An Investigation Of Upper Extremity Motor Impairments In Children Diagnosed With Autism Spectrum Disorder: Motor Planning Vs Motor Execution

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AN INVESTIGATION OF UPPER EXTREMITY MOTOR IMPAIRMENTS IN
CHILDREN DIAGNOSED WITH AUTISM SPECTRUM DISORDER:
MOTOR PLANNING VS MOTOR EXECUTION

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DEDICATION

This dissertation is dedicated to the children with Autism involved in my studies, who showed me that they are brilliant, witty, and hilarious and that maybe the world should accommodate to them, not the other way around.
AN INVESTIGATION OF UPPER EXTREMITY MOTOR IMPAIRMENTS IN CHILDREN DIAGNOSED WITH AUTISM SPECTRUM DISORDER:

MOTOR PLANNING VS MOTOR EXECUTION

by

PATRICK A. CERECERES, M.S.

DISSERTATION

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ABSTRACT

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder typically diagnosed when a child displays social and communication impairments, repetitive behaviors, and rhythmic movements like hand flapping. This disorder is unique because of the high variability of symptoms displayed between each individual who is diagnosed. Because of this, no neurological or physiological test exists to diagnose a child with ASD. Current diagnostic tests are various forms of interviews or observations which an experienced clinician must administer. While these tests have been instrumental in diagnosing children with ASD, many go undiagnosed, which can be detrimental as they transition into adulthood. Current literature indicates that children with ASD also display motor abnormalities. However, they are only considered secondary symptoms. The first forms of communication comes through movement at 3 months after birth. This is well before the formation of language, which begins around 12 months. Ultimately, because children with ASD display motor abnormalities, it is believed that they impact the early development of social and communication skills.

The purpose of this dissertation was to further the current literature on the motor abnormalities displayed by children with ASD through a series of experiments to test their motor planning and execution when compared to children considered neurotypical. The experiments indicated no difference in motor planning and execution between the children with ASD and those considered neurotypical. This is primarily due to small sample sizes and the nature of the studies, which only included children with mild forms of ASD. Due to the high variability between each individual with the disorder, it is suggested that implementing a single-subject design could aid in identifying the actual cause of motor abnormalities exhibited by these children. Furthermore, future studies should aim for a more inclusive method of all children on the spectrum.
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1. MOTOR DEFICIENCIES AMONG CHILDREN WITH AUTISM SPECTRUM DISORDER

1.1. Autism Spectrum Disorder

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by repetitive and restricted behavioral patterns along with impaired communication and social skills (American Psychiatric Association, 2013). ASD is classified as a social and communicative disorder. However, recent research suggests that this disorder can also be associated with various movement disorders such as muscle tremors, clumsiness, and incoordination (Bell et al., 2019). In a disorder like autism, where the communication and social deficits can hinder normal development in childhood and adolescence, movement deficiencies only further these hindrances and harm these individuals as they transition to adulthood (Robledo et al., 2012). The movement disorders that have been associated with ASD include ataxia (Fatemi & Folsom, 2013), akinesia, dyskinesia, bradykinesia, Tourette Syndrome (Donnellan et al., 2012), catatonic-like symptoms (Breen & Hare, 2017), and ambulatory impairments (Dufek et al., 2017; Eggleston et al., 2017; Eggleston, Landers, et al., 2018). Due to the high prevalence of movement disorders associated with ASD, it has led researchers to hypothesize that it could be a movement disorder itself. Past research also indicates that ASD could be a dysfunction of the cerebellum and basal ganglia (Nayate et al., 2005).

The communication and social symptoms associated with ASD must be present during the child’s early development and cause significant clinical impairment in the child’s function; however, they may not be evident during diagnosis (Hassall, 2016). Due to the high variabilities in symptoms between children with ASD, there is a spectrum in the severity of the disorder between each child, meaning that no two diagnoses are the same (Paquet et al., 2016). The cause
of ASD has been the cause of intense investigation for many years, where researchers have proposed that various genetic susceptibilities to different environmental factors lead to an increased risk of ASD (Landrigan, 2010; Kreiser & White, 2014).

While genetics contribute to ASD (Landrigan, 2010), there are discrepancies in explaining the clinical and epidemiological aspects of ASD (Daniels, 2006), which have led to the hypothesis that environmental exposure has a role in the causation of the disorder (Santangelo & Tsatsanis, 2005). There is support from many researchers that there is a need to understand the vulnerability of the developing human brain when exposed to toxins (Sealey et al., 2016). Moreover, evidence suggests that various genetic and environmental factors could be caused by brain formation abnormalities that induce ASD behavior (Bailey et al., 1995; Bolton et al., 1994).

1.1.1. Prevalence

Approximately 1 in 59 children in the United States have been diagnosed with ASD (Maenner, 2020). This statistic is 10% higher than previous results from 2014 and approximately 175% higher than results reported between 2000-2002 (Maenner, 2020). Research has also found that ASD is not limited to any race, ethnic, or socioeconomic group, and it is four times more common in males than females (Maenner, 2020). Moreover, 1 in 6 children aged 3-17 years old were diagnosed with a developmental disorder, including ASD, attention-deficit/hyperactivity disorder, blindness, and cerebral palsy, between 2009-2017 (Zablotsky et al., 2019). This indicates that more children every year are being diagnosed with a disorder like ASD, further highlighting the importance of research regarding ASD as a social/communicative disorder and a movement disorder.

The increasing prevalence of ASD has emerged as a significant health concern as more families are seeking social, educational, and health care services for the disorder than previously reported (Lyall et al., 2017). More individuals are being diagnosed with ASD there; therefore, a more
considerable burden is placed on the healthcare system to help aid families with the needs of their children. As of 2010, it is estimated that 7.7 million individuals diagnosed with ASD had to adjust their life circumstances to accommodate the disorder. It was the leading cause of mental disability among children under the age of five (Baxter et al., 2015). The increasing prevalence of ASD not only has placed an increased mental burden on these individuals and their families but there is also a high economic burden as well, where it is estimated that ASD accounts for approximately $1.5-2.5 million USD for each individual (Buescher et al., 2014). Cumulatively, this accounts for $250 billion in medical costs throughout the United States (Buescher et al., 2014). As of 2015, it was estimated that the economic burden of ASD was $286 billion and is expected to reach $461 billion by the year 2025 (Leigh & Du, 2015).

1.1.2. Diagnosis

While there appears to be a physical manifestation of the ASD, whether in motor deficits or social and communication deficits, there is no biological test to diagnose the disorder (Baird et al., 2003). Moreover, while researchers agree that ASD is a neurobiological disorder, there have not been consistent results in finding diagnostic markers via brain imaging (Baird et al., 2003). Diagnosis based on core impairments and behaviors varies highly, making diagnostic cut-offs challenging to define (Wing, 1988).

To properly diagnose ASD in a child, physicians must look at the child’s developmental and behavioral history. This involves a professional following a child through regular check-ups to determine if the child is meeting development milestones on time. ASD can be diagnosed as early as 18 months of age, while a diagnosis by an experienced professional by the age of 2 years is considered reliable (Lord et al., 2006). When a physician diagnoses a child with ASD, they will be diagnosed with a level severity of the disorder as well. There are three levels of ASD in a formal
diagnosis as indicated by the *Diagnostic and Statistical Manual of Mental Disorders*, fifth edition (DSM-V) (American Psychiatric Association, 2013). Level 1 is the least severe form of ASD and is viewed as a mild form of the disorder. These individuals require some support as they may struggle in social situations and may exhibit some forms of restrictive or repetitive behaviors (Gilmore, 2019). These individuals are able to communicate verbally and are able to have relationships but they may struggle at times. Level 2 is the mid-range of the disorder and these children will require more support than those in Level 1 (Gilmore, 2019). These children may or may not communicate verbally and they need more support when participating in social activities. They also display more repetitive behaviors and have routines that they must stick to or they will feel uncomfortable or upset. The most severe level is Level 3, where the children will require a large amount of support to accomplish daily tasks because they display repetitive behaviors which impact their independent functioning (Gilmore, 2019). Children with a Level 3 diagnosis of ASD are most nonverbal and struggle greatly with unexpected events.

The consensus among professionals is that early diagnosis of ASD is crucial to ensure the child receives the services and support needed to live a healthy life (Hyman et al., 2020). The issue, however, comes back to the spectrum of symptoms exhibited by individuals with the disorder. This can lead some children to be diagnosed with ASD later in life and, unfortunately, miss crucial therapy and support available to them (Baird et al., 2003).

The lack of consistent neuroanatomical abnormalities or biochemical indicators between individuals with ASD makes it increasingly hard for physicians and other healthcare professionals to diagnose and provide care for this population (Landrigan, 2010). It was previously believed that a diagnosis for ASD could come from signs of motor impairment and lack of coordination (Jones & Prior, 1985), and past research has shown that children with ASD exhibit motor development
that is inconsistent with their chronological age level (DeMyer et al., 1981). While evidence shows that motor impairment may be a sign of ASD in a child, it is not listed as diagnosis criteria according to the DSM-V (American Psychiatric Association, 2013).

Fortunately, several instruments have been developed to aid professionals in the assessment and diagnosis process. These instruments involve history taking, known as the autism diagnostic interview and the diagnostic interview for social and communication disorders, which are semi-structured interviews (Lord et al., 1994; Wing et al., 2002). Another commonly used instrument is the autism diagnostic observation schedule (ADOS), a play-based interactive assessment completed by a professional (Lord et al., 2000). After completing the evaluation, it is then up to coordination between health professionals and parents to provide the appropriate care and therapy for the child.

While these assessments have helped improve the diagnostic process for ASD, it is believed that motor deficits should be considered a core feature of ASD because they can further affect functions that are critical to social and communication development (Dziuk et al., 2007). An example of this is stereotypic movement, like hand-flapping, which may lead to misunderstandings between individuals with ASD and those who are considered neurotypically developing (NT), leading to further miscommunication (Lee & Bo, 2015). Furthermore, identifying motor deficits as a core feature of ASD can also help professionals differentiate individuals with ASD from other neurodevelopmental disorders (Ozonoff et al., 2008; Fournier et al., 2010). Motor abnormalities and delays in motor development have been shown as early as the first year of life, which precedes normal development of communication and social skills (Leary & Hill, 1996). Therefore, evaluations of a child’s motor development can help with the early identification of ASD (Esposito & Pasca, 2013), leading to early intervention to help the child in the future.
Past research has shown that the use of standardized motor tests, like the Henderson Test of Motor Impairment, the Movement Assessment Battery for Children, and the Bruininks-Oseretsky Test of Motor Proficiency, have all reported inconsistent results when aiming to understand the movement profile of an individual with ASD (Papadopoulos et al., 2012). However, it is believed that the use of kinematic analysis of children with ASD can be used to find consistencies in motor deficiencies among these individuals (Papadopoulos et al., 2012). Recent studies using a kinematic analysis have shown that children with ASD show greater lower extremity stiffness during gait when compared to children considered NT (Eggleston, Harry, et al., 2018). This difference in gait can be attributed to differences in sensory processing among children with ASD. However, much more research is needed to determine the optimal way to assess motor deficiencies to be considered a core feature during diagnosis among children with ASD (Lloyd et al., 2013).
1.2. Early Motor Impairment

In what is widely considered one of the earliest works to explore motor behavior among children with ASD, Kanner (1943) observed 11 children who had signs of the disorder (Paquet et al., 2016). While he observed that the most notable symptoms of ASD were the impairment of social, emotional, and communication skills, he also noted several aspects of motor development in which the children showed deficiencies. While some of the patients in his study met typical motor milestones and their fine motor skills were well-developed, some showed gross motor deficits (Sacrey et al., 2014; Paquet et al., 2016).

Parent interview-based studies have reported that children with ASD are late acquiring motor abilities, like holding up their heads, sitting, walking, and postural adjustments (Ornitz et al., 1977). Ornitz et al. (1977) reported that 47.2% of children with ASD involved in the study walked without support by the same age as 97.2% of children considered NT. The authors theorized that a dysfunction in the vestibular mechanisms might contribute to the perception of movement and balance by children with ASD (Ornitz et al., 1977; Paquet et al., 2016). A more recent study of similar scope has revealed that parents reported their child with ASD had unusual motor activity like poor imitation skills, clumsiness, and coordination difficulties within the first two years of the child’s life (Dewrang & Sandberg, 2010).

Past studies have reported that in the early years of life, children with ASD display hypotonia and postural instability (Adrien et al., 1993), a lack of rotation around the longitudinal axis when turning over, difficulty sitting, little arm support when crawling, and asymmetric arm swinging when walking (Teitelbaum et al., 1998). Recent research has focused on the motor developments of children with ASD, where motor characteristics like hypoactivity (Adrien et al., 1993; Maestro et al., 2005), motor stereotypies (Loh et al., 2007; Watt et al., 2008), and postural instability
It is widely agreed that, among the aforementioned motor impairments, children with ASD also show altered gross coordination and gait (Ghaziuddin & Butler, 1998) along with impairments when performing intentional movements, manual praxis, and movement planning (Dziuk et al., 2007; Ming et al., 2007).

A past prospective study (Bhat et al., 2012) took a sample of 24 infants of siblings with ASD, and 24 infants considered low risk for ASD aged 3-6 months and assessed their gross motor development using the Alberta Infant Motor Scale (AIMS; Piper & Darrah, 1994) and the Mullen Scales of Early Learning (MSEL; Mullen, 1995). Their results showed that the infants with siblings with ASD showed motor delays and communication delays compared to the low-risk infants. A similar study (Rowberry et al., 2015) took infants with siblings with ASD and low-risk infants and assessed motor delay using the MSEL while also assessing the infants using the ADOS toddler module (ADOS-T; Lord et al., 2000) and the ADOS. Their results found a significant difference in motor delay between the groups at 12-months, where the siblings of children with ASD showed significant gross motor delay and imitation and were later diagnosed with ASD at 24 months of age. The authors suggest that the delay in motor development could have contributed to deficits in social and communication skills among the children with ASD (Rowberry et al., 2015).

1.2.1. Motor Imitation Impairment

Overall, the use of motor skill performance when diagnosing a child with ASD is based on gestures, stereotypies, and imitation (Lord et al., 2006). One of the most commonly affected areas in children with ASD is the ability to imitate the actions of others when asked to do so by someone else (Shih et al., 2010). Otherwise known as motor imitation, this skill is a complex developmental phenomenon that is essential for children to learn new behaviors. It also plays a role in transferring cultural knowledge to the child (Whiten et al., 2009). Imitation is a crucial developmental
milestone that infants use to understand people around them and serves as one of the first forms of communication an individual will develop (Uzgiris, 1981; Meltzoff & Moore, 1994). As highlighted previously, the early motor impairments exhibited by children with ASD leads to an impairment in the development of imitation as a skill. This motor impairment has an impact on the development of imitation, so much so that it is believed that much of the social deficits experienced by children with ASD can be traced back to the underdevelopment of imitation skills (Rogers & Pennington, 1991; Smith & Bryson, 1994).

Reciprocal imitation training has been developed in order to help teach the importance of imitation to social development among children with ASD (Ingersoll, 2012). This training uses a combination of behavioral and developmental strategies to teach imitation in a social context. While this training has been shown to improve social development among children with ASD, mediation analyses revealed that the improvement was not due to the improvement of imitation (Ingersoll, 2012). This further highlights the need for research and targeted therapy to improve motor planning and control among these children, which can have larger impacts on the other neurological deficits associated with the disorder.

Furthermore, imitation dysfunction in children with ASD could be due to a disruption in the development of mirror neurons (Dapretto et al., 2006). Mirror neurons play an important role in action understanding and imitation and a disruption in the development of these neurons could explain the dysfunction exhibited by children with ASD (Dapretto et al., 2006; Rizzolatti & Craighero, 2004). Previous research has indicated that children with ASD showed no mirror neuron activity in the inferior frontal gyrus when performing an imitation task (Dapretto et al., 2006). The researchers also found an inverse relationship between the severity of social symptoms exhibited by the children and their inferior frontal gyrus activation during the task. This indicates
that children who suffer from more severe social issues are more likely to have an underdeveloped area of the brain responsible for mirror neuron activity.

1.2.2. Gross and Fine Motor Impairment

Previous research on motor skills among children with ASD have revealed that these individuals display both fine and gross motor skill impairment (Fournier et al., 2010; Downey & Rapport, 2012). Fine motor skills are finite movements that are produced by the body’s small muscle groups, usually found in the hands, fingers, wrists, and toes (Schmidt & Lee, 2011). This is opposed to gross motor skills, which are movements that involve large muscle groups such as the arms, legs, and the trunk. Gross motor skills are largely responsible for moving the body in space and engaging in activities that require a large amount of movement (Schmidt & Lee, 2011). Past research has investigated both sets of motor skills to determine which have a higher impact on the development of a child with ASD.

One study (Provost et al., 2007) administered two tests, the Bayley and Peabody scales, to evaluate motor development in young children with ASD and compared findings to children considered NT. The findings revealed that nearly all of the children with ASD showed some form of either fine or gross motor delay and the authors went on to recommend that motor development tests be administered when diagnosing a child with ASD (Provost et al., 2007). Other previous studies have also investigated this phenomena, either directly with children with ASD (Ming et al., 2007) or with children who are siblings of children with ASD, who were then later diagnosed with ASD themselves (Bhat et al., 2012). Both studies found that gross and fine motor delay is common among children with ASD. One issue is that fact that ASD is a separate disorder from developmental delay (DD) however the two are often listed as similar in nature. Therefore, it has been difficult to differentiate between children with ASD and children with DD in terms of fine
and gross motor impairment and more research is needed in order to determine the role these motor delays have on the development of communication and social skills among children with ASD (Provost et al., 2007).

**1.3. Brain Mechanism**

Prior to the execution of a movement, neurons in the motor cortex of the cerebrum begin to fire in anticipation of actual movement (Svoboda & Li, 2018). This indicates that there is an internal process that occurs where the brain will plan and execute any given movement. During the motor planning (or movement preparation), information in the brain flows from sensory areas to the motor cortex, located immediately anterior to the central sulcus in the cerebrum. Planning for a movement occurs in the prefrontal cortex and information is then sent to the premotor cortex (a subset of the motor cortex) where the information is sequenced. From there, information is then transmitted to the motor cortex, where the initiation and production of the movement occurs (Bear et al., 2016).

**1.3.1. Cerebellum**

A prevailing theory, in regard to ASD, is that there are abnormalities within this flow of information which cause disturbances in both the planning and the execution of a movement (Nebel et al., 2014). Previous studies have revealed that the difficulties with motor execution experienced by individuals with ASD is a reflection of both structural and functional abnormalities within the brain networks that control motor control and learning (Herbert et al., 2004). Moreover, studies have shown that there is a correlation with increased white matter volume in the primary motor cortex and motor performance deficit within this population (Mostofsky et al., 2007). Further investigations have revealed that children with ASD have atypical involvement of the motor control network during the various stages of movement learning (Müller et al., 2004). This
further highlights that the frequency of cerebellar anatomic abnormalities that are found in individuals with ASD (Marko et al., 2015).

These abnormalities in the cerebellum may stem from abnormal sizes of Purkinje cells, enlarged cerebellar hemisphere volume, or reduced volume in cerebellar vermis (Marko et al., 2015). While damage to the cerebellum can lead to many cognitive deficits, one prominent symptom of cerebellar damage is motor learning impairment (Donchin et al., 2012). It is believed that cerebellar-dependent motor learning occurs through the construction of internal models of action where the brain will predict sensory consequences of movement (Izawa et al., 2012). If the sensory feedback is different than what was predicted, then the resulting prediction error will update the internal model and therefore change the normal process of motor learning (Donchin et al., 2012). This altered motor learning model produces a variety of motor impairments, such as impaired simple timed movement (Jansiewicz et al., 2006), skilled gestures (Dowell et al., 2009) and imitation (Dziuk et al., 2007). Therefore, examining how children with ASD use internal models to learn and adapt movements is crucial given impaired motor learning can further impact communication and social skills of the child (Gidley Larson & Mostofsky, 2008).

Recent research revealed that, when completing a reaching task while experiencing perturbations, children with ASD constructed an internal model that was different than children considered NT (Haswell et al., 2009). In this study, researchers had children with ASD play a game where they held a robotic arm and reached to capture “animals that had escaped from a zoo,” where the zoo animals represented three different targets in the apparatus. The robot arm would perturb the children’s arm movements, creating a force field that the children had to learn to deal with when playing the game. Prior to beginning the game, both children with ASD and children considered NT produced unperturbed straight reaching movements which served as a baseline
measure. Then, both groups of children played the game with the force field present. The researchers quantified the generalization learning patterns of the children by computing the peak lateral force produced by the child and comparing it to the ideal force required to compensate for the perturbation. The results showed that the children considered NT used both intrinsic and extrinsic feedback to learn from the task and create a generalized pattern of movement that would compensate for the perturbations. The children with ASD, however, relied more on extrinsic feedback (like proprioception) to form a generalized pattern of movement that would allow them to accomplish the task. Furthermore, the researchers hypothesized that the heavy reliance on proprioception to complete the task could be due to anatomical miswiring between the motor cortex and the cerebellum of the ASD brain, leading to dysfunction when using intrinsic feedback to produce movement (Haswell et al., 2009).

Children considered NT construct an internal movement model using stimuli from the surrounding environment and their position in space. An individual with cerebellar abnormalities, however, may have impaired reaction to this stimulus which then alters the temporal order of events and precision of their movement (Cerminara et al., 2009). This could then have an effect on the execution of goal directed movements among this population because the prediction and anticipation of certain stimuli would be altered (Ito, 2008; Corben et al., 2011). The cerebellum and the cerebral cortex will compare discrepancies between predicted and actual movement based on stimuli from the external environment and will alter future movements (Ito, 2008). Due to evidence that children with ASD may experience abnormalities in their cerebellum, and specially the way they create internal models of movement, it is likely that these abnormalities play a large role in the motor development of the child and could further impact their communication and social skills.
1.3.2. Basal Ganglia

Another region of the brain that is involved in the information flow that leads to movement is the basal ganglia. This is a group of subcortical nuclei that have a large impact on motor planning along with executive functions, behaviors, and emotions (Lanciego et al., 2012). The basal ganglia are mostly associated with performance and acquisition of a new task and reinforcement learning that creates habitual responses which are automatically performed by the motor circuit. Abnormalities to the basal ganglia often lead to kinetic (hypo/hyper) movement disorders like parkinsonism and dyskinesia (Lanciego et al., 2012).

There is increasing evidence children with ASD have basal ganglia dysfunction which leads to impairments in the development of motor skills, communicative skills, and social skills along with repetitive behavior and stereotypies which are often associated with the disorder (Ravizza et al., 2013). When comparing the basal ganglia between children with ASD and children considered NT, children with ASD exhibited shape abnormalities of the basal ganglia. More specifically, the children with ASD showed surface deformation in the caudate, globus, pallidus, and putamen (Qiu et al., 2010). The main function of the putamen is to use sensory input to guide goal directed movements and to sequence skilled movements. It is likely that the variation in size, when compared to children considered NT, contributes to the impairment motor development of children with ASD (Qiu et al., 2010).

While motor impairment among children with ASD appears to be a prevalent symptom, the variation of motor impairment between individual persons with the disorder makes it difficult to assign as a core symptom of the disorder (Ming et al., 2007). However, due to the abundance of literature that have pinpointed motor impairment as one of the initial symptoms of ASD, further research into the motor control, learning, and development of this population is crucial.
2. GOAL-DIRECTED MOVEMENTS

2.1. Early Research

A goal-directed movement is a type of self-directed movement where an individual is directing their movement towards or away from another location or object (Opfer, 2002). In the seminal paper for goal directed movement by Woodworth (1899), researchers studied goal directed movement characteristics through an aiming procedure, where participants made horizontal sliding movements between two fixed distances. This allowed the researchers to examine spatial accuracy and consistency of the movement endpoints while also investigating spatial and temporal trajectories (Woodworth, 1899). The study concluded that there are two distinct phases of this type of movement: 1) the initial impulse phase to begin the movement, and 2) the current control phase occurring during the movement. The initial impulse phase is dependent on the planning process within the motor cortex which helps bring the limb in the vicinity of the their goal. Once the limb is in the region of their target, external feedback is used to allow the limb to be accurate. This is known as the homing phase, where proprioceptive feedback is used to give information about the relative position of the limb and the target, and it allows the motor system to make adjusts to the movement so they can hit the target (Woodworth, 1899). These findings allowed Woodworth (1899) to determine that there is a tradeoff between directed movements.

2.2. Fitts Law

Goal directed movement was expanded on by Fitts (1954), where the first relationship of speed and accuracy through a self-paced, cyclical tapping movement. In this study, participants were required to tap continuously between two different targets. The width of the targets would widen, therefore making the task more difficult. This study revealed that there is a linear relationship between the of index of difficulty (ID) and movement time (MT), known as the speed/accuracy
tradeoff, where an individual has to adapt to constraints from both speed and accuracy during a goal directed movement (Fitts, 1954). The individual has to accept that an increase in time spent during a movement will lead to a lesser degree of terminal accuracy and vice versa, thereby creating what is known as Fitts’ Law. From this, the equation: \( MT = a + b[\log_2(2A/W)] \) was created and allowed Fitts to reduce the complex relationship between motor control and environmental constraints into a one-dimensional problem which relates two scalar variables and captures the essence of goal directedness (Smits-Engelsman et al., 2002; Huys et al., 2010).

Previous studies have sought to explain the mechanism of the speed/accuracy tradeoff, one of which from Meyer et al. (1988) who suggested that a goal directed movement included an initial and secondary phase, both of which are operate under different control processes. The initial impulse is considered the primary movement and is thought to be accomplished through motor planning. This phase begins with the execution of a movement towards a goal and ends when the location of the target has been identified (Meyer et al., 1988). The secondary phase is known as the error correction phase and is based off visual and proprioceptive feedback information. Meyer et al. (1988) further hypothesized that there is a compromise between initial movement speed and corrective sub movements, where the faster the movement the more likely there are to be spatial errors.
3. MOVEMENT STRUCTURE OF CHILDREN WITH ASD

3.1. Motor Behavior, Learning, and Control

Motor behavior is an academic field of research that saw its beginnings as far back as 200 BC, where Greek philosophers began to believe that the brain is what controls the movements of the hands, feet, and mouth. It wasn’t until the early 20th century, however, that the actual field of motor behavior was established (Clark & Oliveira, 2006). Overall, motor behavior is the study of how motor skills are learned and controlled as an individual develops from a child through adulthood (Thomas et al., 2008). Within the field of motor behavior, there are two sub-topics: motor learning and motor control.

3.1.1. Motor learning

Motor learning refers to the process of learning a skill and refining that skill through practice. As an individual practices a skill, the way they perform the skill should become more smooth and accurate over time (Adams, 1971). This means that motor learning can be broken down into two further sub-categories, skill acquisition and skill adaptation (Kitago & Krakauer, 2013).

Skill acquisition refers to the learning of a new skill, such as riding a bike or hitting a baseball for the first time. As is commonly known when learning a new skill, it takes time and practice to gain true acquisition of the skill. One way that researchers can quantify skill acquisition is by studying the speed/accuracy trade-off an individual will go through while learning a new skill. Once a new skill is being learned, the individual will make many errors if they try to complete the skill too quickly. In order to limit the amount of errors they are experiencing, the individual will slow down to become more accurate. As the individual completes more practice trials, they will be able to complete the skill at a faster rate with less errors and it is at this time that the skill has been acquired in the motor system (Reis et al., 2009; Shmuelof et al., 2012).
While it can take days, weeks, or years to acquire a new skill, the adaptation of a skill happens much sooner than that. Skill adaptation occurs when an individual is completing a skill in a new environment and the motor loop in charge of the skill must deal with any novel external stimulus. These external stimuli will cause error during skill execution, however, because the skill had already been learned by the individual, the motor loop is able to make changes in response to the external stimuli quickly. Research has shown that healthy individuals are able to adapt their movements during a task in a new environment and they are able to perform the skill almost free from error in a single practice session (Shadmehr & Mussa-Ivaldi, 1994). Another aspect of skill adaptation is that the adaptation that occurs can result in a change that outlasts the period spent training the skill (Schmidt et al., 2018). This ultimately means that motor learning is a series of practicing to learn a new skill and adapting the way you achieve that skill if the environment around you provides stimulus that could cause errors. Once a skill has been learned, the individual must be able to store the motor loop responsible for that movement so they can replicate the movement later when needed. The ability to regulate the mechanisms and information stored for the production of a movement is known as motor control (Kenyon & Blackinton, 2011).

3.1.2. Motor control

There are many theories that seek to account for how motor control works. Early works described a “motor program,” where information from the outcome of past movements are stored for later, when the movements might be needed in a similar or different environment. Currently, these theories have been replaced with “systems theory” which will be described later.

Adams (1971) theorized that the processing of afferent information when completing goal-directed movements of skills was in a closed-loop. Adams (1971) stated that, in order to learn a skill, two types of memory: memory trace and perceptual trace, was required. Memory trace, which
is like recall memory, is part of the loop that chooses the initial direction of the movement and accounts for early portions of the movement. Perceptual trace, which is like recognition memory, guides the limb to the correct position for the movement. An individual will do this by comparing incoming feedback to perceptual trace and will adjust or correct their movement based on past experiences of completing the movement. If the individual experiences an error, they will correct it based on their past movements and if they are accurate, this will help improve both memory trace and perceptual trace (Adams, 1971). While this was an important theory for the study of motor learning, Adams (1971) did not account for mapping between motor programs and different movements that needed to be accomplished. For the closed-loop theory to be plausible, the Central Nervous System (CNS) would need to have a large storage capacity to account for all possible motor programs. This was not possible, however so Schmidt (1975) improved upon this theory with Schmidt’s schema theory (Schmidt et al., 2018).

Due to the CNS storage problem posed by motor learning theories at the time, Schmidt (1975) proposed that there was a generalized motor program (GMP) that represented a class of movements that could be used to accomplish movements that were similar in nature. If a new skill needed to be acquired, an individual would use feedback gained from attempting the skill and it would “improve” the existing GMP for that movement. If a new skill was totally novel to the existing GMPs of an individual, then a new GMP would be formed and all related skills would fall under it (Schmidt et al., 2018). According to Schmidt’s schema theory, four sources of information are stored after an individual attempts a movement: 1) proprioceptive information of the limbs and the body during the movement, 2) the response of the initial GMP such as speed and force of the movement, 3) sensory consequences of the movement, and 4) the outcome of the movement.
According to this schema theory, an individual will use all this information to improve upon an existed GMP for a movement or create a new GMP if the movement is completely novel.

Another motor control theory is one that states that a task is accomplished through an integrated or dynamically based system. These theories state that when an individual is completing a skill or a movement, they are constrained by three mechanisms: action, perception, and cognition. Action refers to the motor system itself (i.e. muscle tone, muscle strength, and range of motion deficits). Perception refers to factors that affect or limit the amount of sensory information coming into the system. Cognition refers to the attention, emotions, and motivation of the individual to complete the movement or skill. This theory argues that these constraints must also be taken into account when looking at a motor loop responsible for a movement, as they can affect the outcome of the movement as well (Shumway-Cook & Woollacott, 2007).

Motor learning and motor control both combine to create what is known as motor behavior. Motor learning is the process in which an individual learns a new skill and how they can improve and adapt that skill through practice. Motor control refers to the motor loops responsible for creating more complicated movements, where more than one skill may be needed to accomplish a task. It is through the study of both fields that researchers can understand the movements of any population and these movements are learned, retained, and improved on as the individual goes on through life.

3.2. Motor Planning Impairments among Children with ASD

Motor planning is the process of changing a current state of movement into a desired state through a sequence of motor commands (Gowen & Hamilton, 2013). Planning will begin before a movement is initiated, but the inverse of this model allows for continuous control of action and correction of errors during the execution of this movement (Gowen & Hamilton, 2013). The
simplest way to assess motor planning in an individual is to measure reaction time before a movement is performed in accordance with a certain stimulus. This allows you to have a basic measure of the time it takes an individual to formulate a motor plan and then execute said plan.

Motor planning among adolescents with ASD when compared to adolescents considered NT has been the subject of investigation in previous studies. In one such study, researchers took individuals between the age of 10-18, both with a diagnosis of ASD and those considered NT, and had them perform rapid reciprocal aiming movements between two targets on a response board (Rinehart et al., 2001). The participants were required to begin at the start position located at the bottom middle of the board (closest to them) and when ready, a light would appear at the top of the board (furthest away from them) on either the left or right of their starting position. During the task, the researchers measured the participants’ response to the illuminated light. The results of the study revealed that the adolescents with ASD exhibited normal execution of movements between targets, however, they showed anomalies in movement preparation and their movement pattern was not reflective of the movement they had prepared. In other words, they adolescents with ASD responded to the target significantly slower than those considered NT (Rinehart et al., 2001). These findings were consistent with other research (Hughes, 1996) which reported that individuals with ASD have atypical movement planning and anticipation of a motor response. These results indicate that individuals with ASD show deficits in the phase of movement preparation (immediately before execution) which should be the most optimal. This implies that these individuals have a disturbance of the supplementary motor area circuitry which results in difficulties in the initiation of a motor program (Rinehart et al., 2001).

A similar study by the same research group expanded on these findings by including a kinematic assessment while individuals with ASD performing the same reciprocal aiming task
(Rinehart et al., 2006). The task for this study was completed on a digitized tablet and stylus connected to a laptop. The use of the stylus to move between targets allowed the researchers to obtain position data, which was recorded in the X and Y axes. Furthermore, the researchers also collected response time, total movement time, and asymmetry ratio, measured by time to peak velocity divided by the movement time and reflective of the shape of the movement trajectory. This study also expanded on the previous one by included three different levels of manipulation (or lack of) on the reciprocal aiming task. For level one, there was no manipulation and participants were asked to move between targets as quickly as possible. For level two, participants were told by the researchers which side of the board most of the targets would appear, however the targets would appear on the opposite side, inhibiting the preparatory motor program made by the individuals. The third level was similar to level two, except the individuals were told to move to the opposite side of where they saw the target. The results of this study revealed that the participants with ASD showed clear deficits in motor preparation across all three levels. The results of level three revealed that there were clear motor preparation deficits regardless if the movement was predictable or unpredictable, indicating that there is a dysfunction in motor anticipation among individuals with ASD.

A more recent study (Dowd et al., 2012) investigated a similar phenomenon with younger children with ASD, ages 3-7. The apparatus consisted of a similar digitized tablet and stylus and the children were asked to move quickly between targets while maintaining accuracy. A second part of the study had the children perform the same task, but with a distractor presented on the tablet. The results revealed that the younger children with ASD exhibited more variability in movement preparation that a group of children considered NT, furthering the hypothesis that individuals with ASD have motor preparation dysfunction when accomplishing a task. The results
from the visual distractor portion of the study did show any kinematic differences when compared to the simple task. This indicates that visual perceptual integration is not impaired among these individuals during the motor preparation phase (Dowd et al., 2012).

3.3. Motor Execution Impairments among Children with ASD

Following the motor planning phase is the actual execution of the movement. As opposed to research regarding movement planning, previous research has shown that children with ASD do not show signs of motor planning deficit, but instead show signs of motor execution dysfunction (Mari et al., 2003). In this study, children with ASD aged 7-13 years were instructed to reach and grasp either a large or small cube placed 18cm or 28 cm in front of them. In order to determine where on the spectrum each child was on, the researchers used IQ as a way to distinguish of the children were low ability, average ability, or high ability. The results of the study revealed that, when compared to age-matched children considered NT, the children with ASD of all ability levels showed significant kinematic differences. The low ability children displayed bradykinesia along with longer movement duration, longer deceleration time, and longer amplitude peak velocity. The high ability group displayed a faster reach for the object but were not as accurate as the children considered NT. These results indicated that children with ASD may develop a strategy during the movement planning phase but are unable to successfully execute that strategy (Mari et al., 2003).

A similar study (Forti et al., 2011) examined the ability of children with ASD to pick up an object and transport the object from one location to another and placing the object in a hole. When compared to children considered NT, there were no significant variations in initial movement phases or accuracy, however the children with ASD displayed higher velocities, additional corrective sub-movements, and motor slowing during the homing phase of the task. This indicates
that the children with ASD were able to successfully place the object in a hole, but they took a different path of children considered NT which could be due to their inability to process real-time external feedback on their movement or from a lack of capacity to create a motor plan prior to executing the task (Forti et al., 2011).

A more recent study investigated which functional system motor deficits may originate among children with ASD (Stoit et al., 2013). This study took 31 children and adolescents (both with ASD or considered NT) and had them perform a reach and grasping task. This task included cuing from the researchers, where the children would receive information on where the object would be located or how they should grasp the object. The results of the study indicated that the children with ASD did not show delays in reaction times when compared to the children considered NT, however they did have delayed movement times. The authors suggested that this was due to a deficit in actioning chaining, stemming from the functional model that supports a feedforward model (Stoit et al., 2013).

As opposed to a neural feedback model, where the nervous system will use external feedback to adjust movement, a feedforward model is on where the nervous system predicts how to best counter external forces (Maeda et al., 2018). The results of the previous study indicate that children with ASD exhibit deficits when predicting how a movement will be accomplished. This is similar to the studies that focused on the motor planning phase of movement among these children, where it is believed that children with ASD are unable properly plan out a movement. This goes against the studies from Mari et al. (2003) and Forti et al. (2011), who indicate that the issue is based on the execution of the movement itself. The lack of consensus regarding motor planning and execution among children with ASD highlights the need for studies which aim to investigate both phenomena.
3.4. Apraxia and children diagnosed with ASD

Current literature also suggests that two-thirds of children diagnosed with ASD exhibit signs of childhood apraxia (Tierney et al., 2015). Childhood apraxia is a neurological speech disorder where the precision of movements required for speech is impaired because there are deficits in neuromuscular control (Association AS-L-H, 2007). This means that children with apraxia are unable to produce sounds which are necessary for speech because they have deficits in motor planning and execution in the muscles which are involved (Tierney et al., 2015). Therefore, based on current knowledge surrounding the motor deficits exhibited by children diagnosed with ASD, apraxia is often listed as a comorbidity of the disorder.

Due to the abundance of literature regarding deficits in motor planning and execution among children with ASD which not only affects how they move and manipulate objects in the environment around them, said deficits may also be impacting they way they are able to formulate sounds to produce speech. As stated previously, motor deficits exhibited by this population is only listed as secondary criteria for diagnosis of the disorder. However, in a neurotypical developmental process, children being to generate movement patterns prior to the formation of speech. Therefore, it can be hypothesized that the motor deficits experienced by children with ASD are not only a secondary marker of the disorder, but they could also be a primary marker which effects their language and social skills later in life. Currently, there is a lack of literature regarding the motor planning and execution of children with ASD which indicates that there is a large gap in knowledge when aiming to better understand this broad disorder.
4. CONCEPTUAL FRAMEWORK

As previously stated, children with ASD experience social, communication, and language deficits which are considered core symptoms of the disorder and are used as criteria for diagnosis. These children also experience motor deficits like ataxia, dyskinesia, stereotypies, and incoordination; however, these are only considered associative symptoms and are not used as direct criteria for diagnosis. Recent evidence has shown that the motor deficits experienced by these children occur at a very young age and could have a negative impact on how they interact with the world around them. These motor deficits could impact the way children with ASD play with their peers which is crucial for building the foundations of social skills that will develop as they grow older. Therefore, it appears as though a combination of motor deficits and social communication skills are intertwined and lead to the deficits experienced by children with the disorder.

The motor deficits experienced by these children is apparent, however, literature regarding the root cause of the deficits is lacking and inconsistent. Some evidence suggests that children with ASD experience motor planning deficits, linked to basal ganglia and premotor cortex dysfunction. Other evidence suggests that children with ASD instead experience motor execution deficits linked to motor cortex and cerebellum dysfunction. As previously highlighted, motor deficits appear to be a common symptom of the disorder, but the gaps in literature regarding the root cause of these deficits hinder the case for them to be listed as diagnostic criteria. Therefore, there is a need for future research to investigate the root causes of motor deficits among children with ASD which will help give a complete picture of the disorder and potential better aid clinicians when diagnosing these individuals with the disorder. Autism is a spectrum disorder which includes a very wide variety of individuals with a wide variety of symptoms and issues related to the disorder. This
means that ASD is a complex and sometimes mysterious disorder that is difficult to consistently diagnose.

A puzzle is often used to represent the disorder and is also the perfect way to represent the basis of this write-up regarding the motor impairments seen among individuals with ASD. First off, we have the cores symptoms: social deficits, communication and language dysfunction, and repetitive behaviors. We also know that stereotypies like hand flapping, ear flapping, body rocking (Ghanizadeh, 2010) are associated symptoms of the disorder. While there has been mounting evidence that motor impairment is a common symptom of ASD, the inconsistent and lacking literature regarding motor planning vs. motor execution as the root cause of motor impairment leads to difficulty in understand where and how this piece fits in the puzzle (Fig. 1).

![Figure 1. The conceptual framework for missing information regarding motor impairment experienced by children with ASD.](image)

Therefore, the purpose of this write-up is to propose a research regimen aimed at investigating the motor impairments experienced by children with ASD through two interconnected studies, highlighted below.
Table 1. Break down of 2 studies included in this dissertation

<table>
<thead>
<tr>
<th></th>
<th>Study 1</th>
<th>Study 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Title</strong></td>
<td>Reach estimation, action and execution among children with Autism Spectrum Disorder</td>
<td>Discrete vs Reciprocal targeting with and without haptic feedback among children with Autism Spectrum Disorder</td>
</tr>
</tbody>
</table>
| **Purpose**         | *P1*: To observe the internal models of motor planning for ipsilateral, midline, and contralateral movements of the hand  
*P2*: To establish the differences of motor execution among children with ASD vs children considered NT | To understand the kinematic components of discrete and reciprocal goal-directed movements among children with ASD |
| **Hypothesis**      | *H1*: Children with ASD will display abnormal internal models of action in reach estimation  
*H2*: Children with ASD will display performance differences in kinematic measures compare to children considered NT  
*H3*: The scores from Experiment 1 will present a strong predictive correlation to the hypothesized disrupted kinematic measures | *H1*: Children with ASD will exhibit task specific motor deficits in goal-directed aiming  
*H2*: Children with ASD will exhibit kinematic differences when compared to children considered NT |

These studies will seek to further the field of research regarding the upper extremity motor impairments experienced by children with ASD. **Study 1** will seek to identify the internal models of action during a protocol where children with ASD will be asked if they are able to reach a target projected in front of them on the ipsilateral and contralateral sides of their body, and at their midline. This study will then be expanded on, where they will sit in the same apparatus but they will be asked to physically place a wooden block on a target. This study will help to identify any disruptions in kinematic measures these children may experience, and their results will be compared to children considered NT. **Study 2**, will seek to identify the any motor deficits experienced by children with ASD while they are completing discrete and reciprocal aiming tasks. Moreover, this was be expanded in a second part, where the children experienced haptic feedback through both the discrete and reciprocal aiming tasks. While this study is different from the
previous study, it further expands on the research regarding goal-oriented tasks and compares two different scenarios which the children may have difficulty achieving.

Therefore, each study will build off each other by aiming to identify two questions among this population:

1) When given a scenario to plan out a goal-oriented task (but not actually asked to perform that task), do children with ASD experience motor planning deficits and how different are those deficits when compared to children considered NT?

2) When asked to perform a goal-oriented task, like placing a wooden block on a target present before them, do children with ASD experience kinematic differences when accomplishing this task when compared to children considered NT?

3) Not all goal-oriented tasks are the same, where some tasks may require discrete movements like pointing to a target and stopping before going back to another target, others may require reciprocal movements like movement back and forth continuously between targets. Therefore, do children with ASD experience motor deficits when completing discrete and reciprocal aiming tasks? Furthermore, do these children experience difficulties that are to children considered NT?

It should be noted that data for each of these studies have been previously collected and will undergo future analysis to determine the true impact each study has on current literature regarding motor impairments among children with ASD. The aim of these studies is to highlight the motor deficits experienced by children with ASD and to investigate where exactly the deficits lie. While there have been inconsistencies in literature regarding motor deficits regarding children with ASD, the goal of these studies is to fill in the gaps of the literature and to gain more insight into the motor deficits among children with ASD.
5. REACH ESTIMATION AND ACTION AMONG CHILDREN DIAGNOSED AUTISM SPECTRUM DISORDER

5.1. Introduction

While children with ASD experience impairments communicative and social skills, along with a number of motor deficits, past research has also revealed that these children also experience reaching and grasping deficits, however literature on this topic is limited and inconclusive (Sacrey et al., 2014). The reaching deficits experienced by children with ASD have not been completely characterized, a past study found that their motor delays correlate with speech delays which further inhibits their communication and social skills (Bhat et al., 2011). The ability to plan, execute, and correct ongoing movement is a crucial aspect when completing an action toward a goal (Elliott et al., 2010). These abilities are inhibited among children with ASD and have a negative impact on how these children play, explore, and function in daily life (Goodgold-Edwards, 1985).

A previous study (Caçola et al., 2014) explored reach estimation among children with developmental coordination disorder (DCD). Reach estimation is better known as motor imagery, which are the visuomotor process that occur prior to execution of a movement. In this study, researchers used a projector to display a target on to a table where either children with DCD or children considered NT were seated. Once the target was displayed on the table, the participants were asked to kinesthetically “feel” like they were reaching out to the target and to report if they could or could not reach the target. This was then repeated two more times, except the children had either a 20 cm or 40 cm tool. Their results revealed that children with DCD have difficulties estimating their reach but only with a tool in their hand.

This study is of interest due to the closeness in nature of DCD and ASD, however DCD is typically considered more of a motor deficit disorder as opposed to ASD which has been explained
in great length previously in this paper. However, because it is believed that children with ASD experience motor deficits, a study of this kind can be replicated among these children. With respect to children with ASD, no study to date (aside from anecdotal evidence described in OT/PT websites) has investigated the visuomotor aspect of movement (motor imagery) formation prior to execution.

Motor imagery, or kinesthetic imagery, is an active cognitive process where the representation of a specific action is internally reproduced in working memory without any motor output (Decety & Grèzes, 1999). This is considered a form of motor cognition or a cognitive level of action processing, which is responsible for recognizing, anticipating, predicting, and producing goal oriented movements (Gabbard, 2009).

Contralateral reaching (midline crossing) is a developmental skills that has been shown to increase linearly in children considered NT between the ages of 2-6 (Stilwell, 1987). This is an important milestone for children and can be assessed using sensory integration testing. Moreover, the decrease or lack of contralateral reaching will lead to decreased used in the contralateral hand. While the study by Stilwell (1987) lead to discoveries in contralateral hand reaching in young children, there are few studies that have investigated this phenomenon in children considered NT and even less so among children with ASD. It can still be hypothesized, however, that if children with ASD show a lack of development of contralateral reaching can lead to further deficits in sensory integration, communication, and motor functioning. A study by Norris et al. (2008) ipsilateral functional reaching increases linearly with age from age 3 to 5. This finding is important because it allows researchers to understand what is considered normal functional reaching development in young children and will clinicians to better treat non-normally developing children, such as those with ASD (Norris et al., 2008).
Bhat et al. (2011) suggested that reaching impairments experienced by children with ASD could be due to weakness, abnormal muscle tone, incoordination, and poor balance. The issues with coordination could affect their ability to perceive the world around them and communicate with other children around them. Previously in this paper it was highlighted that a study by Provost et al. (2007) found that the motor delay experienced among children with ASD leads to motor dysfunction and could be the potential cause of a reaching-grasping impairment. Another previous study concluded that children with ASD had cerebellar dysfunction which led to feedforward and feedback mechanisms, but they did not specifically highlight how this impairs the reaching among these individuals (Mosconi et al., 2015).

5.2. Purpose

There is a scarcity in literature regarding internal models of movement planning and action among children with ASD. While there have been previous studies that have investigated the motor deficits experienced by children with ASD, there has been a lack of literature regarding functional reach among these children. Previous studies have highlighted that the motor dysfunction experienced by children with ASD could lead to further communication and social impairments among these children which are the core symptoms of the disorder. However, there is lack of literature regarding functional reach among children with ASD even though previous literature has shown the importance of reaching and grasping on the motor, communication, and social development of young children (Lobo et al., 2013).

This study was split into two different experiments, where the reach estimation of children with ASD was determined and then the actual movement of these children was tested. The purpose of Experiment 1 was to observe and discuss the developmental motor impairments, such as motor delay, seen in children with ASD, specifically with planning of movements ipsilateral and
contralateral to the right hand. It was hypothesized that children with ASD will display disrupted internal models of action in reach estimation when compared to children considered NT.

The purpose of Experiment 2 was to establish if differences exist between children with ASD and children who are NT in the execution of a functional reach task to the ipsilateral and contralateral side of the body. Moreover, another purpose is to analyze if internal models of action (reach estimation) from Study 1 to predict motor behavior in children with ASD. This study has two hypotheses: 1) Children with ASD will display performance differences in kinematic measures compared to children considered NT, and 2) the scores from Study 1 will present a strong predictive correlation to the hypothesized disrupted kinematic measures among the ASD group.

5.3. Methodology

5.3.1. Participants

Children (N=13) aged 6-12 were recruited from the El Paso community to participate in this study (Tables 1, 2). Inclusion criteria for this study included a formal diagnosis of ASD (for the ASD group) from a physician, all children from both groups must have the ability to understand prompts and correctly follow the instructions of the researcher, and all children must be free from any other neuromuscular disorder or disease which would prevent them from completing the experiment. It should be noted that this inclusion criteria limited the study to children exhibiting mild or moderate autism. This population consisted of ten children with a diagnosis of Level 1 ASD and three children considered NT. Parents and guardians of all children read and signed a parent permission form and a child assent for was signed by all participants after researchers read and explained the document to them. Parents and guardians were required to always stay in the testing room and were told, along with the participants, that they could terminate their participation in the study at any time.
Table 2. Age and sex data for each participant in the ASD and NT groups.

<table>
<thead>
<tr>
<th>ASD</th>
<th>NT</th>
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<tbody>
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<td>Age</td>
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<td>11</td>
<td>M</td>
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Table 3. Mean age data for both the ASD and NT group.

<table>
<thead>
<tr>
<th>Means</th>
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<th>NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
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<td>4</td>
</tr>
<tr>
<td>Age (±std)</td>
<td>8.82(±1.72)</td>
<td>8.75(±1.70)</td>
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5.3.2. Apparatus

Experiment 1

Children sat comfortable in a height adjustable chair at a children’s height table. Participants were instructed to sit up tall and place both shoulders against the back of the chair. Then, with their right hand, they reached out as far as possible on the table without removing their back from making contact with the chair. Participants performed this for 3 trials and the average distance reached was labeled as the maximum voluntary reach (MVR). Following the establishment of the MVR, participants were instructed to sit tall at the table, with their backs still against the chair and their hands resting comfortably in their lap (Fig. 2).
Figure 2. The apparatus used for this study where a projector was mounted overhead to display targets directly on the table in front of the children.

Experiment 2

Children donned a motion capture glove with three spherical retroreflective markers placed on the metacarpophalangeal joints of the thumb, middle finger, and little finger. Using the same apparatus from the reach estimation experiment, children were seated comfortably in a height adjustable chair at a children’s height table. The same process to locate the MVR was conducted, where the children reached out as far as possible while keeping their back against the chair (Fig. 3).
Figure 3. The apparatus is the same from Study 1, however this time the children were given a wooden block to place on to the target when displayed in front of them.

5.3.3. Procedure

Experiment 1

Once seated at the apparatus participants were informed that a single-colored circle will light up in various places on top of the table. This was done with a projector pointing down on to the table from a custom-built archway (Fig. 1). It is important to note that the lights in the lab were lowered and the table was covered in black felt to prevent participants from using visual cues on the surface of the table. Participants were instructed to reply with a verbal “yes” or “no,” indicating if they thought they could successfully reach the target or not. Seven possible target combinations, with 4 inside of the MVR zone, will be displayed on the midline of their body along with their right and left sides of their body, totaling 21 possible targets. All targets were randomly displayed in 4 different rounds, for a total of 84 trials.
Experiment 2

Once the child was seated and ready to begin, they were given a wooden block and positioned in the starting position, where their right hand rested, block in hand, on the table, the left-hand comfortable resting in their lap and with their back against the chair. The children were then told that a target would display once they were set in the starting position and they were to place the block on the target as quickly and accurately as possible. A total of 9 targets were displayed, 3 at the midline of the child’s body, 3 to left and 3 to the right. This was completed for 4 rounds for a total of 63 trials. It is important to note that all targets were displayed within the MVR of the child. Kinematic data was recorded using an 8-camera three-dimensional motion capture system (Optitrak Motive, OR, USA).

5.3.4. Analysis

Experiment 1

Independent t-tests will be used to identify differences in reach estimation between groups (ASD, NT) using visuomotor accuracy scores (% correct Yes/No) for each target. This will be repeated for the contralateral (left) and ipsilateral (right) hemispheres and at the midline. For experiment 1, only six children with ASD and two children with NT were included in the analysis. The children not included in the analysis were unable to understand the reach estimation instructions, therefore their data could not be included for analysis.

Experiment 2

The dependent temporal variables (Acceleration, Velocity) will be analyzed in separate Hemisphere (Dominant, Non-dominant, Midline) x Classification (ASD, NT) analyses of variance (ANOVAs).
A Pearson correlation for a predictive relationship of reach estimation visuomotor accuracy (% correct Yes/No) and reach action (velocity and acceleration of movement) will also be run for the ASD group. An alpha level < 0.05 will be considered significant.

5.4. Results

Experiment 1

There was no significant difference on visuomotor accuracy scores at the midline between the ASD group (M = 0.95, SD = 0.13) and the NT group (M = 1, SD = 0); t(6) = -0.85, p = 0.42. There was no significant difference on visuomotor accuracy scores at the ipsilateral (right) hemisphere between the ASD group (M = 0.67, SD = 0.44) and the NT group (M = 1, SD = 0); t(6) = -1.02, p = 0.35. There was no significant difference on visuomotor accuracy scores at the contralateral (left) hemisphere between the ASD group (M = 0.79, SD = 0.40) and the NT group (M = 1, SD = 0); t(6) = -0.70, p = 0.51. These results indicate that there was no difference between each group when asked to estimate their ability to reach out and touch a target presented in front of them, as shown in Figure 4.
Figure 4. Results for reach estimation visuomotor accuracy at the midline, contralateral, and ipsilateral for both groups (ASD, NT). The dark grey color represents the ASD group and the light grey color represents the NT group.
Experiment 2

Midline targets

There were no significant differences in velocity and acceleration between groups at all midline targets presented to the children (Table 3).

Table 4. Means, Standard deviations, and One-way Analyses of Variance in Velocity and Acceleration at each target at the midline. Target 1 was the closest to the participant and Target 3 was the furthest (closest to MVR).

<table>
<thead>
<tr>
<th>Measure</th>
<th>ASD</th>
<th>NT</th>
<th>F(1,11)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Target 1 velocity</td>
<td>0.008</td>
<td>0.009</td>
<td>0.021</td>
<td>0.030</td>
</tr>
<tr>
<td>(cm/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target 1 acceleration</td>
<td>-0.001</td>
<td>0.001</td>
<td>-0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>(cm/s²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target 2 velocity</td>
<td>0.015</td>
<td>0.026</td>
<td>0.013</td>
<td>0.017</td>
</tr>
<tr>
<td>(cm/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target 2 acceleration</td>
<td>-0.001</td>
<td>0.002</td>
<td>-0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>(cm/s²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target 3 velocity</td>
<td>0.016</td>
<td>0.027</td>
<td>0.000</td>
<td>0.007</td>
</tr>
<tr>
<td>(cm/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target 3 acceleration</td>
<td>-0.001</td>
<td>0.0023</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>(cm/s²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Contralateral (left) targets

There were no significant differences in velocity and acceleration between groups at all contralateral (left) targets presented to the children (Table 4).
Table 5. Means, Standard deviations, and One-way Analyses of Variance in Velocity and Acceleration at each target on the contralateral (left) side. Target 1 was the closest to the participant and Target 3 was the furthest (closest to MVR).

<table>
<thead>
<tr>
<th>Measure</th>
<th>ASD</th>
<th>NT</th>
<th>F(1,11)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target 1 velocity (cm/s)</td>
<td>0.005</td>
<td>0.017</td>
<td>0.002</td>
<td>0.008</td>
</tr>
<tr>
<td>Target 1 acceleration (cm/s²)</td>
<td>-0.004</td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Target 2 velocity (cm/s)</td>
<td>0.010</td>
<td>0.014</td>
<td>0.002</td>
<td>0.009</td>
</tr>
<tr>
<td>Target 2 acceleration (cm/s²)</td>
<td>-0.000</td>
<td>0.001</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Target 3 velocity (cm/s)</td>
<td>0.030</td>
<td>0.047</td>
<td>0.005</td>
<td>0.008</td>
</tr>
<tr>
<td>Target 3 acceleration (cm/s²)</td>
<td>-0.002</td>
<td>0.003</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Ipsilateral (right) targets

There were no significant differences in velocity and acceleration between groups at all ipsilateral (right) targets presented to the children (Table 5).

Table 6. Means, Standard deviations, and One-way Analyses of Variance in Velocity and Acceleration at each target on the ipsilateral (right) side. Target 1 was the closest to the participant and Target 3 was the furthest (closest to MVR).

<table>
<thead>
<tr>
<th>Measure</th>
<th>ASD</th>
<th>NT</th>
<th>F(1,11)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target 1 velocity (cm/s)</td>
<td>-0.008</td>
<td>0.020</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>Target 1 acceleration (cm/s²)</td>
<td>-0.000</td>
<td>-0.000</td>
<td>-0.005</td>
<td>0.018</td>
</tr>
<tr>
<td>Target 2 velocity (cm/s)</td>
<td>0.008</td>
<td>0.027</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Target 2 acceleration (cm/s²)</td>
<td>-0.001</td>
<td>0.001</td>
<td>-0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Target 3 velocity (cm/s)</td>
<td>0.007</td>
<td>0.012</td>
<td>-0.000</td>
<td>0.0003</td>
</tr>
<tr>
<td>Target 3 acceleration (cm/s²)</td>
<td>-0.001</td>
<td>0.001</td>
<td>0.008</td>
<td>0.027</td>
</tr>
</tbody>
</table>
Pearson correlation

There was a significance positive correlation among the ASD group between visuomotor accuracy (% correct Yes/No) and their movement velocity for midline Target 1 (closest to them), $r(6) = 0.631$, $p = 0.047$. This indicates that the participants visuomotor accuracy on the midline targets were positively associated with their velocity of movement for Target 1 when reaching out and placing a block on it. There were no other significant correlations between visuomotor accuracy and reach action velocity and acceleration at the remaining midline targets and the any of the ipsilateral and contralateral targets.

5.5. Discussion

There were two purposes for this study: 1) to observe the models of motor planning for the ipsilateral, midline, and contralateral movements of the hand among children with ASD when compared to children considered NT and 2) to establish differences in motor execution when completing a reaching task among children with ASD and children considered NT. This study was split into two experiments; however, they were related in nature. For Experiment 1, it was hypothesized that children with ASD would display abnormal internal models of action in reach estimation. For Experiment 2, it was hypothesized that children with ASD would display performance differences in kinematic measures compared to children considered NT. Finally, it was hypothesized that the scores from Experiment 1 would present a strong correlation with the disrupted kinematic measures among the children with ASD.

Experiment 1

Results from the analysis indicated that there was no significant difference in visuomotor accuracy between the ASD and the NT group. This means that the ASD group had approximately
the same about of accuracy in estimating their reaching abilities as did the NT group. While the sample size was small for each group, there was not trend indicating that there was any difference between the groups. These results contrast with a similar study who performed a similar procedure among children ages 5-11 and adults (Gabbard et al., 2007). This study found there was no significant difference between the children and adult groups in their overall accuracy in estimating their reach. They did find, however, that the child groups exhibited more errors in accuracy of estimation of targets beyond the MVR line, where the adult group had the same amount of error on targets both inside and beyond the MVR line.

While the results of this study did not yield significant differences in visuomotor accuracy between groups as hypothesized, this indicates that children with ASD have the same ability in estimating their reach on targets both within and beyond the MVR line as the children considered NT. Moreover, upon inspection of correct responses between the ASD group and NT group (Fig. 1) it appears as that the children with ASD made the same errors in targets beyond the MVR line as the children considered NT. As highlighted with Gabbard et. al (2007) study, these errors may be due to the fact that the children’s visual pathways are still developing and they may not able to accurately perceive their own abilities without a frame of reference (Gabbard et al., 2007). This contrasts with adults who would have a fully developed visuomotor pathway and would be able to estimate their abilities due more practice with estimating their abilities overall.

There were limitations for this experiment that may have led to the current findings. The first was the inclusion of children with mild ASD in the experiment. This was necessary because the children needed to be able to understand and follow the instructions given to them by the researcher. Our findings did not find a significant difference between the children with ASD and children considered NT, which may indicate that because the children in the study had mild ASD,
their visuomotor pathways may be more fully developed than those who have more severe ASD. A future study with a more sophisticated approach to estimating reach among children with more severe ASD is needed where the children would not need to specifically follow instructions given to them by the researcher. Another limitation was the nature of the study itself. Data from six members of the ASD group and from two of the NT group were included in the statistical analysis. The data excluded was because the participants may not have clearly understood the instructions given to them and said either “yes” or “no” for all targets presented to them. This was for both the ASD groups and the NT groups, indicating further need for a more sophisticated study of this nature.

**Experiment 2**

Statistical analysis indicated that there were no differences between the ASD group and the NT group in velocity and acceleration of movement when reaching out to place a wooden block on a target displayed in front of them. This indicates the children with ASD and the children with NT had similar velocity and acceleration of movement for targets presented at the midline, the ipsilateral (right) and contralateral (left) sides. However, upon inspection of these results, it appears as though there were small but not significant differences between the ASD and NT groups. It was hypothesized that the children with ASD would display motor deficiencies when reaching out and placing the block on the target, specifically on those presented on the contralateral side. The results from the current study indicate however that there was no difference between the groups.

While there was one significant correlation between visuomotor accuracy on targets at the midline and performance velocity of the same targets at the midline, the lack of significant results at the other targets does not allow us to conclude that reach estimation performance can predict
reach action performance. Inspection of Fig. 5&6 shows that the children with ASD were fairly accurate in estimating their ability to reach out and touch a target. This indicates that the motor imagery among the children with ASD was developed enough for them to estimate their own abilities and then successfully place the wooden block on the target.

These results indicate that current group-based statistics may not be suitable for children with ASD. One study investigated gait symmetry among children with ASD (Eggleston et al., 2017). This study used the Model Statistic procedure which is commonly used for single subject-based studies. The results of this study found that children with ASD all displayed unique gait asymmetries, which contrasted similar studies which used group-based statistics. Figure 5a-b displayed examples of velocity and accelerations during the various targets presented to both the children with ASD and children considered NT.
Figure 5. Example of movement velocities and accelerations among a participant diagnosed with ASD during the Experiment.
Upon inspection of the figures above, it is evident that there are slight differences in the movement velocity and acceleration between each group. While the current study was not created in a way to allow for single subject statistics to be used (like the Modal Statistic), future studies similar in nature could address the same research question as this study while looking for differences in movement between each child with ASD.
There were limitations with Experiment 2 as well, most importantly the inclusion of only children with mild ASD. This was necessary because the children needed to be able to understand and perform the reaching task correctly, where children with more severe ASD were not able to be included in the study. Another limitation was the small sample size for both Experiment 1&2. Due to the COVID-19 pandemic, participant recruitment and data collection abruptly halted for this study and the targeted number of participants (20 in each group) was not able to be fulfilled. However, from the small sample size, the results showed that there was not much difference between the ASD group and the NT, further highlighting the need for future studies to incorporate single subject statistics into their studies.

Ultimately, due to the nature of ASD, each child is unique and variable in the way that they view and move in the world around them. While the findings from the current study did not show differences in reach estimation and action between children with ASD and children considered NT, there is still evidence from other previous studies that highlight the motor deficiencies exhibited by children with ASD. Past studies which have investigated the motor development of children have used group-based statistics, however these are not applicable to children with ASD. ASD is a highly variable disorder and no two individuals with the disorder have the same symptoms. More research is needed to understand this complicated disorder with hopes of being able produce earlier diagnosis of ASD and better suited therapy to help these children transition smoothly into adulthood.
6. DISCRETE VS RECIPROCAL TARGETING AMONG CHILDREN WITH AUTISM SPECTRUM DISORDER

6.1. Introduction

In the initial Fitts (1954) paper, the movement between targets was rhythmic and cyclical, otherwise known as a reciprocal movement. Fitts later determined that Fitts’ Law still applies to discrete movements as well, where participants moved a pointer from the starting point to the target and stopping, as opposed to cycling continuously between the two targets (Fitts & Peterson, 1964). More recent research identified, however, that Fitts’ Law appears to be steeper with regard to reciprocal aiming tasks (Guiard, 1997). While Fitts’ Law was established for both reciprocal and discrete movements, those studies compared the two where the interactions were between participant and the targets were the same. Many motor activities are cyclic with targets being at constant variation. While these tasks may comply with Fitts’ Law, cyclic movements are often accomplished in a more ballistic fashion and will rely on more preplanning and external feedback to accomplish the task (Smits-Engelsman et al., 2006). Due to the complex nature of human movement, motor control research focuses on distinct aspect of movement in order to better explain them. This here is where the distinction has been made between discrete and reciprocal movements (Hogan & Sternad, 2007).

Further research revealed that the indices of difficulty of a goal oriented task will elicit either a reciprocal or discrete movement (Buchanan et al., 2006). When performing a task, like that of the Fitts protocol, the pause between movement is known as “dwell time.” As the indices of difficulty changes, the dwell time changes, where a longer dwell time or pause is considered a discrete movement and a short dwell time is a reciprocal movement (Adam & Paas, 1996; Teeken et al., 1996). Nevertheless, Fitt’s Law can be applied when studied movement planning and
execution among children with ASD because it can be applied and quantified in a manner that will allow researchers to expand upon previous knowledge of the disorder. Discrete and reciprocal aiming tasks require very different motor control mechanisms even though the tasks seem similar in nature.

6.2. Purpose

Research regarding movement planning and execution within Fitts Law among children with ASD is lacking, indicating a gap in literature. Past studies which analyzed movement kinematics of individuals with ASD suggest that they suffer disturbances in overall structure of their movements which means that there are impairments in cognitive process, along with motor planning (Glazebrook et al., 2006, 2008) and motor control (Mari et al., 2003; Rosenbaum et al., 2007; Papadopoulos et al., 2012).

Previous research has also found that young children struggle with speed and accuracy when using a mouse to navigate a computer screen and click on a target (Donker & Reitsma, 2007). Participants in the current study used a mouse to complete all tasks ask of them. While research has shown that children can struggle with mouse related tasks, they did find that the shape a target did not hinder speed or accuracy so it is feasible that the children will be able to use the mouse to accomplish tasks required in the current study. Moreover, no current literature has included children with ASD in a study which had them use a mouse to navigate a task and compared their results to children considered NT.

Therefore, this study had the following goals: 1) to further understand the kinematic components of goal-directed upper limb movement among children with ASD by determining where in the formation of their movements were differences in motor control compared to children who are considered NT. 2) To investigate the discrete and reciprocal limb movement kinematics
task among children with ASD while comparing these results to those of children who are considered NT. 3) To investigate the effect an addition of a haptic feedback event (i.e. clicking a mouse) will affect both the discrete and reciprocal tasks.

There were four hypotheses from this study: 1) children with ASD will exhibit motor deficits in goal-directed aiming with discrete and reciprocal tasks, especially in the secondary corrective phase of the movement or homing in on the target. 2) Children with ASD will exhibit kinematic differences in both tasks when compared to children considered NT. 3) Children with ASD will exhibit kinematic differences with the addition of a haptic feedback event when compared to their previous results and 4), children with ASD will experience kinematic differences with the addition of the haptic feedback event when compared to children considered NT.

6.3. Methodology

6.3.1. Participants

Children (N=17) aged 6-12 were recruited from the El Paso community to participate in this study (Table 1). Inclusion criteria for this study included a formal diagnosis of ASD (for the ASD group) from a physician, all children from both groups must have the ability to understand prompts and correctly follow the instructions of the researcher, and all children must be free from any other neuromuscular disorder or disease which would prevent them from completing the experiment. It should be noted that this inclusion criteria limited the study to children exhibiting mild or moderate autism. This population consisted of ten children diagnosed with Level 1 ASD (8 male, 2 female; age(±std) = 8.90(±1.92)) and seven (6 male, 1 female; age(±std) = 8.71(±1.49)) children considered NT. Parents and guardians of all children read and signed a parent permission form and a child assent form was signed by all participants after researchers read and explained the document to
them. Parents and guardians were required to always stay in the testing room and were told, along with the participants, that they were free to terminate their participation in the study at any time.

6.3.2. Apparatus

Participants sat at a small rectangular table in a height adjustable chair. A mouse was placed on the right side of the table and was used to collect upper extremity data. A 42-inch television was mounted on the wall at eye level directly in front of the participant, which displayed task and performance feedback (Fig. 7). The custom task was creating using MovAlyzeR Movement Analysis Software (NeuroScript, Tempe, AZ).

![Diagram of Apparatus](image)

Figure 7. Left: the apparatus there the children had a mouse in front of them on a table and their movements were displayed on a screen in front of them. Right: A depiction of the difference between the Discrete and the Reciprocal aiming tasks.

6.3.3. Procedure

All participants (both ASD and NT) were randomly assigned to start with either the Discrete or Reciprocal protocol. Prior to beginning the task, the each participant was allowed to practice with the apparatus with a general example of the task to be undertaken. Participants were seated
with their feet on the ground (or on a box) with their right arm resting on the table while their right hand was on the mouse. Participants were instructed to move the mouse, which moved the cursor to the start position on the screen. This position was highlighted by a grey box on the screen labeled START HERE. The next tasks varied depending on the protocol they were following: the reciprocal task, discrete task, reciprocal with clicking task, and discrete with clicking task.

For the reciprocal task, two targets would appear on the screen and served as the prompt to begin the task. Participants were instructed to move the mouse cursor in and out of two defined target areas on the screen in front of them. The targets would vary in amplitude (size and distance) for a total of 3 ID values (3, 4, & 5). A breakdown of all the possible ID combinations as well as the total random presentations of each event is displayed in Table 1. The participants were given specific instructions to complete this task as fast and accurately as they could. The participants completed a total of 27 trials with 9 unique combinations per ID.

For the Discrete protocol, only a single target would appear once the participant positioned them over the START HERE box. Participants were instructed to move the cursor towards the target as fast as possible while accurately landing on target. Then after a couple seconds, another target would appear, and they would move the cursor as quickly and accurately as possible to that target. The number of ID combinations tested were the same as those in the Reciprocal protocol (Table 1). Participants were asked to complete 36 trials of this task, each lasting 12 seconds.

For the reciprocal with clicking task, this protocol consisted of the same protocols required for the reciprocal task. The difference was the addition of a haptic feedback even at each target which came in the form clicking the mouse when their cursor was over the target. The targets and total number of trials were the same as that of the reciprocal task.
For the discrete with clicking task, the protocols were the same as those of the discrete task with the addition of the haptic feedback event in the form of the clicking the mouse once their cursor reached the target. The target size and width were the same as the discrete task, along with the number of trials. The entire procedure took approximately one hour; however, participants were instructed that they could take as many breaks as possible in order to ensure their comfort during the session.

6.3.4. Analysis

Variables of interest are Duration (Total Time, TT), Peak velocity (PKV), Percent time to peak velocity (TPKV), and Normalized jerk (JRK), and a Pearson correlation was run to examine the linear relationship between movement time (TT) and ID. First, the non-clicking data will be analyzed. The dependent variables of TT, PVEL, %TPV, and NJRK will be analyzed separately by Task (discrete, reciprocal, discrete-clicking, reciprocal-clicking) X Group (ASD, NT) x ID (3, 4, 5) multivariate analysis of variance (MANOVA). Due to the unequal group sizes, a Tukey HSD post hoc test was run to identify between-subject differences (ASD vs NT) for all four tasks and to identify within-subjects differences for each group across all for all four tasks. An alpha < 0.05 will be considered significant for all tests.

6.4. Results

Pearson’s correlation

There was positive significant correlation between total time (TT) and for each ID (3, 4, 5); \( r(15) = .99, p < .01, r(15) = .98, p < .01, r(15) = .97, p < .01 \), respectively. This indicates that as ID increased, total time of movement increased.

Multivariate Analysis of Variance
Total Time (TT)

When comparing groups during the reciprocal-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 12) = .711, p = .235$, Wilks $\Lambda = 1.629$, $\eta^2 = .289$. When comparing groups for the discrete-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = 1.765, p = .212$, Wilks $\Lambda = .675$, $\eta^2 = .325$. When comparing groups for the reciprocal (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = 1.268, p = .333$, Wilks $\Lambda = .743$, $\eta^2 = .257$. When comparing groups for the discrete (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .096, p = .960$, Wilks $\Lambda = .974$, $\eta^2 = .026$.

Peak Velocity (PVEL)

When comparing groups during the reciprocal-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 12) = .712, p = .563$, Wilks $\Lambda = .849$, $\eta^2 = .151$. When comparing groups for the discrete-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .699, p = .572$, Wilks $\Lambda = .840$, $\eta^2 = .160$. When comparing groups for the reciprocal (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = 1.959, p = .179$, Wilks $\Lambda = .652$, $\eta^2 = .348$. When comparing groups for the discrete (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .356, p = .786$, Wilks $\Lambda = .912$, $\eta^2 = .088$.

Percent time to peak velocity (%TPV)
When comparing groups during the reciprocal-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 12) = .775, p = .530$, Wilks $\Lambda = .838$, $\eta^2 = .162$. When comparing groups for the discrete-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = 1.492, p = .271$, Wilks $\Lambda = .711$, $\eta^2 = .289$. When comparing groups for the reciprocal (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .009, p = .999$, Wilks $\Lambda = .997$, $\eta^2 = .003$. When comparing groups for the discrete (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .994, p = .431$, Wilks $\Lambda = .787$, $\eta^2 = .213$.

**Normalized Jerk (NJRK)**

When comparing groups during the reciprocal-clicking task, statistical analysis revealed that there was no significant difference between groups $F(3, 12) = .139, p = .934$, Wilks $\Lambda = .966$, $\eta^2 = .034$. When comparing groups for the discrete-clicking task, statistical analysis revealed that there was, no significant difference between groups $F(3, 11) = 3.386, p = .058$, Wilks $\Lambda = .520$, $\eta^2 = .480$. However, it is evident that there was a trend towards significance for this task (Fig. 7). When comparing groups for the reciprocal (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = 1.140, p = .376$, Wilks $\Lambda = .763$, $\eta^2 = .237$. When comparing groups for the discrete (non-clicking) task, statistical analysis revealed that there was no significant difference between groups $F(3, 11) = .243, p = .864$, Wilks $\Lambda = .938$, $\eta^2 = .062$. 
The purpose of this study is to further current knowledge of how children with ASD navigate and execute discrete and reciprocal goal-oriented tasks. The current study compared the kinematic results of children with ASD to those considered NT. This achieved by having children complete a Fitts-style task, where they had to move a mouse cursor on a computer screen between two targets of varying indices of difficulty (3, 4, 5). Participants completed two reciprocal tasks, where they continuously moved between two targets. Participants also completed two discrete tasks where they would move a mouse to a target and stopped and moved again when instructed by the computer software. Participants completed a simple reciprocal task and then a reciprocal task where they had to move the mouse cursor to a target and click the mouse. All participants

**Figure 8.** Mean NJRK values between groups for the Discrete-clicking task

### 6.5. Discussion

The purpose of this study is to further current knowledge of how children with ASD navigate and execute discrete and reciprocal goal-oriented tasks. The current study compared the kinematic results of children with ASD to those considered NT. This achieved by having children complete a Fitts-style task, where they had to move a mouse cursor on a computer screen between two targets of varying indices of difficulty (3, 4, 5). Participants completed two reciprocal tasks, where they continuously moved between two targets. Participants also completed two discrete tasks where they would move a mouse to a target and stopped and moved again when instructed by the computer software. Participants completed a simple reciprocal task and then a reciprocal task where they had to move the mouse cursor to a target and click the mouse. All participants
completed the same process for the two discrete tasks. Overall, participants completed the following four tasks: Reciprocal, Reciprocal-clicking, Discrete, Discrete-clicking.

Results from the statistical analysis revealed that there was a positive correlation between the total time of movement and the ID of the task, meaning that as the tasks became more difficult, the participants total time to complete the task increased as well. This is consistent with the movement time and ID relationship proposed by Fitts (1954).

All other statistical tests failed to produce a significant result, which is due to the small sample size of participants for each group. One result that is of interest, however, is the normalized jerk results for ID 5 within the discrete-clicking task. For this task, participants from both groups had to complete a discrete task where they moved their cursor to a starting point, and then when instructed by the computer program, moved as quickly to the next target displayed on the screen. Once they reached the target then need to click the mouse cursor on the target. The statistical results did not produce a significant result between groups, however with a p value equal to 0.058, there appears to be a trend with this movement. Jerk, within the field of physics, is the rate at which an objects acceleration changed with respect to time (Eager et al., 2016).

In human movement, specifically goal-directed movement, when an individual has a relatively low jerk score, this means they have completed the movement in a smooth manner. If they have a high jerk score, this means they movement in a quick jerking motion. Figure 2 showed the during the discrete-clicking task, they target with a ID of 5 produced the largest difference between groups where the children considered NT exhibited more jerking motions than the children with ASD. The targets with an ID of 3 and 4 were both increased in the NT group. Without a significant result it is difficult to make a true assumption, however this could indicate that the children in the NT group experienced greater jerk scores because they were anticipating the
movement to the next target and chose to move with greater acceleration than the children in the ASD group. Past research has indicated that as children with NT grow and mature, they develop internal models of action which help them anticipate a movement (Ego et al., 2016). Therefore, a possible explanation for the higher jerk scores in the NT group could mean that these children had already developed enough of an internal model of action which allowed them to anticipate the upcoming movement where the children with ASD did not exhibit this phenomenon.

This study did come with limitations. The first and foremost is the small sample size for each group. While previous research has found that children with ASD have motor deficits and disrupted internal models of action (Haswell et al., 2009), there has still been a lack of literature aiming to solve this puzzle. As indicated with Study 1 from this write-up, studies involving children with ASD could benefit more from a single-subject based format due to the high variability in symptoms exhibited by each individual diagnosed with ASD. The trending results involving the jerk score with the children with ASD, do show promise for future studies to investigate the goal-directed movement among children with ASD in a more robust and applicable manner.
7. CONCLUSION

Autism Spectrum Disorder is categorized by the social and communication deficits exhibited by the individuals who have been diagnosed with the disorder. Aside from these deficits, research has demonstrated that children exhibit motor deficits as well. These deficits, however, are difficult to include as primary diagnosis criteria because they are highly variable between each individual diagnosed with the disorder. The goal of the this write-up was to establish more evidence showing how children with ASD exhibit motor deficiencies when compared to children considered NT. There has been previous research which has highlighted these deficits, therefore this write-up sought to fill in some of those gaps with the hopes of push this field of study closer towards a deeper understanding of the disorder.

While the studies conducted within this write-up did not produce many statistically significant results, this does not mean that children with ASD do not exhibit motor deficiencies. The results from Study 1 and 2 have shown that even with a small sample size, there does appear to be a difference in motor movement between children with ASD and those considered NT. Autism is a disorder that is highly variable between each individual and because of this, it makes if difficult to apply group-based statistics to this population. Therefore, there is a need for future movement-related studies involving children with ASD and the use of single-subject based research. Few studies have employed this tactic with success, however their success has proven that future studies need to be innovative in how movement among children with ASD is approached.

For both studies, both ASD groups consisted of children who were diagnosed with Level 1 autism, which puts them on the less severe aspect of the spectrum. All children communicated verbally and were able to perform manual tasks when asked of them. Overall, this could indicate
that children with Level 1 ASD have less disrupted motor function than those in Level 2 or 3. Future research would have to create a study design that focuses on studying children with Level 2 and 3 ASD because they could display more inhibitions in motor planning and execution.

Previous studies have indicated that the more severe autism is in a child, the less their mirror neurons activate which impacts how they can imitate movements and actions of others around them. This also means that children with less severe autism (Level 1) are able to imitate the actions of others because they have mirror neurons that fire more often and allow them to imitate actions. Within the scope of both studies presented, the researchers demonstrated all tasks to be accomplished by the children ASD. Moreover, all children with ASD involved in the studies were diagnosed with Level 1 Autism which indicates that these children were able to correctly imitate the researchers demonstrations. This could have led to the lack of difference between the ASD groups and NT groups in both studies.

Future studies should aim to be more inclusive of children with Level 2 and 3 diagnoses of ASD, as they have been shown to display disrupted motor function. As highlighted previously, children with more severe disruption in social and communication skills, like those in Level 2 or 3, are more likely to have inhibited development of mirror neurons. Therefore, if children in Level 2 or 3 had been included in the study, there could have been more of a significant difference in the how they execute any type of upper limb movement.

Non-parametric statistics were not used in the primary analysis of both studies because it was believed that their use would not provide any practical significance or would not be representative of the ASD groups as a whole. However, due to the small and uneven sample sizes in both studies, exploratory non-parametric statistics were run to establish any differences between groups.
A Mann-Whitney test was run in Study 1 to investigate differences in movement between groups when performing the reach action task. Results indicated that there was no significance difference between groups and for any dependent variable, meaning that the null hypothesis could not be rejected. These results further highlight the lack of difference between the ASD and NT groups.

A Mann-Whitney test was run in Study 2 to investigate any differences between groups when completing all four discrete vs reciprocal tasks. The only significance found was in the discrete-clicking task for total movement time (TT) and normalized jerk (NJRK) for the targets with an ID of 5. Initial statistical analysis using parametric statistics indicated a trend towards significant difference between groups in NJRK at the ID 5 target. These results further highlight a possible difference in movement anticipation between the ASD group and the NT group.

The ID 5 target is the most difficult target and the NT group had much higher scores indicating that they were moving in a more rushed and jerkling motion. This could indicate that the NT group was anticipating the difficult movement and were therefore moving faster to click the target. The ASD groups displayed similar NRJK values as they did in the ID 4 target. This indicates that the ASD group may not have been anticipating the difficult movement and were moving the same as they had with the other targets. It should be noted, however, that the distributions of the significant values for NJRK and TT at the ID 5 target were asymmetrical between groups which violates an assumption of symmetry for the Mann-Whitney test. This ultimately means that the differences between groups may not carry any practical significance.

Much of the discussion for both studies has focused on the lack of significance between the ASD and NT groups. This does not mean, however, that there is no clinical relevance from the findings in these studies. The participants in both studies were diagnosed with Level 1 ASD, which
means that they have more mild symptoms of autism. This means that these children communicated verbally and had few issues with socialization and repetitive behaviors. Moreover, this also means that these children were able to respond to instructions and carry out tasks they were asked to accomplish. From a clinical perspective, this means that children with Level 1 ASD could be less likely to experience movement difficulties when compared to those diagnosed with Level 2 or 3 ASD. Therefore, therapy for these children could focus more on their social or communication deficits. While children with Level 2 or 3 ASD were not included in this study, future research should focus on these children with regard to their motor abilities. These children require more substantial support than those considered level 1. Moreover, they may also experience repetitive behaviors that impact their ability to carry out daily tasks (Gilmore, 2019).

Previous research from Dapretto et al., 2006 indicated that the more severe social and communication symptoms exhibited by children with ASD, the more likely they are to have underdeveloped mirror neurons. This means that these children would have difficulty imitating movement which further impacts their ability to acquire new motor planning and execution abilities. While the current studies did not show differences in movement ability between the children with ASD (considered Level 1) and the children considered NT, future studies should focus on children who fall within the Levels 2 and 3 domains of the disorder. These children would display more issues with imitating others so a clinical focus on tasks to help build new mirror neurons and new movement pathways would be applicable to these children.

Current diagnostic criteria is sufficient in diagnosing a child at an early age. However it is generally hypothesized that if research can show that motor deficiencies among this population warrant promotion to primary diagnostic criteria, then diagnosis methods can be standardized and can lead to early diagnosis. Once more studies are added to the field of knowledge involving these
individuals, the more understanding researchers will have of the disorder and will therefore be able to provide therapy for these individuals at a young age which will help them as they transition to adulthood later in life.

Much of the discussion in this write-up has focused on the lack of difference between groups and it has been attributed to many factors, like the level of ASD diagnosis and the small population size between groups. It is feasible that these same findings could have come about with a more robust sample size. If this had been the case, this could indicate that children with Level 1 ASD display similar movement abilities as children considered NT. If their movement abilities differ, their differences are not so severe that they would impact the way they manipulate and interact with the world around them. There is still much to discover about this disorder, especially regarding movement in those diagnosed with Level 2 or 3 ASD. Future studies should aim to be more inclusive of these individuals, either through methodology or study design. Fortunately, brain imaging technology has improved vastly in the past decade. This offers more opportunities to study the brain of these children especially during movement. Ultimately, more research is and will always be needed for children with ASD. The current study offers a brief glimpse into children with the disorder and ultimately showed that children with a Level 1 diagnosis of ASD are not significantly different their their NT peers when it comes to upper limb movement.
8. REFERENCES


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9. CURRICULUM VITA

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Patrick A. Cereceres received his Bachelor of Science in Kinesiology from The University of Texas at Austin. He then went on to receive a Master of Science in Kinesiology from The University of Texas at El Paso and continued his graduate work at UTEP in the Interdisciplinary Health Science Ph.D. program. Patrick has conducted research at UTEP since 2014 in Biomechanics and Motor Control, under the direction of Jeffrey Eggleston, Ph.D. and his doctoral advisor Jason Boyle, Ph.D. His topics of study have included lower and upper extremity movement among children with Autism Spectrum Disorder.

Patrick also has extensive teaching experience as well. He began as a Teaching Assistant from 2014-2016. Upon graduation with his Master’s degree he transitioned to an adjunct instructor at both UTEP and El Paso Community College, teaching multiple kinesiology courses from 2017-2021. Currently, Patrick is a full time instructor at Texas Lutheran University and will transition to a tenure-track Assistant Professor upon completion of his doctoral work.

PUBLICATIONS
