A comparison of constrained and unconstrained reaching movements by people with and without Autism

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Abstract

Reaching is a fundamental movement and has been studied widely in the motor control area. Some researchers have used a sliding movement to represent reaching (e.g., Proteau and Mackrous, 2007), while others have used an aiming movement (e.g., Fitts and Peterson, 1954). To my knowledge no one has directly compared the planning and kinematic characteristics of these two movements. These different definitions of reaching movements (aiming and sliding) may also explain why researchers have reported different results when examining reaching movements of individuals with Autism Spectrum Disorder (ASD). The present study designed three movement types to examine how people with and without ASD plan and execute three different types of reaching movements. The results revealed that typically developing (TD) participants were more efficient performing aiming movements compared to sliding movements. Participants with ASD, however, did not show any differences in performing the three types of movements. In addition, TD participants moved faster compared to ASD participants in three dimensional movements, but not in one dimensional and two dimensional movements. Based on the above results it is proposed that the observed difference in movement control resulted from a preference for different sensory feedback for online control of limb movements. The behavioural results observed in the present study are consistent with models of altered brain connections in individuals with ASD.

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Preamble

Reaching to an object quickly and accurately is a complex movement that seems simple. Reaching appears simple because it is a basic movement that most people do in their daily lives. On the other hand, the processes behind reaching are complex. To reach successfully the central nervous system receives different external sensory feedback (e.g. visual, auditory, and somatosensory) and then performs complex internal processes to plan and execute the reaching movement (Binsted et al., 2001).

Reaching is one of the most basic movements and has been widely studied in the motor control area. It has been used to examine the specificity of learning (Mackrous & Proteau, 2007; Proteau, 2005), eye-hand coordination (Binsted et al., 2001), aging on human movement (Halewyck et al., 2014), and movement preparation (Klapp & Erwin, 1976). However, some researchers used an aiming movement as a reaching movement, whereas some researchers used a sliding movement as a reaching movement. Results from these different paradigms are discussed as though these two kinds of movement are the same. When reviewing the literature on ASD and reaching movements, different authors reported different results. Glazebrook et al. (2006) found that people with ASD had longer movement times compared to TD people, but Rinehart et al. (2006) stated that there was no significant difference between people with ASD and TD people in movement time. The different results reported in the ASD studies might be explained by the different movement types used by different authors. The current study therefore examines whether typically developing people use the same strategies in aiming movements and sliding movements and if there is difference between TD people and people with ASD.

Autism spectrum disorders are defined by impairment in communication, social interaction and repetitive behaviors. ASD is a prevalent neurodevelopmental disorder that affects 1 in 68 children (“CDC estimates 1 in 68 children,” 2014). In addition to the widely studied social deficits of people with ASD, more and more researchers (for a review see Fournier et al., 2010) report impairments of autistic people in their fine and gross motor movements, e.g. finger tapping (Mostofsky et al., 2009), reaching and grasping (Mari et al., 2003), and postural control.

Previous studies (Mari et al., 2003; Glazebrook et al., 2006; Rinehart et al., 2006) consistently report that people with ASD had a longer reaction time than typically developing people. That said, there is a debate (Glazebrook et al., 2006; Rinehart et al., 2006) about whether people with ASD also have longer movement times than TD. One explanation for these differences may be that different movement types were used. Glazebrook et al. used aiming movements and found that people with autism were slower during reaching movements than typically developing (TD) people, but researchers (Rinehart et al., 2006) who used sliding movements found that there were no differences between autistic people and TD people.

In conclusion, there were two goals of the current research. 1. To examine how TD participants control and plan three different types of movements. 2. To examine if people with autism had the same characteristics in three different types of movements compared to TD participants.

Introduction

Goal-directed aiming can be divided into two parts: planning and execution. Woodworth published an impressive monograph in 1899. He put forward the two-component model of the execution part: in the first phase the performer brings the limb to the vicinity of the target while in the second phase the performer uses visual information to correct his/her movement in order to reach the target successfully (control phase).

Moreover, the demands for movement planning can be measured by the duration of reaction time (RT). RT is the time from the arrival of unpredicted stimulus to the beginning of the response (Schmidt and Lee, 2011). Henry and Rogers (1960) found that reaction time increased with movement complexities (For more details, see page 2).

Sliding and aiming movements

In everyday life, a variety of tasks require us to reach for and manipulate objects. Reaching movements are therefore one of the basic movements studied in the field of motor control. Researchers have studied reaching movements extensively in order to understand how our nervous system controls our limbs (Mackrous & Proteau, 2007; Proteau, 2005). When making a precise goal-directed hand movement to a target we need to integrate multimodal information, for example visual, auditory and somatosensory sources (Neggers & Bekkering, 1999). Researchers have (e.g., Fitts & Peterson, 1964; Grierson & Elliott, 2007; Elliott, Hansen, Mendoza, & Tremblay, 2004) used aiming movements to study sensory feedback and goal-directed reaching movements, whereas other researchers used sliding movements (Woodworth, 1899; Klapp & Erwin, 1976; Khan, Lawrence, Buckolz & Franks, 2006; Mackrous &

Proteau, 2007) to study sensory-motor control. Because of the different types of sensory feedback, various degrees of freedom, and relative muscle activity in sliding and aiming movements, the two kinds of movements may be controlled differently.

Across the literature aiming and sliding movements are generally assumed to be the same, or at least have the same characteristics. Some obvious differences can be seen in sliding and aiming movements: 1) A sliding movement generates friction, which logically should influence the movement; 2) A sliding movement provides performers with tactile feedback during the movement, which could offer performers additional information for online control (Schlooz & Hustin, 2012).

In addition to the differences in the online control phase, there are also potential dissimilarities in the movement preparation phase between a sliding movement and an aiming movement. Henry and Rogers (1960) conducted a seminal experiment to examine the relationship between simple reaction time and movement complexity. The researchers designed three different movements. Movement A required participants to lift their finger from a key. Movement B required participants to lift their finger from the key and to move upward and forward to grasp a tennis ball. While for movement C, participants were asked to lift their finger and to strike the first ball with the back of his or her finger, then grasp the same ball as movement B. Reaction times from the key of the three different movements were recorded. The results revealed that participants increased their reaction time as movement complexity increased. Related to the present work, for a sliding movement participants will only control their movements in forward and backward directions. An aiming movement requires participants to control the movement in forward and backward directions, as well as in the upward and downward directions. In other words, an aiming movement has more degrees of freedom and could therefore be considered a more complex movement than a sliding movement. As a result, there may exist differences in the reaction time between sliding and aiming movements.

To my knowledge no one has directly compared the planning and kinematic characteristics of these two movements. Current theories/models of motor control have not distinguished between these two movements. One purpose of the current study is therefore to examine possible differences between sliding and aiming movements.

Autism

The characteristics of autism spectrum disorders (ASDs) are defined clinically by impairment in communication, social interaction, and behavioral flexibility (American Psychiatric Association, 2014). ASD is a neurodevelopmental disorder, which usually appears during infancy and childhood. It is diagnosed not by a single symptom, but by a series of characteristics (e.g. impairments in social communication). According to Autism Speaks Canada in 2012, Autism now affects 1 in 88 children, specifically 1 in 54 boys, and the 2012 numbers reflect a 78% increase in reported prevalence in the last 6 years. With such a high prevalence, it is of great significance to understand the nature of this disorder. Moreover, nearly all communication requires motor control, e.g. our eye movements Therefore it is also necessary to study how people with ASD control their movements.

The earliest descriptions of autistic people’s social deficits were by Kanner (1943) and Kanner and Eisenberg (1956). Their papers contained at least 12 different aspects of social impairments. For example, withdrawal from people, lack of attention to people, non-communicative use of language, lack of behavior appropriate to cultural norms. Most of their original observations have been replicated by later studies (Wing & Gould, 1979, Loveland & Landry, 1986).

Because ASD is a developmental disorder, which indicates that the characteristics shown by people with autism spectrum disorder now are accumulations of their previous behaviour and development, many researchers (Volkmar et al., 2005, Noens et al. 2006, Landa et al. 2007) have examined the characteristics of autistic people when they are children. As infants, individuals with ASD show less attention to social stimuli and respond less to their names (Volkmar et al., 2005). Wing (1978) demonstrated that autistic children under 5 years-old were more aloof and detached than typically developing (TD) people. Autistic children from 3 to 5 years-old are less likely to exhibit social understanding, copy and respond to emotions, communicate nonverbally, and play with others (Sigman et al., 2004). Some studies also stressed their deficits in language and communication (Noens et al. 2006). About a third to a half of individuals with autism will not develop enough natural speech to meet their daily communication needs. They have difficulty with imaginative play and with developing symbols into language (Landa et al. 2007). In addition, autistic children do not like to make requests or share experiences, and are more likely to simply repeat others' words (Landa, 2007). Other atypical behaviors are common, such as abnormal eating and atypical movement patterns, but are not included in the definition of disorder (Diagnostics and Statistical Manual 5, 2013).

Joint Attention

Joint attention is the ability to “coordinate attention between interactive social partners with respect to events in order to share an awareness of the objects or events” (Mundy et al., 1986). Some simple actions, like sharing attention through shifting eye gaze and following the gaze of other people, belong to joint attention (Geraldine et al, 2004), which underlie more complex social communicative skills, including language and communication (Baldwin, 1991). Based on the concept of joint attention, eye movements may play an important role in this ability.

Typically developing infants show joint attention at about 12 months old (Carpenter et al., 1998). However, children with autism do not achieve this ability at the same age. Therefore performance on joint attention tasks can be used to distinguish some toddlers and preschool-age children from typically developing children (Sigmen et al., 1992). For a better understanding of the impairment of autistic people's joint attention, Falck-Ytter and Fernell (2012) investigated gaze performance of people with ASD. Compared to a typically developing group, children with autism spectrum disorder exhibited less accurate gaze in an eye tracking task. Moreover, joint attention is considered to be a useful predictor of both concurrent and future language skills in children with autism (Geraldine et al, 2004).

In the early period of life, two types of joint attention will appear: responding to joint attention (RJA) and initiating joint attention (IJA) (Mundy et al., 2009). RJA refers to the ability to follow the gaze or gestures of other people and share a common reference. Whereas IJA means the ability to create a response to the object or event by gaze or gestures spontaneously. The former one emphasizes processing other people's information and the latter one places emphasis on voluntary goal-directed behavior (Mundy et al., 2009). The difficulty people with ASD have with joint attention illustrates that they may have trouble preparing a goal-directed movement. As a result, it is meaningful to study how they prepare movements.

Imitation

Ten years after Kanner's original research on autistic people's social deficits

(1943), Ritvo et al. (1953) demonstrated autistic people’s impairment in imitation. Since then, numerous authors have reported deficits in a variety of imitation tasks (Williams, Whiten, & Singh, 2004). Rogers and Pennington (1991) found that people with autism had difficulty imitating actions with symbolic meaning. Moreover, Stone et al. (1997) investigated movement imitation of people with ASD with different complexities. The researchers compared relative easy movements (imitation of actions with objects and meaningful actions) and relative difficult movement (imitation of body movements and non-meaningful actions). They reported that autistic people had a lower motor imitation scale score in both imitation tasks.

Infant imitation has several functions. During the earliest time of a child's life imitation offers baby a feeling of connectedness. Afterwards, imitation in the middle of the first year of life is responsible for the child’s information of what people do and how people think. Consequently, imitation is also helpful for peer interaction (Rogers et al., 2003). As a result, imitation is an essential ability in a child’s development. Thus deficits exhibited in autistic people’s imitation will have an influence on their language, play, and joint attention (Ingersoll, 2008). We can also regard imitation, e.g. push toy car across table (reach to the car first and then push the car towards the desired direction), as a combination of different basic goal-directed movements, and study a basic goal-directed movement will tell us a specific difference between people with autism and typically developing participants.

Weak Central Coherence

Navon (1977) performed an experiment called the “Navon task” where performers were presented with a large letter shape made up of smaller letters of either the same kind, or a different kind of letter. Participants were required to identify the letters at the global or local level (global level: the large character made out of small characters; local level: the small characters which formed a larger character). The phenomenon that “participants making more errors and being slower to identify the letters at the local than at the global level is called “global advantage”; while the phenomenon that participants being slower to detect the target letter when it is at the local level compared to when it is at global level is called “global interference ”. (Plaisted et al., 1999).

People with autism seem not to have the typical global advantage or the global interference. Instead, people with autism have what has been termed “weak central coherence” (Happé & Frith, 2006). That is “the detail-focused processing style proposed to characterize autism spectrum disorders” (Happé & Frith, 2006), which means that people with autism will focus on the details first instead of the whole view when they use their eyes to read the information from the external world. It is possible that people with ASD have difficulty broadening the spread of visual attention (Mann & Walker, 2003). Based on the weak central coherence theory, people with autism may have difficulty integrating different parts in the environment, which may have an influence on their goal-directed aiming movement, e.g., people with ASD may have difficulty in looking at their fingers and target in the same time to know the relative distance between their fingers and the target.

Autism-Motor

In addition to social and communication deficits, there is debate about autistic people’s motor performance. Some earlier reviews (Hallett et al. 1993; Mayes & Calhoun 2003) state that children with autism spectrum disorder have similar motor development to TD children. More recently researchers report differences in movement performance (Rinehart et al, 2006; Glazebrook et al., 2006, Provost et al.

2006). A synthesis and meta-analysis study reported measurable motor problems associated with ASD (Fournier et al., 2010), especially in their sensory-motor control. In 2003, Molloy et al. recruited 8 autistic children and 8 age-, race-, and gender-matched controls to test their postural stability. They asked the participants to stand quietly with bare feet on a force platform. The independent variables of the experiment included standing either with vision or without vision, and they stood on either a foam pad on top of the force platform, or directly on the platform. They found that children with autism spectrum disorders had significantly larger sway when any sensory input was altered. In addition, removal of vision had a larger impact on sway area than modification of somatosensory feedback, which indicates that the people with autism can adapt to changes in somatosensory information more easily than changes in visual information.

Besides gross motor skills described above, Dominick et al. (2007) reported that a lot of people with autism have problems in their movement related to daily life. As a result, some studies (Glazebrook et al., 2006; Rinehart et al., 2001 & 2006,) focused more on the autistic people’s basic movements, for example, reaching and grasping. Based on the results from these studies (Glazebrook et al., 2006; Rinehart et al., 2001 & 2006), we can find that autistic people have differences in fine motor control from typically developing people.

Mostofsky et al. (2000, 2006, 2009) has consistently examined autistic people’s fine motor skills. Mostofsky et al. (2000) conducted two experiments to measure autistic children’s tests of judgment of explicit time intervals and procedural learning ability. In the test of judgment of explicit time intervals, participants were asked to compare consecutive time intervals generated by two pairs of tones. They were asked to report which duration was shorter and which duration was longer. In the test of procedural learning ability, participants were asked to press one of the four buttons in response to one of the four illuminated open circles that appeared on the screen. The researchers proposed that people with autism have abnormalities in cerebellar-frontal circuitry because of their longer time in procedural learning compared to the TD group. Then in 2006, Mostofsky et al. used the Florida Apraxia Screening Test to examine whether participants with ASD had deficits in skilled motor gestures. The test includes 3 sections: Gestures to Command (25 commands), Gestures to Imitation (25 commands), and Gestures with Tool Use (17 commands). Participants were videotaped during the praxis examination and the videotapes were used for later scoring. The results showed that ASD people produced fewer correct responses in all three sessions. Spatial error was the most common error type in both the ASD and the TD groups, but body-part-for-tool errors were more common in the ASD group. More recently, Mostofsky et al. (2009) used fMRI to examine the brain activity of typically developing and people with high-functioning autism during a finger tapping task. The results demonstrated that people with high functioning autism (HFA) showed decreased activity in the cerebellum, which is an area known to be used for motor control. In addition, these two areas (cerebrum and cerebellum) had a decreased connectivity with each other. Overall there is consistent evidence that abnormalities exist in the brain regions needed for movement control (Mostofsky et al.’s 2000, 2006, 2009; Muller et al., 2001, Allen et al., 2004). Researchers (Woodworth, 1899; Elliott et al., 2010) have studied how TD people plan and execute reaching movements for many years. As a result, we can compare TD people and ASD people by using reaching movements to further understand possible differences in how ASD people perform movements.

Goal-directed aiming

In addition to the two components in goal-directed aiming, Woodworth (1899) also proposed that the initial phase of the movement is more rapid and stereotyped than the last phase, and the last phase becomes discontinuous and discrete. In accordance with Woodworth's theory, Fitts proposed Fitts Law in 1954, which explained the relationship between accuracy and speed, also known as the speed-accuracy trade-off. In the experiment, Fitts required the participants to tap a handheld stylus between two targets as quickly as possible for a predetermined duration. The targets were rectangles and both the width (W) of the target and the amplitude (A) of the movement between them were independent variables in the experiment. The task was scored as the number of taps in 20 seconds. However, the participants should limit the errors (the movement which missed the target) to fewer than 5%. Based on the participants' movement times and different movement amplitudes and target widths, Fitts concluded that:

MT (movement time)=a+b $\log_2(2A/W)$ (A: amplitude, W: Width, a,b: constant)

From the equation, we can see that if the width of the target is smaller or the amplitude between the two targets is farther, the movement time will be longer, which means that the movement has a lower velocity.

In addition to the repetitive aiming movement, Fitts and Peterson (1964) also studied the speed-accuracy tradeoff during discrete aiming movements. They asked subjects to make quick movement towards one of two alternative targets. The researchers concluded that there was also a strong correlation between movement time and index of difficulty for discrete aiming movements. However, the amplitude, and the width of the target had a relative small effect on reaction time.

Models for goal-directed aiming have continued to evolve, including the iterative correction model, the single-correction model, the impulse variability model, and the optimized submovement model (Elliott, Helsen, & Chua, 2001). One recent theory is the multiple-process model (Elliott et al. 2010). This model also stresses that there are two components in a goal-directed movement: a planned component that brings the limb to the target area, and then a corrective portion of the movement that reduces the spatial discrepancy between the limb and the target location. However, Elliott et al.'s (2010) model also proposes that the first phase of the movement is not ballistic. Instead he proposed that people make adjustments to outside forces before they reached peak velocity. Because endpoint variability will increase with movement speed, the performer should find the optimal compromise of speed and endpoint accuracy when they prepare for the movement so that the limb is not located outside the target boundaries on some of the trials (Elliott et al. 2010). Another important point in this model is the energy conservation assumption. Researchers (Chua & Elliott, 1993; Elliott et al, 2004) found that the endpoints of the primary sub-movement undershot the target more than overshot the target. Elliott et al. (2004) suggested that target overshoots were more costly since correcting an overshoot requires the performer to spend energy to change a forward movement to a backward movement and bring the finger to the center of the target.

As is stated above, a reaching movement appears to be a simple movement, but it requires participants to process a lot of information. It also needs coordination in different brain areas, different effectors, and between the brain and effectors. Thus it can be used to examine behavior differences between TD people and ASD people and further deduce possible differences in brain organization.

Movement planning

A small number of researchers have investigated the detailed kinematics of autistic people's movement. Glazebrook et al. (2006) performed an experiment to examine how young adults with autism plan and control their movements. They asked individuals to move their index fingers to one of two targets. The targets were two yellow circles either 1 cm or 2 cm in diameter, which were connected by a horizontal line either 16 cm or 32 cm. There were 8 combinations of the target size and movement amplitude in total. The starting position was defined as the point where the two possible movements (from the starting position to the targets) had an equal index of difficulty. An infra-red emitting diode (IRED) was attached on the index finger of the dominant hand, and a three dimensional motion analysis system (Optotrak, Northern Digital Inc., Waterloo, Ontario) was used to track the trajectory of the diode. The authors reported that autistic participants had a longer reaction time (Rinehart et al., 2006), indicating that they have difficulty in their movement initiation, which is consistent with their difficulty in initiating their speaking (Kleinhans et al., 2005).

Consistent with what Glazebrook et al. found, Rinehart et al. (2006) tested movement kinematics in young people with high-functioning autism and people with Asperger's disorder. A 420 x 420 mm digitizing tablet served as the surface of the targets. The start position was positioned at the bottom, center of the tablet, and targets were positioned in the top left- and right-hand corners of the digitizing tablet. The task was moving a no-ink stylus from the start position to either the left or the right target responding to the illumination of the left or right LED (drawing an imaginary line from the start position to the target). They designed three levels in this experiment. In level 1, performance for target side was in a random order, with 50% left-side and 50% right-side targets; in level 2, there were two conditions for each participant. In one condition 75% of the targets were left-sided, and 25% were right-sided, whereas in the second condition the exact opposite occurred. In addition, participants were instructed on which side the majority of targets would appear; level 3 had the same expectancy manipulation as level 2. However, participants were now required to move to the opposite location of the illumination of the LED. They found that people with autism had a longer reaction time than the controls in level 1. Thus the researchers concluded that people with high-functioning autism have difficulty planning their movement. They speculated that the impairment in planning probably resulted in inadequate output to the pre-motor areas of the brain, including the supplementary motor area. Moreover, Glazebrook et al. (2008) conducted two experiments to examine how individuals plan their movement when advance information is direct versus when a strategy is needed to plan the movement. By means of comparing TD participants and autistic participants, they concluded that both groups of participants use the same pattern when they had advance information while they adopted different methods if a strategy needed to be developed. In the studies stated above, all the researchers (Glazebrook et al., 2006, Rinehart et al., 2006) unanimously stated that people with autism had longer reaction times compared to TD participants.

Motor reaction time and premotor reaction time

Although there is agreement that a longer reaction time exists in autistic people’s movement planning, it is unclear what the specific deficit that leads to the delay is. It is possible to obtain more detailed information from reaction time data in order to assist in answering this question. Botwinick and Thompson (1966) were two of the earliest researchers to study reaction time. They fractionated reaction time into premotor and motor components. They defined the premotor time as the period from the presentation of the stimulus to the appearance of increased muscle firing, while the motor time was that period from this change in action potential to the finger lift response. Generally, researchers (Botwinick & Thompsom, 1966; Anson, 1992) consider the premotor component to represent the time our brain processes the specific information of the upcoming movement and develops a plan for the movement. For example, which muscles will take part in the movement; how much force will the muscles generate? On the other hand, motor reaction time reflects the time for the muscle to produce enough force to initiate the movement. Thus, by using electromyography (EMG) we can get more detailed reaction time information. That is, we can study if people with autism have problems in perceptual and cognitive processing time or they have deficits in motor unit recruitment. Furthermore, we may speculate differences in brain function based on which component(s) of reaction time are longer. More specifically, we can tell if they have difficulty in perceiving the target information and planning the whole movement and/or if they need a longer time to generate a certain amount of force in their muscles.

Movement execution

In addition to the autistic people’s movement planning, only a few studies have investigated how they execute their movements. Mari et al. (2003) tested the reach and grasp ability of individuals with autism. In their experiment, they asked 20 autistic participants and 20 normal participants to reach and grasp two different sized cubes placed at two different distances. They proposed that the autistic people with low IQs had slower peak velocity and peak acceleration in the acceleration phase, however, they have longer deceleration and total movement time. Similar to what

Mari et al. (2003) found in low IQ autistic people, Glazebook et al. (2006) reported that adolescents with autism had similar endpoint accuracy in a goal-directed aiming task to TD people but adolescents with autism had smaller peak velocity and acceleration and more variability in the location of peak velocity and acceleration. In addition, they found that the autistic group had the same endpoint accuracy as the TD group. They explained that the autistic adolescents tried to keep their acceleration and velocity low to make the muscular forces low enough to perform accurate movements.

On the other hand, Rinehart et al. (2006) reported that when reaching to one of two targets on different sides the TD participants and high functioning autism group did not have differences in their movement times. However, if participants were required to move to the opposite side of the illuminated target, the ASD group's movement time was not influenced by the expectancy, whereas the controls were much faster in the expected condition than the unexpected condition. Consistent with Rinehart et al.'s (2006) results in level one (right and left targets were equally probable), more recently Papadopoulos et al. (2010) tested 3 groups of participants: Children diagnosed with high functioning autism (HFA), Asperger's disorder (AD), and typically developing (TD) controls. They required the three groups to perform rapid reciprocal aiming movements between two targets. Participants were instructed to draw 10 continuous sets of straight lines without lifting the stylus from the touchscreen. The authors reported that MTs did not differ, but the HFA group had greater scatter in the endpoint. Therefore, there is an ongoing (Glazebrook et al., 2006; Mari et al., 2003; Rinehart et al., 2006; Papadopoulos et al., 2010) debate about whether individuals with autism need more time to execute reaching movements. Although the above authors use the same dependent measure, movement time, to examine how people with and without autism execute their movements, we can find differences in their experimental design. Given the different findings in previous studies, the present research is designed to investigate: 1) if people with autism have different movement characteristics (e.g. movement time and reaction time) from TD people when they perform goal-directed aiming movements, or 2) do people with autism use different strategies to compensate for their deficits in movement execution.

Some explanations may clarify the various results of the different authors. First of all, comparing Glazebrook et al.'s (2006) experiment to Rinehart et al.'s (2006) and Papadopoulos et al.'s (2010) instruction to the participants, only Glazebrook et al. asked them to move as quickly and as accurately as they could. According to speed-accuracy trade-off, it is plausible for one person to move quickly with a poor accuracy. In addition, in Glazebrook et al.'s (2006) experiment, it was a natural aiming movement: the participants were required to move from the start position to the target. But in Rinehart et al.'s and Papadopoulos et al.'s experiment: they asked the participant to hold a stylus and move it along the table, which would provide participants with additional tactile and proprioceptive feedback, which will provide the people with autism with more information to finish the aiming movement compared to a reaching movement through the air.

Eye-hand coordination

Vision is important in guiding our limbs to a target. Similar to the hand's movement profile we perform a saccadic eye movement that undershoots the target, with subsequent corrective saccades bringing the gaze to the target area (Helsen et al., 2000). Researchers have also found a coupling between the initial saccade completion and the peak acceleration of the hand (Binsted et al., 2001). Our hands are usually at the point of approximately 50% of the total movement distance when they reach their peak velocity (PV). At PV, the point of gaze is either near the target or on the target (Helsen et al., 2000). Thus vision provides us the exact information of target location at the time we begin to slow down our limb velocity, assisting with our ability to bring our hands to the target accurately.

Helsen et al. (2000) examined the coupling of the eye, finger, elbow, and shoulder during a manual aiming movement. Participants were requested to complete a 40cm aiming movement with their dominant hand. They were allowed to move their eyes, hands, elbows, and shoulders freely. The authors reported there was co-occurrence of the first saccade and peak velocity of the finger, elbow and shoulder, which can be interpreted as the visual information was important for online control because when our eyes reached the target, we would start our deceleration phase. During the deceleration phase, the movements of the finger, elbow and shoulder are based on the information from the eye to make the tip of finger land on the target accurately.

In addition to the research about typically developing subjects, Glazebrook et al. (2009) executed an experiment to examine eye-hand coordination in individuals with autism. They asked autistic people and typically developing people to complete 2 blocks of 80 aiming trials, either with or without vision. A motion capture system was used to track the position of hand and an eye tracker was used to record eye movement. They reported that the amplitude of eye movement had more variability compared to TD participants, which was similar to the condition of hand movement. As a result, visual information may not be “enough” for people with ASD to control their movement. Therefore, it is meaningful to study if additional tactile feedback will help people with ASD perform reaching movements.

Haptic sensory feedback

When Hans Asperger first described the characteristics of autism, he focused on hypersensitivity, especially of touch, smell, and taste (Blakemore, et al., 2012). Afterwards, other researchers (Hermelin et al, 1970; Schlooz & Hustin, 2012) investigated the haptic sensory ability of autistic people in a tracking task. Hermelin and O’Connor (1970) tested how autistic and TD children moved a stylus along groove. There were two conditions in their experiment: they asked the participants to use a metal stylus to follow a grooved track either in full vision or no vision conditions. They reported that in the vision condition, the typical group was faster while in the no vision condition, the group with autism was faster. In 2012, Schlooz and Hustin replicated this experiment with people with pervasive developmental disorder (PDD) as their participants. The researchers defined pervasive developmental disorder as a milder form of autism. They calculated the execution time of the tracking task and separated this time into stop time (the intervals during which pen stopped moving) and summed movement time (the time when the pen was moving). Schlooz and Hustion (2012) reported that people with PDD had shorter stop time and summed movement time in the no vision condition while the PPD group and typical developing group were similar in the vision condition, which indicated that people with PDD may benefit more from tactile feedback than the typically developing people when they did not have vision.

Furthermore, Nakano et al. (2012) designed three experiments to examine the haptic-to-visual shape matching ability in autism spectrum disorder. In the first experiment, all participants were required to close their eyes and feel along the edges of two tilted wooden bars using their index fingers to judge which bar was more upright. In the second experiment, all participants were asked to explore wooden blocks of various complex shapes by touching around the peripheral edges of the blocks using their index finger in a clockwise direction with their eyes closed. Then they chose the visual equivalent of the block from three visual shapes; finally, participants were asked to view a depiction of a 3 dimensional target figure and four test figures and select which two of the four test figures were rotations of the target. Comparing the performance of haptic-to-visual intermodal delayed matching between ASD group and TD group, researchers found that ASD group was more accurate when the objects were in curvilinear and rectilinear shapes. Thus the authors concluded that people with autism had a better haptic-to-visual information transfer than the TD people.

In conclusion, based on early and recent research (Hermelin et al, 1970; Schlooz & Hustin, 2012), we may assume that autistic people could have a better (Haswell et al., 2009) use of their tactile feedback when they perform a movement. Thus, we may find differences between reaching movements by ASD and TD participants when there is little or no tactile feedback. When tactile feedback is available there may be no difference between the groups because tactile feedback may help people with ASD improve their movements more compared to TD people.

In summary, I designed three different tasks in my experiment. In each task, there were two targets. The two targets were different sizes and appeared in different locations. However, the two targets had the same index of difficulty according to Fitts' Law (1954). In the first task, performers moved along a track on a piece of Plexiglas® from the start position to one of the two targets, making it a one dimensional movement. In the second task, participants slid on the Plexiglas® from the home position to the target, but without a track. They attempted to draw an imaginary line between the start location and the target (similar to Rinehart’s experiment, but they did not hold a stylus), making it a two dimensional movement. The third task was similar to the first one, except that participant did not contact the Plexiglas® during the movement. The task was an aiming and three dimensional movement, similar to Glazebrook et al.’s (2006) experiment.

Objectives

The purpose of the proposed study was to examine how young adults with and without autism plan and execute movements with different complexities. This study also investigated if people with autism would benefit from added tactile sensory feedback. The specific objectives were:

1. To determine if typically developing (TD) people have the same characteristics of movement planning and execution for aiming and sliding movements.
2. To determine if people with autism have similar movement profiles to TD people when performing different types of reaching movements.
3. To determine if people with autism exhibit the same movement characteristics (e.g. movement time, reaction time, peak velocity) during reaching movements, when it is an aiming movement or a sliding movement.

Method

Participants

Eleven participants (8 male, 3 left-handed (2 female), M=29 years old, SD=5.1) with autism spectrum disorder (ASD) and thirteen typically developing (TD) participants (11 male, 3 left-handed (2 female), M=26 years old, SD=3.5) were recruited into the experiment. The age range of all participants was from 18 to 40 years. Depending on chronological age, the participants with autism were diagnosed previously by a qualified clinician according to the criteria in the DSM-III, DSM-III(R), or DSM-IV (Diagnostic and Statistical Manual of Mental Disorders). None of the participants had experience with these types of experiments. Participants with ASD completed the Peabody Picture Vocabulary Test – Fourth Edition ("an untimed test of receptive vocabulary for Standard American English and provides an estimate of verbal ability and scholastic aptitude") and Raven's Progressive Matrices – Standard Test (which measures the test-taker's reasoning or non-verbal ability). ASD participants either had the two tests on the same day (9 participants) or different days (2 participants) than the movement test. These two tests provided estimates of their verbal and non-verbal abilities. If the people with autism (3 of 11) were not comfortable to take part in the experiment alone, their guardian accompanied them during the experiment.

People with autism spectrum disorder were recruited through associations in Manitoba such as Autism Manitoba, Asperger Manitoba, and the Rehabilitation Centre for Children. In addition, a letter was sent directly to specific individuals who work with this population asking for them to share the opportunity with their groups. The typically developing participants were recruited from the University of Manitoba community through poster advertisements. The movement experiment took about one hour. After the experiment, all participants received a small honorarium to thank them for their time. In addition, of the eleven participants, two reported taking one or more of the following medications: Effexor, Seroquel. All participants or their legal guardians gave informed consent before participating in the study. If a guardian provided informed consent then the participants provided their verbal and written assent. All procedures were approved by the University of Manitoba Education and Nursing Research Ethics Board. Seven of the eleven participants' verbal ability was above 25 years old (maximum score) and the remaining four ranged from 10 years old to 15 years old. Four of the eleven participants' reasoning ability was below 3% of their peers. Six of eleven participants reasoning ability was from 10% to 55% of their peers. One participant's reasoning ability was 90% of his peers. Overall, most participants in current study can be considered high functioning.

Apparatus

Participants sat on a chair to perform all three aiming tasks. A custom reaching surface was built using two light emitting diodes (LEDs) that served as the possible targets. The LEDs were under a piece of Plexiglas® that was located on a height adjustable desk. Four 5cm high wooden cubes were used as the legs of the Plexiglas®. Thus the Plexiglas® was lifted from the surface of table (5cm). The LEDs were placed in the space between the surface of table and the Plexiglas®. There were three reaching movements in the experiment: 1) performers moved in a track (1D movement); 2) participants performed a sliding movement on the Plexiglas® (2D movement); 3) performers executed an aiming movement from home position to the target by lifting their fingers off of the reaching surface. Two pieces of Plexiglas® (see Figure 1) were used as the surface of the movement. One smooth Plexiglas® was the surface of 2D and 3D movements. On the other Plexiglas®, a groove made by laser cut was located in the middle, which would restrict the movement to one direction. During the experiment, the Plexiglas® was switched from one piece to another because participants should finish all the three types of movements. Four LED were placed under the Plexiglas® (2 targets light, 1 fixation light and 1 pseudo-target), in case participants will know the location of the targets when the researcher switched the Plexiglas® (52cm × 52cm).

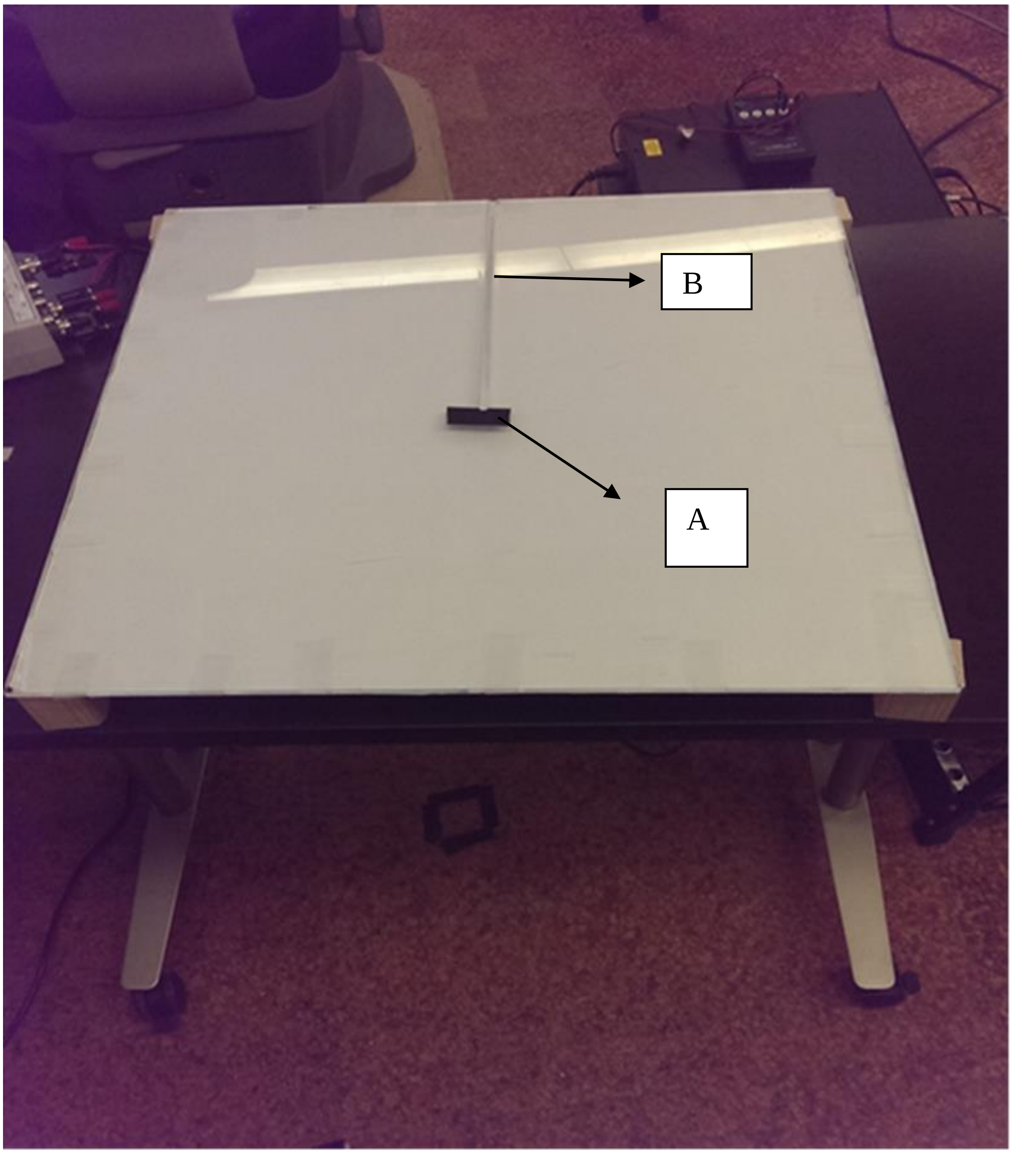

Figure 1. Actual experimental setup. A: start position, B: groove.

In each task, there were two different target locations from the start position, 25cm from the edge of the Plexiglas®. The targets were either 16cm or 20cm from the start position (see Figure 3.). When the target was in the farther location the diameter of the target was 1.25cm, whereas when the location was closer the diameter was 1cm. Thus, the ID of the task was 4 no matter where the target was (according to Fitts' Law: ID = log2(2A/W),where A = amplitude of movement, W = width of target) (Fitts, 1954).

Infrared emitting diodes (IRED) were attached to the index finger, head of ulna, lateral epicondyle of the humerus, and tip of the acromion process (shoulder) (see Figure 2.). Only the kinematic variables (velocity, acceleration and deceleration) of the index finger of the dominant hand were analyzed. A 3D motion analysis system (Optotrak 3D Investigator, Northern Digital Inc., Waterloo, ON) was positioned on the ipsilateral side to the participant's preferred hand in order to detect the position of the IREDs during each trial. Recording time was 3 seconds and the recording frequency was 300 Hz. Using medical tape, a small piece of felt was secured to the tip of the participant's index finger to reduce the friction between the finger and Plexiglas®.

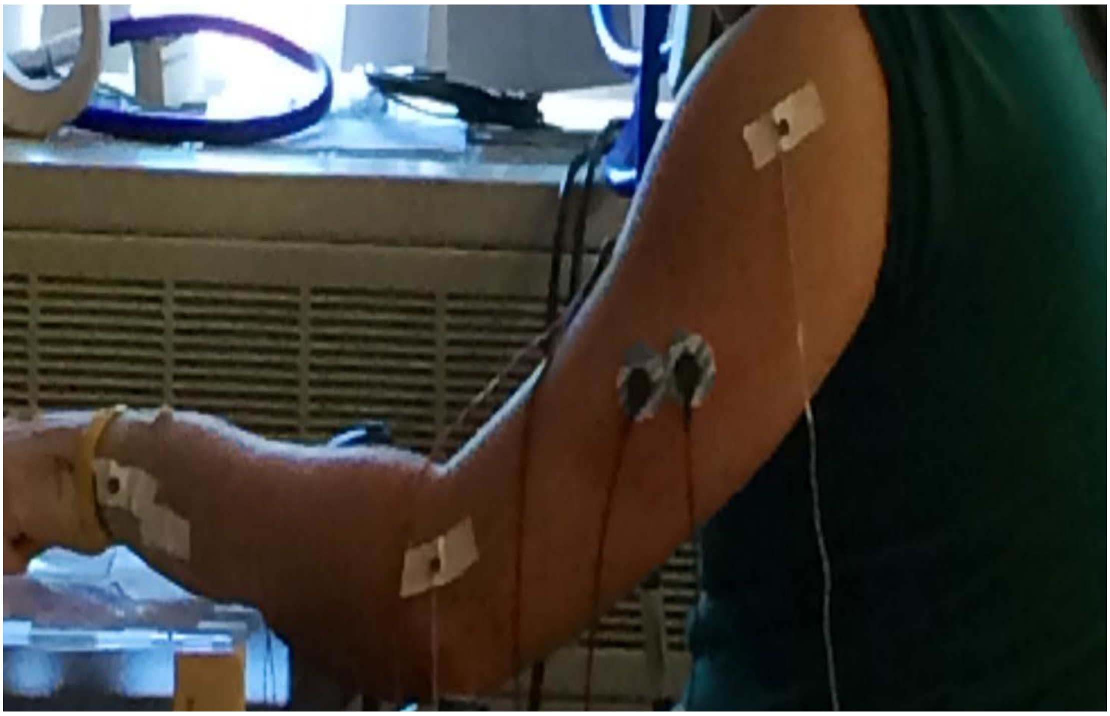

Figure 2. Positions of the infrared emitting diodes (IREDs) and electrodes on the arm. IREDS were placed on the index finger, head of ulna, lateral epicondyle of the humerus, and tip of the acromion process. Electrodes were placed on biceps and triceps, in addition, a ground electrode was placed on the olecranon.

Muscle activity was recorded using a CED 1902 dual system amplifier (Cambridge Electronic Design, Cambridge, UK). Two self-adhesive Kendall Meditrace Ag/AgCl electrodes (Tyco, Mansfield, MA) were positioned on the dominant lateral head of triceps brachii, two electrodes were positioned on the right long head of biceps brachii, and a ground electrode was attached to the olecranon process. The recording sites were shaved (if necessary), scrubbed, and cleansed in order to reduce electrical impedance. Recording time was 3 seconds and recording frequency was 1000 Hz.

Custom software was programmed using E-prime, (v 2.0 Psychology Software Tools Inc., Sharpsburg, PA) to synchronize the recording of the Optotrak, EMG, and presentation of the stimuli for the behavioural task.

Procedure

Prior to performing the task, participants read and signed the consent form. When appropriate (based on ethical guidelines, n=1) a guardian read and signed the consent form and the participant with ASD signed the assent form. The task was explained clearly and demonstrated for participants prior to the experimental trials. A small number of practice trials (<10) were also completed to familiarize participants with the task. The experimental phase began once the participant understood and performed the requested movement comfortably.

At the beginning of the experiment all performers placed their fingers on the home position aligned with their body midline. The angle of their elbow was approximately 90 degrees. Participants were asked to rest their elbow on the Plexiglas® to make sure that their biceps brachii and triceps brachii were relaxed prior to the start of each trial. A green light located between the start position and the smaller target served as a visual ready signal. That is, once the green light was turned on participants were aware that a target would soon appear under the Plexiglas® (800-1300ms). All participants were asked to move as fast and as accurately as they could.

The Optotrak and EMG started recording 500ms before the appearance of the target in order to have a baseline of muscle activity prior to the trial start. The total recording time was 3 seconds. Between each trial, participants had a rest of approximately 2s. In each task, participants performed 30 trials, for a total of 90 trials in the whole experiment. The order of the different movement types was in a pseudorandom order in each group and balanced (See Figure 4.).

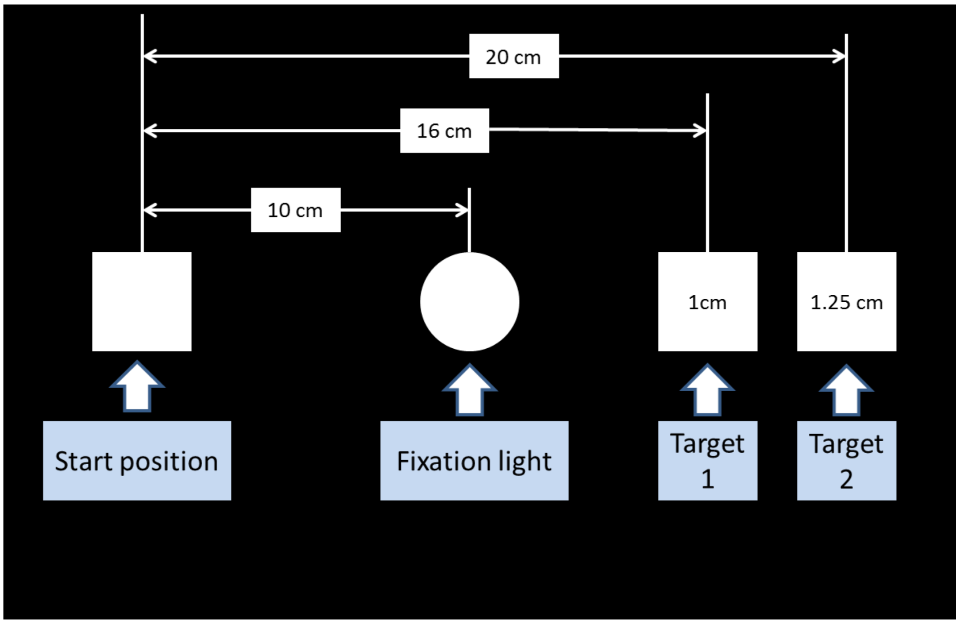

Figure 3. Diagram of target size and location, as well as relative position of start position and fixation light.

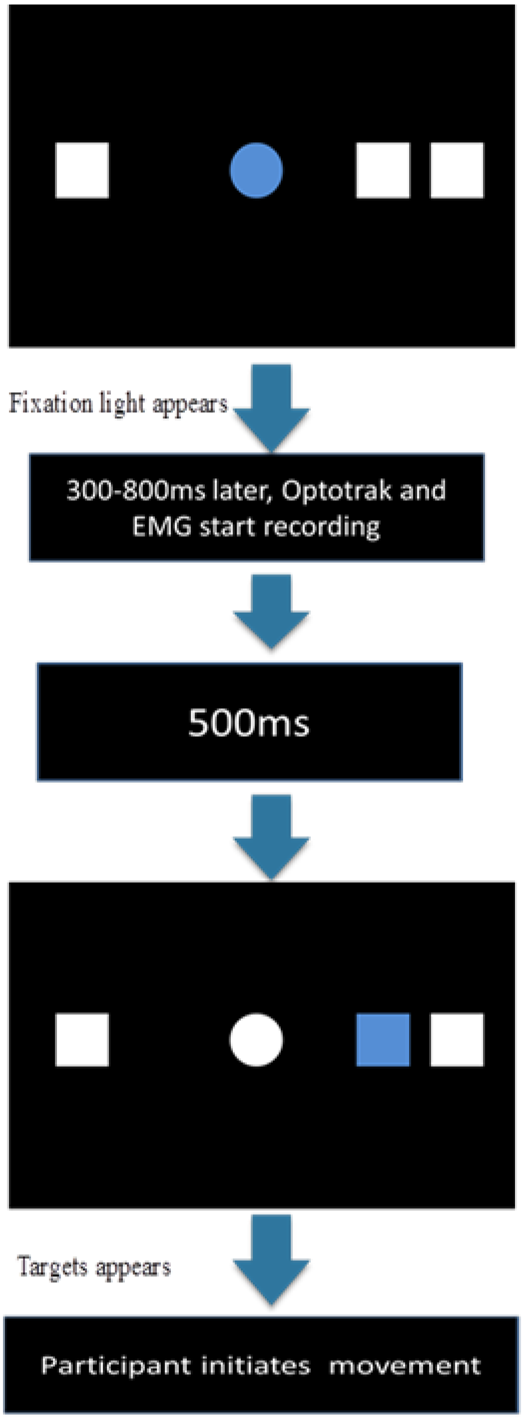

Figure 4. Experiment Procedure (blue: illuminated, white: unilluminated)

Data Analysis and dependent variables

Dependent variables: reaction time, movement time, constant error, variable error, peak velocity, peak acceleration, and peak deceleration were calculated from the three-dimensional displacement data (Optotrak 3D Investigator). Onset of movement was defined as the first frame when velocity exceeded 30mm/s and was maintained for more than 20 milliseconds. Offset of movement was defined as the first frame when velocity was lower than 30mm/s and maintained for more than 20 milliseconds.

Reaction time was fractioned into premotor and motor time using the EMG data. Data of two participants with ASD was removed due to excessive muscle activity in the baseline phase. The onset of motor reaction time was defined as the point at which the agonist muscle activity increased to more than 5 standard deviations above baseline levels (the calculated mean of activity for the 500ms prior to the target appearing). A custom written MatLab program was used to identify the time at which the onset threshold was reached. The onset of agonist muscle activity for the one dimensional and two dimensional movements was calculated from the muscle activity of the triceps brachii. Onset of premotor reaction time in three dimensional movements was calculated from the muscle activity of the biceps brachii. Different muscles were selected because the burst of muscle activity first appeared in biceps when participants performed 3 dimensional movements. Definitions of the dependent variables are presented in Appendix A.

All the data was cleaned before analysis. Any trial that was recorded as an error by the researcher when performing experiment was deleted. For example, participants did not move or participants lost their attention during the movement. In addition, if the number of any dependent variables exceeded the mean plus or minus 2.5 times the standard deviation for that participant, it was deleted as an outlier. Optotrak data for two participants with ASD was removed because of long movement times (beyond the mean plus 2.5SD deviation of the group mean). 7.8% of trials were removed from the Optotrak data because of anticipation, long reaction time or long movement time (beyond average±2.5SD). As a result, 9 ASD participants' and 13 TD participants' Optotrak data was used.

Three TD participants' and one more ASD participant's EMG data were removed because they had muscle activity in the baseline time period. 23.6%of trials were removed from the TD participants' electromyography data and 33.9% of trials were removed from the ASD participants' electromyography data, because these data had negative motor reaction time or the muscle activity in the baseline period. In the end, 8 ASD participants' and 11 TD participants' data was used.

All dependent variables were submitted to a 2 group by 3 movement type mixed analysis of variance (ANOVA) with repeated measures on the second factor. Alpha was set at 0.05 for all analyses and a Tukey's HSD post-hoc procedure was used for main effects or interactions with more than two means.

Results

Table 1 is the summary of the statistical results of dependent variables. An asterisk indicates a significant difference.

Table 1. F values of dependent variables

	Group	M Type	Group*M Type
Reaction Time	F(1,20)=0.43	F(2,40)=0.11	F(2,40)=0.54
Movement Time	F(1,20)=0.46	F(2,40)=1.80	F(2,40)=4.38*
Variable error	F(1,20)=11.1*	F(2,40)=2.82	F(2,40)=1.87
Constant error			
Premotor reaction time	F(1,17)=0.13	F(2,34)=8.92*	F(2,34)=4.19*
Motor reaction time	F(1,17)=1.11	F(2,34)=3.39*	F(2,34)=0.65
Peak acceleration	F(1,20)=0.17	F(2,40)=5.33*	F(2,40)=0.80
Peak velocity	F(1,20)=0.03	F(2,40)=0.27	F(2,40)=2.40
Peak deceleration	F(1,20)=2.93	F(2,40)=3.84*	F(2,40)=0.82
Time to peak velocity	F(1,20)=0.03	F(2,40)=6.13*	F(2,40)=0.73
Time after peak velocity	F(1,20)=0.63	F(2,40)=15.89*	F(2,40)=5.07*

Performance Measures

Reaction time (RT)

No significant effect of group, movement type, or group by movement type interaction was observed in RT, all Fs<1.

Premotor reaction time (PRT)

Both the main effect for movement type, F(2,34)=8.92, *p*<0.01, and movement type by group interaction, F(2, 34)=4.19, $p<0.05$, were significant. Post-hoc analysis of the main effect for movement type using Tukey's HSD (critical value=17.8ms) revealed that participants' premotor reaction times were significantly shorter in 3D movements (M=172ms, SD=38) than 1D (M=201ms, SD=47) and 2D movements (M=201ms, SD=53). . Further analysis of the movement type by group interaction (critical value= 36 ms) indicated that the premotor reaction times of the TD group in 3D movements (M=160ms, SD=35) were shorter compared to 1D (M=208ms, SD=51) and 2D (M=198ms, SD=55) movements. In the TD group the difference between PRT of 3D and 1D movements was 48 ms while the difference between PRT of 3D and 2D movements was 38 ms. This was not the case in ASD group (1D (M=193ms, SD=41), 2D (M=207ms, SD=54), 3D (M=188ms, SD=38)) (see Figure 5.).

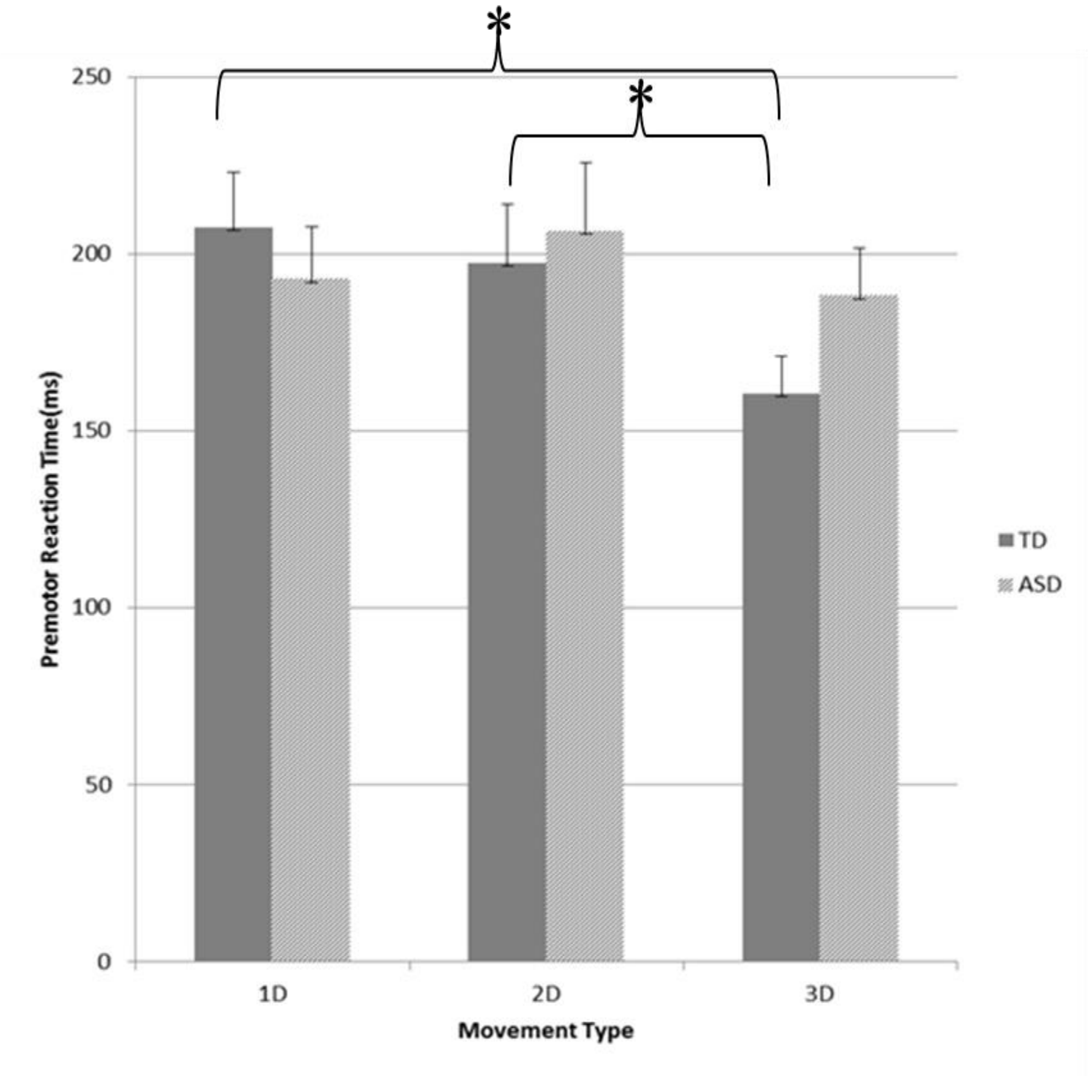

Figure 5. Mean premotor reaction time (ms) and standard error bars as a function of group and movement type.

Motor Reaction time (MRT)

As illustrated in Figure 6, the main effect for movement type, F(2, 34)=3.38, p<0.05 was significant for MRT. Post-hoc analysis using Tukey's HSD (critical value=18.34ms) revealed that participants' motor reaction times were overall longer for 3D movements (M=90ms, SD=35) when compared to 1D (M=69ms, SD=33) and 2D movements (M=65ms, SD=20). The difference between MRT of 3D and 1D was

21ms while the difference between MRT of 3D and 2D movements was 25ms.

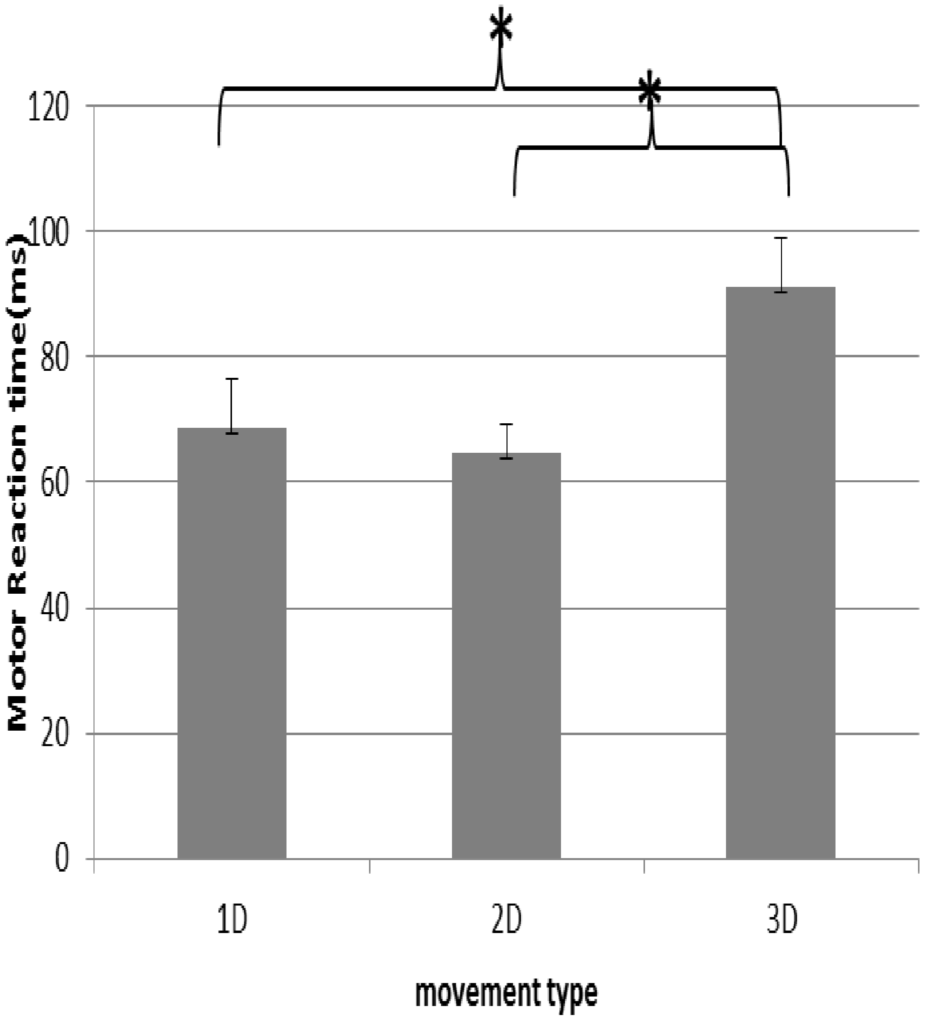

Figure 6. Mean motor reaction time (ms) and standard error bars as a function of movement type.

Movement time (MT)

As predicted by Fitts' Law (1954), no difference in MT between the two target size and location combinations was found. As a result, MTs for the two targets were collapsed.

There was a significant group by movement type interaction. F(2, 40)=4.44, $p<0.05$. Further analysis of the group by movement interaction (critical value=62.4ms) revealed that participants in the TD group were faster when they performed 3D movements (M=421.4ms, SD=64.4) compared to when participants in the ASD group performed 3D movements (M=491.1ms, SD=64.9). The group difference was 69.7ms. In addition, the critical value (62.4ms) was very close to the difference (61.9ms) between MTs of 3D movements and MTs of 1D movements in the ASD group. As a result, we can say there was a trend for participants with ASD to be faster in 1D movements compared to 3D movements (Figure 7).

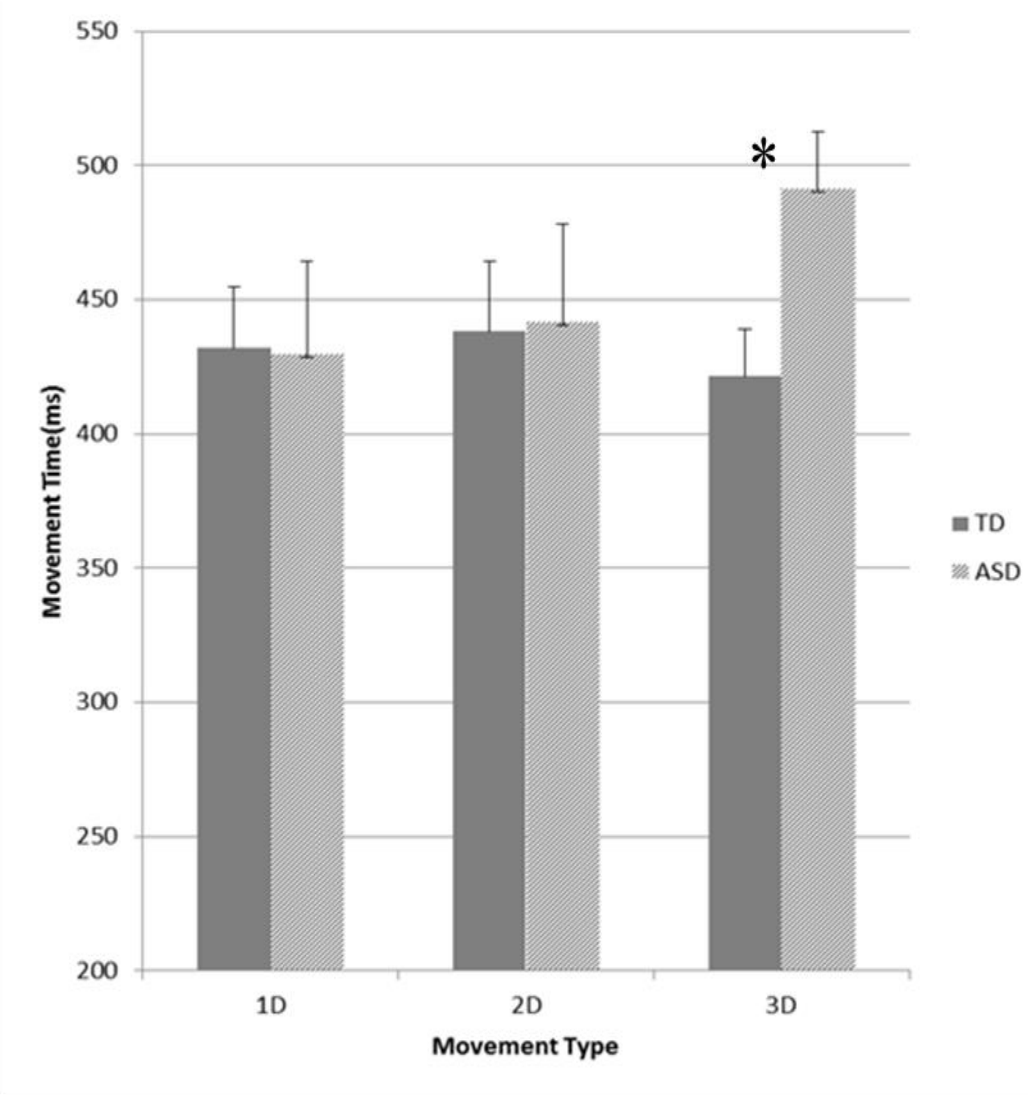

Figure 7. Mean movement time (ms) and standard error bars as a function of group and movement type.

Accuracy

Constant error (CE)

There were no statistically significant differences in CE found in either the primary (forward and backward direction) or secondary axis (leftward and right ward direction). All Fs<1.

Variable error (VE)

The main effect for group, F(1, 20)=11.1 p<0.004, was statistically significant in the primary axis. As illustrated in Figure 8, movement endpoints of the TD participants were more consistent (M=4.33mm, SD=1.51) than the ASD group in (M=5.95mm, SD=2.12) the primary axis. There were no significant main effects for group, movement type, or a significant group by movement type interaction found in the secondary axis.

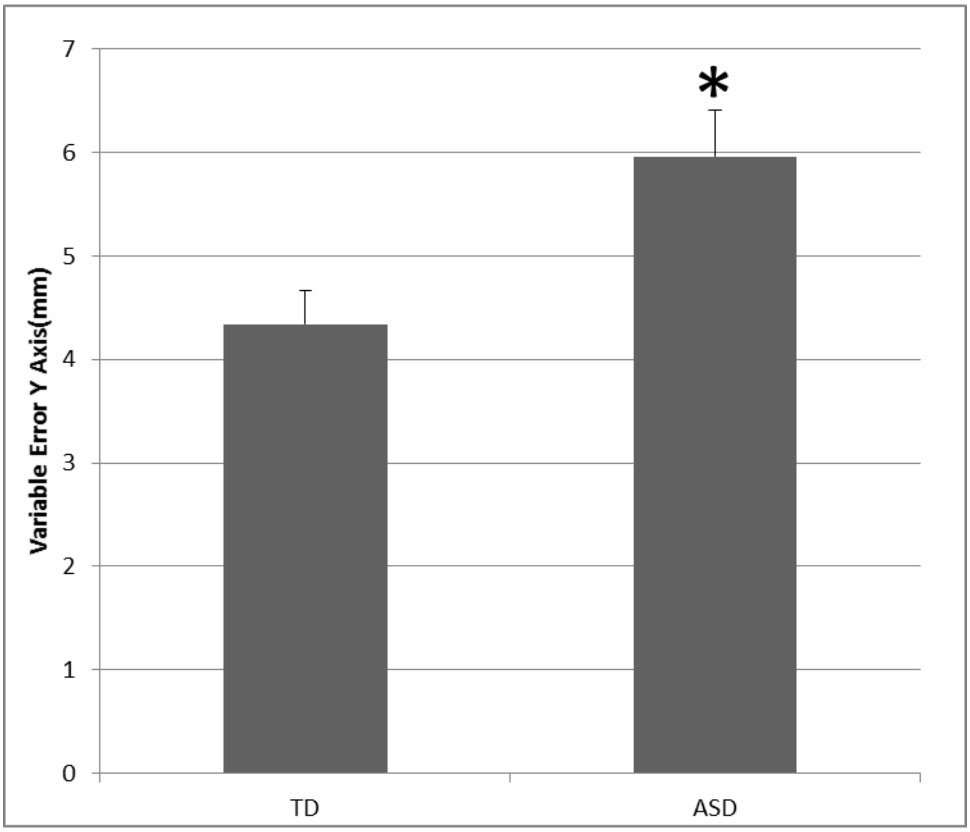

Figure 8. Mean variable error (mm) and standard error bars as a function of group (TD, ASD) in the primary (Y) axis.

Kinematic Measures

Peak acceleration (PA)

The main effect for movement type, F(2,40)=5.34, p<0.01 was significant. Post-hoc analysis using Tukey’s HSD (critical value=1668 mm/s^2) revealed that PAs of participants were overall larger for 3D movements (M=11146mm/s^2, SD=4587) compared to 1D (M=9379mm/s^2, SD=4497, difference between 3D and 1D movements was 1767 mm/s^2) and 2D (M=9016 mm/s^2, SD=4292, difference between 3D and 1D movements was 2160 mm/s^2) movements (see Figure 9.).

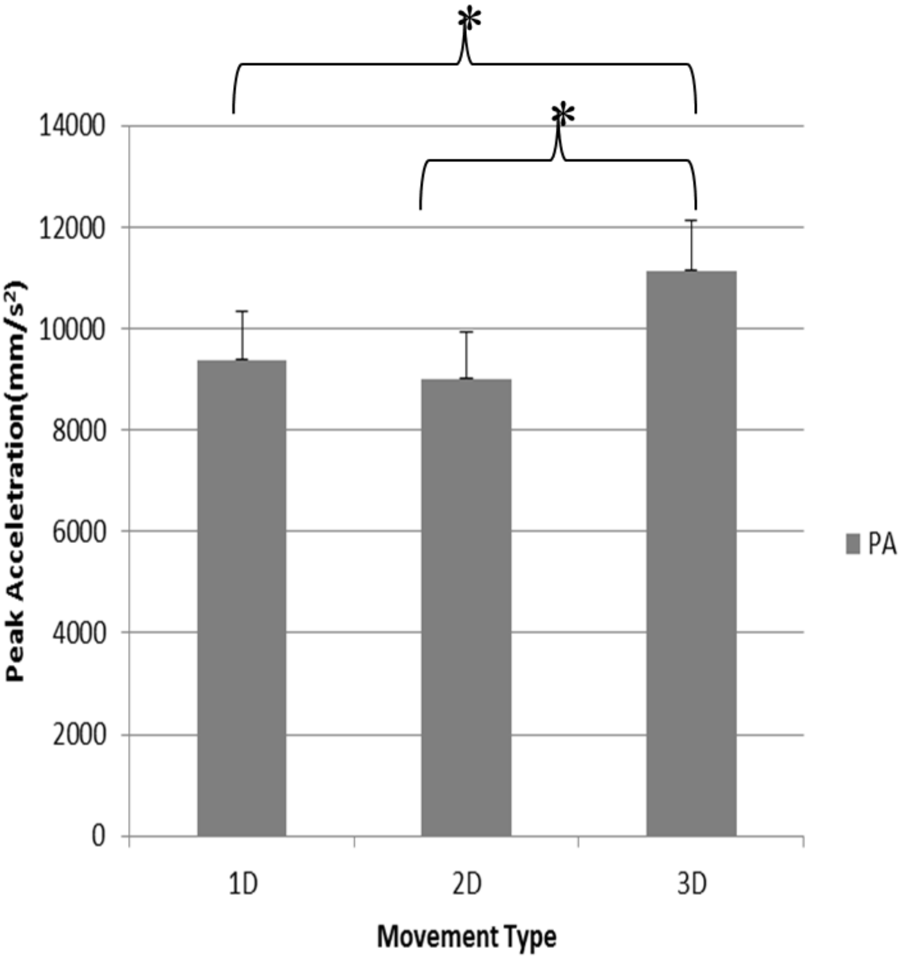

Figure 9. Mean peak acceleration (mm/s^2) and standard error bars as a function of movement type.

Peak Velocity (PV)

No significant effect of group, movement type, or group by movement type interaction was observed in PV, all Fs<1.

Peak Deceleration (PD)

As illustrated in Figure 10, a main effect for movement type, F(2,40)=3.94, $p<0.05$ was significant. Post-hoc analysis using Tukey's HSD (critical value=1492 mm/s^2) revealed that PDs of participants were overall significantly larger in the 3D movements (M=8802mm/s^2, SD=5344) compared to 1D movements (M=7219 mm/s^2, SD=3919, difference between 3D and 1D movements was 1583 mm/s^2). There was a trend for the PD of 3D movements to be larger compared to 1D movements. The difference between 3D and 1D was 1420 mm/s^2 and the critical value was 1492 mm/s^2.

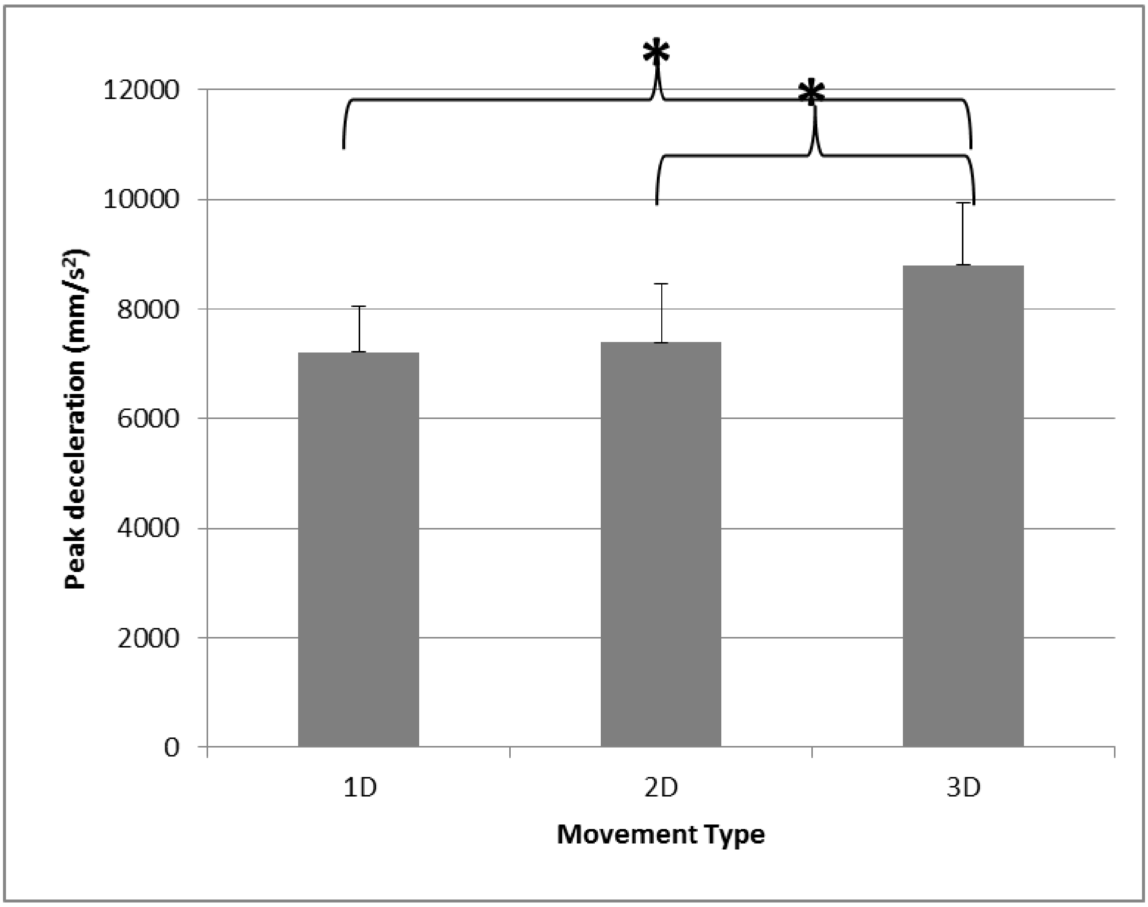

Figure 10. Mean peak deceleration (mm/s^2) and standard error bars as a function of movement type.

Time to Peak Velocity (ttPV)

The main effect for movement type, F(2,40)=6.13, $p<0.01$ was significant. Post-hoc analysis using Tukey's HSD (critical value=21.3ms) revealed that ttPVs of participants were generally shorter in 3D movements (M=163ms, SD=35) compared to 1D (M=194ms, SD=58) and 2D (M=185ms, SD=48) movements. The difference between 3D and 2D movements was 31 ms and the difference between 3D and 1D movements was 22 ms (see Figure 11).

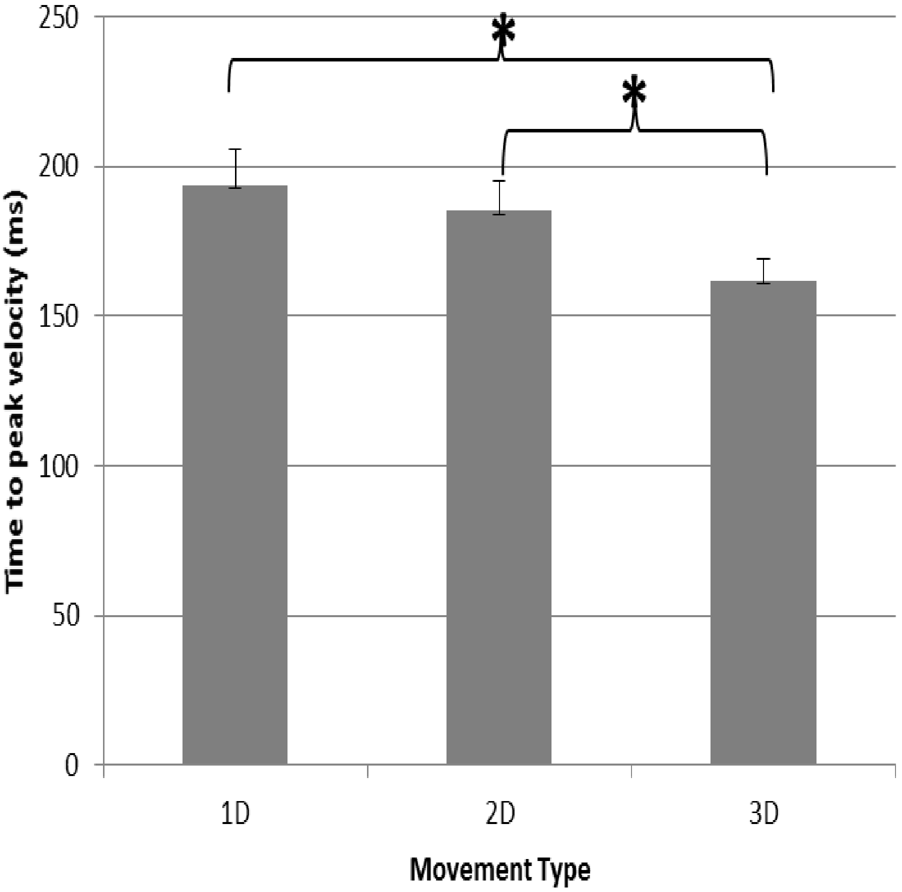

Figure 11. Mean time to peak velocity (ms) and standard error bars as a function of movement type.

Time after peak velocity (taPV)

Both the main effect for movement type, F(2,40)=15.89, p<0.01, and movement type by group interaction, F(2, 40)=5.07, p<0.05, were significant. Post-hoc analysis of main effect for movement type using Tukey's HSD (critical value= 23.7ms) revealed that participants' taPVs were generally significantly longer in 3D movements (M=295ms, SD=56) than 1D (M=241ms, SD=48, the difference between 3D movements and 1D movements was 54ms) and 2D movements (M=256ms, SD=61, the difference between 3D movements and 2D movements was 43ms). Also, further analysis of the movement type by group interaction (critical value 45.5ms) indicated that taPDs of ASD group (M=321ms, SD=63) were longer than those of TD group (M=268ms, SD=39) in 3D movements. But taPDs did not differ in two groups in 1D (ASD group: M=240ms, SD=53. TD group: M=240ms, SD=49) and 2D movements (ASD group: M=254ms, SD=60. TD group: M=257ms, SD=70). In addition, participants in the ASD group spent more time after peak velocity in 3D movements (M=321ms, SD=63) compared to 1D (M=240ms, SD=54, difference between 3D and 1D was 81ms) and 2D (M=255ms, SD=56, difference between 3D and 1D was 66ms) movements (Figure 12).

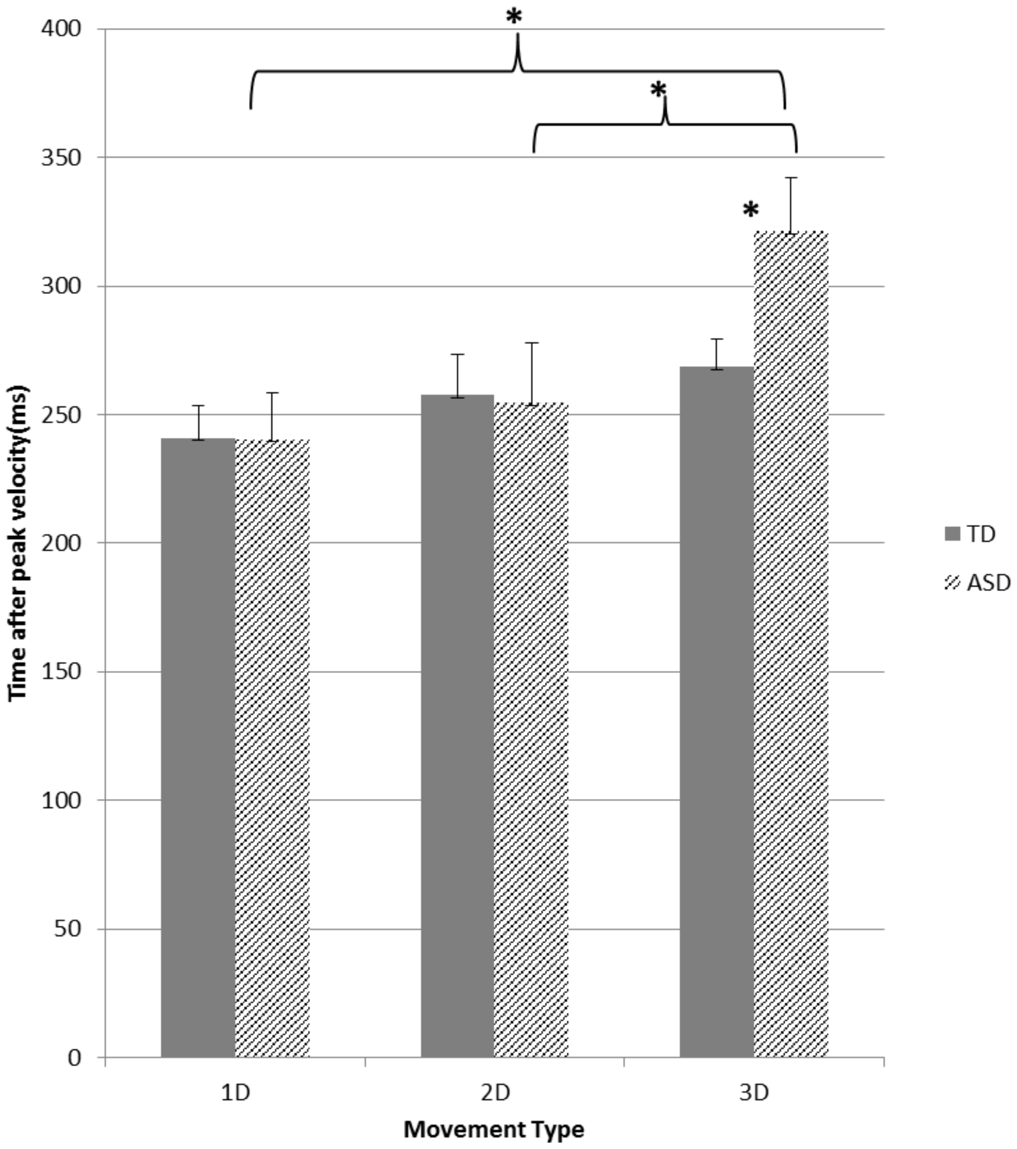

Figure 12. Mean time after peak velocity (ms) and standard error bars as a function of group and movement type.

Spatial Variability at kinematic landmarks (PA, PV, PD END)

Analysis of spatial variability (2 Group by 4 Landmark by 3 Movement type) showed significant main effect for group, F(1, 20)=4.77, *p*<0.05, and landmark, F(3, 60)=50.46, *p*<0.001. Participants in the TD group (M=9.25mm, SD=5.13) were more consistent compared to the ASD group (M=11.4mm, SD=6.5). In addition, participants had less variability at PA and END compared to PV and PD (Figure 13).

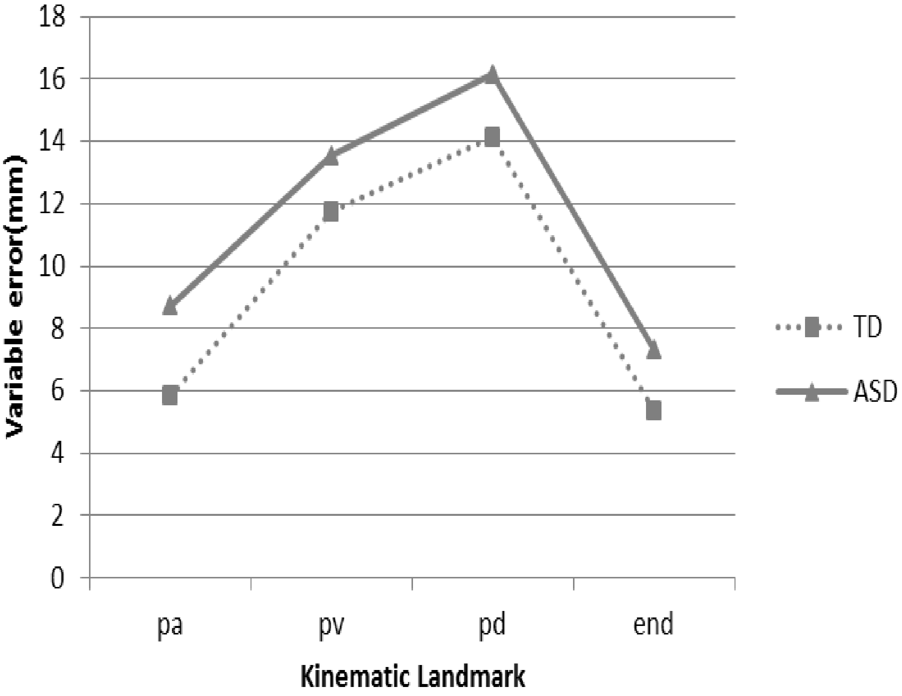

Figure 13. Variable Error at kinematic markers as a function of group.

Discussion

Although researchers consistently report differences in how individuals with ASD perform reaching movements, the specific differences are not consistent or agreed on. One possible reason for the discrepancies is the different types of movements used by different researchers. The current study therefore compared the performance of TD people and individuals with ASD in three different rapid aiming movements with different complexities. Previous studies have mixed sliding movements (Mackrous & Proteau, 2007; Proteau, 2005) and aiming movements (Grierson & Elliott, 2007; Elliott, Hansen, Mendoza, & Tremblay, 2004)) in studying human motor control and treated both types of movements as if these are the same. Researchers also used both sliding and aiming movements to study fine motor control of people with ASD. To clarify potential differences in sliding and aiming movements, and to further understand the strategies of both TD participants and participants with autism, we designed three movements: sliding along a groove, sliding freely on a tabletop, and a natural aiming movement. We used detailed analyses of both performance measures and kinematic measures to clarify the differences between the different movement types in TD participants and participants with Autism. Moreover, an electromyography system was used to measure the onset of muscle activity in both groups. The analysis of the onset of muscle activity (Premotor RT) tells us the time needed for the central nervous system to process the specific information of the target and external environment, develop and initiate a plan for the movement.

Performance Measures

Overall the reaction time of TD and ASD participants did not differ between each other. In addition, reaction times were not significantly different among the three different movements within each group. This first result contradicts previous findings reported in the literature (Mari et al., 2003; Glazebrook et al., 2006; Rinehart et al., 2006). In all cases people with autism required more time to prepare their movements compared to typically developing people. It is possible that differences in the movement type and/or target arrangement led to this difference. Mari et al.’s (2003) experiments used a reaching and grasping task, which was more complex than reaching movements. In Glazebrook et al. (2006) and Rinehart et al.’s (2006) experiments, the possible targets were in two different directions: Right or Left. In the present experiment the targets were always midline. It is also possible that the differences in RT in Glazebrook et al. (2006) and Rinehart et al. (2006) resulted from the poor attention shifting ability of people with ASD (Courchesne et al., 1990; Wainwright-sharp & Bryson, 1993). Therefore, it may be more difficult for the people with ASD to search for targets further away from the fixation cue in left and right hemi-space. Another explanation is that if the target appears on two sides, participants cannot expect where the target will be. In the current study all participants knew the exact direction and hand they would use, as well as the approximate movement distance. As a result, participants could plan most of the movement ahead of time (Rosenbaum, 1980). Bock and Arnord (1992) found that if participants know the movement direction before the movement, they would have a shorter reaction time. In addition, Glazebrook et al. (2008) and Nazarali et al. (2009) reported that both TD people and ASD people could plan ahead if they knew information of the upcoming movement (e.g. direction, hand which they would use, movement amplitude). The ability to plan the movement in advance probably eliminated the different reaction times between the two groups. The latter result is different from the previous hypothesis that participants would have a longer reaction time in 3D movements because of the higher complexity. However, the results of the fractionated reaction time provided us a better understanding of the planning portion. Only participants in the TD group had longer premotor reaction times in 1D and 2D movements compared to 3D movements. One explanation for this difference is that TD participants perform countless 3D movements in their daily life. For example, when they use their phones, when they reach and grasp a cup, and when they eat, they will perform aiming movements. On the other hand, there are not many activities that require us to slide our finger (1D and 2D movements) and therefore 1D and 2D movements may not be performed as often as a 3D movement in our daily life. In summary, TD participants were faster in processing the stimulus information and planning the movement when performing aiming movements compared to sliding movements. This result is consistent with Ando, Kida and Odo (2002), who found that with practice (three blocks of 25 trials five days a week for three weeks) participants' premotor reaction times improved (i.e., were shorter). However, premotor reaction time did not vary among the three different movements in people with autism.

The current study also found TD people had shorter movement times compared to ASD people for 3D movements. But the movement times for 1D and 2D movements did not differ between the two groups. The first result was consistent with what Glazebrook et al. (2006) found. These researchers reported that people with autism required more time to execute their aiming movements. The latter finding is consistent with Rinehart et al.'s (2006) result that people with autism did not exhibit motor slowness. It is possible that people with ASD benefited from the additional tactile feedback, but TD participants did not gain any additional benefit from the additional feedback. On the other hand, aiming movements may be more difficult for individuals with autism to execute due to the additional degree(s) of freedom compared to sliding movements. That is, people with ASD may spend more time executing aiming movements since aiming movements may be more difficult to control. The two groups did not vary in their endpoint accuracy. However, the TD group had an overall larger variable error than the ASD group, which is similar to Glazebrook et al.’s (2006) and Papadopoulos et al.’s (2012) results. More endpoint variability reflects deficits in feedforward and feedback control, which is a function of the cerebellum (Bastian, 2006). Rosenbaum (1991) demonstrated that people with a cerebellum lesion had difficulty landing on the target. In addition to the variability at the endpoint, people with ASD also exhibited larger overall variability at kinematic landmarks (peak acceleration, peak velocity and peak deceleration). According to Timmann et al. (2001), cerebellar patients and unskilled participants had more variability in finger position when they perform overarm throwing movements. Based on this finding, people with ASD may have problems in their cerebellum area.

Kinematic Measures

As is discussed above, for 3D movements the ASD group spent more time after peak velocity compared to the TD group; but the two groups did not differ in time to peak velocity. The reason why other researchers (Glazebrook et al., 2006 & Rinehart et al., 2006) found different reaction times, but the current study did not can be used to explain this discrepancy since there is thought to be only a small amount of online control from movement initiation to when people reach peak velocity (Elliott et al., 2010). This period is closely related to movement preparation. Relative to other studies, the current study decreased the difficulty of movement preparation as the target always appeared in the same direction. As a result, people with ASD may have been better able to prepare their movements ahead of time compared to previous studies (Glazebrook et al., 2006, Rinehart et al., 2006). Post Hoc analysis (Tukey's HSD, group by movement interaction) of time after peak velocity also revealed that the ASD group spent more time from deceleration initiation to movement end in 3D movements compared to the TD group. This result reveals that people with autism may have difficulty in using visual feedback to control their movement compared to TD people. However, when participants had additional tactile feedback (1D and 2D movements), people with ASD had shorter time after peak velocity in 1D and 2D movements compared to 3D movements, but this phenomenon did not exist in the TD group. This result indicates that tactile feedback helped improve the performance in ASD group, but not in the TD group. Mostofsky et al. (2009) stated that people with autism had better local connections than global connections in the cortical regions of the brain. The distance between the primary visual cortex and the primary motor cortex is further than that between the primary somatosensory cortex and the primary motor cortex. Therefore there may be more connections between the frontal lobe and parietal lobe. As a result, tactile feedback may be more important for movement execution in the ASD group compared to the TD group. In the TD group, visual feedback is a primary source for online control. Thus, the additional tactile feedback did not change their performance significantly. This explanation is consistent with Haswell et al. (2009), who reported that people with ASD relied more on their proprioceptive feedback instead of visual feedback when they learned a novel reaching movement.

The current study found that participants had larger peak acceleration, larger peak deceleration, and shorter time to peak velocity in 3D movements compared to 1D and 2D movements. All three factors contributed to a faster reaching movement. Higher peak accelerations are thought to reflect a more pre-planned movement, which means that participants have better pre-planning when they performed a three dimensional movement. In other words, participants are more familiar with 3D movements compared to 1D and 2D movements. A shorter time to peak velocity will help the performer have more time in the subsequent control phase which in turn will make the endpoint more accurate. Higher peak decelerations means that the control phase was more effective. The instructions for all participants were to: “perform as quickly and as accurately as you could”. A higher peak deceleration would help participants to land on the target more quickly, which will optimize their performance and make the movement as fast and accurate as possible. In summary, the difference between the three kinds of movements may be a result of practice. That is, people use 3D movements much more than 1D and 2D movements to complete activities of daily living.

However, for both groups the larger peak acceleration, larger peak deceleration, and shorter time to peak velocity in 3D movements did not result in shorter movement times. In fact the longer time after peak velocity in 3D movements, when compared to 1D and 2D movements, eliminated any time advantage participants in both groups built before they reached peak velocity. Thus, the movement times did not differ through three different movement types. Participants in the ASD group spent significantly more time after peak velocity compared to TD group. This longer duration made the overall movement time of 3D movements even longer for participants in the ASD group. There was also a trend for participants with ASD to be faster performing 1D movements compared to 3D movements. However, the overall pattern of the two groups was similar (no statistical differences were found in ttPV/MT and taPV/MT. The above pattern of results is consistent with 3D movements being more difficult for individuals with ASD to control.

Effect of practice and constrained movements

In the current study, we found that both TD and ASD participants had better performance in the acceleration phase of the 1D and 2D movements compared to 3D movements. There are three possible explanations.

Schneider and Shiffrin (1977) proposed the controlled processing theory. Controlled processing is slow, attention demanding, serial in nature, and strongly volitional. In contrast to controlled processing, Schneider, Dumais and Shiffrin (1984) proposed another processing: automatic processing, which is fast, not attention demanding, parallel in nature, and not volitional. It is possible that when we perform an aiming movement that is included in our everyday life, it is controlled more automatically. However, participants may use more controlled processing for a sliding movement compared to an aiming movement.

The results of premotor reaction time can be also explained by the controlled processing theory. Premotor reaction time is the time from stimulus onset to the initiation of muscle activity. It consists of stimulus identification, response selection, and response programming. Stimulus identification (target appeared) and response selection (moving finger from start position to the light) were identical for the three different movement types. Therefore it follows that as a result of practice participants had more automatic processes for the motor programming phase when performing aiming movements compared to performing sliding movements.

Another explanation is the Schema theory proposed by Schmidt in 1975. Schema theory proposes that people first select a generalized motor program (GMP) when they perform a movement, then add parameters as required to specify how the movement is executed in a specific condition. In Schema theory, there are two kinds of memory: recall memory and recognition memory. Recall memory is proposed to be responsible for movement production and recognition memory is proposed to be used for movement evaluation. For example, drawing a picture using one’s dominant hand requires more recall memory, and using one’s non-dominant hand to draw the same picture may require more recognition memory. Comparing planning of sliding movements and aiming movements, the former probably requires more recognition memory while the latter one needs more recall memory in both planning and execution phases.

A third explanation is that 1D and 2D movements are more constrained movements compared to 3D movements. 3D movements are natural reaching movements as participants were able to move in all dimensions. In 1D and 2D movements, the degree(s) of freedom participants had available were constrained to fewer dimensions. Planning 3D reaching movements may therefore be easier and more familiar for participants, which resulted in higher PV and shorter time to peak velocity. When performing 1D and 2D movements, participants should try to limit their movements in the designated dimensions, which may have led to longer time to peak velocity. That said, it should be noted that for individuals with ASD the opposite pattern was present during the primary control phase (time after peak velocity) which suggests that participants with ASD have more difficulty performing 3D movements.

Limitations

One limitation of the current study is the number of participants in the ASD group. Only eleven participants are included, which is not necessarily a representative sample, and two participants' data were removed as the mean of their movement times were longer than the mean of all plus 2.5 standard deviations. As ASD is a disorder with large variability, more participants will make the results more accurate. Moreover, the ASD group can be divided into more detailed subgroups, e.g. Asperger group and Autism group. A larger sample would allow more specific analyses related to diagnosis.

Another limitation is the electromyography testing. Some of the people with ASD found it difficult to follow the instruction to "relax your muscles" in order to get the baseline needed for calculating onset of muscle activity. On the other hand, TD participants could easily follow this instruction and stay relaxed until the appearance of the target. However, some of the people with ASD found it hard to follow this instruction. When processing their EMG data, the researcher found that some of the participants with autism had a lot of muscle activity in their baseline. As a result, it was difficult to calculate their premotor reaction time.

A third limitation is that the current experiment was performed in two labs, one with a big window and one without. Though there are blinds to block the sunshine in the lab with windows, it is still hard to make the light the same all the time.

Future Directions

One future direction is to examine the effect of practice of one dimensional movements in the TD group. The current study found that the TD participants were more effective and consistent when they performed a three dimensional (aiming) movement compared to a one dimensional movement. One explanation for the result is that participants perform a lot of aiming movements in their daily life, but they do not often execute sliding movements. To confirm this, we can design an experiment to see if people will improve their performance after practicing one dimensional (sliding) movements.

Another future direction is to compare sliding movements between TD participants and ASD participants in a No Vision condition. In the current study, vision was the dominant source of sensory feedback. It may overwhelm other sources of feedback (proprioception, tactile). When vision is removed, participants will rely more on proprioceptive feedback in the control phase. According to the finding that people with ASD have more local connections in their brain, they may have better performance compared to TD participants in a no vision condition.

A third future direction is to examine how people adjust their movements to a perturbation in a more familiar movement (three dimensional) and a less familiar movement (one dimensional). Based on the current study, participants had better preparation of the three dimensional movements compared to one dimensional and two dimensional movements. It was considered that at the very beginning of goal-directed movement, the movement was ballistic. However, more recent studies found that people make some adjustment before they reached peak velocity. But only few researches have studied the online control before participants reached peak velocity

(Grierson & Elliott, 2008). As a result, it will be meaningful to study how people adjust their movements to a perturbation in a more familiar movement (three dimensional) and a less familiar movement (one dimensional).

Conclusion

The current study examined how people with and without autism plan and executing three different reaching movements. The results from the current study showed that TD participants used different strategies to plan and execute the three different reaching movements. Participants were more efficient in three dimensional movements compared to one dimensional and two dimensional movements in the pre-planned phase. In addition, ASD participants showed similar movement patterns (ttPV/MT) in the three different movement types. However, the ASD group spent more time to execute three dimensional movements compared to the TD group though the two groups showed similar movement patterns. But movement times between the two groups did not differ in one dimensional and two dimensional movements. One explanation for the above difference is that individuals with ASD may have difficulty in using visual feedback to guide their movements. Additional tactile sensory feedback during one and two-dimensional movements help them to land on the target more quickly and maintain the accuracy at the same time. The longer movement times of the ASD group when performing 3D movements was due to longer times after peak velocity. Therefore, it is also possible that the longer MTs associated with 3D movements for the ASD group specifically may reflect difficulty controlling the additional degrees of freedom associated with aiming (3D) movements. The former explanation is consistent with previously reported behavioural and brain imaging research that has reported different brain connections (Mostofsky & Even, 2011) in ASD participants that indicate they may rely more on proprioceptive feedback to control a movement (Haswell et al., 2009).

References

Ando, S., Kida, N., & Oda, S. (2002). Practice effects on reaction time for peripheral and central visual fields. *Perceptual and Motor Skills*, *95*, 747–751.

Autism Speaks (2013). Autism speaks. Retrieved from http://www.autismspeaks.ca/

Ballanger, B., & Boulinguez, P. (2009). Short communication EMG as a key tool to assess motor lateralization and hand reaction time asymmetries, *179*, 85–89. http://doi.org/10.1016/j.jneumeth.2009.01.005

Berardelli, A., Hallett, M., Roth, J. C., Agostino, R., Manfredi, M., & Thompson, P. D. (1996). Single-joint rapid arm movements in normal subjects and in patients with motor disorders. *Brain*, 661–674.

Binsted, G., Chua, R., Helsen, W., & Elliott, D. (2001). Eye-hand coordination in goal-directed aiming. *Human Movement Science*, *20*(4-5), 563–85. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11750678

Blakemore, S.-J., Tavassoli, T., Calò, S., Thomas, R. M., Catmur, C., Frith, U., & Haggard, P. (2006). Tactile sensitivity in Asperger syndrome. *Brain and Cognition*, *61*(1), 5–13. http://doi.org/10.1016/j.bandc.2005.12.013

Bock, O., & Arnold, K. (1992). Motor control prior to movement onset: preparatory mechanisms for aiming at visual targets *Experimental Brain Research*, 9, 209–216.

CDC estimates 1 in 68 children has been identified with autism spectrum disorder. (2014, March 27). Retrieved March 26, 2015, from http://www.cdc.gov/media/releases/2014/p0327-autism-spectrum-disorder.html

Chua, R., & Elliott, D. (1993). Visual regulation of manual aiming. *Human Movement Science*, *12*(4), 365–401. http://doi.org/10.1016/0167-9457(93)90026-L

Courchesne, E., Townsend, J., Akshoomoff, N., Saitoh. O., Yeung-Courchesne, R., Lincoln, A., James, H., Haas, R., & Lau, L. (1994). Impairment in Shifting Attention in Autistic and Cerebellar Patients. *Behavioral Neuroscience, 108*(5), 848-865.

Dominick, K. C., Ornstein, N., Lainhart, J., Tager-flusberg, H., & Folstein, S. (2007). Atypical behaviors in children with autism and children with a history of language impairment, *28*, 145–162. http://doi.org/10.1016/j.ridd.2006.02.003

Dowd, A. M., McGinley, J. L., Taffe, J. R., & Rinehart, N. J. (2012). Do planning and visual integration difficulties underpin motor dysfunction in autism? A kinematic study of young children with autism. *Journal of Autism and Developmental Disorders, 42*(8), 1539–48. http://doi.org/10.1007/s10803-011-1385-8

Elliott, D., Hansen, S., Grierson, L. E. M., Lyons, J., Bennett, S. J., & Hayes, S. J. (2010). Goal-directed aiming: two components but multiple processes. *Psychological Bulletin*, *136*(6), 1023–44. http://doi.org/10.1037/a0020958

Elliott, D., Hansen, S., Mendoza, J., & Tremblay, L. (2004). Learning to optimize speed, accuracy, and energy expenditure: a framework for understanding speed-accuracy relations in goal-directed aiming. *Journal of Motor Behavior*, *36*(3), 339–51. http://doi.org/10.3200/JMBR.36.3.339-351

Field, T., Sanders, C., & Nadel, J. (2001). Children with Autism Display more Social Behaviors after Repeated Imitation Sessions. *Autism*, *5*(3), 317–323. http://doi.org/10.1177/1362361301005003008

Forgaard, C. J., Maslovat, D., Carlsen, A. N., Chua, R., & Franks, I. M. (2013). Startle reveals independent preparation and initiation of triphasic EMG burst components in targeted ballistic movements. *Journal of Neurophysiology*, (August). http://doi.org/10.1152/jn.00888.2012

Fournier, K. a, Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: a synthesis and meta-analysis. *Journal of Autism and Developmental Disorders*, *40*(10), 1227–40. http://doi.org/10.1007/s10803-010-0981-3

Glazebrook, C., Gonzalez, D., Hansen, S., & Elliott, D. (2009b). The role of vision for online control of manual aiming movements in persons with autism spectrum disorders. *Autism: The International Journal of Research and Practice*, *13*(4), 411–33. http://doi.org/10.1177/1362361309105659

Glazebrook, C. M., & Elliott, D. (2008). How do Individuals with Autism Plan Their Movements?, 114–126. http://doi.org/10.1007/s10803-007-0369-1

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, 244–264.

Grierson, L. E. M., & Elliott, D. (2008). Kinematic analysis of goal-directed aims made against early and late perturbations: an investigation of the relative influence of two online control processes. *Human Movement Science*, *27*(6), 839–56. http://doi.org/10.1016/j.humov.2008.06.001

Happé, F., & Frith, U. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *36*(1), 5–25. http://doi.org/10.1007/s10803-005-0039-0

Haswell, C. C., Izawa, J., Dowell, L. R., Mostofsky, S. H., & Shadmehr, R. (2009). Representation of internal models of action in the autistic brain. *Nature Neuroscience*, *12*(8), 970–2. http://doi.org/10.1038/nn.2356

Helsen, W. F., Elliott, D., Starkes, J. L., & Ricker, K. L. (2000). Coupling of eye, finger, elbow, and shoulder movements during manual aiming. *Journal of Motor Behavior*, *32*(3), 241–8. http://doi.org/10.1080/00222890009601375.

Ingersoll, B. (2008). Imitation in Autism Implications for the Treatment of Imitation deficits and social communication, *21*(2), 107–119.

Kelso, J. a, Fink, P. W., DeLaplain, C. R., & Carson, R. G. (2001). Haptic information stabilizes and destabilizes coordination dynamics. *Proceedings. Biological Sciences / The Royal Society*, *268*(1472), 1207–13. http://doi.org/10.1098/rspb.2001.1620

Khan, M. a., Franks, I. M., & Goodman, D. (2010). The Effect of Practice on the Control of Rapid Aiming Movements: Evidence for an Interdependency Between Programming and Feedback Processing. *The Quarterly Journal of Experimental Psychology Section A*, *51*(2), 425–443. http://doi.org/10.1080/713755756

Koldewyn, K., Whitney, D., & Rivera, S. M. (2010). The psychophysics of visual motion and global form processing in autism, (2009). http://doi.org/10.1093/brain/awp272

Light, K. E., Reilly, M. A., Behrman, A. L., & Spirduso, W. W. (1996). Reaction Times and Movement Times: Benefits of Practice to Younger and Older Adults, 27–41.

Loveland, K. a, & Landry, S. H. (1986). Joint attention and language in autism and developmental language delay. *Journal of Autism and Developmental Disorders*, *16*(3), 335–49. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3558291

Mackrous, I., & Proteau, L. (2007). Specificity of practice results from differences in movement planning strategies. *Experimental Brain Research*, *183*(2), 181–93. http://doi.org/10.1007/s00221-007-1031-z

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003). The reach-to-grasp movement in children with autism spectrum disorder, (January), 393–403. http://doi.org/10.1098/rstb.2002.1205

Molloy, C. a, Dietrich, K. N., & Bhattacharya, A. (2003). Postural stability in children with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *33*(6), 643–52. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14714933

Mostofsky, S. H., Dubey, P., Jerath, V. K., Jansiewicz, E. M., Goldberg, M. C., & Denckla, M. B. (2006). Developmental dyspraxia is not limited to imitation in children with autism spectrum disorders. *Journal of the International Neuropsychological Society: JINS*, *12*(3), 314–26. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16903124

Mostofsky, S. H., & Ewen, J. B. (2011). Altered connectivity and action model formation in autism is autism. *The Neuroscientist: A Review Journal Bringing Neurobiology, Neurology and Psychiatry*, *17*(4), 437–48. http://doi.org/10.1177/1073858410392381

Mostofsky, S. H., Goldberg, M. C., Landa, R. J., & Denckla, M. B. (2000). Evidence for a deficit in procedural learning in children and adolescents with autism: implications for cerebellar contribution. *Journal of the International*

Neuropsychological Society: JINS, *6*(7), 752–9. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11105465

Mostofsky, S. H., Powell, S. K., Simmonds, D. J., Goldberg, M. C., Caffo, B., & Pekar, J. J. (2009). Decreased connectivity and cerebellar activity in autism during motor task performance. *Brain: A Journal of Neurology*, *132*(Pt 9), 2413–25. http://doi.org/10.1093/brain/awp088

Nakano, T., Kato, N., & Kitazawa, S. (2012). Superior haptic-to-visual shape matching in autism spectrum disorders. *Neuropsychologia*, *50*(5), 696–703. http://doi.org/10.1016/j.neuropsychologia.2011.12.024

Papadopoulos, N., McGinley, J., Tonge, B. J., Bradshaw, J. L., Saunders, K., & Rinehart, N. J. (2012). An investigation of upper limb motor function in high functioning autism and Asperger’s disorder using a repetitive Fitts' aiming task. *Research in Autism Spectrum Disorders*, *6*(1), 286–292. http://doi.org/10.1016/j.rasd.2011.05.010

Plaisted, K., Swettenham, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *40*(5), 733–42. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10433407

Plamondon, R., Djioua, M., & Mathieu, P. a. (2012). Time-dependence between upper arm muscles activity during rapid movements: Observation of the proportional effects predicted by the kinematic theory. *Human Movement Science*. http://doi.org/10.1016/j.humov.2012.07.006

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*(6), 757–67. http://doi.org/10.1007/s10803-006-0118-x

Saunders, J. a, & Knill, D. C. (2004). Visual feedback control of hand movements. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *24*(13), 3223–34. http://doi.org/10.1523/JNEUROSCI.4319-03.2004

Schlooz, W. a. J. M., & Hulstijn, W. (2012). Atypical visuomotor performance in children with PDD. *Research in Autism Spectrum Disorders*, *6*(1), 326–336. http://doi.org/10.1016/j.rasd.2011.06.006

Sigman, M., Dijamco, A., Gratier, M., & Rozga, A. (2004). Early detection of core deficits in autism. *Mental Retardation and Developmental Disabilities Research Reviews*, *10*(4), 221–33. http://doi.org/10.1002/mrdd.20046

Simmons, R. W., Wass, T., Thomas, J. D., & Riley, E. P. (2002). Fractionated simple and choice reaction time in children with prenatal exposure to alcohol. *Alcoholism, Clinical and Experimental Research*, *26*(9), 1412–9. http://doi.org/10.1097/01.ALC.0000030563.14827.29

Solomon, H. Y., & Turvey, M. T. (1988). Haptically perceiving the distances reachable with hand-held objects. *Journal of Experimental Psychology: Human Perception and Performance*, *14*(3), 404–427. http://doi.org/10.1037//0096-1523.14.3.404

Stone, W. L., Ousley, O. Y., & Littleford, C. D. (1997). Motor Imitation in Young Children with Autism: What ' s the Object?, 25(6), 475–485.

Timmann, D., Citron, R., Watts, S., Hore, J., Kurtzer, I., Trautman, P., … Harris, C. (2001). Increased Variability in Finger Position Occurs Throughout Overarm Throws Made by Cerebellar and Unskilled Subjects Increased Variability in Finger Position Occurs Throughout Overarm Throws Made by Cerebellar and Unskilled Subjects. *J Neurophysiol*, *86*(6), 2690–2702.

Wagner, J. M., Dromerick, A. W., Sahrmann, S. A., & Lang, C. E. (2007). Upper extremity muscle activation during recovery of reaching in subjects with post-stroke hemiparesis, *118*, 164–176. http://doi.org/10.1016/j.clinph.2006.09.022

Whyatt, C., & Craig, C. M. (2013). Research in Autism Spectrum Disorders Interceptive skills in children aged 9 – 11 years , diagnosed with Autism Spectrum Disorder. *Research in Autism Spectrum Disorders*, *7*(5), 613–623. http://doi.org/10.1016/j.rasd.2013.01.003

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*(3), 285–99. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15264497

Appendix A

Reaction time: From the time when the target appears to the time when participants leave the start position. (How long the performers plan and prepare their movement)

Premotor (Reaction) time: From the time when target appears to the time when there is a burst in participant's muscle. (How long our central nervous system needs to organize the specific information of the upcoming movement, and initiate a movement plan.)

Motor (Reaction) time: From the time when there is a burst in the agonist muscle to the initiation of the movement (the time the muscle requires to produce enough force to initiate the movement)

Movement time: From the time when participants leave the home position to the time when they reach the target. (How long participants take to execute their movement)

Constant Error: Distance from endpoint to the center of the target. (Accuracy of the endpoint)

Variable Error: standard deviation at endpoint. (How consistent their movements are).

Peak Velocity: Maximum velocity during the movement.

Peak Acceleration: Maximum acceleration during the movement.

Peak deceleration: Maximum deceleration during the movement.

Appendix B

UNIVERSITY OF MANITOBA

FACULTY OF KINESIOLOGY AND RECREATION MANAGEMENT

319 Max Bell Centre
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Winnipeg, MB R3T 2N2
Telephone (204) 474-8773
cheryl.glazebrook@umanitoba.ca

ASSENT FORM: Individuals with Autism
How do individuals with and without autism plan and execute three different reaching movements?

PRINICIPAL INVESTIGATOR:

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SUPERVISOR:

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OTHER INVESTIGATORS:

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Student Research Assistants:

Aric Bremer, Kelsey Brown, Brie Page, Tamires Prado
Faculty of Kinesiology & Recreation Management

SOURCE OF SUPPORT: MHRC Establishment Grant

WHY YOU ARE HERE?

We are interested in better understanding how you perform three aiming tasks with different complexities. This form tells you about the study. If there is anything you do not understand, please ask your parent, your guardian or the study staff.

WHY ARE THEY DOING THIS STUDY?

We are doing this study to see how you perform three different aiming tasks. We want to see if we can learn about how you perform these tasks so that we can help design new activities. You can choose to do one, more, or none of the activities that we tell you about.

WHAT WILL HAPPEN?

If you want to be in the study these things will happen:

1. We will put electrodes on your muscles so we can know your muscle activity during your movement.

2. We will ask you to put a small marker on your finger, wrist, and arm so that we can record how you move your arm

3. We will ask to perform three different movements. The study will last about 1 hour.

4. You will also be asked to complete two other activities. For the first one the investigator will read a word out loud and you will be asked to point to the picture that is the same as the word. For the second one you will look at different pictures of patterns and pick the piece that completes the pattern. Together these activities will take less than 1 hour to complete.

5. If we do everything in one day it will take about 2 hours to complete. We can take breaks any time you would like to. You can just tell me.

6. We will ask you parent or guardian to write down any medications you take.

7. If you would like your parent or guardian to stay here during the testing just ask him or her if that is okay.

WHAT IF YOU HAVE ANY QUESTIONS?

You can ask questions any time, now or later.

WHO WILL KNOW WHAT I DID IN THE STUDY?

Any information you give to the study staff will be kept secret. Only the researchers will be able to look at any of the information you provide us. The researchers will make a report but no one will know who completed the activities because your name will not be on any study paper and no one but the study staff will know that it was you who was in the study.

DO YOU HAVE TO BE IN THE STUDY?

You do not have to be in the study. No one will be upset if you don't want to do this. If you don't want to be in this study, just say so. We will also ask your parents if they would like you to be in the study. Even if your parents want you to be in the study you can still say no. Even if you say yes now you can change your mind later. It's up to you.

DO YOU HAVE ANY QUESTIONS?
WHAT QUESTIONS DO YOU HAVE?

Assent

I want to take part in this study. I know I can change my mind at any time.

Name: ___________________________ Verbal assent given Yes
Print name of Participant

________________________ ___________ ________________
Signature of Participant Age Date

I confirm that I have explained the study to the participant to the extent compatible with the participants understanding, and that the participant has agreed to be in the study.

_____________________ ________________ _____________
Printed name of Signature of Date
Person obtaining assent Person obtaining assent

FUTURE STUDIES:

The researchers will do other studies like the one you are doing today. Is it okay with you if we ask you if you would like to participate in another study? You can change your mind at any time. We will also ask your Mom/Dad/Guardian.

Appendix C

UNIVERSITY OF MANITOBA

FACULTY OF KINESIOLOGY
AND RECREATION
MANAGEMENT

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INFORMED CONSENT FORM: Parent/Guardian/Individual with ASD

How do individuals with and without autism plan and execute three different reaching movements

PRINICIPAL INVESTIGATOR:

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Faculty of Kinesiology & Recreation Management

SOURCE OF SUPPORT: MHRC Establishment Grant

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PURPOSE: We are interested in learning how individuals with and without an Autism Spectrum Disorder plan and execute 1 dimensional, 2 dimensional and 3 dimensional aiming movements.

DESCRIPTION: During the study, you will be asked to make a series of aiming movement to target lights. An electromyography (EMG) machine will be used to record your muscle activity when performing these tasks and an OPTOTRAK 3D motion analysis system will be used to record your finger and hand movements. Prior to this task, you will be asked to fill out a brief demographics questionnaire that inquires about your age, gender, handedness, whether you wear glasses, specific ASD diagnosis, and any medications that you take. The whole procedure will take less than one hour to complete.

You will also be asked to complete two other activities. For the first one the investigator will read a word out loud and you will be asked to point to the picture that is the same as the word (the Peabody Picture Vocabulary Test). For the second one you will look at different pictures of patterns and pick the piece that completes the pattern (Raven's Progressive Matrices). Together these activities will take less than 1 hour to complete

RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in the arm you are pointing with. While this may be frustrating to you, there will always be an investigator with you to assist you and support you. In addition, the EMG electrodes may cause minor skin irritation. The experimenter will demonstrate on his/herself so that you aware what will happen before making a decision.

Participation in this experiment will not directly lead to any health benefits. You will gain hands on knowledge of advanced movement analysis equipment and current perceptual-motor research. Participation in this experiment will contribute to our understanding of how humans interact with their environment that will in turn contribute to the design of human-computer interfaces and rehabilitation programs.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. You will not receive payment. If you require transportation to the Perceptual-Motor Behaviour Laboratory at the University of Manitoba we will provide a taxi to and from the study. Participants will receive a gift card for Tim Hortons to thank the participants for donating their time. The amount of the gift card will be proportional to the time duration of the study. Specifically, ten dollars per hour, rounded up to the nearest half hour. For example, if the protocol is 90 minutes then participants will receive a $15 gift card.

CONFIDENTIALITY: Your information will be kept confidential. You will be referred to by a code number. All files containing identifying information (specifically the consent forms) will be stored in a locked cabinet separate from data with your code number. Your consent forms will only be accessible by the investigators and student research assistants and will be destroyed 5 years after the completion of the study (approximately December, 2019). All papers containing identifying information will be shredded and all electronic files containing identifying information will be deleted. Only Drs. Glazebrook and Passmore, or students: Ran Zheng, Aric Bremer, Kelsey Brown, Brie Page and Aric Bremer will have access to any lists that contain identifying information. In summary, all papers and electronic files containing personal information will only be accessible by the investigators and will be shredded, deleted or destroyed, 5 years after the completion of the study by Dr. Glazebrook.

Results will be presented at academic conferences, invited presentations, and published in peer reviewed academic journals. In almost all cases only group means will be presented. In some cases individual movement will be presented (a graph that depicts one movement pathway. This data will contain no identifiable information and therefore your anonymity will be maintained.

DEBRIEFING: Upon completion of the study the Student Research Assistant will describe the research
questions we are testing. If you would like to know the results of the study you may contact the
Principal Investigator (Ran Zheng) in approximately 4 months and he will email a summary of the findings. If you like you may also contact Mr. Zheng's supervisor, Dr. Glazebrook for a copy of the results.

VOLUNTARY CONSENT: If you do not wish to participate in the study, you are free to leave without consequence and we thank you for your consideration. Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you simply have to tell the student research assistant. If you wish for your data not to be used you just have to tell the student research assistant and we will delete your data at that time. If you choose to withdraw from the study you will still receive compensation (gift card) for the time you have participated.
The University of Manitoba Research Ethics Board(s) and a representative(s) of the University of Manitoba Research Quality Management / Assurance office may also require access to your research records for safety and quality assurance purposes.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or margaret.bowman@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

____
Printed Name of Participant/Parent/Guardian

____
Relationship to Participant

____________________________________ ________________________________
Signature of Participant/Parent/Guardian Date

____
Printed Name of Investigator

____________________________________ ________________________________
Signature of Investigator Date

Appendix D

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INFORMED CONSENT FORM: Age-matched controls

How do individuals with and without autism plan and execute three different reaching movements

PRINICIPAL INVESTIGATOR:
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SUPERVISOR:
Dr. Cheryl Glazebrook
Faculty of Kinesiology & Recreation Management
Health, Leisure, & Human Performance Research Institute
University of Manitoba
(204) 474-8773
cheryl.glazebrook@umanitoba.ca

OTHER INVESTIGATORS:
Dr. Steven Passmore
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Student Research Assistants:
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Faculty of Kinesiology & Recreation Management

SOURCE OF SUPPORT: MHRC Establishment Grant

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RISKS AND BENEFITS: There are no evident risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in the arm you are pointing with. While this may be frustrating to you, there will always be an investigator with you to assist you and support you. In addition, the EMG electrodes may cause minor skin irritation. The experimenter will demonstrate on his/herself so that you aware what will happen before making a decision.

Participation in this experiment will not directly lead to any health benefits. You will gain hands on knowledge of advanced movement analysis equipment and current perceptual-motor research. Participation in this experiment will contribute to our understanding of how humans interact with their environment that will in turn contribute to the design of human-computer interfaces and rehabilitation programs.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. You will not receive payment. If you require transportation to the Perceptual-Motor Behaviour Laboratory at the University of Manitoba we will provide a taxi to and from the study. Participants will receive a gift card for Tim Hortons to thank the participants for donating their time. The amount of the gift card will be proportional to the time duration of the study. Specifically, ten dollars per hour, rounded up to the nearest half hour. For example, if the protocol is 90 minutes then participants will receive a $15 gift card.

CONFIDENTIALITY: Your information will be kept confidential. You will be referred to by a code number. All files containing identifying information (specifically the consent forms) will be stored in a locked cabinet separate from data with your code number. Your files will only be accessible by the investigators and student research assistants, and will be destroyed 5 years after the completion of the study (approximately December, 2019). All papers containing identifying information will be shredded. Only Ran Zheng, Aric Bremer, Kelsey Brown, Brie Page and Aric Bremer will have access to any lists that contain identifying information. Dr. Glazebrook will not be aware of who participates in the study as control participants. She will not access the consent forms unless she is required to produce the documents by Research Ethics and Compliance. She will not know your identity, except if you request for Dr. Glazebrook to email you a summary of the findings. In summary, all papers and electronic files containing personal information will only be accessible by the investigators and will be shredded, deleted or destroyed, 5 years after the completion of the study by Dr. Glazebrook.

Results will be presented at academic conferences, invited presentations, and published in peer reviewed academic journals. In almost all cases only group means will be presented. In some cases individual movements will be presented (a graph that depicts one movement pathway). This data will contain no identifiable information and therefore your anonymity will be maintained.

DEBRIEFING: Upon completion of the study the Student Research Assistant will describe the research
questions we are testing. If you would like to know the results of the study you may contact the
Principal Investigator (Ran Zheng) in approximately 4 months and he will email a summary of the findings. You can also choose to email Dr. Glazebrook, but if you do then she will know that you were a participant.

VOLUNTARY CONSENT: If you do not wish to participate in the study, you are free to leave without consequence and we thank you for your consideration. Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you simply have to tell the student research assistant. If you wish for your data not to be used you just have to tell the student research assistant and we will delete your data right away. If you choose to withdraw from the study you will still receive compensation (gift card) for the time you have participated.
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____
Printed Name of Participant

____________________________________ ________________________________

Signature of Participant Date

Printed Name of Investigator

Signature of Investigator Date

Additional Information:

If you would like to receive a general summary of the results from this study when it is completed, please complete your electronic or mailing address below:

Email Address:

Mailing Address: