibility is an inherent part of the standardized protocol to adjust to the needs of the child being assessed. Based on these guidelines, we therefore modified the *TGMD-2* and individualized instruction to allow each child to perform each movement skill to their greatest potential.

Performance of the *TGMD-2* was videotaped. To ensure accuracy of scoring, a second graduate student scored approximately 30% of the *TGMD-2* assessments to provide an estimate of interrater agreement. Percentage of exact agreement on each performance criteria was determined for all twelve skills. Agreement of 95.5%, 92.9%, 90.6%, and 95.5% was found for the ASD, CA, DEV, and MA groups, respectively.

Results

Table 2 shows the mean and range of scores on each of the *TGMD-2* subtests for each group comparison. High scores were expected for participants in the CA group given the *TGMD-2* was standardized for use with children ages 3 to 10 years. Raw scores of 47 and 48 reflect the highest standard score and were operationally defined as a ceiling effect. This ceiling was found for 28% and 20% of participants in the CA group, on locomotor and object control subtests, respectively. Similarly, 44% and 16% of children with ASD scored within the lowest standard score on the locomotor and object control subtests, suggesting a floor effect. These scores violate assumptions of normality, making parametric analyses inappropriate. Mann-Whitney U analyses were used to conduct for group differences on the dependent variables.

[place Table 2 about here]

The ASD and CA groups were significantly different on the mean locomotor score ($p < .01$). Locomotor scores for the children with ASD ranged from 8 to 44 ($M = 25.6$), while the locomotor scores of the CA group ranged from 39 to 48 ($M = 45.3$). Similarly, significant differences were found between scores on the object control subtest ($p < .01$). The object control scores of the ASD group ranged from 11 to 43 ($M = 27.8$), while the score of the CA group ranged from 39 to 48 ($M = 44.3$).

Three children from the ASD group scored too low to be matched to a school-aged individual in the DEV group on locomotor score, therefore, the performance of 22 children with ASD was compared to 22 children in the DEV group. Following the removal of these three children, the mean locomotor score of the participants with ASD was 27.9, with raw scores ranging from 10 to 44. The raw scores of the DEV group had a mean of 28.5 and ranged from 13 to 43. Since these groups were specifically matched on the sum of raw scores from the locomotor subtest of the TGMD-2 (+/-3), these groups did not differ significantly on locomotor performance ($p = .72$)[3]. Performance on the object control subtest was also very similar ($p = .81$)[4], demonstrating an even profile of development across locomotor and object control skills for both the ASD and DEV groups. The ASD group had a mean score of 29.0 with scores ranging from 11 to 43, while the DEV group had a mean score of 28.6 with scores ranging from 16 to

43. Children with a mean age of 5.9 years (4.9 – 6.9) were necessary to developmentally-match these groups on overall movement skill (see Table 1), which demonstrates the extent of delay in the development of these skills among children with ASD.

Mental age equivalence was determined for 21 children with ASD; however two children could not be matched to an individual in the MA group because they scored too low for comparison to a school-based sample. Therefore, movement skill performance of 19 children with ASD was compared to 19 typically developing children matched closely on MA (+/- 3 months). Following the removal of these two children for this comparison, the mean locomotor score of the children with ASD again increased slightly to 28.5, with scores ranging from 10 to 44. Although matched closely on MA equivalence, the children in the MA group had a significantly greater mean locomotor score of 40.0 ($p < .01$), with scores ranging from 23 to 46. Similarly, the performance of these groups also differed significantly on the performance of object control skills ($p < .01$). The children with ASD had a mean score of 28.9, with scores ranging from 11 to 43, while the MA group had a significantly greater mean object control score of 37.4, with scores ranging from 21 to 47.

Discussion

This study moved beyond typical age and normative comparisons to include two developmentally-matched comparison groups to explore the nature of the differences in the development of fundamental movement skills among children with ASD. Comparisons between school aged children with ASD and their same age peers confirmed expected differences in movement skill performance (Berkeley et al., 2001). These differences are consistent with most of the motor abilities literature examining children with ASD (e.g., Provost et al., 2007) and general reviews of movement behaviour in the ASD field (e.g., Baranek, Parham, & Bodfish, 2005).

Overall, majority of children with ASD included in this study were able to perform the skills in the *TGMD-2.* Their low scores reflect the poor quality of how they performed the skills; with some of the skills there appeared to be consistent qualitative differences. They had particular difficulty coordinating movements that involved both sides of their body or both arms and legs. For example, during the horizontal jump, the timing and coordination was awkward. It was almost like each body segment acted independently on the others: knees would bend, then arms would swing back, and then the child would jump forward. Very few children with ASD actually swung their arms forward during the jump to generate force and even fewer used their arms on landing to slow down their forward momentum. In addition to not being coordinated or moving in opposition with their legs (Morin & Reid, 1985), arm movements often seemed to be inappropriate or nonfunctional. For example, while hopping arms were often flailing instead of being used to generate force. Many children with ASD also had specific difficulty controlling the force and direction of the ball when throwing (DeMyer, 1976; Morin & Reid, 1985; Reid et al., 1983) or kicking, which may be that very few followed through afterwards. Also when kicking, some of the children with ASD approached the ball, stopped, and then kicked the ball. This lack of forward progression would negatively impact the force of the ball being kicked. Similarly, very few children with ASD met all five criteria for the strike, yet majority did make contact with the ball. They had particular difficulty rotating their bodies and transferring their weight forward prior to contacting the ball in order to transfer force to the ball on contact. Collectively, these observations suggest that movement differences commonly reflected two concepts related to momentum/force and timing/coordination.

The findings of this study suggest similar impairment in locomotor and object control skills, not in accord with Berkeley et al. (2001) who reported relative strengths in object control skills. There are several reasons that may explain these different findings. Berkeley and colleagues' sample was comprised of 6 to 8 year olds with high-functioning autism, whereas the participants in the current study were 9 to 12 year olds spanning the full range of ASD. Performance of object control skills relies heavily on practice and experience performing the skills; increasing performance differences with age may reflect a lack of practice in children with ASD (Wall, 2004). It is also likely that groups of children across the full range of ASD will demonstrate different patterns of performance across tasks when compared to children with HFA (Jarrold & Brock, 2004). Also, Berkeley and colleagues (2001) attributed the relative strength of object control skills to the inclusion of their high-functioning sample in mainstream schools, affording increased opportunities for development of these skills in physical education or organized play environments alongside typically developing peers. The children with ASD included in our study also participated in a well structured physical education program at their school, although it was not an inclusive school. The more advanced object control skills evident in Berkeley et al. (2001) may have been influenced by learning these skills alongside typically peers who may have functioned as appropriate models. The differences between these studies may reflect the different composition of our samples and/or the nature of attending an inclusive school.

However, to understand differences in movement skill development, it is important to demonstrate the extent of the differences relative to developmental level. Comparison to the second group who were developmentally-matched on locomotor skill facilitated this understanding. Despite the modifications made to the *TGMD-2*, which would seemingly afford children with ASD greater likelihood of successful performance, they performed similarly to typically developing children approximately half their age, suggesting a significant delay in development. It is the extent of this delay, early in development and prior to adolescence when differences might be expected to increase, which suggests that a unique pattern, or a deficit, in development may exist among children and adolescents with ASD.

At some point, a delay becomes a deficit (Rogers & Williams, 2006), but how much of a delay must exist before it is considered a deficit? Comparison to the third group, matched on MA equivalence, permits exploration of potential deviances in development by considering the extent of delays relative to developmental level (Burack et al., 2002). The results of the current study indicated that, despite being closely matched on MA, participants with ASD were significantly poorer on locomotor and object control skills and these performance differences cannot be directly attributed to cognitive level. Alternatively, the extent of these differences seemingly indicates different patterns, or potential deficits, in the development of fundamental movement skills.

Implications for Instruction

If the development of fundamental movement skills is simply delayed among children with ASD, the principles of providing instruction would follow typical patterns of development, but would be targeted towards younger individuals. Instruction would focus on providing increased opportunities with guided practice. For example, a young child with Down syndrome takes significantly longer to walk independently, although skill progressions occur in the same order as for typically developing children. With appropriate intervention and increased opportunity to walk on "baby treadmills", walking can be facilitated in young children with Down syndrome (e.g., Looper, Wu, Barroso, Ulrich, & Ulrich, 2006). Similarly, throwing technique is positively influenced when specific instruction or cues accompany practice (Fronske, Blakemore, & Abendroth-Smith, 1997).

Instruction for individuals with a deficit in development would be individualized, based on the current strengths and levels of functioning unique to each individual, rather than on typical patterns, per se. Instruction would continue to be an important aspect of learning, but would be tailored to the child's level of understanding, preferred methods of communication, and would be systematic to allow the child to focus on one thing at a time (Staples, Todd, & Reid, 2006). For example, when learning to throw a ball, task analysis would provide a breakdown for each movement component. Visual cues such as a circle on the floor in front of the opposite foot may initially need to accompany verbal instructions to remind the child which foot steps forward. Once the child has mastered stepping forward with their opposite foot to the throwing arm, then how the arm prepares to throw becomes the focus. Physical manipulation of their arm may facilitate early learning of the movement patterns used to throw a ball. Among typically developing children, much of this learning occurs by watching more skilled individuals, including peers, perform the movement. Children with ASD often do not benefit from observing others in the same way as they may focus on the ball or just the arm rather than the components that constitute the entire throw. However, their attention can be directed to key aspects of a demonstration by simply telling them exactly what they should be looking at (Reid, O'Connor, & Lloyd, 2003).

Differences in the provision of instruction related to delays or deficits in development are important to implement from a theoretical perspective. However, empirical evidence differentiating ‘delay instruction’ from ‘deficit instruction’ in the movement domain has yet to be published. The distinction between delays and deficits that we have made in this paper does seem relevant to other disciplines exploring approaches to instruction or intervention among children and adolescents with ASD, although systematic differentiation between these terms is lacking. The question of delay versus deficit has also surrounded the development of imitation abilities among children with ASD (Rogers & Williams, 2006). Yet it is difficult to determine if young children with ASD experience a delay in development or rather a deficit in the ability to perform imitative tasks? Similarly, majority of children with ASD begin to speak later than their typically developing peers and considerable variability exists in the rate at which language develops (see Tager-Flusberg, Paul, & Lord, 2005, p. for review). Longitudinal studies examining trajectories of development will contribute to understanding the nature of delays and deficits and will have likely implications when it comes to the provision of instruction or approaches to intervention.

Conclusions

The nature of ASD is integrally related to development given the defining behaviours and characteristics are evident early in life and pervade nearly every aspect of subsequent development. The findings from this study suggest that performance of fundamental movement skills among most children with ASD is considerably delayed by late childhood. Determining at what point in development these movement skills becomes impaired is critical; longitudinal studies of children with ASD during critical periods of movement skill development will inform understanding of trajectories and rates of development and may provide insight related to associated factors. This study was limited to children who were 9 to 12 years of age; however, we recognize the importance of examining developmental trajectories of younger children with ASD as behaviours are developmental in nature and are likely to change with increasing age and the acquisition of increasingly complex skills. It is also likely that different developmental trajectories also exist among children with ASD (Burack et al., 2002); comparisons within the group of children with ASD would likely provide additional insight regarding the development of movement skills. However, this study was limited to twenty-five children and comparisons between the children with ASD and their typically developing peers. Although the results of this study provide initial support regarding deficits in the development of fundamental movement skills, additional longitudinal and within group research will be necessary to confirm such speculation.

References

American Psychiatric Association (2000). *Diagnostic and Statistical Manual of Mental Disorders* (4th ed. - Text Revision). Washington, DC: Author.

Asperger, H. (1944). Die 'autistischen psychopathen' im kindesalter. *Archiv fur Psychiatrie und Nervenkrankheiten, 117*, 76-136.

Asperger, H. (1991). 'Autistic psychopathy' in childhood (U. Frith, Trans.). In U. Frith (Ed.), *Autism and Asperger syndrome* (pp. 37-92). Cambridge, UK: Cambridge University Press.

Baranek, G. T., Parham, D., & Bodfish, J. W. (2005). Sensory and motor features in autism: Assessment and intervention. In F. R. Volkmar, R. Paul, A. Klin & D. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders* (Vol. 2, pp. 831-857). Hobenken, NJ: John Wiley.

Berkeley, S. L., Zittel, L. L., Pitney, L. V., & Nichols, S. E. (2001). Locomotor and object control skills of children diagnosed with autism. *Adapted Physical Activity Quarterly, 18*, 405-416.

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks-Oseretsky Test of Motor Proficiency* (2nd ed.). Windsor: NFER-Nelson.

Burack, J. A., Iarocci, G., Bowler, D., & Mottron, L. (2002). Benefits and pitfalls in the merging of disciplines: The example of developmental psychopathology and the study of persons with autism. *Development and Psychopathology, 14*, 225-237.

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Champaign, IL: Human Kinetics.

Constantino, J. N., & Gruber, C. P. (2005). *The Social Responsiveness Scale (SRS) manual*. Los Angeles, CA: Western Psychological Services.

DeMyer, M. K. (1976). Motor, perceptual-motor, intellectual disabilities of autistic children. In L. Wing (Ed.), *Early Childhood Autism* (pp. 169-193). New York: Pergamon Press.

Dewey, D., Cantell, M., & Crawford, S. G. (2007). Motor and gestural performance in children with autism spectrum disorders, developmental coordination disorder, and/or attention deficit hyperactivity disorder. *Journal of the International Neuropsychological Society, 13*, 246-256.

Folio, M. R., & Fewell, R. R. (2000). *Peabody Developmental Motor Scales examiner's manual* (2nd ed.). Austin: Pro-Ed.

Fronske, H., Blakemore, C., & Abendroth-Smith, J. (1997). The effect of critical cue on overhand throwing efficiency of elementary school children. *Physical Educator, 54*, 88-95.

Ghaziuddin, M., & Butler, E. (1998). Clumsiness in autism and Asperger syndrome: A further report. *Journal of Intellectual Disability Research, 42*, 43-48.

Green, D., Baird, G., Barnett, A. L., Henderson, L., Huber, J., & Henderson, S. E. (2002). The severity and nature of motor impairment in Asperger's syndrome: A comparison with specific developmental disorder of motor function. *Journal of Child Psychology and Psychiatry, 43*(5), 1-14.

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement Assessment Battery for Children* (2nd ed.). London: Pearson Assessment.

Jarrold, C., & Brock, J. (2004). To match or not to match? Methodological issues in autism-related research. *Journal of Autism and Developmental Disorders, 34*, 81-86.

Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child, 2*, 217-250.

Looper, J., Wu, J., Barroso, R. A., Ulrich, D., & Ulrich, B. D. (2006). Changes in step variability of new walkers with typical development and with Down syndrome. *Journal of Motor Behavior, 38*, 367-372.

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (2002). *Autism Diagnostic Observation Schedule: Manual*. Los Angeles, CA: Western Psychological Services.

Magill, R. A. (1998). *Motor learning: Concepts and applications* (5th ed.). Boston: McGraw-Hill.

Mervis, C. B., & Klein-Tasman, B. P. (2004). Methodological issues in group-matching designs: α levels for control variable comparisons and measurement characteristics of control and target variables. *Journal of Autism and Developmental Disorders, 34*, 7-17.

Morin, B., & Reid, G. (1985). A quantitative and qualitative assessment of autistic individuals on selected motor tasks. *Adapted Physical Activity Quarterly, 2*, 43-55.

National Research Council (2001). *Educating children with autism: Report of the committee on educational interventions in children with autism* Washington, DC: National Academy Press

Provost, B., Heimerl, S., & Lopez, B. R. (2007). Levels of gross and fine motor development in young children with autism spectrum disorder. *Physical and Occupational Therapy in Pediatrics, 27*(3), 21-36.

Reid, G., Collier, D., & Morin, B. (1983). The motor performance of autistic individuals. In R. Eason, T. Smith & F. Caron (Eds.), *Adapted physical activity* (pp. 201-218). Champaign, IL: Human Kinetics.

Reid, G., O'Connor, J., & Lloyd, M. (2003). The autism spectrum disorders: Physical activity instruction. *Palaestra, 19*(2), 20-26, 47-48.

Rogers, S. J., & Williams, J. H. G. (2006). Imitation in autism: Findings and controversies. In S. J. Rogers & J. H. G. Williams (Eds.), *Imitation and the social mind: Autism and typical development*. New York, NY: The Guilford Press.

Roid, G. H., & Miller, L. J. (1997). *Leiter international performance scale - revised*. Wood Dale, IL: Stoeling.

Staples, K., Todd, T., & Reid, G. (2006). Physical activity instruction and autism spectrum disorders. *ACHPER Healthy Lifestyles Journal, 53*(3-4), 17-23.

Tager-Flusberg, H., Paul, R., & Lord, C. (2005). Language and communication in autism. In F. R. Volkmar, R. Paul, A. Klin & D. Cohen (Eds.), *Handbook of autism and pervasive developmental disorders* (3rd ed., pp. 335-364). New Jersey: John Wiley & Sons, Inc.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.). Austin, TX: Pro-Ed.

Wall, A. E. (2004). The developmental skill-learning gap hypothesis: Implications for children with movement difficulties. *Adapted Physical Activity Quarterly, 21*, 196-218.

Author Note

Kerri L. Staples

Greg Reid

Department of Kinesiology and Physical Education

McGill University

Montréal, QC, Canada

Kerri L. Staples is now in at the University of Regina. This research was part of a doctoral dissertation supported by an Autism Research Training program (CIHR, Autism Speaks, and FRSQ), Social Sciences and Humanities Research Council of Canada, and research grants from McGill University and Special Olympics awarded to the first author. Thank-you to Matt Steven, Alissa Apa, Myléne Boudreau, and Emma Steven for their invaluable assistance throughout data collection and analysis. A huge thank-you goes to the schools, teachers, and children who made this research possible. A version of this manuscript was presented at the North American Federation of Adapted Physical Activity.

Correspondence concerning this article should be addressed to:

Kerri L. Staples

Faculty of Kinesiology and Health Studies

University of Regina

Regina, SK, Canada S4S 0A2

kerri.staples@uregina.ca

Footnotes

[1] To ensure the children included in each of the comparison groups were typically developing, a variety of measures were taken. Students with any formal record of learning disability or developmental disorder in their school files were excluded. The physical educator and homeroom teacher of each student also confirmed typical development.

[2] ASD was primary diagnosis for all children included in the ASD group; no child had record of seizure disorder.

[3] A power analysis with effect size of .10 and a power of.06 supported sufficient sample size to demonstrate no difference between these groups on the locomotor skills.

[4] A power analysis with effect size of .01 and a power of .05 again supported sufficient sample size to demonstrate no performance difference between these groups on object control skills.

Table 1

Participant Demographics by Group

	GROUP			
	ASD 21M, 4F	CA 21M, 4F	DEV 18M, 4F	MA 16M, 3F
AGE (range)	11.15 years (9.1 – 12.8)	11.11 years (9.2 – 12.6)	5.87 years (4.9 – 6.9)	7.75 years (4.9 – 10.7)
DIAGNOSIS	12 AUTISM 13 PDD-NOS 2 AS			
FSIQ (range)	63 (34 – 104)			
MA (range)	7.36 years (3.9 – 10.7)			

ASD = autism spectrum disorders; CA = chronological age-matched group; DEV = developmentally-matched group; MA = mental age-matched group; PDD-NOS = pervasive developmental disorder – not otherwise specified; AS = Asperger syndrome; FSIQ = full scale IQ (*Leiter-R*); MA = mental age equivalence (*Leiter-R*)

Table 2
Raw Scores Based on Performance of Test of Gross Motor Development – 2nd edition

	ASD n = 25	CA n = 25	ASD n = 22 [a]	DEV n = 22 [a]	ASD n = 19 [b]	MA n = 19 [b]
LOCOMOTOR	25.60 [c] (8 - 44)	45.32 [c] (42 - 48)	27.91 [d] (10 - 44)	28.45 [d] (13 - 43)	28.53 [c] (9 - 44)	39.95 [c] (23 - 46)
OBJECT CONTROL	27.80 [c] (11 - 43)	44.32 [c] (39 - 48)	29.00 [e] (11 - 43)	28.64 [e] (16 - 43)	28.89 [c] (11 - 43)	37.37 [c] (21 - 47)

ASD = autism spectrum disorders; CA = chronological age-matched group; DEV = developmentally-matched group; MA = mental age-matched group
Note: Maximum raw score for each subtest is 48

[a] Three participants with ASD could not be matched to school-aged child in DEV group and were removed from analysis comparing ASD and DEV.

[b] Two participants with ASD could not be matched to school-aged child in MA group and were removed from analysis comparing ASD and MA.

[c] $p < .01$

[d] $p = .72$

[e] $p = .81$

Bridging Manuscripts

Chapter 2 described a study demonstrating that children with ASD perform fundamental movement skills poorly compared to same aged peers, suggesting a delay in their development of movement skills. When matched on locomotor skill performance, children with ASD perform similarly to children approximately half their age, demonstrating the extent of this delay. Comparisons to a third group matched on mental age equivalence revealed that the movement skills of children with ASD are more impaired than would be expected for their cognitive level. This study is the first to move beyond normative comparisons and control for three developmental variables (chronological age, movement skill, mental age) to explore the nature of these performance differences. The results suggest the movement skills of children with ASD may reflect both delays and deficits in development. Differences in development among children with ASD are commonly described in terms of an underlying deficit in executive functioning (Ozonoff, Pennington, & Rogers, 1991) and while all executive functions play important roles in development, planning has been implicated specifically to account for differences in performance of movement skills (Hughes, 1996). However, tasks that have been used with children to examine movement planning have not been evaluated formally for use with children with ASD, and most have not included fundamental movement skills. Therefore, the study in chapter 3 conducted the initial development and validation of an obstacle course task to provide a movement-based estimate of planning specific to use with children with ASD.

Chapter Three

Development and Validation of a Movement Planning Task for Children with Autism Spectrum Disorders

Kerri Staples & Greg Reid

Abstract

The purpose of this study was to continue development and validation of an obstacle course to provide an estimate of motor planning among children with ASD. The obstacle course required moving over or under eight horizontal barriers that varied in height relative to each child. Twenty-five children with ASD (ages 9 to 12 years) and two comparison groups of typically developing children strategically matched on developmental variables participated. Cronbach alpha scores were sufficient to support reliability of this obstacle course. Motor planning was assessed by acts of hesitation (ACTS) and hesitation time (HES), executive functioning by a standardized questionnaire, and movement execution by obstacle course time and the *Test of Gross Motor Development*. Results supported concurrent validity of the motor planning inferences since ACTS had moderate with executive functioning and movement execution measures. Clinical validation was supported given that motor planning measures were able to distinguish between the ASD and comparison groups. Overall, this obstacle course displayed sufficient reliability and validity to warrant further development.

Key words: autism spectrum disorders, motor planning, movement, task validation

Development and Validation of a Movement Planning Task for Children with Autism Spectrum Disorders

It is generally accepted that movement skills of children with autism spectrum disorders (ASD) are poor compared to peers without ASD, yet an understanding of the underlying reasons for this poor performance is limited (Smith, 2000). While motor planning has been specifically implicated in their movement difficulties (McEvoy, Rogers, & Pennington, 1993) this underlying ability must be inferred from the performance on tasks that include movement sequences requiring multiple steps, one of which is planning, to perform (e.g., Hughes, 1996). Planning falls under the realm of executive functions, and refers to a wide range of underlying cognitive processes that are responsible for purposeful, goal-directed, and problem-solving behaviours (Gioia, Isquith, Guy, & Kentworthy, 2000). Collectively, executive functions maintain appropriate strategies to plan and execute a specific goal by organizing, regulating, and modifying behaviours relative to constantly changing task demands (Bennetto & Pennington, 2003; Ozonoff, 1995).

Executive functioning is also one of the primary theoretical explanations for ASD and is based on a hierarchical model reflecting regulatory functions relative to higher, or executive, levels of cognition (Stuss & Benson, 1986). Characteristic behaviours can be described in terms of an executive processing impairment; much of the empirical support for this theoretical account is based on the common behaviours among individuals with (frontal lobe) brain injuries and individuals with ASD (Damasio & Maurer, 1978). For example, brain lesions in the prefrontal cortex disrupt planning and execution of complex behaviours without affecting other perceptual-motor processes (Pennington, Rogers, Bennetto, Griffith, Reed, & Shyu, 1997). Planning deficits have been found consistently among children and adolescents with ASD relative to typically developing comparison groups on executive functioning tasks (e.g., Landa & Goldberg, 2005; Ozonoff & Jensen, 1999; Prior & Hoffman, 1990; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2005). However, the results from these studies do not inform our understanding of why children with ASD have difficulty performing fundamental movement skills. With respect to assessment of motor planning abilities among children with ASD, a number of measurement issues are apparent. These issues include (a) tasks consisting of unfamiliar and seemingly unrelated movement sequences without a definite end, (b) tasks requiring complex instructions, and (c) laboratory-contrived tasks.

Children and adolescents with ASD have impaired performance on a variety of reach-to –grasp tasks (e.g., Mari, Castiello, Marks, Marraffa, & Prior, 2003). Many of these simple movement sequences consist of a series of unrelated tasks without a natural flow or definite end and the goal of the task may not be interpreted in the same way by a young child with ASD as is intended by the research. As such, Hughes (1996) adapted a simple reach-to-grasp task to include a more purposeful and definite end, thereby creating a reach-to-grasp-and-place task which afforded a more specific goal-directed action. Ecologically valid skills that are deemed to be more purposeful by the child in terms of actions they are familiar with are more representative of a child's movement and therefore planning capabilities (Burton & Miller, 1998).

One study that examined performance of goal-directed locomotion demonstrated that children with ASD and their typically developing peers use similar locomotor strategies (Vernazza-Martin, et al., 2005). However, the most significant finding of this research may have been that while children with ASD walked in the intended direction of a goal, the majority did not actually achieve the experimenter-imposed goal of the task. While the researchers interpreted this as supportive of a motor planning deficit, it is also possible that the goal of the task was not clearly understood, or was not found to be meaningful by the child. These alternative interpretations underscore the importance of a meaningful task goal that is clearly understood by the child.

Instructions regarding the task goal and purpose need to be conveyed in a simple and straightforward manner due to the range of cognitive abilities associated with ASD (National Research Council, 2001, p. 82). The provision of instruction is further confounded because many children with ASD also have difficulty with imitation (Williams, Whiten, & Singh, 2004). If a demonstration is essential to learning what is required to perform a task, it may not be an effective means to communicate task information to many children with ASD. Nonetheless, to make accurate inferences regarding performance on a task, it is essential to ensure that each child understands the goal of the task.

Many of the motor planning tasks used for individuals with ASD have been laboratory-contrived and consist of fine motor, or single limb, movements. The measurement of these manipulative tasks such as reach-to-grasp (Mari, et al., 2003), goal-directed reaching (e.g., Hughes & Russell, 1993; Rinehart, Bellgrove, Tonge, Brereton, Howells-Rankin, & Bradshaw, 2006), or aiming (e.g., Glazebrook, Elliott, & Lyons, 2006; Glazebrook, Elliott, & Szatmari, 2008), require an extensive number of trials and are therefore limited to high-functioning and/or older individuals with ASD who can maintain attention for extended periods of time. Even with the provision of frequent breaks, this number of trials is unrealistic for many individuals with ASD. Research on motor planning in children with ASD is limited by the lack of challenging, yet developmentally appropriate tasks that permit assessment of children and adolescents with ASD who span across levels of cognitive functioning associated with this disorder.

The purpose of the current study was to further develop a movement-based estimate of motor planning that will overcome some of these articulated measurement issues and contribute to an understanding of why many children with ASD have difficulty performing fundamental movement skills. Many children with ASD have additional difficulty performing skills or completing tasks in unfamiliar environments. In order to facilitate performance and allow each child to demonstrate their true capabilities, this obstacle course required performance of fundamental locomotor skills (i.e., running, jumping) commonly used during play and physical education and was administered in each participant's school gymnasium. To accommodate the full range of cognitive abilities among the children with ASD, the task included a combination of simple movement sequences (i.e., over or under) and precise instructions were provided. Each participant was instructed to move over or under the barriers and touch the wall at the other end. Furthermore, the exact movement skills required were not specified -- each participant could move through the obstacle course using locomotor skills of their preference, which facilitated the provision of instruction without demonstration.

Staples (2006) conducted the initial development and validation of this 8-barrier obstacle course. Content-related validity and the measures as accurate inferences of motor planning were supported by ongoing discussion and feedback from multiple experts. Criterion-related validity was established with high correlations between two motor planning measures from the obstacle course and two scores from a standardized executive functioning questionnaire (ranging from .65 to .78), lending support that measures on the obstacle course were tapping similar executive function constructs. Item analysis and estimates of internal consistency (Cronbach alpha) indicated barrier heights at 40 and 50% of each participant's standing height were most indicative of planning. However, this initial work was limited to ten children with ASD and did not include comparison groups; further task development and validation was warranted.

Reliability

The reliability of measurement reflects the consistency or extent to which a measure is able to achieve the same result on repeated trials. At least four estimates of reliability may be considered: (a) internal consistency, (b) test-retest, (c) split-half, and (d) inter-rater (Stevens, 2009). However, test-retest reliability was deemed inappropriate because executive functions require novelty of the task (Denckla, 1994) in order to be assessed accurately. To determine split-half reliability, the different barrier heights would be divided into two even sets and the total score for each half would be determined. The split-half reliability would correlate these two total scores. In this study, Chronbach alpha was used to provide an estimate of internal consistency. This estimate of reliability was preferred as it calculates all possible split-half estimates from the same sample, rather than providing a single split-half estimate.

Validity

Validity reflects whether or not the measure assesses the specific construct of interest. Ecological validity is also an important aspect of task development – ideally tasks should be related to everyday functioning (Bryant, 2000). This obstacle course was developed by combining everyday locomotor skills in a familiar and functional context, the child's school gymnasium. Further validation of this obstacle course included evidence to support content, criterion, and construct-related validity as outlined by Bryant (2000).

Content-related evidence. Content validity reflects the degree to which the obstacle course and its' measures reflect motor planning. Based on a thorough review of both motor control and ASD literature, motor planning was defined as the conception and organization of a movement sequence which requires the ability to think ahead and anticipate possible problems and alternatives with respect to the selected movements (Hughes, Russell, & Robbins, 1994; McEvoy, et al., 1993). Since motor planning has been both conceptually and operationally defined in a multitude of ways, the design of this obstacle course and its' measures of motor planning were collectively agreed upon by experts from multiple fields (Bryant, 2000; Yun & Ulrich, 2002) including motor control, ASD, adapted physical activity, and cognitive psychology.

Criterion-related evidence. Concurrent validity examines the relationship between scores on two measures that were obtained at the same time (Bryant, 2000; Yun & Ulrich, 2002). In this study, correlations between measures of the obstacle course performance and measures of executive functioning were calculated. High correlations would demonstrate measures of motor planning from the obstacle course tapping into the same constructs measured with a standardized executive function assessment. Although not a measure of planning per se, high correlations would also be expected between the measures on the obstacle course and movement execution, given that both are based on movement skill performance.

Construct-related evidence. Construct validity examines whether a measure, or operational definition, assesses the underlying construct that it intends to measure (Bryant, 2000). Convergent validity is similar to concurrent validity (see above) in that it examines the degree to which multiple measures of the same construct are correlated with each other. Discriminant validity was used in this study to support construct validity. Clinical validation is an important component of discriminant validity, as it examines the accuracy with which the mean differences on a particular measure can be used to differentiate between groups (Bryant, 2000). These results have greater meaning if the measures are able to discriminate between groups that are very similar, or matched closely on a control variable related to the task.

Method

Participants

Twenty-five children with ASD ages 9.1 to 12.8 years (*M* = 11.15 years) participated. They reflected full range of ASD in terms of sex (21 boys, 4 girls), diagnosis (11 autistic disorder, 12 PDDNOS, 2 Asperger disorder), and cognitive functioning (full scale IQ ranging from 34 to 104; *M* = 63) as determined by the *Leiter-R* (Roid & Miller, 1997). They attended the same school for children with developmental disabilities and school records indicated clinical diagnosis of ASD based on *DSM-IV-R* criteria (American Psychiatric Association, 2000). The *Autism Diagnostic Observation Schedule* (Lord, Rutter, DiLavore, & Risi, 2002) or the *Social Responsiveness Scale* (Constantino & Gruber, 2005) were administered in conjunction with diagnostic information obtained from school records to support ASD diagnosis for each participant. Anticipatory locomotor adjustments during obstacle avoidance tasks are expected by age 7 years in typically developing children (McFadyen, Malouin, & Dumas, 2001). The age range of the ASD group was therefore carefully chosen so that planning abilities would be expected for children of this age.

Two typically developing comparison groups were individually-matched to the children with ASD on specific developmental variables that were guided by the specific research questions (Burack, Iarocci, Bowler, & Mottron, 2002). The first comparison group (n = 25) was matched on sex and chronological age (CA; +/- 3 months) and ranged from 9.2 to 12.6 years (*M* = 11.11 years). This comparison provides a baseline for what should be expected on the obstacle course for same age peers.

The second comparison group (n= 22) consisted of younger, typically developing children developmentally-matched (DEV) on movement skill performance based on the raw score of the locomotor subtest of the *TGMD-2* (+/- 3). Given the observable nature of movement skills, and since scoring on the *TGMD-2* is based on mastery of performance, it was possible to match 22 of the children with ASD closely. The locomotor raw score of three children with ASD was too low to be matched to a school-aged comparison sample; therefore, this developmentally-matched group consisted only of 22 children aged 4.9 to 6.9 years (*M* = 5.87 years) -- approximately half the age of the children with ASD. Since the ASD and DEV groups were individually-matched on (locomotor) movement skill, observable differences on obstacle course performance (which requires similar locomotor skills) can be inferred as being indicative of underlying differences (such as motor planning) rather than locomotor skill differences (Sigman & Ruskin, 1999).

Instruments

Obstacle course. The obstacle course consisted of eight adjustable, horizontal barriers placed in sequential fashion creating systematic and alternating heights based on 30, 40, 50, and 60% of each participant's standing height (Figure 1). The barrier heights are therefore constant relative to the standing height of each participant. The distance between barriers was 2 meters, with the starting and finishing lines clearly marked with orange cones 2 meters beyond each end. The total distance of the obstacle course was therefore 18 meters.

During each trial of the obstacle course, each of the four barrier heights were encountered twice. A trial consisted of moving through the obstacle course (18 meters) going over or under the barriers using locomotor skills of their choice. The order of barriers was changed systematically for each trial, resulting in a slightly different task for each pass through to re-introduce some level of unfamiliarity back into the executive function task (Denckla, 1994). They were asked to move through the course four times, twice at each of two speeds, self-determined or as fast as possible. The order was counter-balanced among participants.

Each barrier consisted of two standards and a crossbar, which were designed similar to high jump standards. If contact was made with the barriers, the crossbar would fall forward and not hurt the participant. The standards were 150 cm tall, including the base of support, and were constructed from 3.3 cm square lumber calibrated with holes drilled in 2 cm increments to allow for accurate and efficient changing of heights for each participant. The base of support was designed to provide ample support so the standards would not fall over if knocked or bumped.

Two standard digital video cameras were placed around the obstacle course, focused on four barriers each, collectively providing a clear view of movement through all barriers. The performance of the obstacle course was filmed at a rate of 30 frames per second, an acceptable speed for assessing human activities (Nigg & Cole, 1994).

Measurement

Motor planning. Acts of hesitation (ACTS) was a frequency measure; each act was inferred as being a change in the initial plan. For example, after a participant lifted their foot to go over the barrier, they may have put that same foot back down, and decided to go under or lead with their other foot. That was one ACT. A stutter-step was also observed when a change in the lead foot occurred. This would also be coded as an act of hesitation since it represents a change in the initial plan. Sometimes participants would walk right up to the barrier and stop, look at it, and then decide whether to go over or under. The number of ACTS for each barrier height was a sum for the four encounters at that height at each of two speeds; the total ACTS was a sum of all ACTS at all four barrier heights and across all four trials.

Hesitation time (HES) was the time spent executing ACTS. Not surprisingly, when time was spent making changes to the (initial) plan, more time was also required with respect to the initiation and execution of that plan. Therefore, hesitation time was also included in overall execution time.

Movement Execution. Execution time (EXEC) was a sum of the time required to clear each barrier, a measure of movement execution rather than planning per se, although it is acknowledged that some acts of hesitation were ongoing and inevitably were included in EXEC. Children with ASD do not move efficiently (e.g., Damasio & Maurer, 1978; Reid, Collier, & Morin, 1983) and one would expect them to move more slowly through the complete set of barriers.

When going over a barrier, time was measured from when the first foot was lifted to clear the barrier, until the time when both feet were in clear contact with the ground on the other side of the barrier. In the case of crawling under the barriers, time as measured from the first hand made contact with the ground, just prior to the barrier, until both feet were clearly across on the other side of the barrier. Specific time segmented frames were used to determine execution time, which was defined as the summed time (sec.) taken to clear each barrier, instead of the time from beginning to end of the obstacle course.

The Test *of Gross Motor Development* (*TGMD-2*) is a normative and criterion-referenced assessment that emphasizes the components of a movement skill sequence rather than the end product of performance (Ulrich, 2000). It provides a developmental framework to examine the performance of 12 fundamental movement skills divided evenly into locomotor and object control subtests. The total score for each subtest can range from 0 to 48 with the higher score being an indication of greater proficiency. Since the movements through the obstacle course were locomotor in nature, the raw score from the locomotor subtest was used as a control variable on which to match the DEV comparison group. The performance of this assessment was videotaped in order to facilitate accurate scoring and inter-rater agreement at a later time.

Executive functioning. The *Behavior Rating Inventory of Executive Function* (*BRIEF*) is a questionnaire designed to assess executive function behaviours in school-age children (Gioia et al., 2000). Since English was not the first language for some of the parents of the children with ASD, the teacher version of the *BRIEF* was used. This also provided some consistency across the school environment because all participants with ASD attended the same school. The *BRIEF* is comprised of 86 statements, divided into eight components that measure different aspects of executive functioning (a) inhibit, (b) shift, (c) emotional control, (d) initiate, (e) working memory, (f) plan, (g) organize, and (h) monitor. Each statement is scored based on the occurrence of that behaviour: 1 never, 2 sometimes, and 3 often. There is a score for each of the eight components, as well as an overall global executive composite score. High scores are indicative of greater levels of impairment. The planning score (PLAN) and the overall composite score (*BRIEF*) were used as measures of executive functioning in this research. While each of the eight subtests may contribute to understanding different aspects of the obstacle course performance, it was expected that the planning score and an overall executive functioning score would be most related to the construct that the obstacle course task in this study was purported to measure -- motor planning.

The internal consistency of the teacher version of the *BRIEF* is high (r = .80 to .98) and test-retest reliability shows stability over a 2 to 6 week period (r = .83 to .92), suggesting high reliability in its use (Gioia, et al., 2000). Content validity was based on interviews with parents, teachers, and agreement from neuropsychologists. Criterion validity was established by comparing the subscales of the *BRIEF* with other behavior rating scales and clinical validation was used to demonstrate the BRIEF could accurately differentiate different profiles of executive functioning among children with a variety of clinical disorders (Gioia, et al., 2000). Overall, the reliability and validity of the *BRIEF* was found to be adequate for use as a comparison measure of executive functioning and planning for purposes of this study.

Field notes and observations. Specific notes were taken following each assessment with respect to the testing conditions and the behaviours of participants. Detailed observations were also recorded during the videotape analysis of the obstacle course performance.

Procedure

This research study was approved by the institutional review board at the author's university. Approval was also obtained from the respective school boards and schools where data were collected. Once school approval was obtained, potential participants were identified, informed consent was obtained from the parent or guardian, and assent was obtained from all participants. The researcher then observed and assisted in physical education classes for several weeks, to facilitate familiarity with the participants. At this time, the researcher was also able to observe each participant's instructional preferences in order to interact with them in a manner which would maximize performance on each of the movement assessments. This familiarization phase was especially important with the ASD and DEV groups.

Participants were assessed individually in their school gymnasium on two separate occasions. On the first day the *TGMD-2* was administered and on the second day the obstacle course task. It was emphasized that there was no right or wrong way to move through the obstacle course. The participants were asked to complete the obstacle course using two different speeds (a) twice choosing their own speed (self-determined) and (b) twice moving as fast as possible (fast). The order was counter-balanced. The homeroom teacher of each participant in the ASD group completed the *BRIEF* questionnaire.

Data Analysis

Speed (self-determined or fast as possible) was thought to be a potential task constraint, adding a dimension to motor planning that would increase tasks demands. To assess influence of speed, ACTS and HES were compared for the two speeds using nonparametric analysis (Mann-Whitney U) and multivariate analysis of variance (MANOVA), respectively. No differences between speeds were found at any barrier height nor when all four barrier heights were considered together for either variable. These results were consistent for each group and when all three groups were considered together; the two speed conditions were collapsed for subsequent analyses. (see Appendices L and M).

It was thought that order of the task (i.e., previous exposure and familiarity with the task) might also influence hesitation. Since the obstacle course task consisted of four trials, the first and second trials were compared with the third and fourth. Mann-Whitney U and MANOVA were again used to determine the influence of order on ACTS and HES, respectively. When all three groups were considered together, significant differences were not found with respect to order at any barrier height nor when all heights were considered simultaneously.

However, when the CA group was examined separately the order of the task did significantly influence overall HES ($p < .05$), although barrier height reflecting 60% of the participant's standing height was the only barrier that was found to be significantly different ($p = .03$). Results based on the overall analyses (combining all three groups) allowed us to sum scores across order conditions for subsequent analyses. (see Appendices L and M).

The development and validation of this obstacle course task as a measure of motor planning was for specific use with children with ASD. Beyond group comparisons to establish clinical validation (i.e., clinical validation), other analyses were based on the ASD group only.

Reliability. In order to determine the task's internal consistency, an item analysis (Cronbach alpha) examined ACTS and HES at each of the barrier heights. This analysis also determined the contributions of each barrier height as an inference of motor planning. Interrater agreement was established by two independent researchers according to the pre-determined operational definitions on 25% of the trials (1 trial for each participant). Agreement was determined for HES and EXEC (+/- 2 frames per second). This estimate of interrater agreement not only determined the researcher's reliability and consistent use of the operational definitions, but it also contributed to establishing support for content validity of the development of this obstacle course task. Interrater agreement was also established on approximately 30% of the *TGMD-2* scores.

Validity. To examine concurrent validity, relationships among measures of motor planning (ACTS, HES), measures of movement execution (*TGMD-2*, EXEC) and executive functioning scores (*BRIEF*, PLAN) were examined using Pearson-Product moment correlation coefficients. To examine clinical validity, comparisons were made between the ASD group and each of the comparison groups (CA and DEV) on ACTS to determine if the measures of motor planning[1] could differentiate among groups. Because each participant in the ASD group was strategically matched to a participant in each of the two comparison groups, comparisons between the CA and DEV groups would not contribute to the validity of this obstacle course task for use with children with ASD. Therefore, separate analyses were used to compare the children with ASD with the children in each of the comparison groups.

Results

Descriptive Statistics

Means, standard deviations, and skewness for each of the obstacle course dependent variables are listed in Table 1. As expected many children with ASD moved through the obstacle course very slowly and EXEC was skewed for the ASD group; however, there was still a full range of scores among children with ASD. On the other hand, hesitation was minimal in each of the comparison groups, resulting in skewed distributions for HES. In fact, majority of children in the CA group achieved perfect scores (i.e., no hesitation), resulting in a skewed distribution with limited variability. However, central limit theorem (Stevens, 2009) predicts that skewed data will have very little impact on overall power of parametric analyses and therefore these analyses remain appropriate. Descriptive statistics are also presented for the *TGMD-2* and *BRIEF* in Table 1.

Reliability

The internal consistency of the obstacle course task for the ASD group was determined for ACTS and HES based on Cronbach alpha scores. Alpha coefficients were determined for each barrier height and when all barrier heights were included in the item analysis, significant alpha values resulted for both ACTS ($r = .62$, $p < .01$) and HES ($r = .43$, $p = .04$).

Interrater agreement ranging from 86 to 100% was found for ACTS, HES and EXEC demonstrating the operational definitions were clearly defined and could be reliably scored. Interrater agreement was also determined on the locomotor scores from the *TGMD-2* and agreement ranging between 91 and 95% was found.

Validity

Correlation coefficients (see Table 2) examined the relationship among measures of motor planning (ACTS, HES), movement execution (*TGMD-2*, EXEC), and executive functioning (PLAN, *BRIEF*). As expected, the two measures of motor planning (ACTS, HES) were highly correlated with each other ($r = .87$, $p < .01$) and moderately but significantly correlated with measures of movement execution (*TGMD-2*, EXEC) and executive functioning (*BRIEF*, PLAN). Moderate correlations were found between ACTS and measures of movement execution: *TGMD-2* ($r = - .53$, $p < .01$) and EXEC ($r = .60$, $p < .01$) as well as between ACTS and measures of executive functioning: *BRIEF* ($r = .49$, $p < .05$) and PLAN ($r = .48$, $p < .05$).

Clinical (i.e., discriminant) validity was used to determine if ACTS, as an inference of motor planning from the obstacle course task, was able to differentiate between groups. Table 3 provides the mean and range of ACTS for each group at each barrier height as well as for total ACTS. The Mann-Whitney results comparing the ASD and CA groups indicated significant differences at all barrier heights ($p < .01$) except the one reflecting 60% of the participant's height ($p = .13$). Despite being closely matched on locomotor skill, comparison between the ASD and younger DEV groups showed that mean ranks comparing ACTS were significantly different at barrier heights reflecting 40% ($p < .01$) and 50% ($p = .04$) of their height and total ACTS ($p < .01$) across all barrier heights.

Discussion

The purpose of the current study was to continue development and validation of a motor planning task that included fundamental movement skills in an ecologically valid setting that would encourage children with ASD of all abilities to complete. This 8-barrier obstacle course encouraged children to navigate and negotiate each barrier by choosing the movement pattern most suitable to their skill level. By constraining the task to one of two movement patterns (over or under), yet still providing the participant choice, a plausible inference of motor planning was possible.

Previous motor planning tasks examining locomotion and obstacle avoidance strategies among typically developing children have been more laboratory-contrived in nature (e.g., Grasso, Assaiante, Prévost, & Berthoz, 1998; Ledebt, Bril, & Brenière, 1998; Pryde, Roy, & Patla, 1997). Although familiar and functional skills were used in the performance of these tasks, they also included relatively complex instructions (i.e., different instructions for each condition) and potentially distracting and unfamiliar environments (i.e., laboratory with force platform, obstacles of different shapes, sizes, and colours). Many of these tasks have also constrained the participant's means of avoiding the obstacle to a single strategy, either stepping over (e.g., McFadyen, et al., 2001) or around the obstacle (e.g., Vallis & McFadyen, 2003), rather than providing options that are typically available when confronting an obstacle (i.e., over, under, or around). While these tasks provide very detailed kinematic information about specific movement parameters and contribute greatly to understanding how movements are planned among typically developing children, these obstacle avoidance tasks have not been evaluated formally for children with ASD. This study examined the psychometric properties of a movement planning task for specific use with children and adolescents with ASD.

Reliability

Cronbach alpha coefficients were used to determine the internal consistency among the barrier heights. While ACTS approached acceptable internal consistency, HES was rather low. Based on this result, greater emphasis will be placed on ACTS as a measure of motor planning. Based on the item analysis, barrier heights reflecting 40 and 50% of each participant's height seemed most indicative of planning. Overall, the reliability of the task was adequate and significant (ACTS $r = .62$ and HES $r = .43$). While correlation coefficients did not reach .7, they do appear sufficiently high given reliability is based on ACTS and HES at only 4 barrier heights for each analysis. The inclusion of only four items (barrier heights) in each analysis decreases the likelihood of obtaining high Cronbach alpha as this value depends partly on the number of items (Nunnaly, 1978). The inclusion of additional barriers based on 35, 45, and 55% of each participant's height would likely have increased planning demands for the children and influenced overall alpha scores. Nonetheless, these moderate alpha scores also recognize that planning is not the only underlying cognitive function that is active during performance of the obstacle course. While the precise contributions of additional cognitive functions are beyond the scope of this paper, their involvement is acknowledged by the author.

Validity

Initial content-related evidence was derived by agreement of a panel of movement experts on the operational definitions of the motor planning measures. High interrater agreement for ACTS, HES, and EXEC demonstrated reliable interpretation of the operational definitions and scoring across all tasks. This agreement also supports the content-related validity of this obstacle course task.

Criterion-related evidence was supported by both concurrent and clinical validity. The correlation patterns among measures of motor planning (ACTS, HES), movement execution (*TGMD-2*, EXEC), and executive functioning (*BRIEF*, PLAN) provided concurrent validity support. As expected, the two measures of motor planning (ACTS, HES) were highly correlated with each other as more acts of hesitation should lead to more time hesitating. Both measures of motor planning (ACTS, HES) were moderately correlated with the two movement execution measures. Given that motor planning was being inferred from movement skill performance, a relationship between motor planning and movement execution variables (-.50 to .67) was expected. A negative value was expected for correlations between motor planning measures and the *TGMD-2* because increasing scores on the *TGMD-2* are indicative of greater movement proficiency and generally speaking, less planning difficulty should be associated with increased performance proficiency on the *TGMD-2*. On the other hand, EXEC was a timed execution variable; positive correlations were expected between the motor planning measures and EXEC because greater frequency of ACTS and time spent hesitating would also result in longer EXEC time.

Since (motor) planning is theoretically an aspect of executive functioning (Gioia, et al., 2000), it was also expected that moderate correlations would exist among motor planning and executive functioning variables. Significant correlations between ACTS and both executive function measures (PLAN, *BRIEF*) and between HES and PLAN support this theoretical prediction. In general, the motor planning measures conceived and defined for this study were moderately related to executive functioning (and planning) as assessed by the teacher version of the *BRIEF.*

While many of the correlations did reach significance, it is important to note that floor effects likely reduced the strength of the relationships between measures. For example, 44% (11 of 25) of children with ASD scored within the lowest standard score on the locomotor subtest of the TGMD-2; 20% (5 of 25) and 56% (14 of 25) scored under the 10th percentile on the planning component and overall composite score of the *BRIEF*, respectively. Furthermore, the teacher version is a general measure of executive function based on classroom behaviour rather than movement behaviour. The different environments may play a factor in the teacher's ratings on the *BRIEF* and the participant's performance on the obstacle course task. Despite a full range of scores among children with ASD on both the *TGMD-2* and the *BRIEF*, these extreme scores suggest floor effects, which inevitably skewed the data and may have contributed to the overall (decreased) value of these correlations (Glass & Hopkins, 1996).

Evidence of clinical (i.e., discriminant) validity was supported by performance on the obstacle course, which differentiated children with ASD from the two comparison groups; significantly more motor planning difficulties were associated with ASD. As expected, ACTS between children with ASD and their CA peers was significantly different for total ACTS and at all barrier heights with the exception of barrier 60%. The lack of difference at 60% can be attributed to the fact that everyone went under this barrier and it was not therefore really a 'barrier' for which a plan had to be made. Overall, the children in the CA group did not hesitate very frequently and therefore seemed to plan their movements prior to the obstacle course or very quickly (i.e., ongoing) during it. Children with ASD, on the other hand, hesitated more often, especially when approaching barriers reflecting 40 and 50% of their height. These barriers afforded almost equal opportunity to move over or under and therefore required greater planning to determine their movement patterns. While examination of motor planning abilities among children with ASD relative to their chronological age-matched peers has primarily been constrained to laboratory based estimates, the findings of this study are supported by previous research examining performance of goal-directed aiming (Rinehart, et al., 2006), reach and grasp (Mari, et al., 2003), and tower (Verté, et al., 2005) tasks.

Comparisons between the ASD and DEV groups were most informative because the children were individually-matched on locomotor skill. Since performance of the obstacle course task requires use of these same skills, we assume that observable differences on this task should therefore reflect underlying differences (in motor planning). Despite being closely matched on locomotor skill, children with ASD had significantly greater ACTS and HES at barrier heights reflecting 40 and 50% of their standing height (the barriers deemed most indicative of planning based on item analysis) than the younger DEV group. This finding suggests that despite having similar movement skills, children with ASD still have greater difficulty planning for and negotiating obstacles in their movement paths. While previous research examining motor planning has also found performance differences relative to younger typically developing children on tower and reaching tasks (e.g., Hughes, 1996; Hughes, et al., 1994), these studies did not specifically match the groups on a control variable related to the experimental task to account for developmental differences. The current study moved beyond previous research by matching the second comparison group to the children with ASD on movement skill to facilitate understanding of motor planning abilities. Overall, children with ASD do demonstrate significant delays in development of fundamental movement skills and their performance is increasingly impaired when challenged to plan movements for a novel task that utilizes these same locomotor skills.

Conclusions

Overall, the obstacle course appears to be a valid and reliable measure of motor planning that warrants further development. Consistent with Staples (2006), the item analysis demonstrated that barrier heights at 40 and 50% are the best indicators of motor planning difficulties, suggesting that some children with ASD are better able to recognize the affordances of the barriers and prepare their movements accordingly when the choices are constrained or the available movement patterns are more obvious (i.e., at barrier heights 30 and 60%). Ecological validity would support the inclusion of additional barriers in future research since they might add variability to the task demands as in obstacles encountered in daily activities.

While the inferences made from this obstacle course contribute to an increased understanding of the underlying processes involved in the demonstrable movement impairments among children with ASD, the present research is not without its' limitations. First, the complexity of the task was kept to a minimum to afford majority of children with ASD the opportunity to participate. However, the simplicity of the task likely did not challenge the higher functioning children with ASD or the children in the comparison groups as much as it could have. Second, while the ecological validity of the environment (i.e., gymnasium) can be considered a strength of the study, the implementation of this task is limited to a gymnasium due to the length of the obstacle course. Third, the distance between consecutive barriers could also be adjusted for each participant. Although the length of the entire obstacle course would not be the same, the distance between would be relative to the height or leg length for each participant and would afford more precise comparisons across children of different ages and sizes. Finally, this study was limited to children with ASD who were 9 to 12 years of age. Since behaviours among children with ASD are developmental in nature, and planning abilities are likely to change with age and performance of increasingly complex movement skills, it is important to continue use of this task with both younger and older children with ASD to examine trajectories of development in terms of motor planning abilities. Regardless, the reliability and validity of this obstacle course, as well as the inferences made from the measures suggest that continued evaluation of this task as an assessment of motor planning is justified.

References

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders*. (4th ed. - Text Revision). Washington, DC: Author.

Bennetto, L., & Pennington, B. F. (2003). Executive functioning in normal and abnormal development. In S. J. Segalowitz & I. Rapin (Eds.), *Handbook of neuropsychology* (Vol. 8(2), pp. 785-802). Amsterdam: Elsevier Sciences.

Bryant, F. B. (2000). Assessing the validity of measurement. In L. G. Grimm & P. R. Yarnold (Eds.), *Reading and understanding more multivariate statistics* (pp. 99-146). Washington, DC: American Psychological Association.

Burack, J. A., Iarocci, G., Bowler, D., & Mottron, L. (2002). Benefits and pitfalls in the merging of disciplines: The example of developmental psychopathology and the study of persons with autism. [Review]. *Development and Psychopathology, 14*, 225-237.

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Champaign, IL: Human Kinetics.

Constantino, J. N., & Gruber, C. P. (2005). *The Social Responsiveness Scale (SRS) manual*. Los Angeles, CA: Western Psychological Services.

Damasio, A. R., & Maurer, R. G. (1978). A neurological model for childhood autism. *Archives of Neurology, 35*, 777-786.

Denckla, M. B. (1994). Measurement of executive function. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities* (pp. 117-142). Baltimore: Brookes.

Gioia, G. A., Isquith, P. K., Guy, S. C., & Kentworthy, L. (2000). *Behavior Rating Inventory of Executive Function*. Lutz, FL: Psychological Assessment Resources.

Glass, G. V., & Hopkins, K. D. (1996). *Statistical methods in education and psychology* (3rd ed.). Boston, MA: Allyn and Bacon.

Glazebrook, C. M., Elliott, D., & Lyons, J. (2006). A kinematic analysis of how young adults with and without autism plan and control goal-directed movements. *Motor Control, 10*, 244-264.

Glazebrook, C. M., Elliott, D., & Szatmari, P. (2008). How do individuals with autism plan their movements? *Journal of Autism and Developmental Disorders, 38*, 114-126.

Grasso, R., Assaiante, C., Prévost, P., & Berthoz, A. (1998). Development of anticipatory orienting strategies during locomotor tasks in children. *Neuroscience and Biobehavioral Reviews, 22*, 533-539.

Hughes, C. (1996). Brief report: Planning problems in autism at the level of motor control. *Journal of Autism and Developmental Disorders, 26*, 99-107.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: It's implications for theories of autism. *Developmental Psychology, 29*, 498-510.

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*, 477-492.

Landa, R. J., & Goldberg, M. C. (2005). Language, social, and executive functions in high functioning autism: A continuum of performance. *Journal of Autism and Developmental Disorders, 35*, 557-573.

Ledebt, A., Bril, B., & Brenière, Y. (1998). The build-up of anticipatory behaviour: An analysis of the development of gait initiation in children. *Experimental Brain Research, 120*, 9-17.

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (2002). *Autism Diagnostic Observation Schedule: Manual*. Los Angeles, CA: Western Psychological Services.

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences, 358*, 393-403.

McEvoy, R. E., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology and Psychiatry, 34*, 563-578.

McFadyen, B. J., Malouin, F., & Dumas, F. (2001). Anticipatory locomotor control for obstacle avoidance in mid-childhood aged children. *Gait and Posture, 13*, 7-16.

National Research Council. (2001). *Educating children with autism: Report of the committee on educational interventions in children with autism*. Washington, DC: National Academy Press.

Nigg, B. M., & Cole, G. K. (1994). Measuring teachniques. In B. M. Nigg & W. Herzog (Eds.), *Biomechanics of the musculoskeletal system* (pp. 263-285). New Yor, NY: Jogn Wiley & Sons.

Nunnaly, J. (1978). *Psychometric theory* (2nd ed.). New York, NY: McGraw-Hill.

Ozonoff, S. (1995). Executive functions in autism. In E. Schopler & G. M. Mesibov (Eds.), *Learning and cognition in autism. Current issues in autism* (pp. 199-219). New York: Plenum Press.

Ozonoff, S., & Jensen, J. (1999). Brief report: Specific executive function profiles in three neurodevelopmental disorders. *Journal of Autism and Developmental Disorders, 29*, 171-177.

Pennington, B. F., Rogers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity tests of the executive dysfunction hypothesis of autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 143-178). Oxford, UK: Oxford University Press.

Prior, M. R., & Hoffman, W. (1990). Brief report: Neuropsychological testing of autistic children through an exploration with frontal lobe tests. *Journal of Autism and Developmental Disorders, 20*, 581-590.

Pryde, K. M., Roy, E. A., & Patla, A. E. (1997). Age-related trends in locomotor ability and obstacle avoidance. *Human Movement Science, 16*, 507-516.

Reid, G., Collier, D., & Morin, B. (1983). The motor performance of autistic individuals. In R. Eason, T. Smith & F. Caron (Eds.), *Adapted physical activity* (pp. 201-218). Champaign, IL: Human Kinetics.

Rinehart, N. J., Bellgrove, M. A., Tonge, B. J., Brereton, A. V., Howells-Rankin, D., & Bradshaw, J. L. (2006). An examination of movement kinematics in young people with high-functioning autism and Asperger's disorder: Further evidence for a motor planning deficit. *Journal of Autism and Developmental Disorders, 36*, 757-767.

Roid, G. H., & Miller, L. J. (1997). *Leiter international performance scale - revised*. Wood Dale, IL: Stoeling.

Sigman, M., & Ruskin, E. (1999). Continuity and change in the social competence of children with autism, down syndrome, and developmental delays. *Monographs of the Society for Research in Child Development, 64*, 1-139.

Smith, I. M. (2000). Motor functioning in Asperger syndrome. In A. Klin, F. R. Volkmar & S. S. Sparrows (Eds.), *Asperger syndrome* (pp. 97-124). New York, NY: The Guilford Press.

Staples, K. (2006). *Development of a gross motor task to assess motor planning of children with autism spectrum disorders*. McGill University, Montreal, QC.

Stevens, J. P. (2009). *Applied multivariate statistics for the social sciences* (5th ed.). New York, NY: Taylor & Francis Group.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes*. New York, NY: Raven.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.). Austin, TX: Pro-Ed.

Vallis, L. A., & McFadyen, B. J. (2003). Locomotor adjustments for circumvention of an obstacle in the travel path. *Experimental Brain Research, 152*, 409-414.

Vernazza-Martin, S., Martin, N., Vernazza, A., Lepellec-Muller, A., Rufo, M., Massion, J., et al. (2005). Goal directed locomotion and balance control in autistic children. *Journal of Autism and Developmental Disorders, 35*, 91-102.

Verté, S., Geurts, H. M., Roeyers, H., Oosterlaan, J., & Sergeant, J. A. (2005). Executive functioning in children with autism and Tourette syndrome. *Development and Psychopathology, 17*, 415-445.

Williams, J. H. G., Whiten, A., & Singh, T. (2004). A systematic review of action imitation in autistic spectrum disorder. *Journal of Autism and Developmental Disorders, 34*, 285-299.

Yun, J., & Ulrich, D. A. (2002). Estimating measurement validity: A tutorial. *Adapted Physical Activity Quarterly, 19*, 32-47.

Footnotes

[1] Similar analysis was done for HES and the same results were found. The detailed analysis and results will be discussed in a subsequent paper.

Figure 1.

Diagram of obstacle course task depicting order of barrier heights and placement of barriers and cameras.

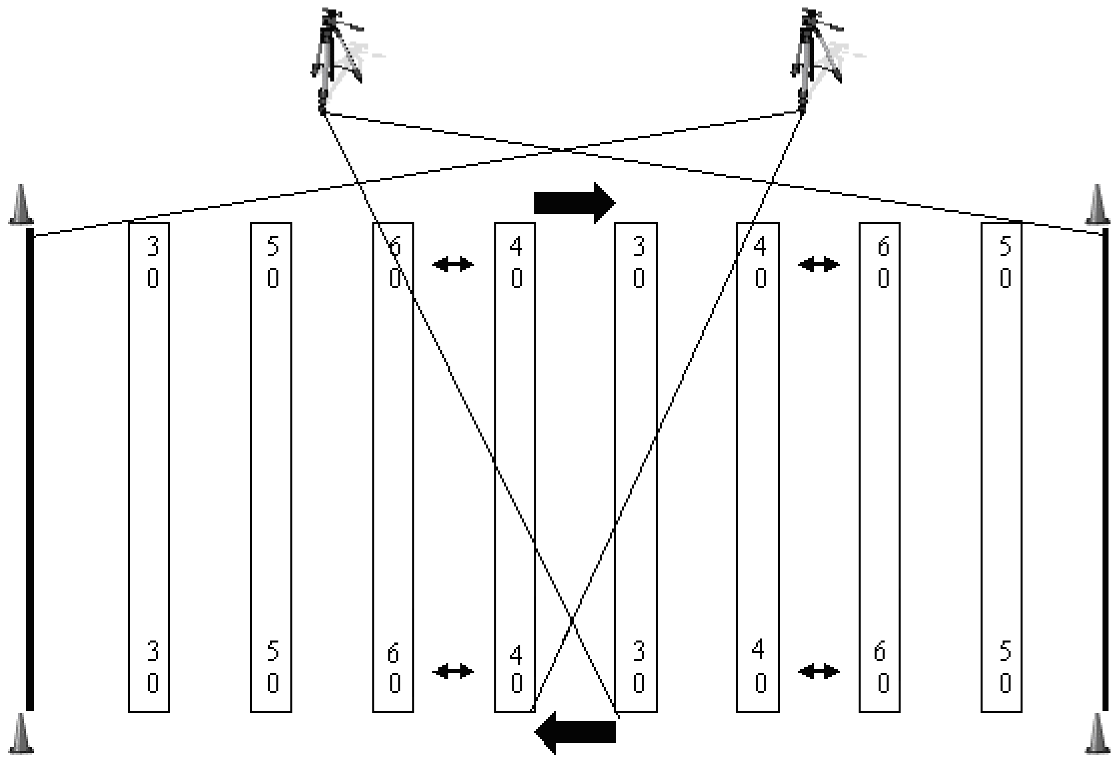

Table 1

Descriptive Statistics for Three Groups of Participants – Mean ± Standard Deviation (skewness)

	ASD n = 25	CA n = 25		ASD n = 22	DEV n = 22	
ACTS	7.8 ± 4.88 (-.02)	1.32 ± 1.49 (.71)	Z = - 4.75 p < .01	8.0 ± 5.10 (-.10)	3.55 ± 2.44 (.31)	Z = - 2.83 p < .01
HES	8.9s ± 6.5 (.26)	.5s ± .7 (2.17)	F (4, 45) = 9.79 p < .01	9.3s ± 6.7 (.13)	2.5s ± 2.2 (1.04)	F (4, 39) = 4.80 p < .01
TGMD-2	25.60 ± 9.36 (-.13)	45.32 ± 2.19 (-.47)	p < .01	27.91 ± 8.90 (.03)	28.45 ± 7.04 (.40)	p = .72
EXEC	65.9s ± 32.5 (1.5)	29.6s ± 5.6 (.64)	F(4,45) = 7.39 p < .01	66.6s ± 32.7 (1.67)	42.7s ± 12.6 (1.06)	F (4, 39) = 2.69 p = .05
BRIEF	70.52 ± 9.7 (-.12)			69.61 ± 9.58 (.05)		
PLAN	61.6 ± 11.8 (.40)			60.87 ± 12.03 (.57)		

ACTS = acts of hesitation; HES = hesitation time; *TGMD-2* = raw score from locomotor subtest of *Test of Gross Motor Development* (2^{nd} ed.); EXEC = execution time; *BRIEF* = composite T score from *Behavior Rating Inventory of Executive Functioning*; PLAN = T score from planning component of *BRIEF*

Note: Scores from the *BRIEF* (and its planning component) are not reported for the comparison groups because the teacher questionnaire required the teacher's to rate the executive functioning of each child relative to other children in their classroom. The children with ASD attended a segregated for children with developmental disabilities, while the typically developing comparison groups attended a mainstream school. Therefore the frame of reference that teachers used was different and as a result, comparisons between the ASD and comparison groups were not informative.

Table 2

Pearson Product-Moment Correlation Coefficients among Motor Planning, Movement Execution, and Executive Functioning Measures for the ASD group

	Motor Planning		Movement Execution		Executive Functioning	
	ACTS	HES	*TGMD-2*	EXEC	*BRIEF*	PLAN
ACTS	--	.87**	- .53**	.60**	.49*	.48*
HES		--	- .50*	.67**	.41*	.37
TGMD-2			--	- .60**	- .30	- .19
EXEC				--	.27	.40*
BRIEF					--	.93**
PLAN						--

ACTS = acts of hesitation; HES = hesitation time; *TGMD-2* = raw score from locomotor subtest of *Test of Gross Motor Development* (2nd ed.); EXEC = execution time; *BRIEF* = composite score from *Behavior Rating Inventory of Executive Functioning*; PLAN = planning component from *BRIEF*

** $p < .01$
* $p < .05$

Note: Only results from ASD group are included as development and validation of obstacle course task were specific to use with children with ASD.

Table 3

Frequency of Acts of Hesitations (ACTS) and Statistical Significance for the three Groups at each Barrier Height

	ASD n = 25	CA n = 25		ASD n = 22	DEV n = 22	
ACTS 30	1.72 ± 1.93	.04 ± .20	Z = -4.25, p < .01	1.36 ± 1.65	.73 ± .88	Z = -1.44, p = .15
ACTS 40	3.56 ± 2.18	.76 ± .97	Z= -4.67, p < .01	3.64 ± 2.24	1.55 ± 1.57	Z = =3.34, p < .01
ACTS 50	1.60 ± 1.44	.28 ± .61	Z = -3.67, p < .01	1.68 ± 1.52	.68 ± .78	Z = -2.06, p < .05
ACTS 60	.92 ± 1.50	.24 ± .44	Z = -1.54, p = .13	.91 ± 1.51	.59 ± 1.01	Z = -.81, p = .42
TOTAL ACTS	7.80 ± 4.88	1.32 ± 1.49	Z = -4.75, p < .01	7.59 ± 5.13	3.55 ± 2.44	Z = -2.83, p < .01

Note: Each value is sum of two speed conditions (2 trials at each speed equals sum of 4 trials)

Bridging Manuscripts

Chapter 3 described the initial development and validation of an obstacle course task designed to provide a movement-based estimate of planning that could be used with children with ASD. This task was found to have sufficient reliability and validity. To better understand the differences in movement skill performance that were described in chapter 2, chapter 4 describes a study that used this obstacle course to examine how children with ASD plan and execute locomotor skills. When compared to the three typically developing comparison groups used in chapter 2, children with ASD are impaired in both the planning and execution of fundamental movement skills. These performance differences are more than would be expected given their movement skill or mental age equivalence, which provides initial support that a deficit in planning is likely associated with impaired performance of fundamental movement skills by children with ASD.

Chapter Four

How do Children with Autism Spectrum Disorders Plan Movement Skills?

Kerri Staples & Greg Reid

Abstract

Twenty-five children (ages 9 to 12 years) with autism spectrum disorders (ASD) were compared to three groups of typically developing children on an obstacle course to examine how they plan and execute fundamental movement skills. Movement planning was assessed by acts of hesitation (ACTS) and hesitation time (HES), while movement execution was assessed by execution time (EXEC), movement pattern, and success. Each comparison group was individually-matched on a developmental variable to afford unique perspectives regarding how children with ASD plan their movements. Compared to a group matched on chronological age, children with ASD take longer to plan and execute their movements. Comparisons to younger children matched on locomotor movement skill (ages 4 to 6 years) or mental age equivalence (ages 4 to 10 years) revealed that while the groups choose similar movement patterns and achieved similar levels of success, children with ASD required more time to plan and execute their movements. Overall, the results provide support that children with ASD have difficulty planning their movements and this difficulty is beyond what would be expected given their chronological age, movement skill, or mental age.

Key words: movement planning; movement execution; autism spectrum disorders

How do Children with Autism Spectrum Disorders Plan Movement Skills?

Performance of fundamental movement skills among children with ASD is poor compared to their same age peers without autism (Berkeley, Zittel, Pitney, & Nichols, 2001) and these movement skill differences may become exacerbated with age (Staples, 2009). It has been suggested that planning, rather than execution of movements, underlies these performance differences (e.g., Hughes, 1996; Rinehart, Bradshaw, Brereton, & Tonge, 2001). However, planning is an underlying process and must be inferred from performance of tasks that combine a series of simple, or relatively discrete, movement skills. In this study, planning was operationalized as the conception and organization of a movement sequence (Hughes, Russell, & Robbins, 1994).

The majority of planning studies in ASD have used goal-directed reaching (Hughes, 1996; Hughes & Russell, 1993; Mari, Castiello, Marks, Marraffa, & Prior, 2003; Rinehart, Bellgrove, Tonge, Brereton, Howells-Rankin, & Bradshaw, 2006; Rinehart, et al., 2001) or aiming tasks (Glazebrook, Elliott, & Lyons, 2006; Glazebrook, Elliott, & Szatmari, 2008). These tasks generally consisted of multiple trials of discrete movements where specific task constraints, such as the size or distance of a target, were manipulated to examine how individuals with ASD adapt their movement plans accordingly (Glazebrook, et al., 2006; Glazebrook, et al., 2008; Mari, et al., 2003). Planning has been inferred based on observed movement patterns, reaction time, or movement time.

Hughes (1996) examined hand positioning during a reach, grasp, and place task; planning inferred from the final hand position. If the hand was in a comfortable position at the end of the movement, planning was deemed to be successful. Children and adolescents with ASD had greater difficulty completing trials that required advanced planning, that is beginning a movement in an awkward manner in order to finish the movement comfortably. Children with ASD were also less likely to retrieve an object when required to coordinate two movements (Hughes & Russell, 1993). Reaching and grasping movements seemed independent of each other, with the grasping movement beginning after the reaching movement was finished instead of the movements being coordinated together (Mari, et al., 2003).

Individuals with ASD also demonstrate particular difficulty on tasks with timed components such as reaction and movement time. While individuals with ASD can execute movements required for goal-directed aiming tasks, they take significantly longer to prepare and perform the movements (Glazebrook, et al., 2006; Glazebrook, et al., 2008; Rinehart, et al., 2006; Rinehart, et al., 2001). Movement time would be expected to decrease with each subsequent trial as participants should begin to anticipate upcoming movements and execute them faster. This anticipation was not seen among children and adolescents with ASD (Rinehart, et al., 2001).

Differences in reaction and/or movement time suggest that individuals with ASD are able to plan their movements, but may do so differently and perhaps not as efficiently as their typically developing peers. These studies have increased our understanding of how individuals with ASD plan movements to pick up an object and modify their reach toward a target. While this research provides some insight regarding how movements are planned, a more complete understanding of how fundamental movement skills (i.e., running and jumping) are planned in the context of obstacle avoidance necessitates use of an ecologically valid task that also requires performance of fundamental locomotor skills.

The performance of fundamental movement skills also needs to be considered relative to development and age. Previous research has compared performance of individuals with ASD to typically developing peers matched on chronological age (e.g., Glazebrook, et al., 2006; Glazebrook, et al., 2008; Mari, et al., 2003) or chronological age and IQ (e.g., Rinehart, et al., 2006; Rinehart, et al., 2001). While comparisons to individuals matched on chronological age allow inferences regarding differences in performance, they tell us very little about timing and rate of development, per se (Burack, Iarocci, Bowler, & Mottron, 2002). Comparisons to younger typically developing children facilitate inferences regarding extent of performance differences (Hughes, 1996; Hughes & Russell, 1993). However, to understand these differences in the context of the task, the groups need to be matched on a control variable related to the task (Burack, et al., 2002), this matching has not occurred in any planning study.

Staples (2006, 2009) recognized this need for an estimate of movement planning that would facilitate understanding of how children with ASD plan and execute fundamental movement skills; an obstacle course task was developed and validated for use with children with ASD (Staples, 2009). The purpose of the current study was to examine how children with ASD plan and perform movement skills that are essential for play and participation in physical education contexts compared to three groups of typically developing peers individually-matched on chronological age, movement skill, or mental age.

Method

Participants

Twenty-five children with ASD were compared to three typically developing comparison groups, each individually matched on different developmental variables: (a) chronological age, (b) movement skill performance, and (c) mental age. The children with ASD were aged 9.1 to 12.8 years (*M* = 11.2 years) and reflected the full range of ASD in terms of sex (21 boys, 4 girls), diagnosis (11 autistic disorder, 12 PDDNOS, 2 Asperger disorder), and cognitive functioning (full scale IQ ranging from 34 to 104; *M* = 63). The *Leiter-R* (Roid & Miller, 1997) was administered to 21 of 25[1] children to provide a measure of IQ (*M* = 63, ranging between 34 and 104) and mental age (MA) equivalence (*M* = 7.4 years, ranging between 3.9 and 10.7 years).

Those with ASD attended a school for children with developmental disabilities; school records indicated clinical diagnosis of ASD made by a psychiatrist based on *DSM-IV-R* criteria (American Psychiatric Association, 2000). The *Autism Diagnostic Observation Schedule* (*ADOS*; Lord, Rutter, DiLavore, & Risi, 2002) or the *Social Responsiveness Scale* (*SRS*; Constantino & Gruber, 2005) were administered by a trained graduate student to support the ASD diagnosis for each participant. The *ADOS* is a semi-structured, standardized assessment consisting of activities that facilitate direct observation of social and communication behaviours. The *SRS* is a parent questionnaire designed to assess impairment in social interaction or reciprocity among school-aged children and adolescents with ASD.

In typical development, stable locomotor patterns are expected at approximately 5 years of age (McFadyen, Malouin, & Dumas, 2001) and anticipatory locomotor adjustments during obstacle avoidance tasks by approximately 7 to 9 years of age (McFadyen, et al., 2001). The age range of the children with ASD ensured that majority of children would be able to move successfully through the obstacle course task, and a wide range of planning abilities should be present. The ages of the children with ASD was limited to a narrow range (Mervis & Klein-Tasman, 2004) in order to make accurate inferences regarding the development of planning abilities, but prior to puberty where maturation may confound interpretation of results.

The first comparison group matched on chronological age (CA; +/- 3 months) ranged from 9.2 to 12.6 years of age (*M* = 11.11 years). Given their age and assumed typical development, this group was expected to have established motor planning abilities and to perform very well on the obstacle course.

The second and third comparison groups were comprised of younger typically developing children. The second group was matched on sex and raw score of the locomotor subtest of the *Test of Gross Motor Development* (*TGMD-2*; +/- 3), a normative and criterion-referenced assessment (Ulrich, 2000). However, the raw score of three children with ASD was too low to be matched to a school-aged comparison sample; thus this developmentally-matched (DEV) group consisted of 22 children aged 4.9 to 6.9 years (*M* = 5.87 years) --

approximately half the age of the ASD group. By matching these groups closely on locomotor skill, differences in obstacle course performance can be attributed to underlying differences such as motor planning (Burack, Iarocci, Flanagan, & Bowler, 2004; Sigman & Ruskin, 1999), rather than locomotor performance.

The third comparison group was matched on mental age equivalence (MA; +/- 3 months) as determined by the *Leiter-R*. Only 21 of the children with ASD had MA scores. Two of the 21 children had MA too low to be matched to school-aged comparison sample and were removed from further analysis. Therefore, this group was comprised of 19 typically developing children ranging in age from 4.9 to 10.7 years (*M* = 7.75 years). This group provided a comparison taking into account general cognitive functioning. Executive functions, including planning, are underlying components of cognition that emerge early in life with important changes occurring between approximately 2 and 5 years of age (Zelazo & Müller, 2004) and majority of functions established by age 8 years (Case, 1992). The early school years correspond to a period of significant development in executive function abilities; therefore, accounting for cognition during this time period is essential to understanding the developmental course of planning. Given ASD and MA groups are matched closely on MA and planning falls under the realm of cognition, these groups would be expected to perform similarly on measures of motor planning.

All procedures were carried out under IRB approval at the author's university. Approval was obtained from the respective school boards, parent committees, and school principals. Participants were identified following school approval; informed consent from the parent or guardian and assent from each participant were obtained.

Instruments

The obstacle course (Staples, 2009) consisted of eight adjustable, horizontal barriers placed in sequential fashion creating systematic and alternating heights based on 30, 40, 50, and 60% of each participant's standing height (Figure 1). The barrier heights are therefore constant relative to the standing height of each participant. The distance between barriers was 2 meters, with the starting and finishing lines clearly marked with orange cones 2 meters beyond each end. The total distance of the obstacle course was therefore 18 meters.

A trial consisted of moving over or under the eight barriers using locomotor skills of their choice. The four barrier heights were each encountered twice during each trial. The order of barriers was changed systematically for each trial, so that each trial was unfamiliar and required planning (Denckla, 1994). They were asked to move through the course four times, twice at a self-determined speed and twice as fast as possible. The order was counter-balanced.

Dependent Variables

The first movement planning variable was frequency of acts of hesitation (ACTS), inferred as a change from an initial plan. For example, after lifting a foot to go over the barrier, the participant may have put that same foot down, and decided to go under, or to lead with the other foot. A stutter-step or a change in the lead foot was also considered an ACT since it represented a change in the initial plan. ACTS was the frequency at each barrier height summed across the eight encounters at that height (four at each of two speeds); total ACTS was a sum of all ACTS at all four barrier heights (32). The second movement planning variable was hesitation time (HES) the duration spent executing ACTS and was a sum at each barrier height. Not surprisingly, when time was used making changes to the (initial) plan, more time was required to initiate and execute that plan.

The first movement execution variable was execution time (EXEC), the sum of time required to clear each barrier rather than time to move through the entire obstacle course. When going over a barrier, time was measured from the first foot lift until the both feet contacted the ground on the other side of the barrier. In the case of going under the barriers, time was measured from when the first hand made contact with the ground until both feet were across the barrier. Choice of movement pattern (i.e., over or under) used to negotiate each barrier was the second movement execution variable and was recorded as the frequency of moving over the barriers. The third movement execution variable was frequency of success, passing over or under a barrier without knocking it down.

Procedure

Data were collected at a private school for students with developmental disabilities and a regular elementary school. The researcher assisted in physical education classes at both schools for several weeks to facilitate the participants becoming familiar with her, which was especially important for the ASD group and the younger typically developing children. She was also able to observe each participant's instructional preferences in order to interact in a manner to optimize their obstacle course performance. Participants were assessed individually in their school gymnasium on two separate days. On the first day the *TGMD-2* was administered and on a second day the obstacle course task where it was emphasized that there was no right or wrong way to move through it. Both assessments were videotaped for later scoring and to establish interrater agreement.

Data Analysis

Means and standard deviations were examined for the movement planning (Tables 1 and 2) and execution variables (Tables 3-5). Initial validation of the obstacle course (Staples, 2009) found that speed and order did not contribute to differences in ACTS or HES, which allowed scores to be summed across both speed and order conditions for subsequent analyses (see Appendices L and M). In the present study, the influence of speed and order on EXEC (see Appendix N), frequency of success (see Appendix P), and movement pattern (see Appendix O) were also examined. Significant differences were not found and dependent variables were summed across speed and order.

Mann-Whitney U analyses were conducted to determine group differences on the frequency variables: ACTS, movement pattern, and success. Multivariate analysis of variance (MANOVA) was used to examine group differences on interval variables: HES and EXEC. Effect sizes are based on multivariate partial eta squared (η_p^2). Analyses of Variance (ANOVA) on each dependent variable were conducted as follow-up tests to the MANOVA. Follow-up ANOVA used a Bonferroni correction to adjust for multiple ANOVAs; each was tested at the .01 level.

Pearson Product Moment correlations between age and IQ with each of the motor planning and movement execution variables were evaluated in the ASD group to investigate the influence of age and levels of functioning on the obstacle course performance. The influence of age among the three groups of typically developing children was also examined by correlations with each of the dependent variables.

Results and Discussion

Descriptive statistics and results are provided for ASD versus each of the three comparison groups (see Tables 1-5). Skewed distributions were found for some of the variables, although performance on each spanned the full range of scores. For example, many of the children in the ASD and DEV groups moved through the obstacle course very slowly, as expected given previous ASD research examining movement behaviour, and the age of the DEV group. Similarly, there was virtually no hesitation and limited variability in HES scores among all three comparison groups resulting in skewed distributions. Parametric analyses remain appropriate given that central limit theorem predicts skewed data will have limited impact on the overall power (Stevens, 2009) and scores span the full range of distribution for each variable.

Interrater agreement was established by two independent researchers on 25% of the obstacle course trials (1 trial for each participant) according to the operational definitions for the dependent variables ACTS, HES, and EXEC (+/- 2 frames per second). Interrater agreement was very good, ranging from 86 to 100%. To ensure precise matching, approximately 30% of the TGMD-2 assessments for the ASD and DEV groups were also scored by an independent researcher to establish interrater agreement, resulting in agreements of 96% and 91% for the ASD and DEV groups, respectively.

Although the obstacle course was developed and validated for use with children with ASD (Staples, 2009), all correlations between age and the dependent variables were significant ($p < .01$) for the typically developing comparison children when the three comparison groups were combined ($r = .412$ to . 590). See Appendix Q. Older children hesitated less, executed their movements faster, moved over the barriers with greater frequency, and with greater success than did the younger children. This is consistent with other developmental trends in movement (Haywood & Getchell, 2008) and supports use of the obstacle course with typically developing children.

Chronological age ranged from 9.2 to 12.6 years and IQ from 34 to 104 for the children with ASD, but none of the correlation coefficients with motor planning or movement execution variables were significant. Neither age ($r = -.065$ to $-.386$) nor IQ ($r = .156$ to $-.360$) was associated with performance of the children with ASD on the obstacle course task (see Appendix Q). These findings are not consistent with previous research using goal-directed aiming tasks that suggest that adults (Glazebrook, et al., 2006) and children (Mari, et al., 2003) with ASD with higher IQ are able to prepare and execute their movements more quickly. While the IQ of the children with ASD included in the current study spanned the range of functioning, their age was constrained to a narrow range. While the difference in findings may reflect the limited range of age (9 to 12 years) among the children with ASD, these findings may also reflect the nature of the task and the movement skills used. For example, the obstacle course used in the current study was performed in each child's school gymnasium, a familiar environment, and required the performance of locomotor skills that were also familiar to the children in that physical education environment. If movement skills and motor planning abilities among children with ASD followed a typical developmental trajectory but were simply delayed, developmental trends would be expected for both age and IQ. Based on these relationships, our findings would suggest that movement skills and motor planning abilities among children with ASD do not follow the same developmental trajectory as in typical development. Of course, comparisons between children with ASD and their typically developing peers on variables related to planning and execution of movement skills are necessary to confirm such speculation.

Movement Planning

Table 1 provides descriptive statistics and results of the Mann-Whitney analyses of ACTS at each barrier height and total ACTS for ASD and the comparison groups. Table 2 provides descriptive statistics and MANOVA results for HES. Significant differences in ACTS between ASD and CA were found at all barrier heights ($p < .01$) except the one reflecting 60% of the participant's height ($p = .13$). In terms of HES, a main effect was found based on barrier height, Wilks's $\Lambda = .54$, $F(4, 45) = 9.79$, $p < .01$, the effect size being quite strong at .47. ANOVA comparing ASD and CA at each barrier height was significant ($p < .01$). While ACTS was not significant between ASD and CA at the barrier height reflecting 60%, HES was. This difference between ACTS and HES demonstrates that while children in the ASD and CA groups committed similar number of ACTs, children with ASD still required more time to plan their movement at 60%. Overall, CA demonstrated fewer ACTS and used less time to plan their movements at each of the barriers.

Since ASD and DEV were matched closely on locomotor skills, and performance of the obstacle course required similar locomotor skills, performance differences should be attributable to underlying differences (e.g., movement planning). The ASD group had significantly more ACTS at barrier heights reflecting 40% ($p < .01$) and 50% ($p < .05$) of their height and more total ACTS ($p < .01$) across all barrier heights than DEV. A main effect of barrier height was also found on HES, Wilks's $\Lambda = .68$, $F(4, 39) = 4.51$, $p < .01$; effect size.32. Follow-up ANOVA were significant at barrier 40 and 50%, the two barriers that challenged the children in terms of planning (Staples, 2009), which suggests that the planning difficulties among children with ASD cannot be directly attributed to delays in movement skill development. Performance differences in planning at 40 and 50% remain despite the children with ASD being approximately twice the age of the DEV group.

Even though ASD and MA were matched closely on MA, ASD had significantly more ACTS at barrier heights reflecting 40% ($p < .01$) and 50% ($p < .05$) of their height and total ACTS ($p < .01$). Significant differences in HES were also found with respect to overall barrier height, Wilks's $\Lambda = .59$, $F(4, 33) = 5.70$, $p < .01$ with effect size of .41 and follow-up ANOVA were significant at all barrier heights ($p < .01$). However, after applying a Bonferroni correction, HES at barrier height 60% was no longer significant ($p = .03$). Key differences in hesitation between ASD and MA do exist, particularly at barriers indicative of the greatest degree of planning. The results suggest children with ASD have difficulty planning their movements beyond what might be expected for their MA.

In general, the planning differences between ASD and the three control groups were greatest at barrier heights 40% and 50 %. Determining whether to move over or under a barrier requires perception of which movement patterns are possible based on understanding their body's dimensions and capabilities relative to the obstacles in their environment. Affordances are opportunities for movements or actions taking into consideration personal, task, and environmental constraints (Gibson, 1977). It was expected that majority of children would easily recognize the affordances available at barriers heights of 30 and 60% and therefore hesitation at these barriers would be minimal. Children who have established movement planning abilities should be able to recognize and plan upcoming movements prior to arriving at each barrier and therefore would start to configure their body earlier. It is likely that movement sequences could be planned beforehand (Fitts & Peterson, 1964) with ongoing modification as the movements are being executed, rather than planning for each barrier. While it was expected that children with ASD and younger typically developing children would have greater difficulty negotiating barriers because stable planning abilities are not expected until 7 to 9 years of age (Pryde, Roy, & Patla, 1997), planning differences between them were not expected. Determining a movement plan is seemingly more difficult and time consuming for children with ASD (Hill, 2004). A child who is not able to perceive affordances until they have a direct comparison with their own body will likely stop or move very slow at each barrier to determine their capabilities; this constant comparison of course influences speed and overall execution time.

The findings are consistent with previous studies that inferred movement planning from longer reaction or response times on reaching or aiming tasks (Mari, et al., 2003; Rinehart, et al., 2006; Rinehart, et al., 2001). Children with ASD hesitated more frequently and took longer to plan their movements when approaching the barriers compared to all three comparison groups. Furthermore, both ACTS and HES show developmental trends for the typically developing comparison groups; observed patterns of performance among children with ASD do not fit these trends, suggesting that children with ASD may demonstrate unique patterns of development of movement planning. Despite being matched to DEV and MA groups on movement skill and MA, respectively, significant differences in movement planning were still found, suggesting these variables cannot entirely account for why these differences in movement planning exist among children with ASD.

Movement Execution

MANOVA were used to examine differences between ASD and each comparison group on EXEC (Table 3). Significant differences in EXEC were found between ASD and CA (Wilks's $\Lambda = .60$, $F(4, 45) = 7.39$, $p < .01$; effect size .40); ASD and DEV (Wilks's $\Lambda = .78$, $F(4, 39) = 2.69$, $p < .05$; effect size .22); and ASD and MA (Wilks's $\Lambda = .62$, $F(4, 33) = 5.03$, $p < .01$; effect size .38). Follow-up ANOVA were conducted to determine influence of each barrier height. All comparisons with CA or MA were significant at each height ($p < .01$); with the exception of 60% after adjusting alpha values using Bonferroni correction ($p = .015$). This finding was not unexpected as all children moved under this barrier and with relative ease. Significant differences on EXEC were also found comparing ASD and DEV at barrier heights reflecting 40% ($p < .01$) and 50% ($p < .01$) of their height. The children with ASD essentially took longer to execute their movements than the children in all of the comparison groups. Perhaps most informative is that significant differences in movement execution were still found between ASD and DEV at two barrier heights despite being matched closely on locomotor skill.

Mann-Whitney analysis was used to examine the choice of movement pattern (i.e., over or under) for each group compared to the children with ASD (Table 4). Children in all groups tended to move over the barrier at 30% of height, ranging from 78% in the DEV group to 100% in the CA group; similarly, more than 99% of all children moved under the 60% barrier. The choice of movement pattern at barriers reflecting 30 and 60% of each child's height were likely obvious to participants, as it was difficult to move under barrier height 30 and almost impossible physically to go over 60. Even though the choice of movement pattern was seemingly obvious to most children at these barriers heights, the EXEC results indicate that the ASD group still moved significantly slower than CA and MA when negotiating barriers 30 and 60%. This finding suggests that differences in movement skill performance extend beyond recognition of affordances and may be better accounted for in terms of movement planning.

Key differences on the movement execution variable of movement pattern emerged among the groups at barriers reflecting 40 and 50% of their height – the barriers also deemed most indicative of planning based on initial development and validation of this obstacle course task (Staples, 2009). Only 30% of DEV attempted to move over the barrier at 40%, while 38% of ASD, 42% of MA, and 74% of CA did so. Very few children in the ASD and DEV groups attempted to move over the barrier at 50% (less than 1.5%), while only 3% in the MA and 12% in the CA groups did so. Clearance of 50% would likely require advanced planning and increased speed when approaching it in order to move over efficiently. When all barrier heights were considered together, DEV attempted to move over the barriers 27% of the time, ASD 30%, MA 34%, and CA 47%. Generally, with increasing age children attempted to move over the barriers with greater frequency. Given that barrier heights were relative to each participant's height, age cannot account entirely for this trend and it is likely that experience plays a role in how children perceive their movement capabilities relative to an object. However, the children with ASD would logically have more experience performing these locomotor skills than the younger DEV and MA groups, which suggests factors beyond experience contribute to how children with ASD recognize the affordances of a barrier and choose their movement pattern.

Understanding choice of movement pattern also requires consideration of success, for it might be argued that moving under barriers was a safer movement option. Descriptive statistics and percentages of success for each group are reported in Table 5. Overall, CA was more successful than ASD at barrier 30% ($p < .01$) and total success when all barrier heights were considered together ($p < .05$). While similar rates of success were found at barriers 40, 50, and 60%, the children with ASD chose less challenging movement patterns than CA, moving under barriers at 40 and 50% more frequently. Comparisons between the ASD and the two comparison groups matched on movement skill and mental age revealed similar rates of successful clearance of the barriers. These findings are not unexpected given these comparison groups were younger; ASD and DEV were also matched specifically on locomotor skills, which were related to performance on the obstacle course task. Similar patterns of execution (i.e., movement pattern and success) were seen between children with ASD and younger, typically developing children as in previous research (Hughes, 1996), yet children with ASD still required more time to plan and execute their movements (Mari, et al., 2003; Rinehart, et al., 2006; Rinehart, et al., 2001).

Children with ASD may intentionally slow their movements to compensate for impaired performance, to enable them to perform the skills, and in some cases achieve similar levels of success. This idea of a speed-accuracy tradeoff (Fitts & Peterson, 1964) is not new. Generally speaking, it takes longer to perform movements requiring accurate responses, and vice versa. Moving slower may be a strategy that many children with ASD have developed to enhance success, in this case moving through the obstacle course. On the other hand, many of the typically developing children seemingly attempted to optimize their movement times and challenge themselves by going over more frequently, albeit sometimes at the expense of knocking down the barrier. When compared to their same age peers, children with ASD perform poorly on both speed and accuracy as they move slower and knock down more barriers. When compared to younger children matched on movement skill or MA who achieved similar levels of success, the children with ASD moved significantly slower in order to do so, suggesting they may have difficulty finding a balance between speed and accuracy.

The overall performance of children with ASD was similar to the younger DEV and MA groups in terms of movement pattern chosen and success. Despite being matched closely on locomotor skill to the DEV group, children with ASD still required more time to plan and to perform their movements. In terms of movement execution, children with ASD performed significantly slower than MA at all barriers and than DEV at 40 and 50% as well as overall EXEC. The present study is the first to control for three variables by using three planned comparisons in a search for evidence of delays and/or deficits in this form of executive functioning. Typical developmental trajectories serve as direct comparison for understanding delays and deficits. If planning abilities among children with ASD were delayed, performance would be similar to younger individuals and skill progressions would occur in the same order as in typically development children, just at a slower rate. On the other hand, a deficit implies a unique pattern of developmental trajectory that differs from typical development. Results demonstrate children with ASD have difficulty planning their movements beyond what would be expected for their CA, movement skill, or MA equivalence supporting the contention that planning problems, at least with fundamental movement skills, may reflect a deficit in development in addition to a delay.

Conclusions and Future Directions

Overall, movement is a viable means to examine planning, an underlying cognitive function, because of its observable nature. Similar success and movement patterns to younger typically developing children, matched on movement skill or mental age equivalence suggests it is the planning rather than the execution phase that is impaired among children with ASD (Hughes, 1996). Children with ASD do demonstrate the ability to execute simple movements required to negotiate obstacle course (Rinehart, et al., 2006; Rinehart, et al., 2001), yet demonstrate impaired planning of these movements based on ACTS and HES. The results build on previous research that found differences in performance of fundamental movement skills (e.g., Berkeley, et al., 2001) by providing evidence of a planning deficit associated with those movement skills. Impaired planning and increased performance variability are consistent with previous studies, spanning across a variety of tasks and ages (Glazebrook, et al., 2006; Glazebrook, et al., 2008; Hughes, 1996; Mari, et al., 2003; Rinehart, et al., 2006; Rinehart, et al., 2001). Thus, the current study extends ASD planning research by exploring locomotor skills and obstacle avoidance.

However, this study was limited to a small number of children with ASD whose performance spanned across a wide range of scores. Inclusion of a greater number of children would afford examination of within group differences among children with ASD. On the other hand, future research could also explore movement planning among specific groups of children with ASD (i.e., high-functioning autism or Asperger disorder). This obstacle course was simple in design, so that majority of children with ASD would be able to successfully participate. A similar obstacle course, with a more complex design, that can also manipulate the width and/or depth of each barrier as well as the distance between barriers would be essential to examining how such task constraints influence planning. Additional task constraints would necessitate additional movement options (e.g., over, under, or around) and would likely increasing planning demands and posing even greater challenges to children and adolescents with ASD.

In 2001, Rinehart et al. suggested that “poorly planned movements” may be a more accurate description of the impaired movement skills observed among individuals with ASD. The results of our study would support this statement and extend the current understanding of movement planning relative to deficits in development. Although our research does provide initial support regarding unique patterns of development of movement planning abilities among children with ASD, longitudinal designs examining trajectories of development are necessary.

References

American Psychiatric Association. (2000). *Diagnostic and Statistical Manual of Mental Disorders*. (4th ed. - Text Revision). Washington, DC: Author.

Berkeley, S. L., Zittel, L. L., Pitney, L. V., & Nichols, S. E. (2001). Locomotor and object control skills of children diagnosed with autism. *Adapted Physical Activity Quarterly, 18*, 405-416.

Burack, J. A., Iarocci, G., Bowler, D., & Mottron, L. (2002). Benefits and pitfalls in the merging of disciplines: The example of developmental psychopathology and the study of persons with autism. [Review]. *Development and Psychopathology, 14*, 225-237.

Burack, J. A., Iarocci, G., Flanagan, T. D., & Bowler, D. M. (2004). On mosaics and melting pots: Conceptual considerations of comparison and matching strategies. [Review]. *Journal of Autism and Developmental Disorders, 34*, 65-73.

Case, R. (1992). The role of the frontal lobes in the regulation of cognitive development. *Brain and Cognition, 20*, 51-73.

Constantino, J. N., & Gruber, C. P. (2005). *The Social Responsiveness Scale (SRS) manual*. Los Angeles, CA: Western Psychological Services.

Denckla, M. B. (1994). Measurement of executive function. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities* (pp. 117-142). Baltimore: Brookes.

Fitts, P. M., & Peterson, J. R. (1964). Information capacity of discrete motor responses. *Journal of Experimental Psychology: General, 67*, 103-112.

Gibson, J. J. (1977). The theory of affordances. In R. E. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology*. Hillsdale, NJ: Erlbaum.

Glazebrook, C. M., Elliott, D., & Lyons, J. (2006). A kinematic analysis of how young adults with and without autism plan and control goal-directed movements. *Motor Control, 10*, 244-264.

Glazebrook, C. M., Elliott, D., & Szatmari, P. (2008). How do individuals with autism plan their movements? *Journal of Autism and Developmental Disorders, 38*, 114-126.

Haywood, K., & Getchell, N. (2008). *Life Span Motor Development* (5th ed.). Champaign, IL: Human Kinetics.

Hill, E. L. (2004). Executive dysfunction in autism. *Trends in Cognitive Sciences, 8*, 26-32.

Hughes, C. (1996). Brief report: Planning problems in autism at the level of motor control. *Journal of Autism and Developmental Disorders, 26*, 99-107.

Hughes, C., & Russell, J. (1993). Autistic children's difficulty with mental disengagement from an object: It's implications for theories of autism. *Developmental Psychology, 29*, 498-510.

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*, 477-492.

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (2002). *Autism Diagnostic Observation Schedule: Manual*. Los Angeles, CA: Western Psychological Services.

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences, 358*, 393-403.

McFadyen, B. J., Malouin, F., & Dumas, F. (2001). Anticipatory locomotor control for obstacle avoidance in mid-childhood aged children. *Gait and Posture, 13*, 7-16.

Mervis, C. B., & Klein-Tasman, B. P. (2004). Methodological issues in group-matching designs: α levels for control variable comparisons and measurement characteristics of control and target variables. [Review]. *Journal of Autism and Developmental Disorders, 34*, 7-17.

Pryde, K. M., Roy, E. A., & Patla, A. E. (1997). Age-related trends in locomotor ability and obstacle avoidance. *Human Movement Science, 16*, 507-516.

Rinehart, N. J., Bellgrove, M. A., Tonge, B. J., Brereton, A. V., Howells-Rankin, D., & Bradshaw, J. L. (2006). An examination of movement kinematics in young people with high-functioning autism and Asperger's disorder: Further evidence for a motor planning deficit. *Journal of Autism and Developmental Disorders, 36*, 757-767.

Rinehart, N. J., Bradshaw, J. L., Brereton, A. V., & Tonge, B. J. (2001). Movement preparation in high-functioning autism and Asperger disorder: A serial choice reaction task involving motor reprogramming. *Journal of Autism and Developmental Disorders, 31*, 79-88.

Roid, G. H., & Miller, L. J. (1997). *Leiter international performance scale - revised*. Wood Dale, IL: Stoeling.

Sigman, M., & Ruskin, E. (1999). Continuity and change in the social competence of children with autism, down syndrome, and developmental delays. *Monographs of the Society for Research in Child Development, 64*, 1-139.

Staples, K. (2006). *Development of a gross motor task to assess motor planning of children with autism spectrum disorders*. McGill University, Montreal, QC.

Staples, K. (2009). *Fundamental movement skills and motor planning abilities among children with autism spectrum disorders*. doctoral dissertation. McGill University. Montreal, QC.

Stevens, J. P. (2009). *Applied multivariate statistics for the social sciences* (5th ed.). New York, NY: Taylor & Francis Group.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.). Austin, TX: Pro-Ed.

Zelazo, P. D., & Müller, U. (2004). Executive function in typical and atypical development. In U. Goswami (Ed.), *Blackwell Handbook of Childhood Cognitive Development* (pp. 445-469). Malden, MA: Blackwell Publishing.

Footnotes

[1] Four children with ASD were not available when the *Leiter-R* was administered.

Figure 1

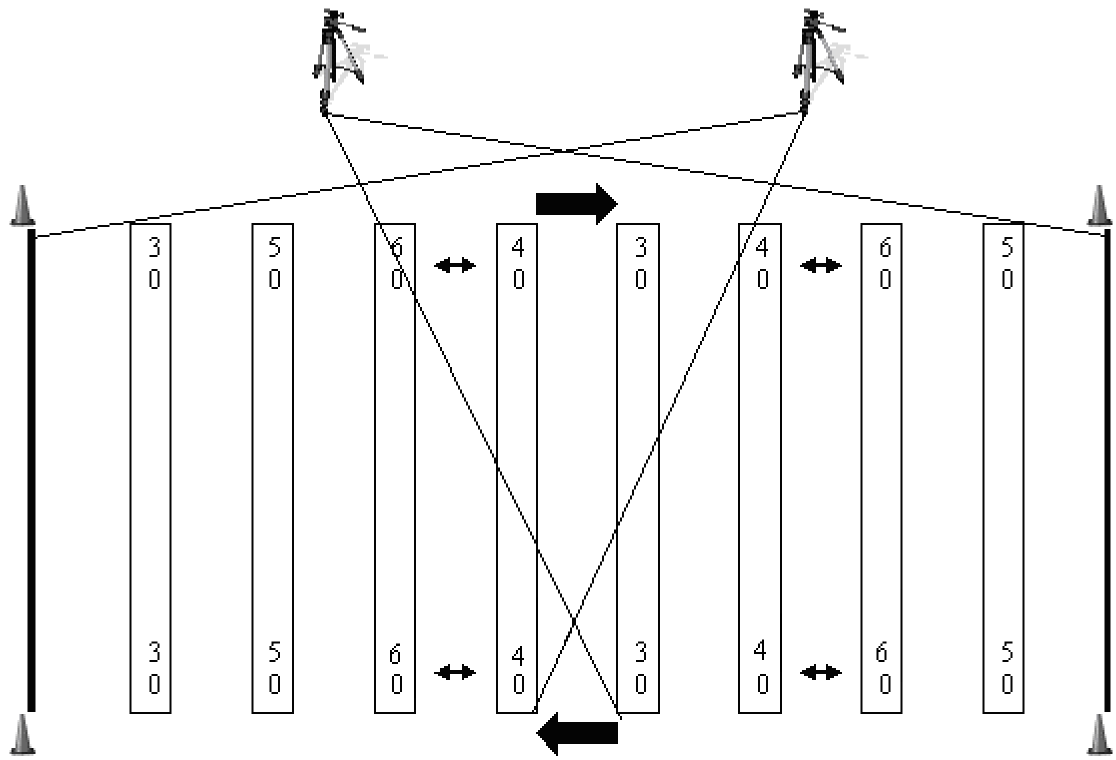

Table 1

Mean ± SD Acts of hesitation (ACTS) at each barrier height and results between ASD and 3 comparison groups

	ACTS 30	ACTS 40	ACTS 50	ACTS 60	TOTAL ACTS
ASD	1.72 ± 1.93	3.56 ± 2.18	1.60 ± 1.44	.92 ± 1.50	7.80 ± 4.88
CA	.04 ± .20	.76 ± .97	.28 ± .61	.24 ± .44	1.32 ± 1.49
(n = 25)	Z = -4.25**	Z = -4.67**	Z = -3.67**	Z = -1.54	Z = -4.75**
ASD	1.36 ± 1.65	3.64 ± 2.24	1.68 ± 1.52	.91 ± 1.51	7.59 ± 5.13
DEV	.73 ± .88	1.55 ± 1.57	.68 ± .78	.59 ± 1.01	3.55 ± 2.44
(n = 22)	Z = -1.44	Z = 3.34**	Z = -2.06*	Z = -.81	Z = -2.83**
ASD	1.26 ± 1.72	3.63 ± 2.06	1.53 ± 1.58	.95 ± 1.62	7.37 ± 5.22
MA	.32 ± .48	1.42 ± 1.35	.21 ± .42	.21 ± .42	2.16 ± 1.64
(n = 19)	Z = -1.65	Z = -3.25**	Z = -2.81*	Z = -1.34	Z = -3.02**

Note: Each value is sum of two trials at each speed condition ~ sum of 4 trials in total

* $p < .05$

** $p < .01$

Table 2

Sum of hesitation time (HES) in seconds for each barrier height and results between ASD and 3 comparison groups

	HES 30	HES 40	HES 50	HES 60
ASD CA (n = 25)	1.6s ± 2.2 .01s ± .03 F(1,48) = 12.59** η_p^2 = .21	3.9s ± 3.4 .2s ± .3 F(1,48) = 28.35** η_p^2 = .37	2.2s ± 2.8 .2s ± .6 F(1,48) = 12.94** η_p^2 = .21	1.2s ± 2.1 .1s ± .1 F(1,48) = 7.67** η_p^2 = .14
ASD DEV (n = 22)	1.2s ± 1.8 .7s ± 1.4 F(1,42) = 1.15 η_p^2 = .03	3.8s ± 3.5 .9s ± 1.1 F(1,42) = 14.36** η_p^2 = .26	2.2s ± 2.9 .5s ± .8 F(1,42) = 7.33* η_p^2 = .15	.9s ± 1.8 .5s ± .9 F(1,42) = 1.02 η_p^2 = .02
ASD MA (n = 19)	1.2s ± 1.9 .1s ± .1 F(1,36) = 7.40* η_p^2 = .17	3.9s ± 3.4 .8s ± 1.1 F(1,36) = 14.82** η_p^2 = .29	2.4s ± 3.2 .1s ± .2 F(1,36) = 10.53** η_p^2 = .23	1.24s ± 2.19 .1s ± .2 F(1,36) = 5.25[a] η_p^2 = .13

* $p < .05$
** $p < .01$
[a] $p = .028$; with Bonferroni correction, $\alpha = .0125$ therefore not significant

Table 3

Execution time (EXEC) in seconds for each barrier height and results between ASD and 3 comparison groups

	EXEC 30	EXEC 40	EXEC 50	EXEC 60
ASD	15.0s ± 10.1	19.3s ± 9.7	16.5s ± 7.6	15.2s ± 7.9
CA	6.6 ± 1.2	8.5s ± 2.5	8.1s ± 1.7	6.4s ± 1.1
(n = 25)	$F(1,48) = 17.11^{**}$ $\eta_p^2 = .26$	$F(1,48) = 28.74^{**}$ $\eta_p^2 = .37$	$F(1,48) = 29.28^{**}$ $\eta_p^2 = .38$	$F(1,48) = 29.85^{**}$ $\eta_p^2 = .38$
ASD	12.8s ± 6.3	17.9s ± 7.9	15.7s ± 6.6	14.2s ± 6.9
DEV	9.5s ± 6.3	12.6s ± 3.0	10.7s ± 2.6	9.9s ± 3.6
(n = 22)	$F(1,42) = 2.96$ $\eta_p^2 = .07$	$F(1,42) = 8.58^{**}$ $\eta_p^2 = .17$	$F(1,42) = 10.98^{**}$ $\eta_p^2 = .21$	$F(1,42) = 6.41^{a}$ $\eta_p^2 = .13$
ASD	12.9s ± 6.7	17.9s ± 8.0	15.5s ± 6.8	13.9s ± 7.3
MA	7.3 ± 2.9	9.9s ± 3.6	8.2s ± 1.8	7.4s ± 1.8
(n = 19)	$F(1,36) = 11.13^{**}$ $\eta_p^2 = .24$	$F(1,36) = 15.43^{**}$ $\eta_p^2 = .30$	$F(1,36) = 20.36^{**}$ $\eta_p^2 = .36$	$F(1,36) = 14.51^{**}$ $\eta_p^2 = .29$

Note: Sum of execution time for all 8 encounters at that barrier height
** $p < .01$
[a] $p = .015$, but not significant b/c Bonferroni alpha = .0125

Table 4

Mean frequency ± SD and percentage of moving over each barrier height between ASD and 3 comparison groups

	OVER 30	OVER 40	OVER 50	OVER 60	TOTAL OVER
ASD	6.32 ± 2.39 (79%)	3.04 ± 2.30 (38%)	.12 ± .44 (2%)	0 (0%)	9.48 ± 4.13 (30%)
CA	8.00 ± 0 (100%)	5.92 ± 2.89 (74%)	.92 ± 2.45 (12%)	.08 ± .28 (1%)	14.92 ± 4.38 (47%)
(n = 25)	Z = -3.68**	Z = -3.39**	Z = -.945	Z = -1.43	Z = -3.87**
ASD	6.77 ± 1.72 (85%)	3.32 ± 2.30 (42%)	.14 ± .47 (2%)	0 (0%)	10.23 ± 3.56 (32%)
DEV	6.23 ± 2.49 (78%)	2.41 ± 2.34 (30%)	.05 ± .21 (1%)	.09 ± .43 (1%)	8.77 ± 3.95 (27%)
(n = 22)	Z = -.83	Z = -1.23	Z = -.62	Z = -1.00	Z = -1.03
ASD	6.74 ± 1.82 (84%)	3.37 ± 2.31 (42%)	.05 ± .23 (1%)	0 (0%)	10.16 ± 3.69 (32%)
MA	7.26 ± 1.85 (91%)	3.32 ± 3.43 (42%)	.21 ± .71 (3%)	.05 ± .23 (1%)	10.84 ± 4.76 (34%)
(n = 19)	Z = -.78	Z = -.55	Z = -.62	Z = -1.00	Z = -.29

Note: Sum of moving 8 trials at each barrier height; total number of trials = 32

** $p < .01$

Table 5

Mean ± SD and percentage of success at each barrier height between ASD and three comparison groups

	SUCCESS 30	SUCCESS 40	SUCCESS 50	SUCCESS 60	TOTAL SUCCESS
ASD	5.96 ± 2.49 (75%)	6.20 ± 1.56 (78%)	7.12 ± .88 (89%)	7.72 ± .54 (97%)	27.0 ± 3.63 (84%)
CA	7.68 ± .56 (96%)	6.76 ± 1.42 (85%)	7.00 ± 1.04 (88%)	7.88 ± .33 (99%)	29.32 ± 2.41 (92%)
(n = 25)	Z = -3.19**	Z = -1.54	Z = -.30	Z = -1.14	Z = -2.36*
ASD	6.41 ± 1.82 (80%)	6.18 ± 1.40 (77%)	7.14 ± .94 (89%)	7.73 ± .55 (97%)	27.45 ± 2.92 (86%)
DEV	6.14 ± 1.70 (77%)	5.45 ± 1.82 (68%)	6.55 ± 1.97 (82%)	7.68 ± .57 (96%)	25.82 ± 4.07 (81%)
(n = 22)	Z = -.70	Z = -1.31	Z = -.60	Z = -.33	Z = -1.33
ASD	6.58 ± 1.77 (82%)	6.26 ± 1.41 (78%)	7.26 ± .81 (91%)	7.79 ± .54 (97%)	27.89 ± 2.89 (87%)
MA	7.53 ± .91 (94%)	6.37 ± .14 (80%)	6.79 ± 1.75 (85%)	7.89 ± .32 (99%)	28.58 ± 3.37 (89%)
(n = 19)	Z = -2.06	Z = -.59	Z = -.66	Z = -.52	Z = -.87

Note: Sum of 8 trials at each barrier height; total number of trials = 32

∗ $p < .05$

∗∗ $p < .01$

Chapter Five

Summary and Contributions

Despite the importance of movement skills to overall development, movement behaviour remains one of the least investigated areas among children with ASD (National Research Council, 2001). Movement behaviour includes all aspects of performance - the observable movements and the underlying processes that are inevitably required to produce them. While there is increasing recognition that performance of fundamental movement skills by children with ASD is poor compared to their peers without ASD (e.g., Berkeley, Zittel, Pitney, & Nichols, 2001), an understanding of how underlying processes such as planning contribute to this impaired performance is still very limited (Smith, 2000).

This doctoral dissertation is comprised of three manuscripts, which collectively address the research questions intended to increase our understanding of how children with ASD plan and perform fundamental movement skills compared to typically developing peers. The first (chapter 2) and third (chapter 4) studies compared the performance of twenty-five children with ASD (ages 9 to 12 years) to three comparison groups individually-matched on chronological age (CA), movement skill (DEV), and mental age equivalence (MA). These planned comparisons were closely matched on specific developmental variables guided by the research questions (Burack, Iarocci, Flanagan, & Bowler, 2004) that were addressed in this dissertation. The specific research questions include: (a) Do children with ASD perform fundamental movement skills differently than their typically developing peers? (b) Are these movement skill differences characterized by delays or deficits in development? (c) What is the relationship between the development of fundamental movement skills and cognition? (d) What is the relationship between planning and executing fundamental movement skills? Is this relationship the same for all children? Each chapter of this dissertation will be discussed in turn.

Autism spectrum disorders are a group of neurodevelopmental disorders without a known cause and as yet, without a specific biological marker or markers. The first chapter provided a brief introduction to ASD and an overview of the complexity of behaviours found among individuals with ASD. Researchers have examined a multitude of contributing factors and attempted to explain the resulting behaviours using a variety of perspectives and methodological frameworks. Executive functioning (Pennington, Rogers, Bennetto, Griffith, Reed, & Shyu, 1997) was adopted as the theoretical perspective for this research. Children with ASD have consistently demonstrated impaired performance on executive function tasks designed to measure planning (e.g., Hughes, 1996); (motor) planning has specific implications for performance of movement skills (Hughes, Russell, & Robbins, 1994).

Summary of Findings

Chapter two provided a brief review of research examining movement skill performance among individuals with ASD. While previous research reported differences in performance of movement skills between children and adolescents with ASD, the comparison groups that were used in those studies did not afford conclusions regarding the nature of the differences. The study reported in Chapter 2 used the *Test of Gross Motor* Development (*TGMD-2*; Ulrich, 2000) to examine the performance of fundamental movement skills (locomotor and object control subtests). The findings were consistent with previous research demonstrating the movement skills of children with ASD are poor compared to their same aged peers without ASD (Berkeley, et al., 2001; DeMyer, 1976; Morin & Reid, 1985; Reid, Collier, & Morin, 1983). The findings increase our understanding of movement behaviour among children with ASD when a second comparison group was matched on locomotor skill performance. Children approximately half the age were required to match the groups closely, demonstrating that children with ASD are significantly delayed in the development of fundamental movement skills. Furthermore, comparisons between ASD and MA groups provided initial evidence to suggest that performance differences reflect more than a delay in development because children with ASD performed significantly worse than would be expected for their MA. Differences in performance of fundamental movement skills cannot be accounted for entirely by cognitive level. Overall, the results from this first study demonstrated that children with ASD demonstrate significant delays and possible deficits in performance of fundamental movement skills.

In order to look at these performance differences further, it is important to understand the processes underlying movement behaviour. However, few tasks have examined how fundamental movement skills are planned and none had been evaluated for use with children with ASD. Tasks have required complex instructions, consisted of unfamiliar movement sequences performed in laboratory-contrived contexts, and have appeared to be too difficult for younger and lower functioning children with ASD. Generally, the tasks used to examine motor planning have not been developmentally-appropriate or meaningful for many children with ASD thus limiting the conclusions that can be drawn from the research. Chapter three described a study that conducted initial development and validation of an obstacle course that was conceptualized as part of my Master's thesis (Staples, 2006) and was designed to overcome several of these methodological limitations. This obstacle course consisted of a series of eight horizontal barriers that vary in height relative to each participant. Performance required children to move over or under the barriers using similar locomotor skills as were assessed in the locomotor subtest of the *TGMD-2.* Overall, the psychometric properties of this obstacle course support the continued evaluation of this task as a means to examine how children with ASD plan fundamental movement skills.

Chapter four used this obstacle course task to examine how children with ASD plan and execute fundamental movement skills. Movement planning was inferred through acts of hesitation and hesitation time, while movement execution was examined based on execution time, movement pattern, and success. When compared to the three groups described earlier, children with ASD were impaired in both planning and executing movements. While, children with ASD did choose similar movement patterns and achieved similar levels of success as the younger DEV group, they still demonstrated greater impairment in both planning and execution of movements than would be expected given their movement skill and MA equivalence. Together these findings provide initial support that fundamental movement skills may not follow the same trajectory as in typical development.

Conclusion

The first (chapter 2) and third (chapter 4) studies were designed to address the first and second research questions – do children with ASD perform fundamental movement skills differently than their typically developing peers and are these differences characterized by delays or deficits in development? The performance of children with ASD was significantly impaired on the *TGMD-2* and obstacle course compared to their same age peers, which supports performance differences found in other studies (e.g., Berkeley, et al., 2001). In both studies, children with ASD performed fundamental movement skills similarly to typically developing children approximately half their age, which demonstrates that children with ASD are significantly delayed in the development of these skills. Similarly, when compared to the MA-matched group, significant performance differences were found and these differences were more than would be expected given cognitive level. The extent of these differences relative to chronological and mental age suggests that development of movement skills by children with ASD reflects both delays and deficits or in all likelihood a different developmental trajectory.

The second research question was answered indirectly through comparisons between children with ASD and younger children matched on MA equivalence. Despite being matched on MA, children with ASD performed significantly poorer on the *TGMD-2* and the obstacle course, indicating that performance differences cannot be accounted for based on cognitive level alone. The third study (chapter 4) examined the relationship between performance of fundamental movement skill and cognition more specifically using correlations between IQ and each of the movement planning and movement execution variables from the obstacle course. Contrary to previous research (Glazebrook, Elliott, & Lyons, 2006; Mari, Castiello, Marks, Marraffa, & Prior, 2003), IQ was not significantly related to performance of children with ASD on the obstacle course in terms of planning or execution. Collectively, these findings suggest that the relationship between cognition and movement, as found in this study, may not be the same as it is among typically developing children (e.g., Wassenberg, et al., 2005).

Finally, the relationship between planning and executing fundamental movement skills was examined in the third study (chapter 4). Comparisons to the DEV group revealed that despite being matched closely on movement skill, children with ASD took longer to plan and perform their movements on the obstacle course task. When the results of studies one (chapter 2) and three (chapter 4) are taken together, children with ASD are significantly delayed in the performance of fundamental movement skill and differences in planning are not accounted for by this delay. Since planning and executing are coupled functionally, we would expect a relationship between them. However, the findings of the third study show the relationship between planning and execution for children with ASD may not be as direct a relationship. Development of movement skills by children with ASD may follow its own unique trajectory, although longitudinal studies are necessary to confirm such speculation and draw conclusions regarding delays and deficits in development.

The third study (chapter 4) was also interested in the influence of age on the obstacle course performance. The three typically developing comparison groups were combined (n = 66) and they ranged in age from 4 to 12 years. Correlations between age and all movement planning and execution variables were significant, demonstrating developmental trends for all dependent variables. However, age did not correlate with any of the movement planning or movement execution variables for the children with ASD. This discrepancy would suggest that planning and execution of fundamental movement skills by children with ASD does not follow a typical trajectory of development. Overall, the findings of this dissertation contribute to an increased understanding of how children with ASD plan and execute fundamental movement skills.

Contributions to Knowledge

The three studies included in this dissertation contribute greatly to the current understanding of how children with ASD plan and perform fundamental movement skills in three specific ways. First, this dissertation is unique in that it compares the performance of children with ASD to three typically developing comparison groups that are individually-matched on different developmental variables: chronological age, movement skill, and mental age equivalence. The inclusion of multiple comparison groups not only controls for three variables thought to be related to movement behaviour, but also allows conclusions relative to delays and deficits in development.

Second, the majority of ASD research includes children with high-functioning autism, rather than ASD which represents the full range of functioning. While some may view the heterogeneity of the children with ASD included in this research as a limitation, inclusion of children with ASD who represent the full range of functioning facilitates understanding of movement behaviour across the spectrum and allows relationships between cognition and movement to be examined. Contrary to previous research (Glazebrook, et al., 2006; Mari, et al., 2003), relationships between IQ and movement planning variables were not significant in this study. The role of IQ in the performance of fundamental movement skills by children with ASD may be different than with adolescents or adults completing reaching or aiming tasks in an unfamiliar laboratory-based task. Or these differences may be related to primary differences between low- and high-functioning children with ASD, as majority of studies include primarily children with only high-functioning autism.

Third, a movement-based estimate of planning was developed and validated in the second and third manuscripts. This obstacle course task fills an existing gap in research examining movement behaviour among children with ASD in an attempt to clarify which aspects of movement skill performance are impaired. Finally, the similarities and differences in findings between the studies included in this study and previous research highlight the importance of using developmentally-appropriate and ecologically valid assessments in research with children with ASD.

The research included in this dissertation was aimed at increasing our understanding of how children with ASD plan and perform fundamental movement skills within an ecological framework (Haywood & Getchell, 2008) and based on observable behaviours. The overriding goal of this research was to provide physical educators and clinicians with a paradigm with which to examine movement performance and provide an empirical judgment with which they could compare how children with ASD planned and performed fundamental movement skills in the context of their classes or clinics. Knowing that children with ASD perform movement skills differently than their same age peers is not informative when it comes to intervention. Differentiating between delays and deficits provides and increased understanding of how fundamental movement skills are developed and performed, although longitudinal studies are required in order to examine rates and trajectories of development. While this differentiation between and instructional strategies seems straight forward, empirical evidence differentiating ‘delay instruction’ from ‘deficit instruction’ in the movement domain has yet to be published. This research is the first to include multiple comparison groups in order to begin to understand the complexity of movement behaviours demonstrated by children with ASD and afford inferences related to delays and deficits in development.

In summary, this dissertation provides a more detailed understanding of how children with ASD plan and execute fundamental movement skills. At the very least, this research demonstrates that in all likelihood the experiences associated with peer interaction and participation in physical education are altered simply because it takes children with ASD longer to plan and perform movement skills. To take these findings one step further, if children with ASD have difficulty planning and executing fundamental movement skill, they would logically have difficulty coordinating their movements with others, further limiting the opportunities with which they have for social interaction with their peers. To facilitate these opportunities, it becomes essential that we focus on intervention strategies to teach children with ASD how to plan their movements more efficiently. Finally, the most consistent findings that emanate from the three studies included in this dissertation is the variability in performance, both within and between children with ASD. Just as there is great heterogeneity in most behaviours among children with ASD, it should not be surprising that they also demonstrate a wide range of movement skills. However, what is a concern is that variability in performance probably means similar variability in success and therefore a limited number of positive experiences associated with performing movement skills. It is my intention to develop effective intervention strategies that can be implemented across settings (i.e., by physical educators, occupational therapists) that will allow children with ASD to acquire requisite movement skills and opportunities to play with their peers.

References

Berkeley, S. L., Zittel, L. L., Pitney, L. V., & Nichols, S. E. (2001). Locomotor and object control skills of children diagnosed with autism. *Adapted Physical Activity Quarterly, 18*, 405-416.

Burack, J. A., Iarocci, G., Flanagan, T. D., & Bowler, D. M. (2004). On mosaics and melting pots: Conceptual considerations of comparison and matching strategies. [Review]. *Journal of Autism and Developmental Disorders, 34*, 65-73.

DeMyer, M. K. (1976). Motor, perceptual-motor, intellectual disabilities of autistic children. In L. Wing (Ed.), *Early Childhood Autism* (pp. 169-193). New York: Pergamon Press.

Glazebrook, C. M., Elliott, D., & Lyons, J. (2006). A kinematic analysis of how young adults with and without autism plan and control goal-directed movements. *Motor Control, 10*, 244-264.

Haywood, K., & Getchell, N. (2008). *Life Span Motor Development* (5th ed.). Champaign, IL: Human Kinetics.

Hughes, C. (1996). Brief report: Planning problems in autism at the level of motor control. *Journal of Autism and Developmental Disorders, 26*, 99-107.

Hughes, C., Russell, J., & Robbins, T. W. (1994). Evidence for executive dysfunction in autism. *Neuropsychologia, 32*, 477-492.

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder. *Philosophical*

Transactions of the Royal Society of London - Series B: Biological Sciences, 358, 393-403.

Morin, B., & Reid, G. (1985). A quantitative and qualitative assessment of autistic individuals on selected motor tasks. *Adapted Physical Activity Quarterly, 2*, 43-55.

National Research Council. (2001). *Educating children with autism: Report of the committee on educational interventions in children with autism*. Washington, DC: National Academy Press.

Pennington, B. F., Rogers, S. J., Bennetto, L., Griffith, E. M., Reed, D. T., & Shyu, V. (1997). Validity tests of the executive dysfunction hypothesis of autism. In J. Russell (Ed.), *Autism as an executive disorder* (pp. 143-178). Oxford, UK: Oxford University Press.

Reid, G., Collier, D., & Morin, B. (1983). The motor performance of autistic individuals. In R. Eason, T. Smith & F. Caron (Eds.), *Adapted physical activity* (pp. 201-218). Champaign, IL: Human Kinetics.

Smith, I. M. (2000). Motor functioning in Asperger syndrome. In A. Klin, F. R. Volkmar & S. S. Sparrows (Eds.), *Asperger syndrome* (pp. 97-124). New York, NY: The Guilford Press.

Staples, K. (2006). *Development of a gross motor task to assess motor planning of children with autism spectrum disorders*. McGill University, Montreal, QC.

Ulrich, D. A. (2000). *Test of Gross Motor Development* (2nd ed.). Austin, TX: Pro-Ed.

Wassenberg, R., Feron, F. J. M., Kessels, A. G. H., Hendriksen, J. G. M., Kalff, A. C., Kroes, M., et al. (2005). Relation between cognitive and motor performance in 5- to 6-year-old children: Results from a large-scale cross-sectional study. *Child Development, 76*, 1092-1103.

Appendices

Appendix A

Note: Removed for final submission

Appendix B

Note: Removed for final submission

Appendix C

Note: Removed for final submission

Appendix D

Note: Removed for final submission

Appendix E

Note: Removed for final submission

Appendix F

Note: Removed for final submission

Appendix G

Note: Removed for final submission

Appendix H

Note: Removed for final submission

Appendix I

Note: Removed for final submission

Appendix J

Note: Removed for final submission

Appendix K

Note: Removed for final submission

Appendix L

Mean rank (from Mann-Whitney analyses) of frequency of acts of hesitation (ACTS) at each barrier height to examine influence of order and speed for the ASD (n = 25), CA (n = 25), and DEV (n = 22) groups included in study 2

	ORDER			SPEED		
	TRIALS 1/2	TRIALS 3/4		SD	FAST	
ACTS 30	75.08	69.92	Z = -.95, p = .34	76.54	68.46	Z = -1.49, p = .14
ACTS 40	72.83	72.17	Z = -.10, p = .92	76.43	68.57	Z = -1.21, p = .23
ACTS 50	77.58	67.42	Z = -1.79, p = .07	73.69	71.31	Z = -.42, p = .67
ACTS 60	77.53	67.47	Z = -2.15, p = .04[a]	71.54	73.46	Z = -.39, p = .70
TOTAL ACTS	77.05	67.95	Z = -1.34, p = .18	75.80	69.20	Z = -.97, p = .33

[a] overall difference in frequency of ACTS between order at barrier height 60%, but not for any of the individual groups

Appendix M

Mean sum ± standard deviation of hesitation time (HES) measured in seconds at each barrier height to examine influence of order and speed for the ASD (n = 25), CA (n = 25), and DEV (n = 22) groups included in study 2

	ORDER			SPEED		
	TRIALS 1/2	TRIALS 3/4		SD	FAST	
HES 30	.44s ± .93	.33s ± .90	F (1,142) = .53, p = .47	.43s ± .93	.34s ± .90	F (1,142) = .40, p = .53
HES 40	.94s ± 1.80	.74s ± 1.62	F (1,142) = .47, p = .49	.85s ± 1.81	.83s ± 1.62	F (1,142) = .00, p = .96
HES 50	.51s ± 1.06	.33s ± .83	F (1,142) = 1.34, p = .25	.49s ± 1.01	.36s ± .90	F (1,142) = .68, p = .41
HES 60	.36s ± 1.03	.19s ± .69	F (1,142) = 1.37, p = .24	.29s ± .86	.27s ± .89	F (1, 142) = .03, p = .87
TOTAL HES	2.26s ± 3.43	1.59s ± 2.79	F (1,142) = 1.61, p = .21	2.06 ± 3.29	1.79s ± 2.99	F (1,142) = .26, p = .61

Appendix N

Mean sum ± standard deviation of execution time (EXEC) measured in seconds at each barrier height to examine influence of order and speed for the ASD (n = 25), CA (n = 25), DEV (n = 22), and MA (n = 19) groups included in study 3

	ORDER			SPEED		
	TRIALS 1/2	TRIALS 3/4		SD	FAST	
EXEC 30	5.13s ± 4.40	4.62s ± 3.08	F (1,180) = .82, p = .34	5.32s ± 4.53	4.43s ± 2.83	F (1,180) = 2.54, p = .11
EXEC 40	6.54s ± 3.68	6.22s ± 3.68	F (1,180) = .34, p = .56	6.71s ± 3.72	6.04s ± 3.61	F (1,180) = 1.52, p = .22
EXEC 50	5.63s ± 3.07	5.50s ± 2.81	F (1,180) = .09, p = .76	5.83s ± 2.98	5.30s ± 2.88	F (1,180) = 1.51, p = .22
EXEC 60	4.94s ± 2.91	4.98s ± 3.25	F (1,180) = .01, p = .93	5.16s ± 3.20	4.76s ± 2.96	F (1, 180) = .75, p = .34
TOTAL EXEC	22.24 ± 12.53	21.32 ± 11.78	F (1,190) = .26, p = .61	23.03± 12.85	20.54± 11.31	F (1,180) = 1.93, p = .17

Appendix O

Mean rank (from Mann-Whitney analyses) of selection of movement pattern (OVER) at each barrier height to examine influence of order and speed for the ASD (n = 25), CA (n = 25), DEV (n = 22), and MA (n = 19) groups included in study 3

	ORDER			SPEED		
	TRIALS 1/2	TRIALS 3/4		SD	FAST	
OVER 30	92.61	90.39	Z = -.39, p = .70	91.82	91.18	Z = -.11, p = .91
OVER 40	94.58	88.42	Z = -.82, p = .41	95.33	87.67	Z = -1.02, p = .31
OVER 50	92.48	90.52	Z = -.55, p = .59	91.48	91.52	Z = -.01, p = .99
OVER 60	92.51	90.49	Z = -1.01, p = .31	90.49	92.51	Z = -1.01, p = .31
TOTAL OVER	95.66	87.34	Z = -1.08, p = .28	94.40	88.60	Z = -.75, p = .45

Appendix P

Mean rank (from Mann-Whitney analyses) of successful clearance (SUCC) at each barrier height to examine influence of order and speed for the ASD (n = 25), CA (n = 25), DEV (n = 22), and MA (n = 19) groups included in study 3

	ORDER			SPEED		
	TRIALS 1/2	TRIALS 3/4		SD	FAST	
SUCC 30	92.58	90.42	Z = -.33, p = .74	89.13	93.87	Z = -.72, p = .47
SUCC 40	87.59	95.41	Z = -1.07, p = .29	92.13	90.87	Z = -.17, p = .86
SUCC 50	86.16	96.84	Z = -1.56, p = .12	94.94	88.06	Z = -1.01, p = .32
SUCC 60	91.95	91.05	Z = -.23, p = .82	89.06	93.94	Z = -1.24, p = .22
TOTAL SUCC	87.08	95.92	Z = -1.15, p = .25	92.15	90.85	Z = -.17, p = .87

Appendix Q

Pearson Product-Moment Correlation Coefficients Examining the Relationship among Age and Full-Scale IQ (FSIQ) for Children with ASD and Age for the CA, DEV, and MA groups Relative to Dependent Variables from the Obstacle Course

	AGE	FSIQ
ASD (n = 25)		
ACTS	- .386	- .360
HES	- .386	- .239
EXEC	- .065	- .282
SUCC	.302	.355
OVER	.308	.156
3 Comparison Groups		
ACTS	- .529**	
HES	- .542**	
EXEC	- .569**	
SUCC	.412**	
OVER	.590**	
CA (n = 25)		
ACTS	- .121	
HES	- .146	
EXEC	- .071	
SUCC	- .206	
OVER	.047	
DEV (n = 22)		
ACTS	- .519**	
HES	- .383	
EXEC	- .232	
SUCC	.583**	
OVER	- .089	
MA (n = 19)		
ACTS	- .542*	
HES	- .539*	
EXEC	- .698**	
SUCC	.242	
OVER	.667**	

* $p < .05$
** $p < .01$