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Assessment of Motor Skills and Functional Performance in Pediatric Population

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To my spiritual master, His Holiness Sri Sri Ravishankar for being my inspiration, my parents for their faith and support, my sister for her love and to the loving memory of my grandfather

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Assessment of Motor Skills and Functional Performance in Pediatric Population

by

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The University of Texas at Austin, 2015

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The early years (1-7 years) provide a window of opportunity to develop fundamental movement skills (FMS) and these are evident during sports and recreational activities. If children cannot build a diverse motor repertoire during the fundamental period they may face a 'proficiency barrier' to gain expertise in context specific movement skills. For typical 7 year olds we make the assumption that their cognitive-motor skills qualify them to perform complex movement activities, however children with neurodevelopmental delay (ND) have been shown to have deficits in cognitive as well as motor functions. A variety of assessment tools are focused on physical competence for activities of daily living in this subset of population. However they are limited in providing information about activities that require coordination of movement sequencing and executive functions. Hence the purpose of this study was to assess and establish developmental trajectories of cognitive and complex motor functions in children and adolescents with and without neurodevelopmental delay. The assessment included an iPad based program that measured executive functions through tests of executive function, trail making test(TMT), reaction times, processing speed test (PST) and static balance on 39 subjects between the age of 7-14 years. The results showed that the choice reaction times were significantly higher in the ND group than the control group. The balance, TMT-B, and the PST showed weak significance but moderate effect size. The hop tests did not show significant differences between the two groups. These results depict the challenges faced by the ND group when subject to complex tasks requiring advanced skills.

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Chapter one

Introduction

The U.S. Department of Health and Human Services recommends that young people between the ages of 6-17 years should participate in at least 60 minutes of physical activity daily. Regular physical activity in childhood and adolescence improves strength and endurance, helps build healthy bones and muscles, helps control weight, reduces anxiety and stress, increases self-esteem, and may improve blood pressure and cholesterol levels. Physical activity levels carry over from early childhood to late childhood and adolescence and hence it is critical to develop and promote positive health behaviors in the early years (Jones, Hinkley, Okely, & Salmon, 2013). The early years provide a window of opportunity to develop fundamental movement skills (FMS) like stability (balance), locomotor skills and object control skills. Locomotor skills include running, galloping, skipping, hopping, sliding, and leaping (Haywood & Getchell, 2005). Object control skills consist of manipulating and projecting objects and include skills such as throwing, catching, bouncing, kicking, striking, and rolling (Haywood & Getchell, 2005).The skills learned in the early childhood are important building blocks for more complex movements (Gallahue & Cleland-Donnelly, 2007). These skills are evident during sports, physical activity and games. If children cannot be proficient in running, jumping, hopping etc. they will be limited in engaging in physical activity because they will lack fundamental skills to be active. Clarke and Metcalfe (2002) described the “mountain of motor development” which states that FMS are precursors to more context specific movements. In other words, to reach the “top of the mountain” of motor development, children must build a diverse motor repertoire in the fundamental period (1- 7 years of age) to apply these skills to more advanced activities like sports and sports related activities (Clark & Metcalfe, 2002).

It is presumed that children naturally acquire the FMS, however many children do not gain proficiency in these skills during the fundamental period (Goodway & Branta, 2003; M. Hamilton, Goodway, & Haubenstricker, 1999). Studies have shown that individuals who participate in sports during early childhood and adolescence will be more physically active in adulthood (Malina, 1996; Tammelin, Näyhä, Hills, & Järvelin, 2003). The positive co-relation between physical activity and motor proficiency is well established (Okely, Booth, & Patterson, 2001; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). Thus the practice of motor skills and amount of time spent in physical activity is directly related to motor expertise in adulthood in the neurotypical population. The advantages of physical activity are applicable to all the subsets of population including those whose development is atypical. For children without a clinical diagnosis, we make the assumption that the perceptual-motor skills of typical 7 year olds qualify them for the significant step up into sport-specific complex movement tasks. The assumption of a normal distribution in performance abilities also leads to the assumption that a proportion of the population will exhibit low motor competence, not identified by a clinical diagnosis. Thus even though they may have basic movement patterns, their low perceptual-motor skill level, however, may place these children at risk for exclusion from recreational and sporting activities.

Children with a diagnosis of developmental delay including Pervasive Developmental Disorders (PDD) often exhibit motor impairments secondary to the diagnosis. The PDD group involves disorders like Autism Spectrum disorder (ASD), Asperger's syndrome, Rett's syndrome, and pervasive developmental disorder not otherwise specified (PDD-NOS) (American Psychiatric Association 2000; World health Organization 1992). Individuals with these disorders show a variety of motor impairments such as deficits in motor coordination, fine motor impairments and gross motor deficits (Dewey, Cantell, & Crawford, 2007; Green et al., 2009).

Besides these, individuals with ASD also have deficits in locomotor and object control skills (Berkeley, Zittel, Pitney, & Nichols, 2001), ball skills, balance and manual dexterity (Manjiviona & Prior, 1995) reach to grasp movement (Mari, Castiello, Marks, Marraffa, & Prior, 2003) and graphomotor skills (Mayes & Calhoun, 2003a).

Bar-or hypothesized the activity gap theory according to which, the participation gap increases between children with movement impairments and their typically developing peers. They tend to engage less in organized sports and physical activity because they face challenges in movement skills which prevent successful completion of many of the games/tasks. (Bar-Or, 1983). According to the skill-learning gap hypothesis (Wall, 2004), children with deficits in motor skills will experience difficulty in engaging in physical activity as they mature because of lack of practice of movement skills in comparison to their peers. This gap is not only limited to participation but also to the skill development which -increases over time. Our purpose in this study is to assess, in this transitional age group (7-14 years) the specific traits and abilities that underlie sport specific skills.

What is unique in this study is the type of movement competence being assessed. Typical clinical assessments of motor skill, such as Bruinincks-Oseretsky Test of Motor Performance, Peabody Developmental Motor Scales 2nd edition (PDMS-2), McCarron Assessment of Neuromuscular Development, Movement Assessment Battery for children (M-ABC), have been used to provide evidence of motor coordination deficits and motor delay/impairment in fine and gross motor skills in children with threshold criteria focused on competence in activities of daily living (Green et al., 2009; Provost, Lopez, & Heimerl, 2007). A variety of assessment tools and methods, including direct observation, self-report, activity monitoring via accelerometers, pedometers etc. have been used to assess physical performance. A limitation of current assessments however, is the focus on physical competence for activities of daily living. The motor competence required for participation in recreational and athletic sport, however, is beyond the minimums required for activities of daily living (ADLs). Clinical movement assessments are focused on ADLs and few assessment instruments exist to provide meaningful information on an individual’s ability to manage the higher performance demand of recreational and athletic activities. None of the above mentioned assessment tools provide an estimate of more complex functional sport performance. The general characterization of this population is that they are competent in activities of daily living. Indeed, they walk through the hallways of schools, manipulate the instruments of eating and self-care, and may even run about on the playground. However, those with neurodevelopmental delay (ND) persistently show diffuse motor impairments in speed of response selection (executive function) (Happé, Booth, Charlton, & Hughes, 2006; Ozonoff, Pennington, & Rogers, 1991) and motor sequencing tasks (e.g., skipping, cut and dodge, catch and throw) (Mari et al., 2003; Page & Boucher, 1998). Individuals with ND are also known to have executive dysfunction (Fischer, Barkley, Smallish, & Fletcher, 2005). For example, individuals with Autism can have deficits in working memory and planning abilities (Hughes, Russell, & Robbins, 1994; Ozonoff & McEvoy, 1994). Children with ADHD have also been shown to have deficits in inhibitory functions and control of stopping ongoing responses (Barkley, 1997) along with deficits in planning abilities and working memory (Lavoie & Charlebois, 1994; Pennington, Groisser, & Welsh, 1993).

The question is, relative to their age-matched, undiagnosed peers, do children with neurodevelopmental delay exhibit an ever-widening gap in functional movement skills and cognitive functions? Can children with developmental delay accept the challenges of functional skills and leisurely sport activities? Thus the purpose of this study is to establish the developmental trajectory of functional performance skills and cognitive functions in children. Without a clinical diagnosis of gross motor delay, the odds of an intervention for improving their motor competency are slim. In this study we will assess the performance of functional motor abilities and skills – activities that require the coordination of executive function with movement sequencing (e.g., coordination of upper and lower limbs in response to a stimulus, selective attention, movement sequencing). This research will fill the gap in our understanding of developmental differences in movement sequencing and contextual problem solving associated with movement skills beyond the activities of daily living.

Hypotheses

Based on the existing literature, we hypothesize that: 1) participants with neurodevelopmental delay will have more postural instability in the static balance tests than the typically developing kids 2) The participants in the ND group will also have slower processing speed times and reaction times than the typically developing population 3) The participants in the ND group will have more dynamic instability in the functional performance tests than the typically developing group

Chapter Two

Literature Review

Functional performance skills demand greater movement competence than fundamental motor skills. Functional performance skills (FPS) are specific, complex movement skills that present an increased performance challenge over fundamental motor skills (FMS). Activities of FPS offer an intermediate context for challenging one's movement competence between FMS and competitive sport or recreational activities. FMS are the building blocks of recreational and sporting skills, but they are typically self-paced and performed under controlled conditions to scale the challenge.

As a child ages, they become involved in games and activities that promote skill development. In athletic activities, the FMS will provide the basis for throwing movements. These can then be developed into the sporting skill for throwing a ball from the outfield to home plate or throwing a javelin. The FMS of hopping becomes the athletic skill for cutting on a football field or for complex jumping like the triple jump. Functional performance skills are not sport specific, but are complex movements that challenge the basic motor abilities of the performer. A functional performance skill of simple hopping can be upgraded to a more challenging FPS of continuous hopping for a specified time period, or hopping along a prescribed course. A FMS of jumping can be progressed to the FPS of jumping for multiples (bounding) or in multiple directions. The activities of FPS reveal more about an individual's balance or strength under more challenging conditions than the simple tests of balance most often used in the developmental literature.

Developmentally, we know a great deal about the age-related expectations for competence in the fundamental movement skills. The leap from FMS to athletic performance, however, is great. The gap between individuals receiving a clinical diagnosis related to poor motor function and the "average" performer accounts for approximately 15% of the population (those between -1 and -2 standard deviations from the mean). Children on the lower ends of the performance scale are typically encouraged to participate in sport and recreational activities, but self-select out of those activities because of low motor competence (Ibrahim & ALI, 2010). Motor competence is not solely dependent upon the structural attributes of the body or measures of muscle strength. The interpretation of sensory cues contributes to the processing of contextual information that aids in the success of response selection and execution.

Typical Motor Development

The earliest movements are slow, small, non-complex and isolated movements in the proximal part of the fetus at the age of 7 weeks and 2 days (Lüchinger, Hadders-Algra, Van Kan, & de Vries, 2008). Motor development is considered as a process which begins before birth and continues after birth throughout adulthood. The term development refers to the phenomenon of change. Motor development can be defined as the changes in motor behavior that occurs during the lifespan, as well as the mechanisms that underlie these changes (Clark & Whitall, 1989). A popular heuristic device which defines the significance of motor skill changes is the 'Mountain of Motor Development' (Clark & Metcalfe, 2002) (Figure 1). The climbing of the mountain characterizes the sequential process to attain the peak i.e. skillfulness, which is determined by time and not the age (Clark, 2005).

Based on the qualitative periods in the lifespan, motor skill behavior is categorized into six different periods (Clark, 1994). These periods are: (a) the reflexive, (b) preadapted, (c) fundamental patterns, (d) context-specific, (e) skillful, and (f) compensation periods. The reflexive period spans from the third gestational month until two weeks after birth. The movements in this period are purely reflexive and produced by specific stimuli. Primitive reflexes like rooting, sucking stepping etc are essential for the interaction with the environment in the first two weeks. The preadapted period begins when species typical behavior starts to develop around two weeks of age. Movements such as crawling, rolling, sitting, feeding and walking begin to emerge which are no longer reflexive but rather are preadapted. This period ends with the attainment of independent locomotion and feeding which typically coincides with the first birthday of the child. The next period, fundamental patterns period intensifies and expands on the locomotor and manipulative skills which act as building blocks for emergence of culturally specific motor skills. For example, walking extends to running, jumping, hopping and galloping; feeding extends to using tools (spoons) and scribbling with pen.

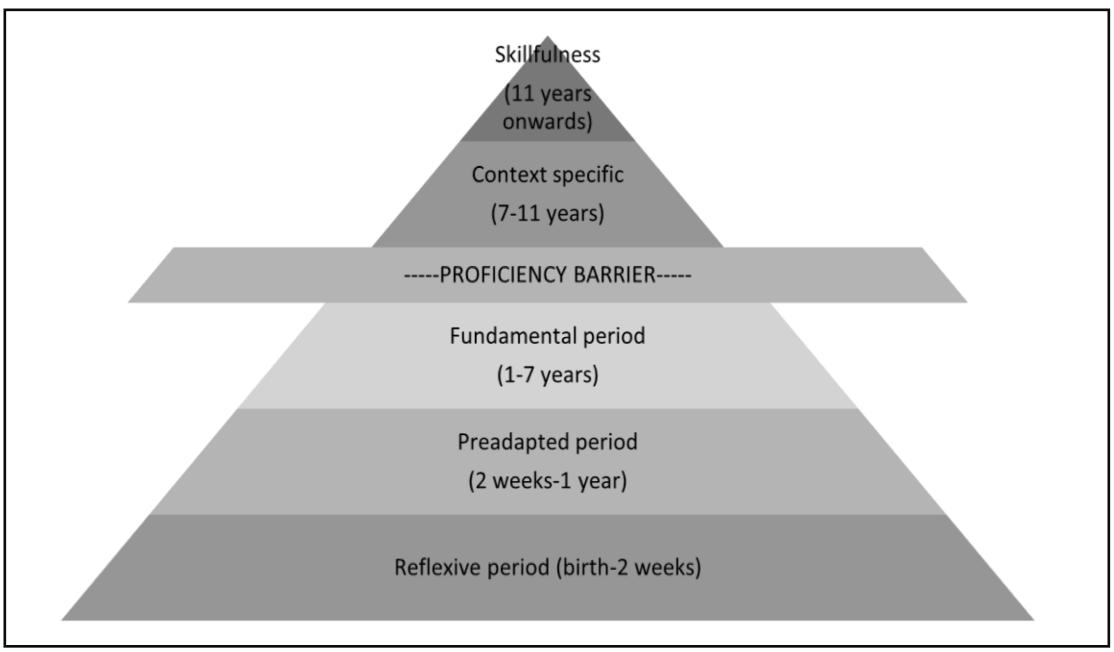


Figure 1- Schematic representation of mountain of motor development. Clark, J. E., & Metcalfe, J. S. (2002). The mountain of motor development: A metaphor. Motor development: Research and reviews, 2, 163-190.

This period will end when the fundamental patterns become integrated to more context specific skills which typically happens around 7 years of age. Scribbling now shifts to writing letters and galloping now shifts to skipping. This phase in movement skill is concurrent with the cognitive development which reflects in the understanding of the performance by the child. This period is followed by the skillful period. Skillful period is denoted by skilled movement which is efficient and can be reliably repeated. The achievement of this period requires years of practice. With dedicated effort and deliberate practice, the individual can gain expertise in a particular movement form. The last phase of motor development is reached when there is requirement for compensation in the movement due to physiological changes in the body. This period is called the compensation period.

In summary, the mountain of motor development is not a theory or a model. It's a framework to understand movement changes across lifespan.

Importance of Fundamental Period

In the initial childhood years, the child develops a set of movement patterns known as the fundamental movement skills (FMS). These skills fall under the fundamental movement period in the mountain of motor development. The movements accomplished in this period provide a foundation for more complex movement later on in life which are evident in sports and various physical activities (Seefedlt 1980; Clark and Metcalfe 2002). Movements are generated based on the interaction of organism with the environment in which it occurs and the skill to be performed (Newell, 1986). According to Seefedlt, if competency is not achieved in these FMS, children will not be able to break through a 'proficiency barrier' and this will limit their participation in sports and recreational activities (Seefedlt 1980) . FMS do not depend on the age but they must be inculcated and practiced repeatedly (Haywood & Getchell, 2014). The accomplishment in this period is not just dependent on maturation. It is the range of movements that support more elaborate movements and drive them towards skilled movements.

A widespread fallacy is that children naturally learn these FMS. However, many children may not be proficient at these skills and thus lacking competence in motor activities in adulthood (Goodway & Branta, 2003; M. Hamilton et al., 1999). Although an elementary pattern of these FMS can be observed in children, a more mature pattern will only develop with deliberate practice and instruction (Clark & Metcalfe, 2002). For example, a walking pattern study by Adolph et al (2003) demonstrated that the duration of time spent in walking was a stronger predictor of that skill than the age of the child (Adolph, Vereijken, & Shrout, 2003)

Children who do not receive sufficient practice and instruction in the fundamental period may exhibit developmental delay in motor skills (Goodway & Branta, 2003). According to National Association of Sport and Physical Education, competency in FMS is categorized as the primary goal in elementary physical education in the US (Sport & Education, 2004). There is strong evidence from cross sectional studies for a positive link between FMS competency and physical activity in adolescents. Not only physical activity, but FMS competency is also positively co-related to cardiorespiratory fitness and negatively corelated to weight status (Lubans, Morgan, Cliff, Barnett, & Okely, 2010)

Based on the mountain of motor development, to reach the 'top of the mountain' and apply these skills in more sport specific activities, one must gain proficiency in the fundamental skills period (Clark & Metcalfe, 2002). For example to do a triple jump on the track and field or to maneuver a ball in soccer across the field, the fundamental skills of hopping and jumping need to be mastered. The fundamental skills of hopping, running, jumping, throwing etc. are often used as a premise for more advanced skills. For example a tennis serve can be considered as a mature pattern of throwing (Zebas & Johnson, 1989). A study by O’keeffe et al demonstrated that participation in a fundamental throw teaching program significantly improved the throw and it also progressed to improvement in badminton overhead clear and javelin throw. This progression did not transpire to sport specific skills in the control group (O'keeffe, Harrison, & Smyth, 2007).

According to Gallahue, specialized movement phase (context specific) has three phases- transitional stage, application stage and lifelong utilization stage (Gallahue & Ozmun, 1998). In the transitional phase, the movements are an extension of FMS which are more mature and complex skills applicable in sports. The application phase allows the individual to make various decisions based on the cognitive sophistication and the previous learning experiences. The lifelong utilization stage represents the pinnacle of development of the motor skills wherein the individual utilizes movements which are a culmination of all the previous phases and continue to apply those skills in the various activities across the lifetime.

In summary, fundamental skills period is a critical stage where the goal is to surpass the proficiency barrier and it is dependent more on exposure and opportunities and less on maturation. It takes dedicated practice to gain expertise and utilize the skilled movements throughout one’s lifetime.

Executive Function in Typical Population

The term executive function is an umbrella term which involves abilities to produce goal directed behavior, inhibition, planning, strategy development and flexibility of action (Stuss & Alexander, 2000). Different aspects of executive function are divided into 4 main phases: it involves representing a problem flexibly, planning organized sequences of thought or action, executing those sequences, and evaluating the results of one's rule use (Zelazo, Carter, Reznick, & Frye, 1997). In this problem solving framework, the execution part begins after selecting a plan of action. This includes *intending*- having plan in mind to direct the thoughts and *rule use*- manifesting the thoughts into action. This is followed by the final phase of problem solving, evaluation which involves error detection and error correction. This framework depicts aspects of executive function in an organized manner and it helps in identifying the loopholes in a temporal sequence of the framework. (Zelazo et al., 1997)

Spurts in executive abilities start developing at the age of 12 months with majority of functions coming together around the age of 8 years (Ardila & Rosselli, 1994; Case, 1992). An immature executive system is available around the age of 8-10 years with effective planning and problem solving skills available around the age of 12-14 years (De Luca et al., 2003). In this same study looking at development of executive function across lifespan, a test on attentional set-shift (shifting attention from one task to another and ignoring unwanted inputs) showed no difference in age groups ranging 8-70 years which shows adult level competence in set-shifting tasks in 8-10 year olds.

A number of studies have used inhibition and working memory as the basis to describe the development of executive function. Studies have shown marked improvement in inhibition responses in early (6-8 years) and middle childhood (9-12 years) with barely any improvement in young adults (18-29 years) and older adults (60-89 years) (Williams, Ponesse, Schachar, Logan, & Tannock, 1999). These findings are in alignment with a study done by Levin et al (1991) in which it was shown that maximum improvement in impulsive errors and missed responses occured in the early (6-8 years) and middle age groups (9-12 years) with minimal improvements in the young adult group (13-15 years)

Executive Function in Atypical Population

Studies have shown the existence and importance of executive dysfunction in several different developmental disorders (Fischer et al., 2005; Ozonoff & Jensen, 1999; Shue & Douglas, 1992). It is hypothesized that there is no difference in the process underlying the typical and the atypical executive functioning. Studies have shown that EF domains like working memory, organization, attentional set-shifting and flexibility may be the predominantly affected cognitive functions in autism (Ozonoff et al., 1991).

Executive dysfunction was evident in several studies that depicted that autistic subjects were more perseverate and inflexible as compared to the controls (Ozonoff & McEvoy, 1994) and also showed deficits in planning abilities and working memory when compared to the control group (Hughes et al., 1994; Ozonoff & McEvoy, 1994). Deficits have also been observed in autistic subjects in tasks that required symbolic information processing (Lewandowski, 1984). Historically, the Wechsler digit symbol substitution test (WDSST) has been used to assess psychomotor speed. However variants of WDSST like symbol digit modalities test (SDMT) and symbol digit coding (SDC) have been recently use due to their brevity, accuracy and availability of computerized versions. SDMT is a simple and practical test to measure information processing speed and has been frequently used to assess cognitive functions in the clinical population (Benedict et al., 2008; Drake et al., 2009; Lewandowski, 1984).

Individuals with autism have also been shown to have deficits in attention shifting and shifting between modalities during reaction time tasks and information processing tasks (Courchesne et al., 1994; Lewandowski, 1984). Tests like stroop test, Wisconsin Card Sorting Test (WCST) have been used in the past to assess executive function and attention related domains in autistic individuals (Minshew, Goldstein, & Siegel, 1997; Ozonoff et al., 1991). On the other hand studies using trail making tests (TMT) and symbol digit modality test have shown significant differences in the autistic and control group (Goldstein, Johnson, & Minshew, 2001). The contrasting results could be explained by the fact that the stroop test involves simple repetitive movements whereas the TMT and the SDMT involved coordinated skilled sequential movements. This suggests that, to detect attentional deficits in the clinical population, novel tasks that require more than simple executive abilities need to be used.

Not all the components of EF are affected in the developmentally delayed population. It has been shown that inhibition may not be a significantly challenged aspect of EF in the autistic individuals (Hill, 2004; Ozonoff & Strayer, 1997). Within the spectrum, there are no significant differences between those with high functioning autism (HFA) and individuals on the autism spectrum (AS) in EF (Ozonoff, South, & Miller, 2000). The executive function of individuals with PDD-NOS falls between HFA and AS individuals (Verte, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006). The developmental trajectory of everyday executive function for the typical population shows decreasing EF problems with increasing age (Huizinga & Smidts, 2010) whereas children with ASD with increasing age show increasing deficits in EF from the normative database (Rosenthal et al., 2013).

Individuals with ADHD have been shown to have by and large similar deficits in domains of EF as autism. Studies have found significant deficits in the planning ability, working memory and inhibition of pre-potent behavior in ADHD subjects as opposed to the control group (Lavoie & Charlebois, 1994; Lufi, Cohen, & Parish-Plass, 1990; Pennington et al., 1993). According to Barkley, children with ADHD are developmentally delayed with regard to inhibitory function (Barkley, 1997). This is one of the major differences between individuals with ASD and ADHD. Individuals with ADHD have significant inhibitory deficits whereas individuals with ASD have deficits with flexibility and perserveration (Ozonoff & Jensen, 1999; Sergeant, 2000). Another study looking at EF in ASD and ADHD in 6-12 years old reported similar results. The ASD group had significant impairments in planning ability and flexibility whereas the ADHD group had deficits in inhibitory functions (Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004). There are two studies that did not find any significant differences in EF in subjects with ADHD compared to a control group (Grodzinsky & Diamond, 1992; Pennington et al., 1993). This could be because of non-longitudinal study.

In summary, individuals with ASD are impaired in planning abilities, working memory and attentional shifting tasks whereas individuals with ADHD show core deficits in inhibitory functions. However, to reach the threshold of the deficit domain, sophisticated rather than simple tasks must be administered.

Relationship between Executive Function and Motor Development

Literature has shown that developmental coordination disorders are not only categorized by motor deficits but are also accompanied by cognitive and behavioral problems (Henderson, 1992). According to Piaget's theory of cognitive development, cognitive development relies on motor development and they cannot be considered separate domains (Piaget & Inhelder, 1969). In a cognitive energetic model, Sergeant (2000) describes executive function at the highest level of his model and links it with motor performance. Since EF involves planning, organizing and evaluation, it is likely to affect motor performance (Sergeant, 2000).

It was believed that motor development starts earlier and matures earlier than executive functioning skills. However, studies have shown that maturation of complex cognitive as well as motor skills continues into early adulthood (Diamond, 2000). Studies have shown that cognitive abilities, behavioral planning and executive functioning start developing between the age of 5-10 years of age which is also a developmentally rich period for motor control and visuomotor coordination and the developmental trajectory continues into adulthood (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Ferrel-Chapus, Hay, Olivier, Bard, & Fleury, 2002).

The link between EF and motor development can be well substantiated with neurobiological evidence as well. By and large it is known that the pre-frontal cortex is associated with cognitive functions and the cerebellum is associated with the motor abilities. However recent research shows that the cerebellum may also participate in some complex cognitive function and the frontal lobe and the basal ganglia may be involved in multifaceted motor and cognitive tasks (Diamond, 2000). This shows the enveloping participation of the cerebellum in both cognitive and motor tasks especially when the task is unique or modified for which executive functions come into play.

A study by Wassenberg et al (2005) showed that certain aspects of cognitive performance like working memory, verbal fluency and visual motor integration are related with motor performance in the age group of 5-6 year olds. These findings are also in alignment with studies looking at the atypical population which show that cognitive and motor performance is related in clinical population like ADHD and DCD (S. S. Hamilton, 2002; Pitcher, Piek, & Hay, 2003). This indicates the parallel development of certain cognitive and motor functions in both typical and atypical population (Wassenberg et al., 2005)

Chapter three

Methods

The assessment of executive functions and functional performance measures contributed to an identification of coordinated complex cognitive and motor skills. In order to assess these measures, two types of tests were used. An iPad based assessment program was used to measure elements of executive function and postural stability. To measure the functional performance of gross motor movement and dynamic balance, we used three different hop tests.

Experimental design

This was an observational and cross-sectional study of individuals between 7 and 14 years of age participating in the study. We recruited typically developing children and adolescents and those with a diagnosis of neurodevelopmental delay. The dependent variables were balance, reaction time, processing speed, visual acuity and a measure of the vestibulo-ocular reflex. Limb symmetry index (LSI), was determined for each of the hop tests. Independent variables were the two groups, typically developing (TD) group and the neurodevelopmental delay (ND) group. The data obtained from the ND population was compared to data from, TD peers on measures of balance, executive function, and movement competence within the age boundaries of 7 to 14 years.

Participants

A total of 39 participants were recruited with 19 participants in the (ND) group and 20 participants in the (TD) group. Participants were recruited through local youth sport and community agencies from central Texas. We recruited participants with a diagnosis of neurodevelopmental disorder by contacts with parent support groups and special education directors of local schools. Additionally, we employed a snowball technique of asking the parents of study participants to distribute information about the study by word-of-mouth to other families. People interested in the study initiated contact with the research team. Upon contact, a cover letter or email containing information about the research project along with the consent forms and screening checklist was distributed or sent out to all families associated with the recruiting groups.

Inclusion/Exclusion criteria

For typically developing participants the inclusion criteria specified that the participant should be between the ages of 7 years (+/- 1 month) and 14 years (+/- 1 month). The exclusion criteria included: presence of an acute illness or injury at the time of testing, any recent surgery that limited physical activity, presence of medical disorders like diabetes, hypertension, history of seizures and dizziness or loss of consciousness.

For the participant with Neurodevelopmental Delay the inclusion criteria included that the participant should be between the ages of 7 years (+/- 1 month) and 14 years (+/- 1 month) and they should have a diagnosis of a neurodevelopmental disorder. Diagnosis was received by parent report. A participant was excluded if they had a diagnosis of a co-morbid condition that negatively impacts physical performance (e.g., cerebral palsy, gross motor delay) or recent injuries (e.g., fractures) that may limited physical activity. Participants must be 6 months post injury if the injury occurred in the lower extremity.

Instrumentation and Assessment

For this study, we used an iPad based assessment program known as the Research App (i-comet technologies, 2013). The iPad serves as a portable assessment tool and the application includes a test battery that includes elements of a neurocognitive exam. It effectively measures several motor skills and cognition by assessing reaction time, processing speed time, and postural stability. The application was developed by Cleveland Clinic as a comprehensive neurocognitive assessment tool. We custom designed a module for our study that allowed us to test only the relevant executive functions based on child configuration and balance tasks for the age specific population. A custom harness belt also comes along with the iPad that can securely hold the iPad when attached on the body at the level of sacrum. The tool kit also includes a 2.5-in thick Airex balance foam pad (Alcan Airex AG, Sins, Switzerland) with which to to conduct the balance tests.

Balance: - A harness with an iPad holder was affixed to the waist and the iPad clipped in. For all the tests the participants had to keep their hands on their waist at the level of the pelvic bone (figure 2). Six main stances were tested on a firm surface first followed by the foam surface with eyes closed (EC) and eyes open (EO): double-leg, single-leg and tandem stance.

An error would be counted if the participant removed their hands from their waist, lifted the heel or the forefoot of the support, flexed at hip greater than 30 degrees, opened their eyes during the EC condition or touched the contralateral foot to the ground during the single leg stance. If a participant stayed in an error position for more than 5 s, an error score of 10 (largest possible error) was recorded. Each stance lasted for 20 s and the errors were recorded on the iPad at the end of each stance.

Reaction time: - The participants performed two types of reaction time tests; simple reaction time and choice reaction time. The participants were told that they were going to play a game called ‘hit the green button’ For simple reaction time test, the participants were asked to touch and hold a button at the bottom of the screen with the index finger of the dominant hand. A yellow spotlight at the top of the screen would appear as the test began. As the spotlight turned green, the participants were required to lift and tap the green spotlight with the same finger as quickly as possible.

Figure 2: Balance Test with the iPad clipped on the harness belt at the level of sacrum

.

For the choice reaction time, there were two spotlights and two buttons instead of one. The participant would touch and hold the two home buttons with both the index fingers. During the test, one spotlight compatible with the right or the left hand would turn green and the other one would turn blue. As one of the lights turned green, the participant was to tap the green light as quickly as possible.

Processing speed task: - In this task a sample screen of the test was shown to the participant which consisted of a box at the top with two rows and the similar box in the middle of the screen. The box at the top was the key to the test which has the symbols in the upper row and numbers (1-9) corresponding to them in the row below. The second box contained only the symbols and an empty row (figure 3). Using the 'Key' box, the participant filled in the empty row by tapping the number corresponding to the symbol in that box. The bottom of the screen had a row of numbers which was used for tapping and filling the empty row. When one row was completed another row would appear. The participant kept filling the rows until the test stopped. The tests lasted for 120 s (2 min). At the end of 120 seconds, the score was recorded in the iPad.

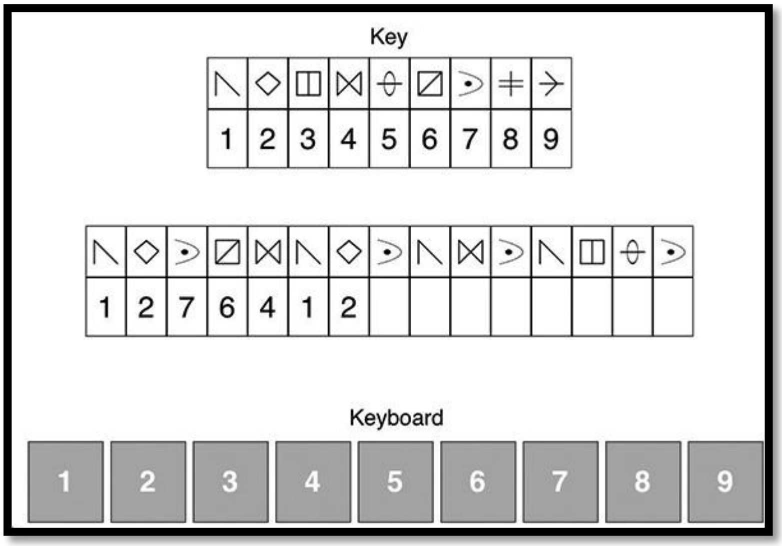
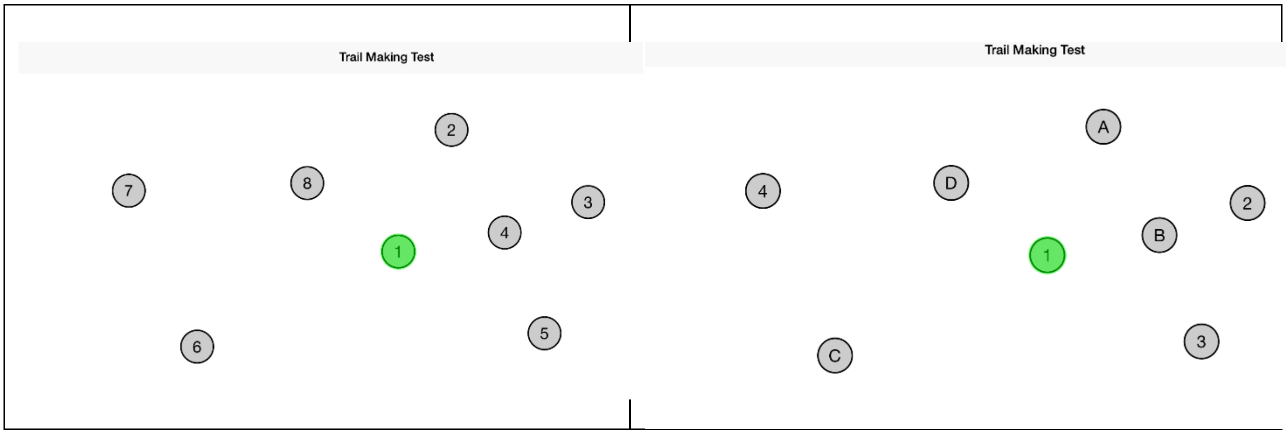


Figure 3: processing speed test

Trail making test: - the participants were told that they were going to play a game called ‘connect the dots’. It consisted of two parts in which the participant was asked to connect a series of dots in order. For the first test, also called TMT A, the participant was presented with only the numbers. The participants are instructed to connect the dots in order without lifting their finger until they were done with the very last number. For the second part, TMT B, a series of numbers and letters were presented in a random order and the participants were to alternately connect the numbers and the letters in order (1-A, 2-B, etc.) (Figure 4) If they lifted the finger in the middle of the test, the trial was disregarded and repeated again.



TMT-A TMT-B

Figure 4: Trail making test (TMT) A and TMT B

Procedures

Prior to participation, the participants were screened to ensure that they met the inclusion criteria. The parents were introduced to the parental permission form and they reviewed and signed it before the beginning the assessment. The participants were given a brief synopsis of the study. They were also given some time to familiarize themselves with the instruments (harness, foam pad, and the iPad). After addressing all their concerns and questions, the study protocol was initiated. Dominance for the upper extremity was determined prior to the test by asking them to write their name on paper. We assessed the participants on their postural stability, reaction time, processing speed as described above, and functional performance tests; single leg hop for distance, crossover hop for distance and figure of eight hop test for time. They are described in brief below. Participants were photographed and video recorded and permission was explicitly obtained in the consent forms.

To test the functional performance levels, we administered three different single leg hop tests. We selected these tests based on their complexity which take them beyond the fundamental skill of jumping with both feet and these tests have been frequently used as indicators of lower extremity control (Noyes, Barber, & Mangine, 1991)

Prior to the tests, we gave verbal instructions on how to perform each functional test as well as a demonstration. Dominance of the lower extremity was determined by asking them to kick a ball. Participants performed a practice trial of each performance test to familiarize themselves with the testing procedures. Subsequently they completed 3 trials at maximal effort. The best of 3 trials was used in the analysis. The order of the functional performance tests and limb was counterbalanced for each test.

Figure-of-8 Hop Test – This test recorded the time taken for a participant to hop on one foot in the shape of figure 8. For the figure-of-8 hop test, a 3 m course demarcated by cones was used. Each participant was instructed to hop on one limb, around the course, as fast as possible. A trial was regarded as unacceptable if the participant touched the contralateral foot down, fell, or did not complete the course as outlined. The trial was repeated if not acceptable. The score was recorded by time in seconds using a stopwatch (ACCUSPLIT Pro Survivor 601X, Livermore, CA) to the nearest 100th of a second. The stopwatch was started as soon as the participant's heel lifted off the ground and stopped as the participant touch the start line after finishing the course.

Triple Leg Hop for Distance – For this test, each participant started by standing on one foot with the heel positioned on a predetermined mark on the floor. Participants performed three consecutive hops for distance, landing on the same leg and sticking the landing for 2 s. A standard roll-out tape-measure was used to record the horizontal displacement, in centimeters, to the heel landing mark. The trial with the greatest horizontal displacement was used for data analysis.

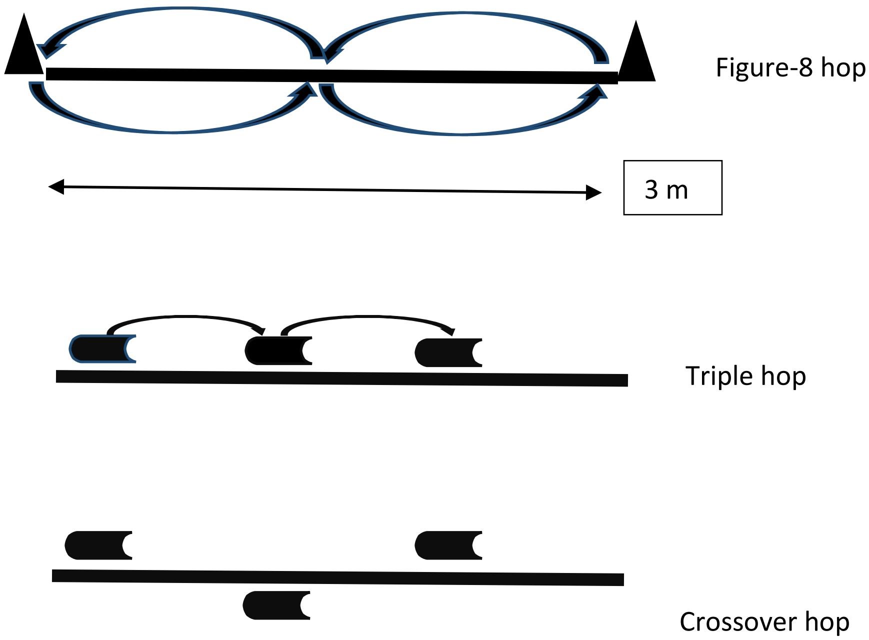


Figure 5: Hop tests

Crossover Hop Test for distance - In the crossover hop test the participants were instructed to hop on one limb over the 15 cm wide line, alternating sides for 3 times, as fast as possible. The distance was measured from the start line to the back of the heel at the landing in centimeters using a standard measure tape. A trial was regarded as unacceptable if the participant touched the contralateral foot down, fell, did not completely clear the width of the line or if they did not stick the landing for 2 s. The participant then performed the test on the opposite lower extremity.

After recording the raw scores for the hop tests, the best score for each limb was used to calculate the limb symmetry index (LSI). To calculate the LSI for the triple hop and crossover hop for distance, the score of the dominant leg was divided by the score of the non-dominant leg and then the result was multiplied by 100. For the figure-of-8 test, the LSI was calculated by using the score of the non-dominant leg divided by the score of dominant leg and the result multiplied by 100 (Noyes, Barber, & Mangine, 1991). A LSI score of less than 85% was considered abnormal.

Although the order of the tests was fairly consistent across the two groups, it was not strict and was changed to accommodate the participant's interest. We generally began with the Simple and choice RT's followed by processing speed test, trail making test, and then balance. After the iPad tests, we then proceeded to the hop tests. The entire testing lasted no longer than 60 min.

Analysis

Statistical analysis of the data was performed using independent t-tests with the above mentioned dependent measures across both the groups using SPSS (v.16) [or PASW Statistics (v.18)] . To control for the experimental-wise error, we used α level of 0.01. Effect size was calculated using correlation coefficient (r)

Chapter four

Results

The purpose of the study was to determine the differences in the developmental trajectories of executive function and functional performance skills in individuals with neurodevelopmental delay (ND) and typically developing (TD) individuals. We hypothesized that 1) participants with ND would have more postural instability in the static balance tests than the TD participants 2) participants in the ND group would also have slower processing speed times and reaction times than their TD peers 3) The ND group would have more dynamic instability in the functional performance test than the TD group. 4) The ND group would not show age related progression on static and dynamic stability, reaction times and processing speed times when compared to the TD group.

The results showed that there was no significant difference in postural stability between the ND group ($M=48.39$, $SD = 17.7$) and the TD group ($M=33.2$, $SD= 11.29$) in the balance tests, $t(36)= 3.18$, $p > 0.01$. However there was a moderate effect size ($r = 0.47$) for group. ND performed more poorly than TD group. Figure 6 shows the difference between the groups and the Figure 7 shows the trend line between the groups across the age range.

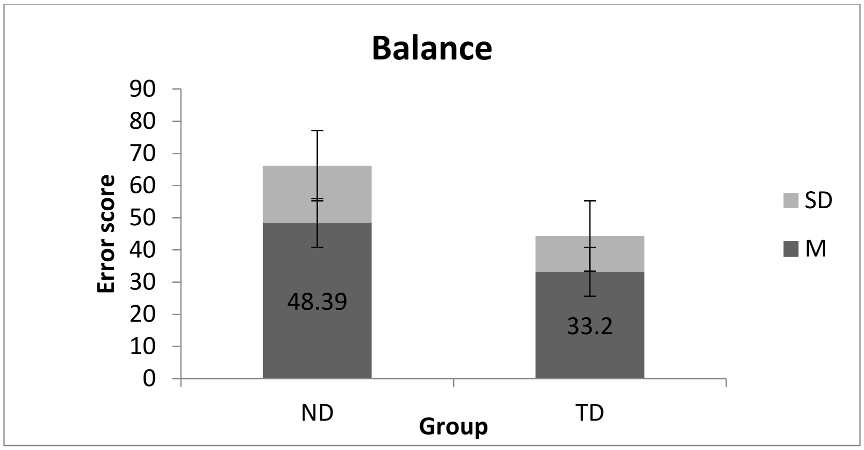


Figure 6: Average difference between the ND and TD group in Balance tests

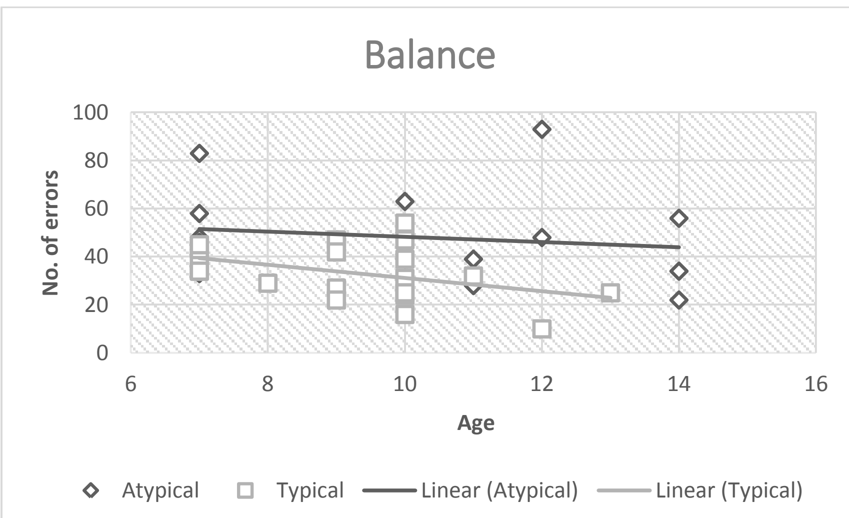


Figure 7: Trend line for the Balance test across the age range between ND and TD group

There was no significant difference in the processing speed times in between the ND (M=30.79, SD = 14.87) and the TD (M= 44.55, SD = 14.25) in the processing speed task PST, $t(37)= -2.9$, $p > 0.01$. However, it did represent a medium sized effect $r = 0.43$Figure 8 shows the difference between the groups and the Figure 9 shows the trendline between the groups across the age range

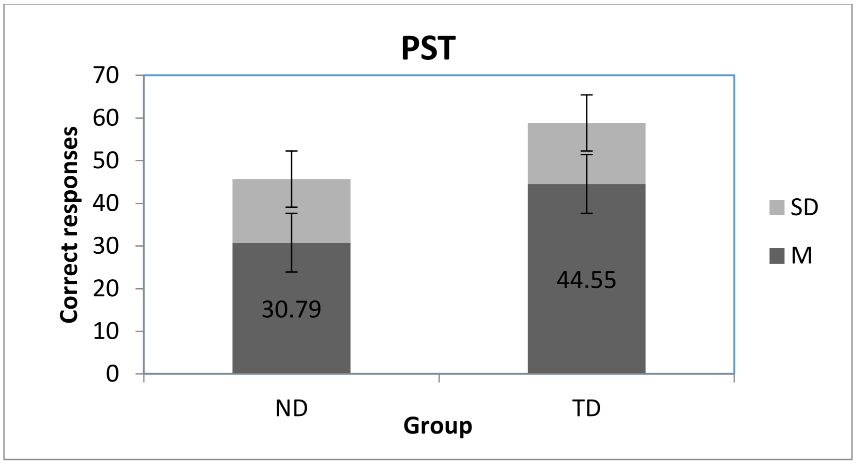


Figure 8: Average difference between ND and TD group in Processing Speed Test (PST)

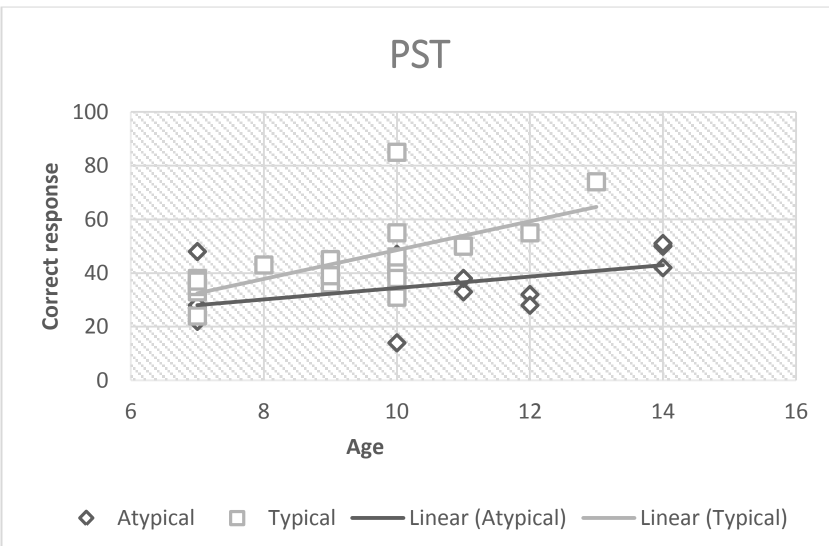


Figure 9: Trend line for Processing Speed Test (PST) across the age range for ND and TD group

The analysis of the reaction times test showed that there was no significant difference between the ND (M=334.12, SD = 52.36) and the TD (M=329.28, SD = 29.33) in the simple reaction time test SRT t(35)= 0.35 , p >0.01. There was a significant difference between the ND (M=519.64, SD = 105) and the TD (M=329.28, SD = 29.33) in the choice reaction time test (CRT), t(36)= 7.78, p <0.01. the effect size for SRT was low *r* = 0.06, but CRT had a high effect size $r = 0.79$. Figure 10 shows the difference between the groups in the RT tests and the Figure 10(a) and 10(b) show the trend line between the groups across the age range

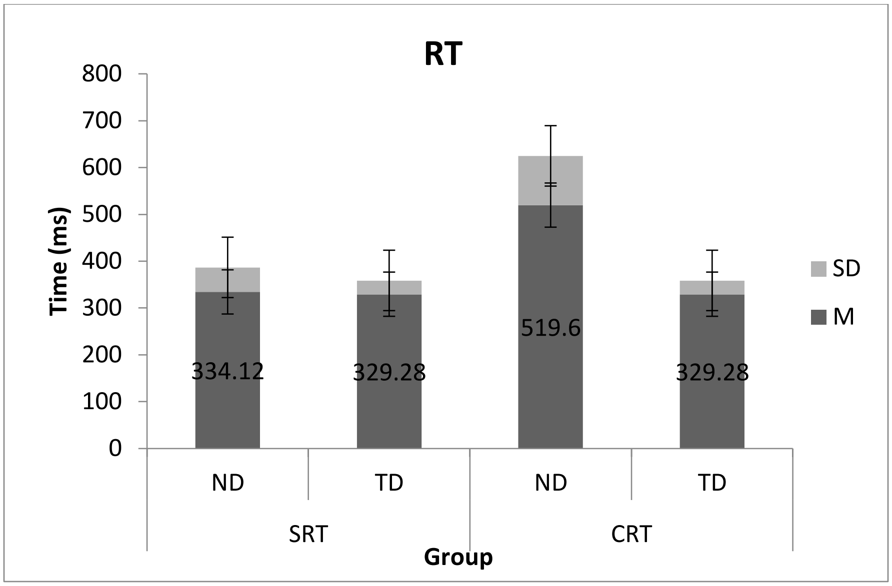


Figure 10: Average difference between ND and TD group in Reaction Times (RT)

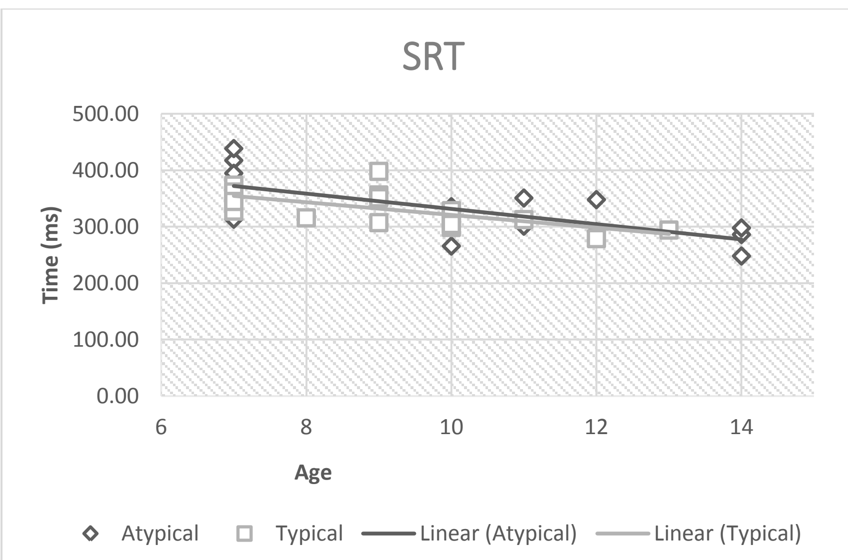


Figure 10(a) : Trend line for Simple reaction test (SRT) across the age range for ND and TD group

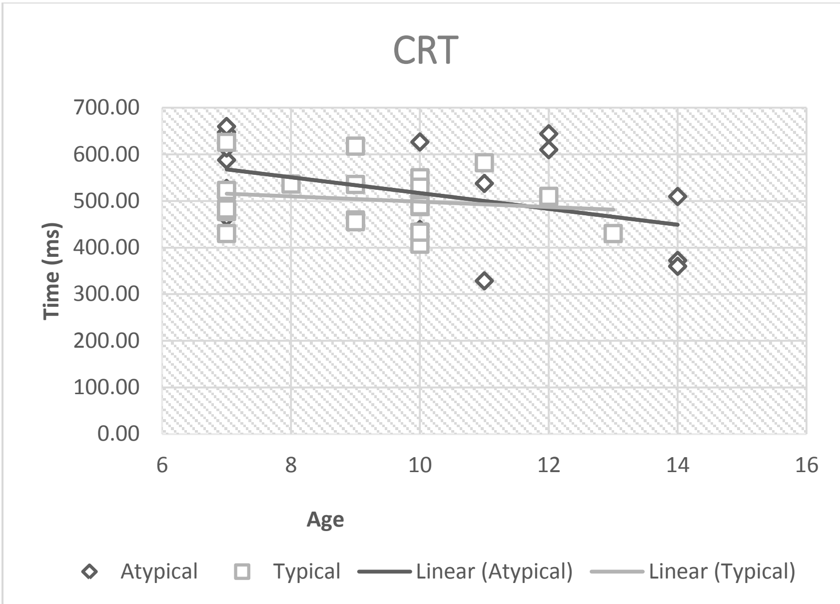


Figure 10 (b): Trend line for Choice reaction times (CRT) across the age range for ND and TD group

The analysis of the trail making tests did not yield significant differences, t (37)= 1.14, $p > 0.1$ between the ND (M= 10.8, SD = 9.0) and the TD (M= 7.8, SD= 4.5) in the TMT-A test. There were no significant differences in the TMT-B test, t (37) = 2.8, $p > 0.01$ between the ND (M=9.85, SD = 4.5) and the TD (M=6.7, SD = 1.8) group. TMT_A showed a small effect size r = 0.18, however TMT_B did show a moderate effect size r = 0.42. Figure 11 shows the difference between the groups and the Figure 11(a) and 11(b) show the trend line between the groups across the age range

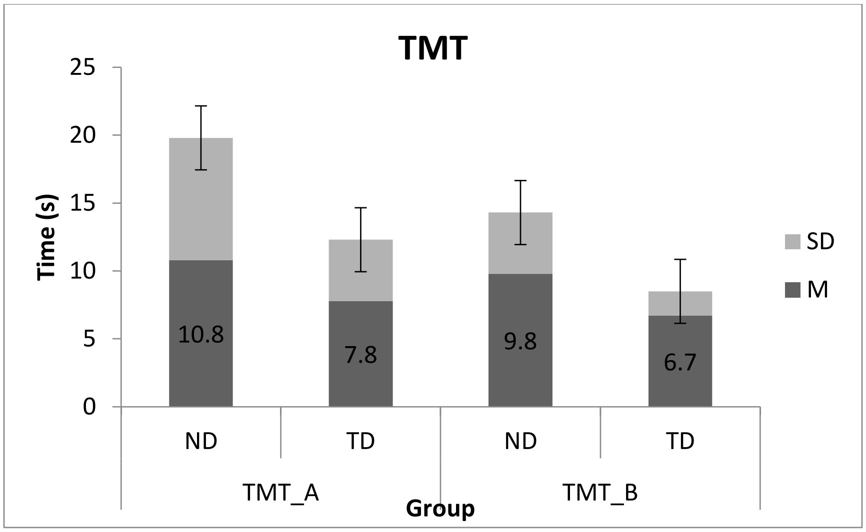


Figure 11: Average difference in Trail making test (TMT) for ND and TD group

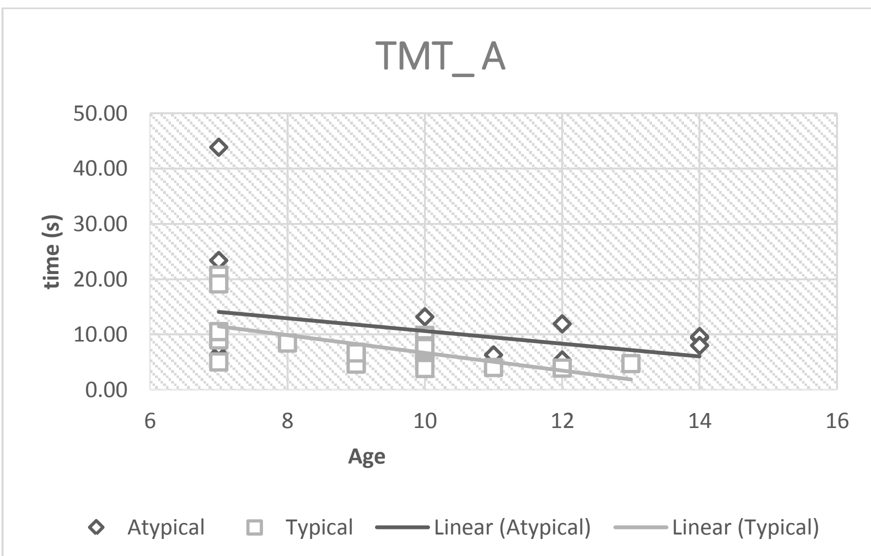


Figure 11(a): Trend line for TMT-A across the age range for ND and TD group

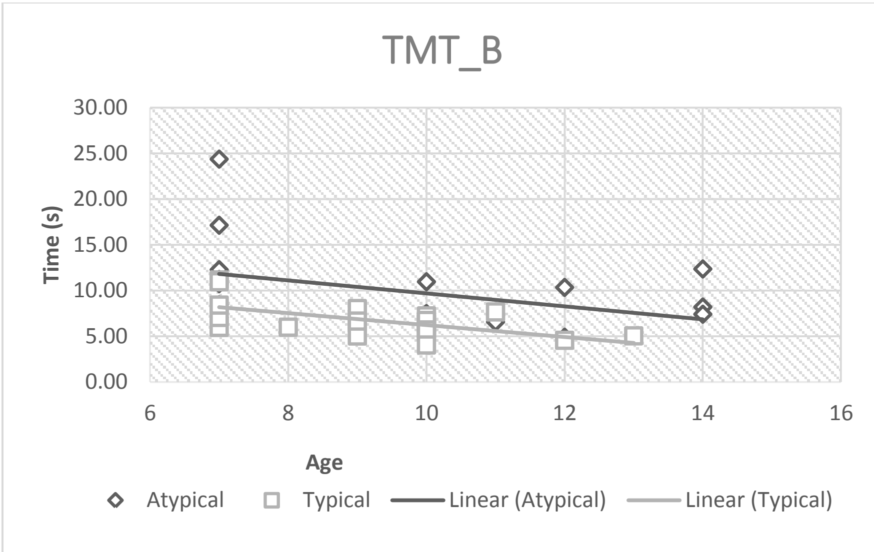


Figure 11(b): Trend line for TMT-B across the age range for ND and TD group

The functional performance tests had three hop tests (HT). The results for the triple hop for distance did not show any significant differences t(36) = -0.213 between the ND (M= 103.9, SD = 31.2) and the TD (M= 105.5, SD = 11.9) group. It showed a small effect size r = 0.04. Figure 12 shows the difference between the groups and the Figure 13 shows the trend line between the groups across the age range

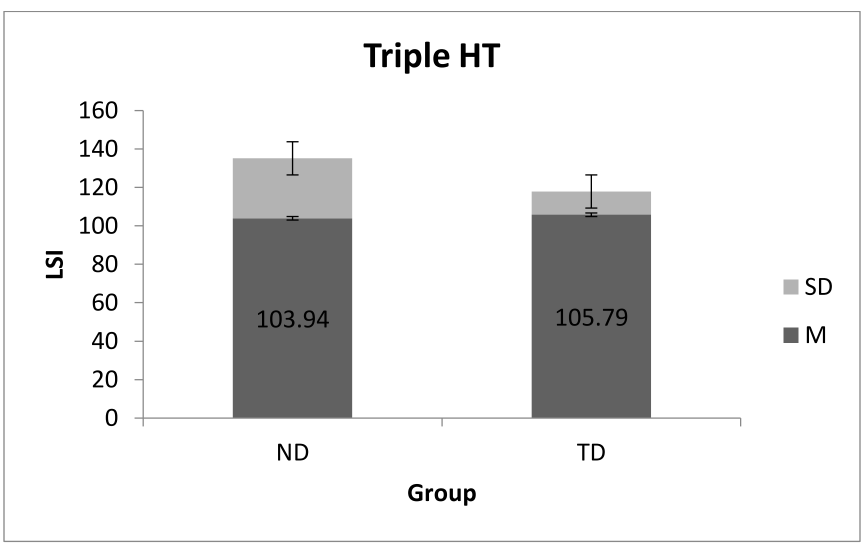


Figure 12: Average difference for triple hop test between ND and TD group

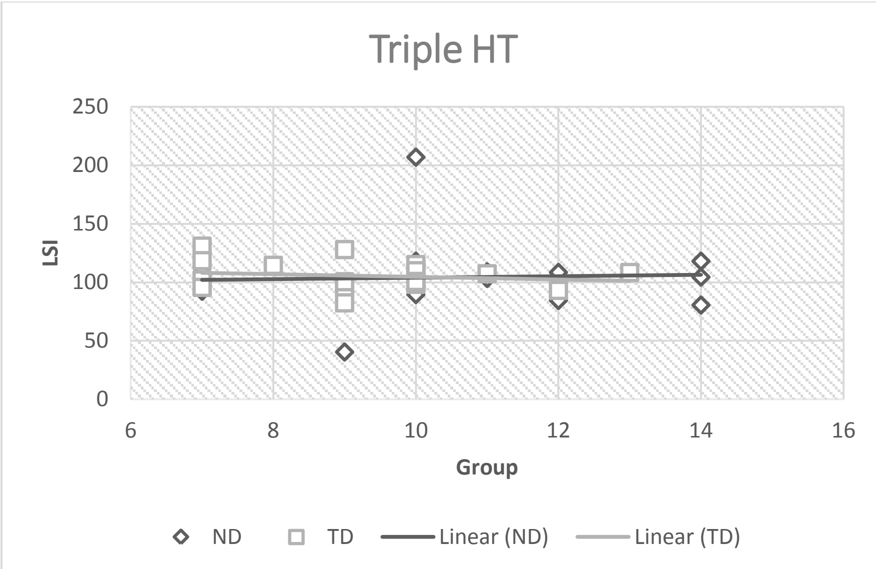


Figure 13: Trend line for triple hop test across the age range for ND and TD group

The crossover hop tests analysis showed no significant results t (35) = -0.413 between the ND (M= 103.2, SD = 25.88) and the TD (M= 106.04, SD = 14.4) group. It showed a small effect size r = 0.07.Figure 14 shows the difference between the groups and the Figure 15 shows the trendline between the groups across the age range

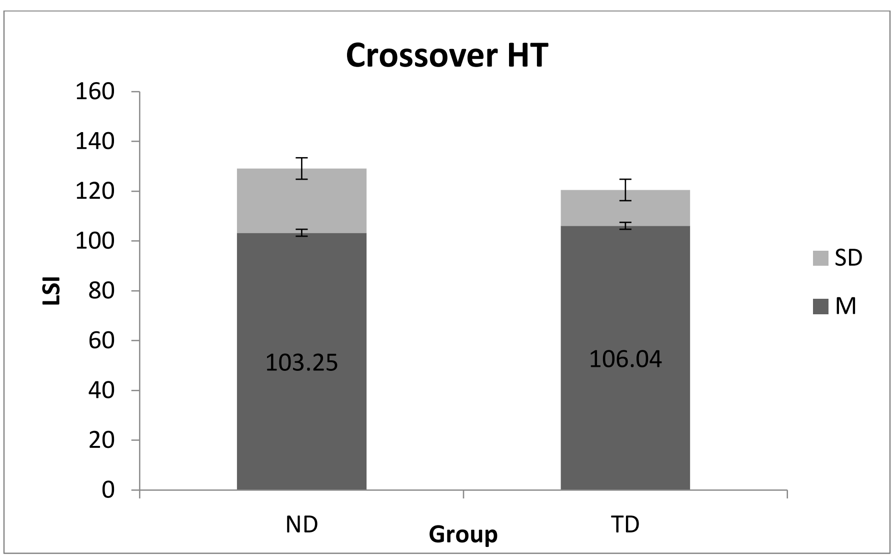


Figure 14: Average difference for crossover hop test between ND and TD group

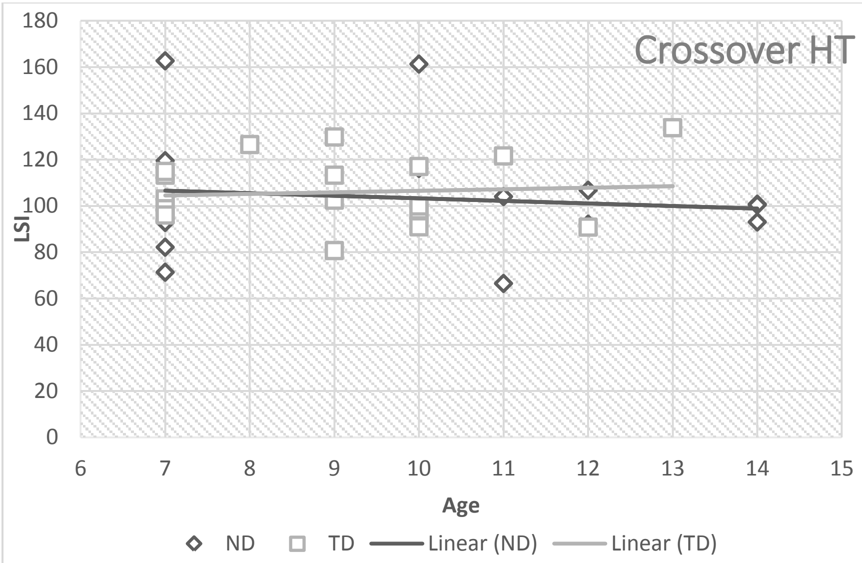


Figure 15: Trend line for crossover hop test across the age range for ND and TD group

The analysis for the figure eight hop test did not yield any significant differences t (34) = -1.1 between the ND (M= 100.7, SD = 12.5) and the TD (M= 105.6, SD = 13.4). It showed a small effect size of 0.19.Figure 16 shows the difference between the groups and the Figure 17 shows the trend line between the groups across the age range

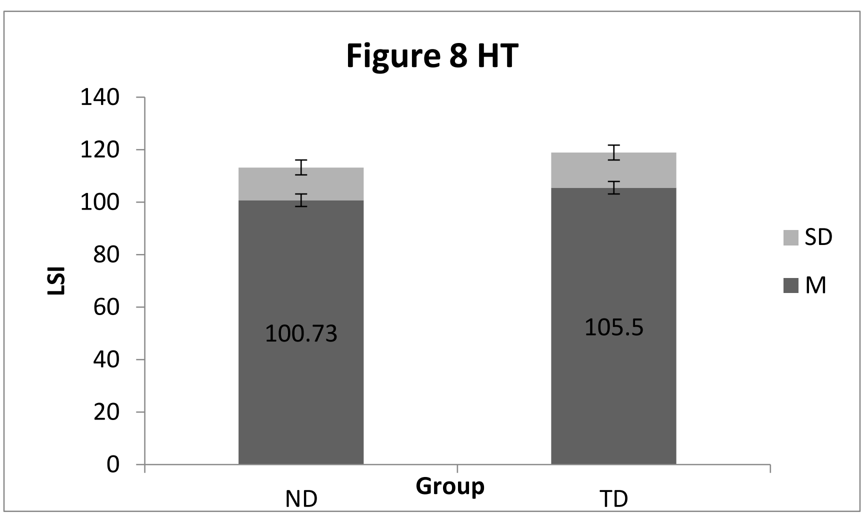


Figure 16: Average difference in figure of 8 hop test across the age range for ND and TD group

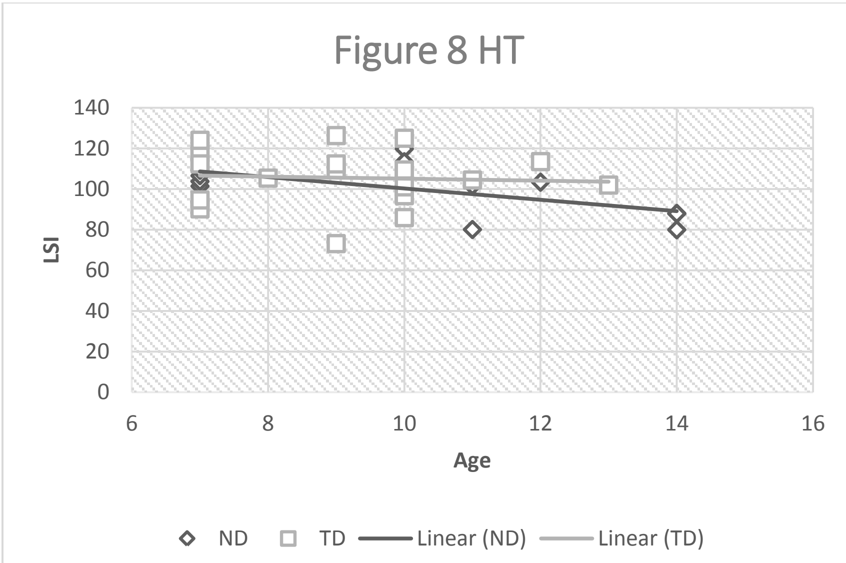


Figure 17 : Trend line for figure of 8 hop test across the age range for ND and TD group

Chapter five

Discussion

The early years (1-7 years) provide a window of opportunity to develop fundamental movement skills (FMS) and these are evident during sports and recreational activities. If children cannot build a diverse motor repertoire during the fundamental period they may face a ‘proficiency barrier’ to gain expertise in context specific movement skills. For typical 7 year olds we make the assumption that their cognitive-motor skills qualify them to perform complex movement activities, however children with neurodevelopmental delay have been shown to have deficits in cognitive as well as motor functions. A variety of assessment tools are focused on physical competence for activities of daily living in this subset of population. However they are limited in providing information about complex motor skills or sport performance. Hence the purpose of this study was to assess and establish developmental trajectories of cognitive and complex motor functions in children and adolescents with and without a clinical diagnosis.

Analysis was done on several variables like postural stability (balance), reaction times (simple and choice), processing speed times, and functional performance measures through three hop tests. The results showed that neurodevelopmentally delayed (ND) group did not show significantly greater postural instability than the typically developing (TD) group ($p > 0.01$). However the developmental trend line between the two groups did show age related changes for static balance. The adolescents in the ND group did have more postural stability than the children, however the trajectory was not quite parallel to the trajectory of the TD group. This is in alignment with the effect size ($r = 0.47$) which shows that although not statistically significant, the ND group does have moderately higher postural instability than the TD group. Past research has shown that children with autism have significantly lower postural stability than the typically developing children (Minshew, Sung, Jones, & Furman, 2004; Molloy, Dietrich, & Bhattacharya, 2003). Our study did not show statistically significant difference but it did show considerable difference. An age related improvement is observed in the ND group however it still does not match the trajectory of the TD group. This can be partly explained by the more complex balance conditions (eyes closed, foam surface, single leg stance) that challenge the somatosensory systems. Children with autism have been shown to have somatosensory integration issues (Molloy et al., 2003).

The analysis of the reaction times shows that there was no significant difference in the simple reaction time (SRT) test ($p > 0.01$) between the two groups and marginal age related difference between the ND and TD group. However, the analysis of the choice reaction time (CRT) test shows that the ND group had significantly slower CRT ($p < 0.01$) than the TD group. Although the pattern of development may not be much different between the two groups but there was significant higher RT in the ND group than the TD group. These results illustrate the very importance of the purpose of this study which was to assess the more complex cognitive and motor abilities by challenging the neuro-motor system. Studies have shown that children with ND have atypical planning abilities and anticipation of motor response (Hughes, 1996; Rinehart, Bradshaw, Brereton, & Tonge, 2001). This difference between the SRT and CRT can also be supported by studies that have shown that children with ND may fail to adjust their motor preparatory time in ‘expected’ versus ‘unexpected’ movement when compared to the TD children (Rinehart et al., 2001).

The trail making test (TMT) has two subtests, TMT-A and TMT-B of which the latter is slightly more complex than TMT-A. The results showed that the ND group did not differ significantly from the TD group ($p > 0.01$) on either of the tests. The ND adolescents did perform slightly better than the younger participants however they did not differ much across the age range than the TD group. On the TMT-B test, although the ND group did not significantly underperform than the TD group, the difference was still considerable ($p = 0.019$, $r = 0.42$). Overall, the TMT test is an indicator of processing speed, motor sequencing and planning abilities and the TMT-B being slightly more complex than TMT-A, is an indicator of mental flexibility and set shifting (shifting the course of ongoing activity). Studies have shown that children with autism have significantly impaired perception of sequencing and motor execution of sequencing (Hermelin & O'connor, 1970).

The results of the processing speed test (PST) showed that the ND group did not have significantly longer processing speed time than the TD group ($p > 0.01$). However a moderate effect size ($r = 0.43$) suggests that the differences were still substantial. The younger individuals did have slower processing speed times than the adolescents in both groups however, children and the adolescents were still slower than their peers in the TD group. Developmental studies have shown that with maturation, the processing speed times improves (Band, van der Molen, Overtoom, & Verbaten, 2000; Ridderinkhof & van der Molen, 1997). However children with autism, ADHD and Asperger’s have been reported to have deficits in processing speed times (Mayes & Calhoun, 2003b, 2007). Although our study did not find significant differences, it still shows a trend of gap between the two groups.

To assess the functional performance levels, we included three hop tests; triple hop test (THT) for distance, crossover hop test (COHT) for distance and figure 8 hop test (FHT) for time. These hop tests give an estimate of dynamic stability and agility. The analysis of the hop tests suggest that the ND group did not differ significantly than the TD group in any of the hop tests. The developmental trend was marginally different yet followed the same pattern between both the groups. These findings thus do not support our hypothesis. Hopping on one leg is considered to be the most complex form of jumping which is frequently used in sports, games, recreational activities (Gabbard, 2011). Expected results were formulated by investigating past research for hop tests. Studies have shown that hopping on one leg can be a used as predictor of motor - competence in children between the age of 7-12 years to identify developmental coordination deficits (Holm, Tveter, Fredriksen, & Vøllestad, 2009). Although our findings do not completely support the literature, it did separate the low functioning individuals from the pool of subjects. All the individuals in the TD group were able to perform the hop tests, however three individuals in the ND group attempted to perform the hop tests but could not do it. One of the reasons of our contradictory results in comparison to the existing studies could be the amount of variability and the scattered distribution of the ND group in terms of functioning and severity of their diagnosis.

In summary, the results of choice reaction time support our hypothesis of the ND group showing significantly longer reaction times than the TD group. Although our hypotheses for the static balance tests, TMT-B and PST were not statistically reinforced, the effect size shows an adequate difference between the two groups. However, the simple reaction time, TMT-A and the functional performance tests did not validate our hypothesis. However it does provide meaningful information. It appears that the individuals with neurodevelopmental delay may be competent with unsophisticated tasks. But they may show deficits when encountered with novel tasks that demand more complex neuro-motor functioning. To substantiate our results and to have statistical backing, we need to have a larger sample size.

Findings from this study help us to further understand the intricacies that exist within development and especially in atypical populations. Evidence from this study adds to the literature that children with neurodevelopmental delay depict variable developmental patterns that are unpredictable. It is important that these delays and inconsistencies be completely understood so these children can also appreciate the benefits of recreational activities and competitive sports. Although advancements are being made in understanding the cognitive and motor abilities in these children, a deeper knowledge is critical that will allow for intervention and advancement in physical activities

Appendix

Screening Checklist for Medical Conditions

Name______________________________________ Gender Male ( ) Female ( )

Age_____________________ DOB_____________________ Dominance_____________________

Diagnosis

( ) Autism ( ) PDD-NOS ( ) Asperger's ( ) ADHD

Diagnosis received from

( ) Pediatrician ( )Neurologist ( ) Psychiatrist/psychologist ( )School-based personnel

( ) Other (describe)____________________

Does your child have any of the medical conditions described below? Please, check all that apply:

Mental Retardation ( ) YES ( ) NO

Epilepsy/Seizures ( ) YES ( ) NO

Down syndrome ( ) YES ( ) NO

Tourette syndrome ( ) YES ( ) NO

Fragile X Syndrome ( ) YES ( ) NO

Tuberous Sclerosis ( ) YES ( ) NO

Hearing or visual defects ( ) YES ( ) NO

Encephalitis ( ) YES ( ) NO

Duchenne muscular dystrophy ( ) YES ( ) NO

Hypotonia/Hypertonia ( ) YES ( ) NO

Other Muscular condition not listed* ( ) YES ( ) NO

*If yes, please explain:

Does your child/you take any kind of medication? If yes, please list below ( ) YES ( ) NO

____
____
____
____

Do you/your child participate in any kind of therapy (PT, OT, speech therapist, other) ( ) YES ( ) NO

If yes, please list below

____
____
____
____
____

Signature of parent/caregiver ____

Signature of participant (above 18 years)____________________________________

Signature of screener __________________________________ Date _____________

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