Developmental Coordination Disorder: The Relationship Between Gait And Attention With Possible Implications For Early Identification And Intervention

Yocheved Bensinger-Brody

Graduate Center, City University of New York

How does access to this work benefit you? Let us know!

Follow this and additional works at: http://academicworks.cuny.edu/gc_etds

Part of the Physical Therapy Commons, and the Psychology Commons

Recommended Citation

Bensinger-Brody, Yocheved, "Developmental Coordination Disorder: The Relationship Between Gait And Attention With Possible Implications For Early Identification And Intervention" (2015). CUNY Academic Works.
http://academicworks.cuny.edu/gc_etds/859

This Dissertation is brought to you by CUNY Academic Works. It has been accepted for inclusion in All Dissertations, Theses, and Capstone Projects (2014-Present) by an authorized administrator of CUNY Academic Works. For more information, please contact deposit@gc.cuny.edu.
DEVELOPMENTAL COORDINATION DISORDER: THE RELATIONSHIP BETWEEN GAIT AND ATTENTION WITH POSSIBLE IMPLICATIONS FOR EARLY IDENTIFICATION AND INTERVENTION

by

YOCHEVED BENSINGER-BRODY

A dissertation submitted to the Graduate Faculty in Psychology in partial fulfillment of the requirements for the degree of Doctor of Philosophy, The City University of New York

2015
This manuscript has been read and accepted for the Graduate Faculty in Psychology in satisfaction of the Dissertation requirements for the degree of Doctor of Philosophy.

Dr. Laraine McDonough
Chair of Examining Committee

Dr. Maureen O’Connor
Acting Executive Officer

Dr. Robert L. Freedland
Dr. Judith M. Gardner
Dr. Laura Rabin
Dr. Laura Reigada

Supervisory Committee
Abstract

DEVELOPMENTAL COORDINATION DISORDER: THE RELATIONSHIP BETWEEN GAIT AND ATTENTION WITH POSSIBLE IMPLICATIONS FOR EARLY IDENTIFICATION AND INTERVENTION

by

Yocheved Bensinger-Brody

Advisor: Laraine McDonough

The aim of this research was to evaluate how increased levels of challenge to attentional capacity would affect the motor planning and coordination in the gait of children at risk of Developmental Coordination Disorder (DCD) across developmental ages. The study incorporated a dual task paradigm requiring both motor and attention performance, with the primary hypothesis that children who are at risk of DCD across different ages (3- to 8 yrs.-of-age) would demonstrate an alteration in their motor strategies if they were simultaneously engaging in an attention task. A secondary hypothesis of this study was that there is an underlying deficit in the attention regulation systems in children with DCD that manifests itself in diminished motor performance. It was postulated that these children would have behaved differentially when tested for other behaviors requiring attention regulation in their neonatal and toddler stages. Children (n=27) ages 3-8-years-old who were part of a longitudinal study at the NYS Institute for Basic Research in Developmental Disabilities were recruited for this study. Selective, age appropriate standardized questionnaires related to motor performance, participation, and behavior, were completed by the children’s parents. Clinical and non-clinical groups were
determined by performance on the Movement Assessment Battery for Children - Second Edition (score <= 16th %). Each child participated in experimental motor tasks with increasing attentional complexity, using a) a computer-based attention task (CAT), requiring response by voice or button press, and b) an assessment of each child’s gait in a fully instrumented gait lab requiring the participant to simply walk, or respond to an image projected at the end of a walkway, with or without the need to move around a barrier (increasing demands of Dual Task). Correlation analyses were performed between the categorical risk variable (risk/no risk) and select variables related to the participants’ qualitative performance during the barrier task, and archival data associated with these participants, including neonatal physiological measures of brain insult and neonatal, infant and toddler behavioral measures of attention, neurobehavioral organization and cognition. **Single Task: CAT.** Across task types, faster reaction times were observed for the older children, with the clinical group demonstrating faster reaction times for the voice response task and slower reaction times for the button press response task. **Single Task: Walking.** There were no differences between age or clinical groups for variables related to balance strategies. **Dual Task: Walking.** Across tasks, faster reaction times were observed across all older children, with a developmental trend of improved reaction time over age for the no-risk group only. Developmental trends were identified related to use of perceptual information and implementation of balance strategies during the varied task types. Across task types, differential compensatory strategies in balance and smoothness of movement were seen between the risk and no-risk groups, with the risk group demonstrating a greater reliance on perceptual information to initiate response to stimulus, as well as implementation of more exaggerated trunkal deviation, jerk, and
effort during the barrier task. **Exploratory Study: Archival Data.** Although no relationship was found between physiological measures of brain insult and categorical risk or experimental variables, the children in the risk group demonstrated trends of performance on early behavioral measures similar to children who have sustained brain insult during the neonatal period. The findings indicate that there were no group differences during the well-practiced motor behavior of walking. However, noticeable differences emerged with the increasing demands of a dual task paradigm for children at risk for DCD. These children have decreased attentional capacity as compared to the children in the non-risk group, and this impacts their postural strategies during dual tasks. Additionally, early behavioral measures of attention, neurobehavioral organization and cognition may potentially serve as indicators of risk of DCD at early ages. Currently, DCD is diagnosed at 6-8-years-of-age, and is assessed using standardized measures in a decontextualized environment. Furthermore, typical care intervention involves a single task oriented approach. Considering that the goal of evaluation and intervention is to better prepare individuals for participation in rich contexts, it is suggested that new models of evaluation and intervention be considered at earlier ages.
Acknowledgements

This dissertation represents the culmination of a nine-year journey in the pursuit of a doctoral degree in psychology. There are many people who have supported me along the way and to whom I am most grateful.

First and foremost I must acknowledge my advisors. At Brooklyn College, Dr. Laraine McDonough agreed to take me in as her student even though I would be conducting my research in a different lab. I recognize that her generosity in doing so and her willingness to help me explore an area of research that was somewhat different from her own are rare gifts that I was lucky to have been the recipient of. I am most grateful for the mentorship and guidance that she has provided me throughout this process, and her expertise in cognitive development has informed my work in ways that I could not have expected. At the NYS Institute for Basic Research in Developmental Disabilities, Dr. Judith M. Gardner and Dr. Bernard Z. Karmel welcomed me to their Infant Development lab from our first meeting, and I knew that I had found the mentors I had been seeking to learn about high-risk infants and their development over time. I am so thankful to have had the opportunity to learn from experts in this field, and their teachings have greatly impacted me. Dr. Robert L. Freedland first started guiding me in his role as Director of the CUNY/IBR Developmental Neuroscience fellowship, of which I was a recipient, and then continued to become my mentor for my doctoral dissertation. Dr. Freedland’s expertise related to applying motion analysis evaluations to atypically developing populations greatly informed my research. Dr. Freedland was instrumental in helping me elaborate my research ideas, and he has demonstrated a magical ability to
make this journey smoother, often anticipating ways to help me before I knew I needed the assistance. My four mentors have relentlessly stood by me throughout these years, and I am honored to call myself their student.

I want to extend my sincere appreciation to my other committee members, Drs. Laura Rabin and Laura Reigada, who offered me tremendous insight and support during this process. I am especially thankful for the ideas they put forth related to ways that I can now further my research.

This study required integration of multiple sources of information, and programming expertise was required to ensure that I was able to elicit the data related to the questions that truly mattered. I am so grateful to Davide Ferrario, the bioengineer who collaborated with me to develop a new protocol for the motion analysis software, and who patiently helped me tweak the protocol many times over the past few years. Dr. Michael Flory spent countless hours helping me extract and organize the data generated by the EPrime software, and he generously provided support related to his expertise in statistics as well.

In addition to my mentors and collaborators, others have assisted me in instrumental ways. At Brooklyn College I am specifically grateful to Dr. Elisabeth Brauner, who, during her tenure as Subprogram Chair, was instrumental in helping me gain admittance to the doctoral program. I am grateful to Dr. David Owen, whose advice about the statistical analyses to consider for my study was critical for the success of my work.

I am thankful for having spent nearly a decade working with and learning from the entire research group in the Infant Development lab at IBR. The group of research
scientists there is committed to their important work related to developmental disabilities, and they are equally committed to the individual children and families that they serve. I am lucky to have so many role models who have also been true friends. Thank you, Dr. Phyllis Kittler, Dr. Ha Thi Thu Phan, and Anne Gordon. In addition to being a role model and friend, Dr. Elizabeth Lennon has been my sounding board for all things research and life related, and her insight has helped me navigate my path.

The support staff in the Infant Development lab has assisted me in countless ways throughout the years. Thank you Felicia Balsamo, Ewa Kozlowski, and Jeanette Mitchell for your assistance and friendship. This research would not have been possible without the participation of the fantastic children and their families who allowed them to take part in the study, and I want to express my sincere appreciation for their interest and for making the process so much fun.

I want to thank my extended family and friends, who have remained supportive of me over the past decade despite the fact that I have been sister/cousin/and friend in abstentia. I am back, and I can’t wait to spend time with all of you!

I dedicate this dissertation to my family. To my parents, who are my staunchest supporters and best friends, words fail to express an adequate amount of love and appreciation. To my husband, who has nearly single-handedly raised our beautiful children while I pursued this degree, thank you for standing by me. To my children, Reva, Ita, Bleema, and Mordechai – at the end, there is only you. I am truly blessed.
TABLE OF CONTENTS:

Copyright page.................................................................ii
Approval page...............................................................iii
Abstract.................................................................iv
Acknowledgments......................................................vii
Table of Contents....................................................x
List of Tables............................................................xii
List of Figures...........................................................xiii

I. INTRODUCTION
Historical Background of DCD........................................1
Diagnostic Criteria and Identified Deficits in DCD..................3
Modular Approaches: Regional Involvement Thought Important for DCD........11
Neural Pathway Approaches: Regional Integration Deficits....................15
Cellular Level Approaches.............................................19
Attention and DCD.......................................................26
Dual Task Paradigm: Posture and Attention..........................28
Purpose of Dissertation..................................................33

II. METHODS
Participants...............................................................35
Standardized Motor Test................................................39
Questionnaires..........................................................39
Experimental Tasks......................................................41

III. DATA PREPARATION/ANALYSIS/RESULTS
Standardized Tests and Questionnaires................................53
Computerized Attention Task............................................55
Gait Evaluation..........................................................60
Dual Tasks....................................................................64
Integration of Attention Data between Computerized Attention Task and Dual Tasks...89
Incorporation of Neonatal, Infant, and Toddler Data.........................92

IV. DISCUSSION
Computerized Attention Task Discussion.............................98
Single Walking Task Discussion........................................99
Dual Walking Task Discussion...........................................100
Dual Task: Completion of Attention Task Discussion.....................105
General Discussion.......................................................105
APPENDICES

A. List of Acronyms Used.................................................................119
B. Means Tables..............................................................................120

BIBLIOGRAPHY
LIST OF TABLES

Table 1: Study Population Breakdown.................................................................38
Table 2: Computerized Attention Task .................................................................45
Table 3: Pearson Correlation Analyses Between Standardized Motor Test and
        Questionnaires.........................................................................................54
Table 4: Subset Participant Breakdown.................................................................82
LIST OF FIGURES

Figure 1a: Schematic of Anatomical Marker Placement………………………………..48
Figure 1b: Schematic of Trunk Deviation Angle…………………………………………..48
Figure 2: 3-Way Age x Risk x Task Interaction: Response Time…………………58
Figure 3: Differences in Elbow Flexion Strategy between Touch and Barrier Tasks
During Image Onset and Change of Direction: Risk……………………………..70
Figure 4: Difference in Trunk Deviation Strategy between Touch and Barrier Tasks:
Risk…………………………………………………………………………………..73
Figure 5: Difference in Distance Covered between Image Onset and Change of
Direction: Task x Risk………………………………………………………………78
Figure 6: Total Ankle Effort Pre and Post Stimulus During the Barrier Task: Risk……84
Figure 7: TaskCompletion Touch and Barrier Tasks: Age x Risk………………………..88
Figure 8: Integrated Task Analysis: Age………………………………………………..90
Figure 9: Integrated Task Analysis: Risk………………………………………………..91
Figure 10: Mean Scores on Motor and Mental Scales of BSID-2 for Risk and Non-Risk
Groups…………………………………………………………………………………..96
CHAPTER 1. INTRODUCTION

I.1 Historical Background of DCD

Developmental Coordination Disorder (DCD) has been recognized as a childhood disorder for nearly a century, first described as developmental apraxia in the 1930’s by Orton (Orton, 1937), who stated that it was one of the six most common developmental disorders. Although put forth by Orton as having significant consequences, as well as a high prevalence, DCD was not discussed again in the literature until the 1960’s and 70’s when several neurologists published case studies of ‘clumsy children’ (Gubbay, Ellis, Walton, & Court, 1965; Dare & Gordon, 1970). The taxonomy used to describe this population was varied and included terms such as developmental apraxia (inability to execute purposeful movement), developmental dyspraxia (decreased ability to execute purposeful movement), ataxia (decreased coordination), clumsiness, and others, as each physician or researcher attempted to describe the behaviors they observed (Reuben & Bawkin, 1968, Miyahara & Mobs, 1995).

While most papers on DCD were descriptive, attempts were made to answer important questions about this population, and some findings and observations continue to be relevant today. Gubbay hypothesized about etiology and implicated brain regions (Gubbay et al., 1965), and later followed up with EEG (Gubbay, 1975) and CT studies (Knuckey, Apsimon & Gubbay, 1983), however findings were heterogeneous and could not be correlated with behavioral observations. Of value was the observation made by Gubbay and colleagues (1965) that many of their clinical participants had histories of complicated gestational, perinatal or neonatal periods, indicating an early ontogeny of the disorder. Dare & Gordon (1970) progressed the field by differentiating children with
motor coordination issues from those with low IQ and those with mild cerebral palsy. Asserting that the DCD population was unique, they were then able to present two hypotheses of etiology. The first is that these children are unable to develop motor plans necessary for automatization of movement, which in turn limits execution of complex skilled movements. The second is that there is a deficiency in children’s perceptual systems. Limitations in the feedback loop prevent or delay acquisition of complex skilled movements. Both of these theories continue to be investigated. In 1973, a standardized tool was published that discriminates ‘clumsy’ children from those who are typically-developing (Gubbay, 1973), and this was an impetus for using standardized tools in future DCD research. A longitudinal study reported by Knuckey and Gubbay (1983) investigated if the behaviors and difficulties observed in childhood persist into adulthood among ‘clumsy’ children. The methodology used was problematic, because participants were tested on the same task items both as children and as adults without consideration that over time and with practice these skills would no longer be challenging. In doing so, the sensitivity of the test was confounded. The researchers’ conclusion that most children with this disorder do not have persisting difficulties into adulthood does not correspond with the current literature, however, the choice of skills tested and the link to psychosocial issues continue to inform research today.

Many of those who reported on the motor skill deficiencies in children with DCD also recognized that the range of symptoms was not limited to the motor domain. Rather, they noted that many in this population had academic, social, and emotional deficiencies as well. The early literature is conflicted, however, as to whether or not these deficiencies
are secondary (Reuben & Bawkin, 1968; Dare & Gordon, 1970), or primary co-developing problems (Gubbay, 1973).

Reuben & Bawkin (1968) proposed clumsiness, or developmental dyspraxia, to be a unique syndrome, however there were those who did not agree. Ingram (1963) contended that clumsiness represents abilities that are within the typical range of performance, and Hall (1988) agreed, posing that if neurological, genetic and congenital disease states are ruled out, clumsiness just represents the lower end of the motor ability curve. Despite the dissenting views, the majority of the research community believed that ‘clumsy’ children represented a unique demographic with developmental delays that have significant implications and that warrant further study. In attempts to unify the taxonomy used in the literature, and to more clearly specify the deficits found in clumsy children, in the early 1990’s the international research community appropriated the name of Developmental Coordination Disorder (DCD) to individuals formally known as ‘clumsy.’

DCD has since appeared in both the Diagnostic and Statistical Manual for Mental Disorders (DSM-IV, 1994; -IVR 2000; V, 2013) and the International Classification of Diseases and Related Health Problems (World Health Organization, 1992).

**I.2 Diagnostic Criteria and Identified Deficits in DCD**

Diagnostic criteria for DCD include an IQ of >70, demonstrable motor delay that surpasses any delay that would be expected for low IQ and which negatively impacts a child’s activities of daily living, and no substantiated neurological pathology (DSM-IVR, 2000). DCD has implications not only for quality of motor skills, but for social inclusion and academic performance as well. Green, Baird and Sugden (2006) reported risk of
psychosocial disorders (including decreased pro-social behavior, poor social skills, emotional and conduct problems such as hyperactivity and inattention, as measured by the Strengths and Difficulties Questionnaire (Goodman, 1997)) in 62% of their DCD participants, and borderline risk in an additional 11%, irrespective of degree of severity of motor impairment. Similarly, in a large cohort study, Lingam and colleagues (2012) found that children with DCD had a two-fold risk of self-reported depression symptoms and a 4-fold risk of parent reported mental health difficulties by age 10. This study was able to identify some mediating factors related to this risk including low self-esteem and having experienced bullying. Based on parent-reported perception of the difficulties that children with DCD experience, Missiuna and colleagues (2007) proposed a trajectory reflecting how early differences in coordination abilities could affect play and academic skills, which in turn affect participation, peer relationships, self-perception, and self-esteem. These collective findings indicate that, as Gubbay (1973) had suggested, psychosocial issues share a primary role within the classification of DCD, but the progressive trajectory of difficulties in these areas may be due to extrinsic factors as well.

Dewey and Wilson (2001) noted that the criterion related to IQ is questionable, and interestingly, this criterion has been removed in the DSM-V (2013). Diagnostics have also proven to be difficult since clinicians and researchers use varied standardized motor assessments. Furthermore, it has been demonstrated that each standardized test identifies a different percentage of children as having DCD, and that the children identified are not always rated in the same way between tests, indicating poor inter-test reliability (Dewey & Wilson, 2001). Additionally, there is no single assessment that is fully comprehensive in addressing the various areas of deficits seen within this population (Geuze, Jongmans,
Schoemaker, & Smits-Engelsman, 2001). Geuze and colleagues (2001) recommended the Movement Assessment Battery for Children (Henderson & Sugden, 1992), as the best assessment available. This test continues to be widely used both clinically and for research purposes, and has been revised as the MABC-2 (Henderson, Sugden & Barnett, 2007). The Developmental Coordination Disorder Questionnaire (DCDQ, Wilson, Crawford, Green, Roberts, Aylott, & Kaplan, 2009) is often reported as well in the literature to account for the criterion requiring functional deficits. As evidence suggests that children with DCD participate less overall as compared to age matched typically developing children, participation in everyday activities questionnaires, such as the Children Participation Questionnaire (CPQ) (Rosenberg, Jarus and Bart, 2010) also have been recommended for use.

Many specific skills have been identified and reported as problematic for those with DCD. Rosenblum and Livneh-Zirinski (2008) performed a detailed analysis of handwriting deficits in children with DCD (7- to 10-years-old) as compared to those written by age-matched typically-developing children. The best single predictor of text belonging to a child with DCD was either limited or inconsistent spacing between letters and words. Additionally, children with DCD overall took longer to write the same amount of text, with fewer letters written within the first minute. Children with DCD also applied less pressure with the pencil, had more ‘in air’ time with the pencil, used more complex transitions between letters and words, and made more errors, as indicated by more erased and overwritten letters. A qualitative study conducted by Summers, Larkin, and Dewey (2008) found that children with DCD also have difficulties with activities of daily living including tying their shoelaces and buttoning their coats for dressing, and
cutting their food for eating. Furthermore, motor skill deficits in this population tend to persist into adulthood, with implications for activities of daily living such as driving a car (Cousins & Smyth, 2003). Thus, deficits found in DCD cannot be accounted for by a model of developmental delay.

Limited ball playing skills, as measured by subscales of standardized tools with tasks requiring throwing a ball to a target from progressive distances, have often been reported in children with DCD (Barnhart, Davenport, Epps & Nordquist, 2003). Recently, poor targeting skills in 11-to13-year-old boys have been associated with less moderate to vigorous physical activity overall (Green, Lingam, Mattocks, et al., 2011). This finding has been further elaborated on by more recent studies, and a new concern is being expressed about childhood obesity. Wagner and colleagues (2011) reported an association between greater severity of DCD and obesity. Beutum, Cordier and Bundy (2013) found that children with DCD engage in less moderate-vigorous physical activity, have higher body mass indices, and have less strength than age-matched peers. They further found that parental activity level and perception moderates these effects. For example, lower levels of parental physical activity patterns are associated with less moderate to vigorous activity in children with DCD, and when parents perceived their child’s motor abilities as inferior, they are less likely to participate in moderate to vigorous physical activity. These findings highlight the multidimensional contributors of DCD and also indicate that children with DCD have risk factors for cardiovascular disease.

In addition to limitations performing specific skills, deficits of underlying processes have been identified. Coleman, Piek, and Livesey (2001) investigated
kinesthetic acuity in 5-to 6 year-old children with DCD. The children were instructed to reach under a surface and hold onto a joystick that was occluded from sight by a cloth. Pictures of animals were placed at different positions on top of the cloth surface. Following passive movement of the joystick, the children were then required to indicate at which targeted position their hand was. The children with DCD had decreased performance on this task as compared to age-matched typically-developing controls. The authors not only discuss how this may be indicative of poor kinesthetic acuity in DCD, but that it might also be related to decreased visuospatial processing, as this task requires both abilities. Goyen and colleagues (2011) tested 8-year-old children diagnosed with DCD who were born premature on the Kinaesthetic Sensitivity Test, a standardized measure of kinaesthetic acuity and memory, and the Developmental Test of Visual – Motor Integration. They did not find any differences in kinesthetic ability between groups, but children with DCD demonstrated more difficulty with visual processing than the others. The results reported by Coleman and colleagues (2001) as described above may be due to the visual processing component of the task. Goyen and colleagues (2011) reported that children with DCD scored lower than control children on the Sensory Integration and Praxis Test, reflecting motor planning difficulties in this group. Alloway and colleagues (2006, 2007) have demonstrated that while children with DCD have deficits in four areas of working memory (including verbal short term, verbal working, visuospatial short term and visuospatial working) their greatest difficulties are in visuospatial working memory (Alloway, 2006, Alloway & Temple, 2007). Furthermore, these authors demonstrated that difficulty on visuospatial working memory tasks differentiates children with DCD from those with moderate learning disabilities (Alloway
& Temple, 2007). One recurring finding reported in the DCD behavioral literature is that there is heterogeneity within the population for each task or underlying process being tested. This has led many to believe that classifications of subgroups of DCD should be developed, each representing deficits in specific areas, and, in fact, attempts to do so are being reported (Poulsen, Johnson, & Ziviani, 2011).

The prevalence rate of DCD in the general population is estimated at 5-8% (Barnhart et al., 2003), and DCD is currently diagnosed when children reach school age, at 6-8 years of age. Geuze and colleagues (2001) have argued that the DSM-IV criterion that motor deficits must negatively affect function (e.g. ball play skills for social function, handwriting for academic function) for classification as DCD makes it difficult to diagnose this disorder in preschool ages. These authors propose that motor deficiencies in younger children that indicate potential risk for functional deficits should be sufficient to provide a diagnosis of DCD (Geuze, et al., 2001). Coleman, Piek, and Livesey (2001) used the MABC to test the motor proficiency of children who were in preschool and they then re-tested these children one year later after they entered primary school. They found that by using this task alone, 76% of the children identified as “at risk” for DCD in preschool continued to present with the same relative level of motor abilities one year later. The authors propose that DCD can be diagnosed at younger ages given the stability of motor performance. However, this stability of performance on the MABC as reported by Coleman et al. (2001), was not replicated by other researchers. Specifically, Van Waelvelde and colleagues (2010) found stability of motor performance on the MABC between the ages of 4-6 and 6-8 in children at risk for autism, but not in other clinical populations (Van Waelvelde, Oostra, Dewitte, et al., 2010).
Towards the goal of earlier identification, there are groups of investigators working to normalize and validate versions of the MABC-2 (Smits-Engelsman, Niemeijer, & van Waelvelde, 2011) and the DCDQ (Rihtman, Wilson, & Parush, 2011) for use with 3-4 year old children. While the concept of identifying DCD in preschool is an important step, there has not been any formal study of early presentation of DCD in infants and toddlers. Lack of information about deficits that present at these young ages precludes earlier identification of DCD, which, in turn, delays intervention.

Evidence that earlier identification of DCD may be possible is found in research involving preterm infants. Lingam and colleagues (2009) found that children who qualified for a diagnosis of DCD at 7.5 years of age were more likely to have been born before 37 weeks gestation and to have been less than 2500 grams at birth. In a large cohort study in China, Hua and colleagues (Hua, Guixiong, Jiang, Zhang, Zhu, & Meng, 2014) found associations between prenatal, perinatal and neonatal factors reported retrospectively and scores on the MABC in 3-5-year-old children. These factors include maternal age, bleeding during pregnancy, fetal distress during delivery, chronic lung disease and hyperbilirubinemia. In a review of 15 studies involving preterm infants by Williams, Lee and Anderson (2009), the pooled estimate prevalence rates of moderate motor impairment was 19% and of mild-moderate motor impairment rates was 40.5%. Their review of the research corroborates the earlier observations made by Gubbay and colleagues (1965) that many patients with DCD had complicated gestational, perinatal or neonatal periods. Additionally, it has been demonstrated that extremely premature infants who require neonatal intensive care demonstrate deficits in motor coordination in both gross and fine motor domains (Hemgren & Persson, 2004), as well as in visual-
perceptual and attention skills (Hemgren & Persson, 2007) at the age of 3. These combined findings suggest that preterm infants are at high risk for DCD.

The benefits of intervention for other disorders (e.g., autism, Down syndrome) during the first 3 years of life are invaluable, and thus, detection of risk of DCD during infancy would be ideal. Developmental programs utilized in early intervention have been shown to benefit motor and cognitive outcomes (Blauw-Hospers, de Graaf-Peters, Dirks, Bos & Hadders-Algra, 2007). In fact, in the New York State Department of Health Clinical Practice Guideline Report of the Recommendations for Motor disorders (NYS DOH, 2011), DCD is highlighted as a neuromotor disorder that is not well understood in infancy, but that should be clinically monitored for during the first 3 years of life due to indications of increased prevalence in high-risk premature populations. While general neuromotor screening tools are available for use in infancy to classify children as having minor neurological dysfunction, which includes DCD (Hadders-Algra, 2003), there is no test available for use in infancy specific for DCD, and there is no indication as to how deficits in this population would present in these younger ages.

Although the etiology of DCD has not yet been established, the literature reflects a current attempt at relating typically reported deficits to specific brain regions that may be implicated in DCD. These proposals are discussed next and are grouped by modular (proposing a singular brain region), neural pathway (proposing neural pathways that are not functioning optimally), and cellular (proposing early insult to neurotransmitter systems) approaches.
I.3 Modular Approaches: Regional Involvement Thought Important for DCD

Considering the cerebellum’s involvement in motor adaptation, motor coordination, and automatization of task, the behavioral and imaging literature have focused on this brain region’s role in DCD. Cantin, Polatajko, Thach, and Jaglal (2007) employed a prism adaptation task requiring 6- to 11-year-old participants to throw a ball towards a target, without, with, and then again without, wearing prism glasses. They sought to test the hypothesis that if children with DCD have cerebellar deficiencies, they would be unable to adapt their motor plan when visual input was skewed. Although participants with DCD demonstrated overall greater variability of performance for target accuracy as compared to age-matched typically-developing participants, when the groups were compared, no statistically significant difference could be found for motor adaptation. It is important to note, however, that within the DCD group there was heterogeneity for rate of motor adaptation, with some demonstrating better adaptation than others. This finding is important, as the abilities within the DCD population are often heterogeneous, and it is possible that some individuals have motor adaptation difficulties, while others do not.

Another group of researchers demonstrated motor adaptation difficulties in participants with DCD when they specifically measured rate of adaptation. Brookes, Nicolson, and Fawcett (2007) conducted a study using a similar prism motor adaptation task with the goal of testing the cerebellar deficit hypothesis, as proposed by Nicolson, Fawcett, and Dean (2001). The cerebellar deficit hypothesis attributes difficulties of skill automatization in dyslexia to mild cerebellar deficits. Brookes and colleagues, (2007) sought to demonstrate that if this is in fact true, children with dyslexia might have
difficulty on a motor adaptation task, a skill also linked with the cerebellum. Additionally, Brookes and colleagues tried to extend this hypothesis to explain deficits seen in children with DCD. The participant groups included in this study were 7- to 15-year-old children who were diagnosed with DCD, with dyslexia, with both DCD and dyslexia, and typically-developing, age-matched controls. Results showed that the clinical groups had slower rates of adaptation to the glasses as compared to the control group. Additionally, when the glasses were removed the clinical groups had a harder time re-adapting to regular vision, evidenced by a greater number of mis-throws than the controls in this condition as well.

O’Hare and Khalid (2002) provided additional support for the cerebellum’s role in DCD through the finding that all of their participants with DCD (7-to 12-years-old) performed poorly on a mini-neurological assessment specific to cerebellar function. It was further found that many, but not all, of these children had writing and reading problems, further supporting the cerebellum’s role in these co-morbid disorders.

Although much of the current literature is focused on the cerebellum as being implicated in DCD, there is evidence that other regions are involved as well. The parietal lobe is responsible for many functions including spatial awareness, motor conceptualization or imagery, and motor planning. Maruff, Wilson, Trebilcock and Currie (1999) discuss previous research that demonstrates congruency between overt motor tasks and motor imagery tasks, in that the time to complete each is the same, and that Fitt’s law (speed-accuracy trade off) holds for both. They additionally note that in patients with lesions in the motor cortex there is decreased quality of performance with the contralateral limb in both tasks, but Fitt’s law is preserved in both scenarios.
However, in patients with parietal lobe injury, the performance degrades only in the overt task, with preservation of Fitt’s law for the overt task only. Considering this evidence they hypothesized that if the etiology of the difficulties experienced by children with DCD is related to an inability to mentally represent movement, on motor imagery tasks their results would not conform to Fitt’s law. Maruff and colleagues (1999) conducted a study with 9- to 10-year-old children with DCD, in which they had to perform a finger pointing task in an overt condition and in a mental imagery condition. Results were compared to those of age-matched typically-developing controls. Both groups’ data conformed to Fitt’s law for the overt behavior, but for the imagined behavior the results for the DCD group did not conform. The authors discuss how the purpose of having a mental representation is having an efferent copy of the intended behavior for use in making on-line adjustments based on the feedback process while moving. If children with DCD do not have this capacity, their feedback system would be reliant on the slower overt copy, which could account for errors in movement plans.

Wilson, Maruff, Butson, and colleagues (2004) further this line of research by differentiating between visual imagery for the mental rotation of objects and motor imagery for the mental rotation of body parts. They discuss that visual imagery activates the occipital and temporal lobes, and the parietal lobe is implicated with motor imagery, or movement of body parts. In their study, 9-to 11-year-old children with DCD were provided with a mental rotation task using a picture of a hand as the stimulus. They found that compared to age-matched typically-developing controls, the children with DCD had a faster response time but an equal error rate, which does not conform to Fitt’s law. They interpreted their findings as further implicating parietal lobe involvement in DCD.
Other research has investigated how different areas of the parietal cortex may be implicated in DCD. The posterior parietal cortex is an association area responsible for many functions including integration of multimodal information for use in motor execution tasks, visuomotor processing, and developing mental representation of movement. The left posterior parietal cortex is implicated with tool use, motor attention tasks, and motor imagery. Kashiwagi, Iwaki, Narumi, Tamai, et al. (2009) reported a study in which a joystick target-tracking task was performed during functional MRI (fMRI) testing to investigate how the left posterior parietal cortex (PPC) functions in 9-to 11-year-old participants diagnosed with DCD, as compared to age-matched typically-developing controls. Results indicated that overall the participants with DCD had less accurate behavioral performance and less activation in the left PPC as compared to the controls. However, Kashiwagi and colleagues (2009) did not indicate which other brain regions the DCD participants activated during the task as potential compensatory strategies.

Another possible brain region of concern with DCD is the corpus callosum, which is responsible for the transferring and sharing of information between hemispheres. Sigmundsson (2003) describes a line of studies testing the visual-motor abilities of 5 to-8-year-old participants with a ‘subset’ of DCD, who had hand eye coordination deficits, as measured by sub-tasks on the MABC. Their results indicate that only these children, as compared to age-matched typically-developing controls, have significantly greater difficulty when using their non-preferred hand (left) on the tasks. Sigmundsson suggests that poor transfer of task performance between arms in this population could be indicative of right hemispheric ‘insufficiency’, or alternatively, there may be deficiency
in the corpus callosum. This study has been criticized for not controlling for ADHD, as it has already been demonstrated that individuals with ADHD have a smaller corpus callosum than controls (Zwicker, Missiuna, & Boyd, 2009), however this specific functional deficit with the non-preferred hand has not been demonstrated in ADHD.

I.4 Neural Pathway Approaches: Regional Integration Deficits

More recent literature indicates that rather than singular brain regions being responsible for the behaviors found in DCD, it is likely that brain networks are implicated. Marien, Wackenier, De Surgeloose et al. (2010) presented a single case study of a 19-year-old with mild ataxia, learning problems and social/affective disorders that could classify her as having DCD. Comprehensive neuropsychological testing was conducted, and results indicated a significantly lower performance scale IQ score as compared to the verbal scale. Additionally, this participant scored very low on scales of visual-motor integration, visual perception and visual-motor coordination, and she did poorly on frontal planning and problem solving tasks. Structural magnetic resonance imaging (MRI) findings demonstrated an atypical fissure in the cerebellar vermis, and a functional neuroimaging tool, single-photon emission computed tomography (SPECT), revealed decreased blood perfusion in areas including the prefrontal and occipital lobes. Since these areas correlated clinically with the behavioral testing, the authors propose that neuropathology of the cerebello-cerebral circuitry may implicated in DCD.

Zwicker, Missiuna, Harris, & Boyd (2010) conducted a behavioral/fMRI study with the intention of further investigating the cerebellum’s role in DCD. However, the study resulted in findings that seem to imply deficits in several different brain network
processes. The authors hypothesized that participants with DCD (9-to 11-years-old) would demonstrate differential cerebellar activation as compared to age-matched typically-developing controls when performing a motor coordination task. The participants performed a trail-tracing task while undergoing fMRI. Although behavioral results indicated no difference between groups for success on the task, there were differences found among brain activation patterns. Some overlap of brain regions was activated between groups, however, there were many differences as well. Overall, more brain regions were activated during the task when performed by the participants with DCD as compared to the control group. Additionally, greater activation in the cerebellum was found in the participants with DCD, specifically in lobule IV, which is involved in visuoperceptual processing.

Zwicker and colleagues (2010) proposed that the participants with DCD relied more heavily on visual feedback than their peers as a compensatory mechanism for decreased feedback from other peripheral sources. Additionally, they attributed the finding that more brain regions were activated by the participants with DCD as indicating that this group required greater effort to successfully complete the task. This explanation is well supported by previous research showing brain activation patterns during tasks for which participants have expertise. Fewer and more precise areas of the brain are activated when the participant is engaging in tasks that have been practiced and are well known, as the brain is able to function with greater efficiency. In contrast, when a task requires more effort, more brain regions are activated (Hill & Schneider 2006). It is possible that the children with DCD required more activation of the cerebellum as well as more total brain activation because they do not have expertise or the ability to automatize motor
tasks that require coordination. If this population has a deficit in the ability to automatize complex tasks, it would imply that each time an individual with DCD performs a task they are reliant on feedback (adjustments to performance are reactive) rather than feed-forward (adjustments to performance are anticipatory) processes, requiring a top-down problem solving strategy (cognitive demands are consistently required). This inability to automatize tasks could potentially explain the increased variability of performance reported by Cantin et al. (2007), as when a task is automatized less variability would be expected. Furthermore, the deficits in timing that were reported by Brookes et al. (2007) could potentially be subsequent to the greater effort required to successfully perform the task among the clinical groups.

Querne and colleagues (Querne, Berquin, Vernier-Hauvette, et al. 2008) conducted an fMRI study to investigate the relationship between anterior and posterior brain regions as a network for attention and action during a go-no/go task in 8-to 12-year-old participants with DCD. The brain regions examined included middle frontal cortex (MFC; responsible for response selection and inhibition of erroneous response) and it’s direct pathway with inferior parietal cortex (IPC; responsible for maintaining activation of competing responses until selection is made), as well as the indirect connections of MFC with the anterior cingulate cortex (ACC; responsible for error detection) and the striatum – basal ganglia (responsible for automatization of movement as well as for inhibition of motor response). Behavioral findings between groups demonstrated that there was no difference in performance for error rate in no/go trials. However, the participants with DCD took longer to respond, had greater variability of time until response, and more instances of failure to respond during the go trials. fMRI revealed that
while the same general network was activated for both groups, there were differences in connectivity between groups for both the direct and indirect pathways. Interestingly, the participants with DCD demonstrated lower connectivity between the striatum (basal ganglia) and the inferior parietal cortex, and greater influence of the anterior cingulate cortex on the inferior parietal cortex as compared to the controls. DCD participants had a stronger activation with ACC than basal ganglia indicating that they rely more heavily on anterior versus posterior brain regions. This finding suggests that the participants with DCD had a difficult time with skill automatization, which is typically facilitated by the basal ganglia, and they subsequently required continued top-down control of skilled complex movement.

As can be inferred from the reviewed studies, DCD has a high co-occurrence rate with attention deficit hyperactivity disorder (ADHD), and language disorders, such as dyslexia. Even in children not diagnosed with these specific disorders, it has been reported that children with probable DCD (scored beneath 15th percentile on motor tests) at 7 years of age had deficits in standardized assessments of attention, social and communication skills, reading, and spelling when they were between 7.5 and 9-years-old (Lingam, et al., 2010). Additional evidence demonstrates that there is also a high co-occurrence rate between DCD and autism spectrum disorders (ASD; Kopp, Beckung, & Gillberg, 2010). In fact, there is much discussion as to whether DCD is a discrete disorder or if it is part of a continuum of developmental disorders having one underlying etiology (Kaplan, Wilson, Dewey & Crawford, 1998). If in fact this is true, Zwicker and colleagues’ (2009) criticism of studies that did not control for co-morbidity of ADHD or dyslexia may not be an ecologically valid or useful one. Additionally, considering the
heterogeneity found between participants with DCD, it does not seem plausible that a single brain region can explain the development of the disorder. Rather, a developmental model that can account for the array of these disorders would better explain the varied presentation of DCD in isolation or as co-occurring with other developmental disorders. The studies that demonstrated brain network differences between participants with DCD and controls (Zwicker, et al., 2010, Querne, et al., 2008) support the hypothesis that DCD is not attributable to one brain structure or region, but that the deficit is on a cellular level with damage to the neurotransmitter or receptor systems that functionally bind regions together. In the next section we will explore a developmental approach as to possible origins of the noted neurological deficits associated with DCD. Specifically, we will be looking at how cellular systems may be altered as a result of early prenatal, perinatal or neonatal insult.

I.5 Cellular Level Approaches

The brainstem, which rapidly develops during the last quarter of gestation, lays the foundation for neurochemical systems that relay information between the brainstem, limbic and cortical levels. Within the brainstem are nuclei of many neurotransmitter systems that project throughout the brain, including acetylcholine, dopamine, norepinephrine, serotonin and histamine. These systems are responsible for neuromodulation, or the slower, broader range regulation of synaptic transmission, and neuronal growth (Blumenfeld, 2002). Deficits in these systems have already been implicated in an array of developmental disorders, including ADHD (norepinephrine), and OCD (serotonin), and they have been used to explain the effects of cocaine exposure
in utero on early behavior (dopamine receptor deficiency hypothesis: Jones, Stanwood, Reinoso, et al., 2000). The dopaminergic nuclei located in the brainstem have three major projection pathways, the mesostriatal, mesolimbic and the mesocortical. The mesostriatal pathway is responsible for aspects of movement control and is also involved in the reward system. This pathway is implicated in Parkinson’s disease. The mesolimbic pathway is responsible for emotional regulation, and has been implicated with schizophrenia. The mesocortical pathway is responsible for working memory, and the attentional aspects of motor initiation (Blumenfeld, 2002), and could potentially be implicated in DCD.

In the neonatal period (birth-1-month) brainstem structures are responsible for arousal and attention. After 3 months, and corresponding with brain maturation and newly established connections between the brainstem and the limbic system, there is developmental furthering of the brainstem’s role in self-regulation. During the second year of life, with the maturation of cortical connections, this system allows for inhibitory control. Gardner, Karmel and colleagues (see Gardner, Karmel and Flory, 2003 for review) have demonstrated how the arousal level of healthy infants allows for the regulation of attention in multiple domains. Those who have sustained early injury to sub-cortical brain regions, as measured by auditory brainstem responses (ABR), or who have been exposed to neurotoxic substances, such as cocaine, do not demonstrate this same relationship between arousal and regulation of attention.

During the neonatal period arousal and attention are closely linked, and depending on their internal level of arousal, infants will prefer to attend to higher or lower levels of stimulation to maintain an optimal state of equilibrium. Healthy neonates spend a longer
time looking at high frequency (8hz) visual stimuli when they are in low arousal states (after feeding) and at low frequency (1hz) visual stimuli when they are in high arousal states (before feeding). In contrast, neonates with abnormal ABRs are poor regulators and they tend to prefer low frequencies of visual stimulation even after they are fed (Gardner, Karmel, & Magnano, 1992). Converging information was demonstrated in a visual recognition memory task (Geva, Gardner, & Karmel, 1999). Healthy neonates preferentially looked at a novel stimulus in low arousal states (after feeding) and at a familiar stimulus in high arousal states (before feeding). This extends the theory that arousal modulated attention in infancy is important for self-regulation and later cognitive processes. There are also indicators that neonatal arousal and regulation are related to motor activity. Early motor activity is modulated by arousal, forming an integrated system that sustains action and regulates responses to environmental stimulation (Gardner, Karmel, Freedland, et al., 2005). Healthy neonates are excellent arousal regulators, seeking stimulation (opening eyes and moving more) when in a low arousal state (the dark), and avoiding stimulation (closing eyes and moving less) when in a high arousal state (the light).

By 3 months of age there is a developmental shift as the connections between the brainstem and higher sensory specific brain regions are established. At this time in development, arousal and attention become more independent processes. Attention is no longer fully modulated by the arousal system and there are more sensory-specific cortical effects on visual preferences than arousal based preferences. Specifically, it has been demonstrated that healthy 4-month-old infants tend to look at higher frequencies of visual stimuli independent of CNS involvement or state of arousal (Gardner & Karmel, 1995)
and at a novel stimulus in a visual recognition memory task (Geva, et al., 1999) regardless of arousal state. Posner and Rothbart (1998) discuss the developmental relationship between self-regulation and attention/cognition. They found that distressed 3-month-old infants are able to inhibit their external expression of distress by looking at novel stimuli, but that when the stimuli are removed they again express their distress at the same level as they had prior to looking.

In typical development there is another shift in the attention system between the ages of 10 and 16 months. Healthy infants demonstrate the emergence of inhibitory control over distractors indicating an emergence of higher cortical centers integrating control over the lower. In general the amount of focused attention increases and distractibility decreases between 10 and 16 months in healthy infants. When compared to infants with atypical ABR’s, healthy 10-month-old infants demonstrate a greater number of looks in focused attention as opposed to casual attention, and by 16 months each instance of focused attention is for a longer duration (Gardner, Karmel, & Flory, 2003).

The effects of arousal and regulation appear to be long lasting. Sheese, Rothbart, Posner, White & Fraundorf (2008) reported a relationship between self-regulation and executive attention abilities in infants as young as 6-7 months old. Executive attention relates to many voluntary functions including error detection, inhibition of response, and sustaining attention for one set of variables while simultaneously processing other stimuli (Posner and Rothbart, 1998). Sheese et al. (2008) argue that as compared to reactive looking, anticipatory saccades during an eye-tracking task are endogenously and voluntarily controlled, as there is no stimulus to elicit the response. They further propose that since earlier work in their lab indicated that anticipatory looking during a spatial-
conflict task was related to conflict resolution during the task as well as to parental reports of self-regulation in 24-to 30- month-old children, anticipatory eye saccades could be used as an indicator of executive attention. In their current study they found that 6-to 7-month-old infants who demonstrated more correct anticipatory saccades in an anticipatory looking task also demonstrated more self-regulatory behaviors when shown a distressing mask, and more cautionary behavior prior to manipulating a novel object.

Freidman, Watamura and Robertson (2005) further demonstrated the lasting effects of an altered system of arousal. In a longitudinal study the motor activity during looking tasks with 3-month-old infants was measured and then parental reports of attention were collected for these same children when they were 8 years old. During the looking task, infants sat in a car seat that was fitted with piezoelectric sensors to record movement activity, and looking was measured by videotape of corneal reflections. The investigators found a correlation between the suppression of motor activity at onset of gaze and the amount of rebound motor activity following this suppression measured at 3 months, and parental reports of inattention and attention problems measured at 8 years of age. Less suppression and more rebound correlated with increased reports of attentional issues, suggesting that this may be an early indicator of ADHD (Friedman, Watamura & Robertson, 2005). This finding is very important, as it supports the notion that behaviors observed in early infancy can be predictive of disorders not typically diagnosed until children are in elementary school.

Additional lines of research are emerging that demonstrate predictive indicators of other disorders not diagnosed until later in development. It was recently found that 4-month-old infants later diagnosed with ASD continued to demonstrate arousal modulated
attention at 4 months, with a greater tendency to look at higher frequencies of visual stimulation when less aroused (Karmel, Gardner, Swenson, Meade, et al., 2010). Moreover, this looking preference was significantly correlated with scores on the Pervasive Developmental Disorder Behavioral Inventory (PDDBI) when these same children were 3 years old, in that the greater their preference for looking at higher frequencies when less aroused, the worse their social discrepancy score was. Additionally, it was retroactively noted that these children had abnormal ABRs with no or minor structural CNS involvement as neonates (Cohen, Rovito-Gomez, Gonzalez, et al., 2011). This evidence suggests that early brainstem insult and arousal modulated attention may be predictive of autism spectrum disorders.

In consideration of this line of behavioral and biological developmental work that relates early sub-cortical injury, arousal modulated attention and regulation to developmental disorders, Geva and Feldman (2008) proposed a neurobiological model that hypothesizes that compromised brainstem functioning (CBSF) in neonates, either lasting or transitory, would be predictive of self-regulatory behavior dysfunction in multiple dimensions at later times in maturation. These authors posit that even transitory dysfunction of the brainstem early in development can disrupt the cascade of maturational connections and has implications for many self-regulatory and cognitive processes later on. Specific predictions are made that poor regulation in the neonatal period will be indicative of later regulatory deficits in one of or multiple co-morbid domains. These include socio-emotional self-regulation, which would result in compliance or behavior problems, inhibitory control system, which would result in executive, verbal and motor function deficits, as well as in cognitive processing skills
which would result in vigilance, voluntary attention and reaction time deficits (Geva and Feldman, 2008). Halperin and Schulz (2006) allude to a similar theoretical perspective related to the neurobiological basis of ADHD. The authors describe in great detail how although the prefrontal cortex is commonly implicated in this disorder, there have been highly inconsistent findings in the literature, suggesting a heterogeneous population. The authors therefore propose that the more likely origin of this deficit lies in a brain region that develops earlier ontogenetically which may be susceptible to early injury, such as the basal ganglia, the cerebellum and the hindbrain/brainstem. They further acknowledge that the specific role of the brainstem in regulating arousal via the norepinephrine system makes this region a likely candidate for ADHD (Halperin and Schulz, 2006).

Considering the physiological and behavioral evidence that healthy brainstem development is required for both early and later regulatory behaviors, as well as evidence that insult to this region, as measured physiologically and behaviorally, is predictive of later developmental disorders, and considering the high rates of co-occurrence between DCD and other developmental disorders, it seems plausible that DCD would also be predicted by early brainstem insult and early self-regulatory dysfunction. Deficit in the attentional networks may therefore be a primary, as opposed to a co-morbid, deficit in DCD. If this is true, it would be expected that when attentional capacity (Kahneman, 1973) is challenged in children with DCD, there would be a subsequent decline in performance.
I.6 Attention and DCD

In fact, there are a number of lines of research in support of the assertion that a deficit in attentional networks may be primary in DCD. As previously noted, Alloway and colleagues have demonstrated that children with DCD have specific difficulty with tasks involving visuospatial working memory (Alloway, 2006; Alloway & Temple, 2007). The authors do not attribute this difficulty to the motor components that are intrinsic to these tasks, rather Alloway (2006) asserts that there is competition for attentional resources when performing visuospatial working memory tasks, as both memory and motor tasks are dually being performed. It should be noted, however, that in a study conducted with adult participants, Duff and Logie (1999), demonstrated that there are separate processes involved with visual memory and perceptual motor skills. In this study the authors provided the participants with two independent tasks; an immediate serial recognition test of line drawings, and a computerized perceptual-motor task requiring them to click on targets as they appeared. Following completion of these tasks, the participants were given a computerized dual task requiring them to click on targets and then recall the line drawings that were depicted on the targets. Results indicated that there was no difference in recognition performance between the single and dual task paradigms. Duff and Logie (1999) argue that these results indicate that there is no competition for attentional resources between visual memory and perceptual motor tasks. Additionally, other researchers argue that contrary to the findings presented by Alloway and colleagues (2006, 2007), children with the sole diagnosis of DCD do not demonstrate these deficits. Crawford and Dewey (2008) tested six groups of 8-to 17-year-old participants on visual perceptual and motor tasks. Three groups included participants with
singular diagnoses of DCD, reading disabilities (RD), or ADHD. An additional three 
groups consisted of participants with multiple diagnoses, including those with DCD and 
RD, those with DCD and ADHD, and those with DCD, RD and ADHD. They found that 
the DCD only group did not score lower than age-matched typically-developing controls 
for any of the visual perceptual measures, but groups that had diagnoses of DCD and one 
or more co-morbidities did. Crawford and Dewey (2008) argue that this over-additive 
finding supports the theory of different etiologies for these various disorders. They 
propose that if there was sharing in etiology, there should be partial sharing of the 
difference. The differences in results presented between Alloway and Temple (2007) and 
the others may be a consequence of the tasks used, as it is possible that the varying tasks 
used between studies may not tap into the same memory systems.

Wilmut and colleagues (Wilmut, Brown, & Wann, 2006) compared the abilities of 
7-year-old children diagnosed with DCD to typically-developing 3,4 and 7-year-old 
controls in a covert orienting of visuospatial attention task, both as a singular task (look), 
as well as in a dual task paradigm with a superimposed motor task (look and hit). The 
looking portion of this task either required shifting of attention alone to look at a 
peripheral light, or disengagement from looking at a central light to shift attention to a 
peripheral light. The children with DCD performed similarly to age-matched controls in 
the singular task, with longer latency of eye saccades in the disengagement and shifting 
trials as compared to the shifting only trials. However, in the disengagement and shifting 
trials during the dual task condition the children with DCD demonstrated a longer 
disengagement period as compared to the 7-year-old typically-developing children. 
Furthermore, the DCD group demonstrated a degradation of the actual motor task, with
slower initiation time as well as decreased accuracy to hit the target as compared to all other groups of children. The authors explained these findings as indicating an immaturity of the motor system in children with DCD, or alternatively, as an inability to accommodate for the attentional load required to disengage attention during a motor task (Wilmut, Brown, & Wann, 2006). Additionally, it has been demonstrated that children with DCD performed progressively better on a spatial reaching task when provided with progressively more pre-cueing (Pettit, Charles, Wilson, Plumb, Brockman, Williams, & Mon-Williams, 2008), possibly indicating that greater arousal of the attention systems facilitates performance in this population.

I.7 Dual Task Paradigm: Posture and Attention

A developmental trend relating to posture and executive attention has been established in healthy children and adults. Reilly and colleagues (Reilly, van Donkelaar, Saavedra & Woollacott, 2008) investigated the developmental relationship between postural control and executive attention. In accordance with Kahneman’s model of attentional capacity (Kahneman, 1973) they hypothesized that adults and older children (7-12 years) would have greater attentional capacity than young children (4-6 years) to dually perform a short term memory task and a postural control task. Developmental trends were found for postural control as well as for the executive function of attention required to perform these memory tasks, with improvement in both areas with age. Furthermore, in line with their hypothesis, only the young children demonstrated a decline in postural performance during the dual task paradigm, with the most decline noted when standing in the most challenging posture of heel-toe (tandem) stance (Reilly,
et al., 2008). Considering that postural stability requires attentional resources (Woollacott & Shumway-Cook, 2002), this dual task paradigm has been used to investigate the role of attention in postural sway among children with DCD.

Laufer, Ashkenazi and Josman (2007) examined how the center of pressure (COP) dimension of postural stability was altered when participants performed a cognitive task while standing on surfaces of varied compliance. Participant groups included 4-to 6-year-old children diagnosed with DCD, as defined by a score that is lower than the 13th percentile on the MABC, as well as in age-matched controls who were typically-developing, as defined by a score that is greater than the 21st percentile on the MABC. Results demonstrated that the children with DCD demonstrated greater postural sway, and more variability of postural sway, as compared to the controls during all conditions. Additionally, only the children with DCD demonstrated an additional decrement of postural stability when the cognitive task was added, regardless of surface. Chen, Tsai, Stoffregen, and Wade (2011) similarly demonstrated that 9-to 10-year-old participants with DCD demonstrated greater overall postural sway during a visual vigilance task as compared to age-matched typically-developing controls. They further demonstrated that although the control participants were able to minimize their postural sway during the most difficult visual task trials in order to focus on the task, the participants with DCD had increased postural sway during these trials. It has been demonstrated that adults who had been diagnosed with DCD as children continue to demonstrate increased postural sway under dual task conditions (Cousins & Smyth, 2003). Stability of this finding over time indicates that delay models of DCD, which postulate that there is an immaturity of the attentional networks in this population, cannot
explain the relationship between attention and motor control. Rather, it must be considered that a deficit of the attentional networks is an important underlying feature of DCD.

As previously discussed, to date there are no standardized tools available to assess children under the age of 6 for DCD. While there is some indication of stability of motor skill performance over time as measured by the MABC (Coleman et al., 2001) there is evidence that this is only true in children at risk for ASD, but not in others (Van Waelvelde et al., 2010). There is additional evidence to suggest that while the MABC is currently the ‘gold standard’ for diagnosing DCD, its value has limitations. Deconinck, De Clerq, Van Coster et al. (2008) found that 6-to 8-year-old children with DCD had greater postural sway under conditions with limited sensory feedback as compared to age-matched typically-developing control subjects, and these same children with DCD scored above the 15th percentile on the balance subsections of the MABC. Deconinck and colleagues (2008) explain that there is a fundamental difference between underlying postural control and functional balance limitations, which could attribute to this discrepancy. Considering this finding as well as the previously noted research that both children (Laufer, Ashkenazi & Josman, 2007) and adults (Cousins & Smyth, 2003) who had been diagnosed with DCD demonstrated greater postural sway during dual task paradigms, it seems prudent that in the attempts to develop tools to identify DCD at younger ages, underlying features of postural control that are unrelated to specific skills should be considered.

Gait is highly organized complex motor skill that relies on postural control, and which has the potential to provide rich measures of coordination. In fact, qualitative and
quantitative measures of gait have been employed in the diagnosis as well as for tracking changes over time in many neurodevelopmental and neurodegenerative disorders (Shumway-Cook & Woollacott, 2011). A number of studies that characterize the gait in children with DCD have been reported. Woodruff and colleagues (Woodruff, Bothwell-Myers, Tingley, & Albert, 2002) developed an index using archival gait data from healthy, typically-developing children. The 4 variables included in the index are percentage of gait cycle at opposite toe off, percentage of cycle in single stance, percentage of cycle at toe off, and step length as percentage of gait cycle. The researchers conducted a 3D video motion analysis gait study with 6-to 7-year-old children diagnosed with DCD, and then compared each child’s most representative trial to the database norms from typically-developing 3-to 7-year-olds. Results indicated that the participants with DCD had greater variability in performance for all four variables, and, overall, the children with DCD were in the abnormal range of the walking index (Woodruff, et al., 2002). This analysis is limited, in that the variables measured are qualitative, and they do not offer any indication as to the process involved in the gait deviations noted. Additionally, although it has been consistently demonstrated that children with DCD demonstrate variable performance, only one representative trial for each participant was compared to the normal index. Furthermore, the participants were matched to archival data based on age only, when in fact other variables, such as height and weight, are important factors to consider when analyzing gait.

Deconinck, De Clercq, Savelsbergh, et al. (2006) also performed a gait study comparing qualitative variables of treadmill walking between participants with DCD and age-matched typically-developing controls. They found that the participants with DCD
had greater cadence (speed) than controls, with related decreased step length and
decreased time spent in double stance. However, when these variables were analyzed
relative to the total gait cycle there were no differences between groups. These
researchers assessed the kinematic variable of joint angle during the gait cycle as well.
They found that as compared to controls, participants with DCD maintained their trunk in
greater forward flexion throughout the cycle, they had more knee flexion during initial
contact and less ankle plantarflexion with toe off. Although kinetic variables were not
explicitly measured, the authors inferentially explained these findings as indicative of
decreased neuromuscular force and the use of compensatory mechanisms for balance in
this population (Deconinck, et al., 2006).

Dual task paradigms requiring completion of various cognitive tasks while
walking have been informative for many populations including the healthy elderly
(Toulotte, Thevenon, Watelain, & Fabre, 2006), individuals with vestibular disorders
(Nascimbeni, Gaffuri, Penno, & Tavoni, 2010), children with cerebral palsy (Reilly,
Woollacott, Donkelaar, & Saavedra, 2008), and adults with Alzheimer’s disease
(Sheridan, Solomont, Kowall, & Hausdorff, 2003). Considering that postural control is
compromised under dual task conditions in DCD, it is expected that there would also be a
degradation of coordination of gait under dual task conditions as well. In fact, one dual
task study has been published comparing the effects of integrating easy (reciting list of
numbers) and difficult (reciting list of numbers backwards) cognitive tasks as well as
easy (holding empty tray) and difficult (holding tray with marbles on it) motor tasks with
a walking task on children aged 4-to-6-years-old with and without a diagnosis of DCD.
For the dual tasks requiring cognitive attention, both groups of children equally
demonstrated changes in spatiotemporal parameters of gait (i.e. velocity, cadence), and neither group was affected by the easy motor task. However, in the condition requiring walking with the superimposed difficult motor task, the children with DCD demonstrated a greater change in spatiotemporal parameters of gait as compared to the typically developing children (Cherng, R.J., Liang, L. Y., Chen, Y.J., & Chen, J.Y., 2009). While this study demonstrated that children with DCD are particularly affected by superimposing motor tasks on one another, the cognitive attention tasks chosen may not have been sufficiently challenging to elicit group differences in postural response.

I.7 Purpose of Dissertation

The aim of this research is to identify stable underlying features of DCD in the context of how deficits in attentional capacity affect postural control and motor coordination in gait. The advantage of studying gait as a model of postural control is that it is a goal directed functional skill that can be measured with very young participants. Additionally, retrospective neonatal data on these children, including physiological measures of early brain stem function and behavioral measures of attention, will be analyzed in an attempt to describe early risk profiles for DCD. This study will contribute to the literature by investigating the role of attention in DCD from the neonatal period through 8 years of age. Additionally, qualitative analysis of free gait (as opposed to walking on a treadmill) in this population has not been fully described using the levels of analyses that will be proposed for this study, and this information can potentially enhance clinical intervention. The findings from this study can also initiate the process of describing early risk profiles as well as developmental trajectories for subgroups of DCD,
which in turn can enable earlier detection and intervention. Earlier intervention could potentially alter the developmental trajectory of this population and improve the prognosis for many children.
CHAPTER II. METHODS

II.1 Participants

Participants for this study were recruited from a population of children who had previously participated in an ongoing longitudinal high-risk infant follow-up study at the Institute for Basic Research in Developmental Disabilities, which is a subsidiary of the New York State Office of Persons with Developmental Disabilities. All children from this population who were between the ages of 3- and 8-years-old were initially considered eligible for recruitment. Exclusion criteria for this study followed the criteria set forth in the DSM-IV for DCD, including having a confirmed neurological diagnosis, such as cerebral palsy, and having an IQ below 70. Since the eligible participants were part of an ongoing longitudinal study the information required to assess the exclusion criteria was available in their charts from past parental report of diagnosis and previously administered Bayley Scales of Infant and Toddler Development, Second Edition (Bayley, 1993). Additional exclusion criteria for this study included known genetic-based markers. An approved IRB addendum allowed contact with parents who had previously consented to be contacted for additional studies. Based on these criteria and parental permission, a total of 27 participants were ultimately recruited. Parents were presented with a new consent for this research project, and either a written or verbal assent was obtained from the children, as appropriate. Based on their performance on a new set of standardized scales, as described below, the 27 participants were divided into a risk group of interest (at risk of DCD) and a control group (no risk), and they were further divided into one of two age groups. See Table 1 below for detailed participant breakdown.
This study was approved by CUNY’s IRB, as well as by the IRB at the Institution for Basic Research. Each child received a small toy or modest gift card of an equivalent denomination for participating in the study, which was provided to all participants, independent of completing all of the required tasks. The parents were offered a choice of free transportation to and from the facility, or compensation of $10 towards the cost of their travel. No additional compensation was provided.

**Determination of Groups.** In an attempt to explain differences on the basis of subject characteristics related to age at testing (Age) and classification of risk for DCD (Risk), analyses of group differences were performed. For ease of analysis and interpretation, categorical factors were formed for each of the independent subject characteristic variables. AGE was divided into two categories: Group 1: age = 3-5 years-old (Mean: 4 years, 6 months, 9 days. Range: 3 years, 4 months to 5 years, 5 months), Group 2: age = 6-8 years-old (Mean 6 years, 9 months and 14 days, Range 6 years to 7 years, 6 months and 29 days). These categories were chosen based on the current trends in diagnosing DCD at school age (6-8) and assigning classification of risk for DCD at preschool age (3-5). The Age factor served to examine the nature of the developmental changes in children’s performance abilities in these singular (attention, gait) and dual tasks.

Classification of risk was also divided into two categories: Group 1: no risk of DCD (MABC-2 score ≥ 25th percentile), Group 2: risk of DCD (MABC-2 score ≤ 16th percentile). This categorization was made in line with the recommendation that scores at the 15th percentile indicate risk, or moderate DCD, and scores at the 5th percentile or
lower indicate definitive or significant DCD (Geuze et al., 2001). The Risk factor served to provide an understanding about how task performance may vary between risk and no-risk groups.
Table 1. Participant Age and Risk Group (N = 27)

<table>
<thead>
<tr>
<th></th>
<th>No-Risk</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young Group:</strong></td>
<td>n = 9 (6M, 3F)</td>
<td>n=4 (4M, 0F)</td>
</tr>
<tr>
<td>(3-to-5-years-old)</td>
<td>Mean: 4 years, 6 months and 9 days</td>
<td></td>
</tr>
<tr>
<td><strong>Older Group:</strong></td>
<td>n= 7 (3M, 4F)</td>
<td>n= 7 (5M, 2F)</td>
</tr>
<tr>
<td>(6-to-8-years-old)</td>
<td>Mean: 6 years, 9 months and 14 days</td>
<td></td>
</tr>
</tbody>
</table>
II.2 Standardized Motor Test

Each of the 27 participants was tested on the Movement Assessment Battery for Children - Second Edition (Movement ABC-2; Henderson & Sugden, 2007), the standardized tool of motor proficiency most commonly employed in DCD research. This test is appropriate for use with children ages 3-to 16-years-old, and it assesses areas of fine motor proficiency, balance, and target throwing/catching skills. This test was partially scored on-line, but was also videotaped for off-line scoring. Based on the performance on the Movement ABC-2, participants were assigned to one of two experimental groups. (Group 1: at-risk of DCD (total test percentile score ≤ 16%), Group 2: no risk of DCD (total test percentile score ≥ 25%). Performance at or below the 16th % on the standardized motor assessment satisfied the first criterion for DCD in the DSM-V, related to decreased motor performance for age. In order to satisfy the second criterion, related to functional ramifications, supplemental parent questionnaires, described below, were used in support of this initial categorization. This approach has been reported by others (Wilson et al., 2004, Ferguson, et al., 2013).

II.3 Questionnaires

The parents of all participants were asked to fill out screening forms pertaining to their children’s motor coordination and attention, with the forms varying depending on age of participant. The Developmental Coordination Disorder Questionnaire (Wilson & Crawford, 2007) is based on a 5-point Likert scale that asks parents to rate their child’s motor performance as compared to his/her peers. This scale has been normed for rating children who are 5-to 15-years-old and is often used in DCD research to qualify
functional deficits that are seen in children with this disorder, with queries related to ball playing skills, fine motor playing skills, ability to learn new motor skills, and apparent quality of movement. This scale was provided to the parents of the participants who are between 5- and 8-years-old, with completed scales obtained for all 16 of the participants at these ages (across risk groups).

The Children Participation Questionnaire (Rosenberg, Jarus & Bart, 2010) is based on a 5-point Likert scale that asks parents to rate their child’s performance in categories of education, social participation, play, leisure, activities of daily living and instrumental activities of daily living. For each category the parent is asked to assess the child’s frequency of participation, degree of assistance required, child’s pleasure in participating, and parental satisfaction of their child’s participation. This scale is valid and reliable for use with children who are 4-to 6-years-old. This scale was chosen to provide further information about possible functional deficits related to motor function, and was provided to the parents of the participants who were between 4- and 6-years of age, with completed scales obtained for 15 of the 21 participants in this age range, and a partially completed scale obtained for one additional participant. Although the questionnaires described thus far are inappropriate for 3-year-old participants, only two of the participants were this age, and they did not receive either questionnaire. The following scale and experimental tasks to be described below are appropriate for this age.

Behaviors related to attention were evaluated using the Conners’ Parent Rating Scale – Revised Short Version. This tool is used to screen children ages 3-to-17-years for behavioral difficulties, including ADHD. This scale was included in this study to screen the participants for behavioral disorders, as it has been established that among children
who are diagnosed with DCD there is a high co-occurrence rate with these types of disorders. Additionally, since this study is specifically investigating the relationship between attention and coordination of gait, it is important to know if the participants have difficulties with attention that may be better attributed to a co-morbid disorder. Completed scales were obtained for all 27 participants.

II.4 Experimental Tasks

Computerized attention task: attention shifting vs. attention disengagement.

Each participant was seated 24” from a 19” (diagonal) computer monitor and was instructed in playing a ‘find the dog’ game, a modified version of a task previously described by Wilmut et al. (2007). Presentation and timing measurements of this game were developed using E-Prime Professional Version 2.0 software. This newly developed game requires the participant to visually fixate on a centralized cue and then respond to a target stimulus randomly presented to the left or right of the cue, either by voice or by lateralized button presses. Integrated into this task are manipulations related to the centralized cue, in that it either disappears prior to the appearance of the target stimulus (requiring attention shifting) or it persists during appearance of the target stimulus (requiring attention disengagement followed by shifting). The attention shifting/disengagement task trials and side of target presentation were randomly presented within the same trial blocks, and were counterbalanced across participants. The older participants (6-to 8-years-old) were presented with both the target stimulus and a distracting stimulus that served to increase the perceptual load. The younger participants (3-to 5-years-old) were presented with only the target stimulus, a less demanding version
of the task that required attention shifting or attention disengagement without any other distracting stimuli on the screen. (See Table 2 for additional ask details)

**Computerized attention task: voice response.** Previous work has demonstrated that for simple reaction tasks, following rescaling of response times to a standard scale, there is no difference between simple key press (hand already on key) and voice modes of response (De-Marchis, 2013). In this computerized attention task a voice response mode was implemented to isolate the participants’ decision time related to the attention component of the task (saw dog) without requiring any gross motor response.¹

For the voice response blocks, the participants were verbally instructed to place their hands on their lap and to visually focus on a central cue (video of kaleidoscope). They were instructed to say ‘dog’ out loud as soon as they saw a picture of a dog appear on the screen. The voice signal was transmitted through an external microphone and responses were assessed by the EPrime program for reaction time. Based on the participant’s response, the experimenter used a programmed key press to indicate accuracy of response, which was integrated into the EPrime program. The participants were provided with 4 practice trials (attention R, attention L, disengagement R, disengagement L) requiring the voice response, and feedback about performance was provided for these trials. Following the practice trials there were two randomized blocks of 8 trials each (See Table 2).

**Computerized attention task: button-press response.** The button press response was implemented to measure the participants’ ability to respond to the attention task with a gross motor response. This task was more complex than the voice response task, as it

¹ In hindsight, it might have been better to have implemented a single button press task with hand resting on button in place of this voice response task for consistency of mode of response.
required participants to make a choice decision (saw a dog on a specific side), as well as to activate and execute a gross motor response to move their hand towards the button located on the side corresponding to the target’s location. Wilmut et al. (2007) found that as compared to typically developing children, children with DCD had a longer disengagement time when a motor response was required (hitting target). A 6” blue pad was placed on the table top 2” away from the participant. Two red 2.5” wide circular low resistance switch buttons were situated, one on the right and one on the left of the blue pad. The experimenter verbally asked the participants and the participants’ parents which hand the participants’ preferred to write with, and this was determined to be the participants’ dominant hand. The participants were then verbally instructed to place their non-dominant hand onto their lap and to place their dominant hand on the blue pad and to visually focus on a central cue (video of kaleidoscope). Participants were instructed to keep their hand on the blue pad until they saw a picture of a dog on the screen, and to then use only that hand to press the button that is on the side corresponding to the target stimulus (see Table 2 for task sequence). The experimenter determined that the participant was looking at the central cue prior to initiating each trial. The participants were provided with 4 practice trials (attention shifting (central cue disappeared) R, attention shifting (central cue disappeared), L disengagement (central cue preserved) R, disengagement (central cue preserved) L), and feedback about performance was provided for these trials. Following the practice trials there were two randomized blocks of 8 button press trials each.

Although a protocol was in place to adjust task difficulty for age if necessary, all children were able to successfully complete the task associated with their age group.
Reaction time and accuracy for both the verbal and button press responses were tabulated by the E-Prime program. The entire session was video recorded for off-line assessment of task errors and participant ability to inhibit responses until the target stimulus was presented.
Table 2. Computerized Attention Task

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Attention Shifting Task (central cue disappears)</th>
<th>Attention Disengagement Task (central cue remains constant)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-to 5-year-olds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central cue (gaze directing cue centered in screen)</td>
<td>Disappears (Gap 1000 ms)</td>
<td>Remains (1000 ms)</td>
</tr>
<tr>
<td>Target Stimulus</td>
<td>On Right or Left of Screen (until response/10000 ms max)</td>
<td>On Right or left of Screen with central cue still present (until response/10000 ms max)</td>
</tr>
<tr>
<td>Participant Response</td>
<td>Voice (“dog”) Button Press on Right or Left</td>
<td>Voice (“dog”) Button Press on Right or Left</td>
</tr>
<tr>
<td>6-to 8-year-olds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central cue (gaze directing cue centered in screen)</td>
<td>Disappears (Gap 1000 ms)</td>
<td>Remains (1000 ms)</td>
</tr>
<tr>
<td>Target Stimulus</td>
<td>On Right or Left of Screen (until response/10000 ms max)</td>
<td>On Right or left of Screen with central cue still present (until response/10000 ms max)</td>
</tr>
<tr>
<td>Distracting Stimulus (picture of other animal, similar color hue)</td>
<td>On opposite side of screen from target</td>
<td>On opposite side of screen from target</td>
</tr>
<tr>
<td>Participant Response</td>
<td>Voice (“dog”) Button Press on Right or Left</td>
<td>Voice (“dog”) Button Press on Right or Left</td>
</tr>
</tbody>
</table>
**Gait evaluation.** Quantitative and qualitative assessments of each child’s gait were evaluated in a fully instrumented gait and movement laboratory. The 3D-movement acquisition and video recording was conducted using an optoelectronic system with passive markers for kinematic (i.e. joint angles) movement evaluation (BTS SMART-D Motion Analysis System; Milan, Italy), and a video recording system in synchrony with the optoelectronic system (BTS VIXTA, Milan, Italy) in a 20' x 28' data acquisition space. The SMART-D system performs a real time processing of images from 9 fixed infrared cameras to extract the reflectance of passive markers (with a diameter of 15 mm), which are positioned on specific anatomical landmarks of the child using hypoallergenic adhesive discs, 3M 2181 (see figure 1). In addition, electromyogram (EMG) data were collected using wireless 16-bit EMG probes with the differential amplifier placed at a 4 cm distance following the International Society for Electrophysiology and Kinesiology (ISEK) guidelines to reduce noise and artifacts. Following cleansing of the skin with rubbing alcohol, the leads were placed with disposable pre-gelled electrodes parallel to the muscle fibers on the muscle belly of each child’s bilateral hamstring, quadriceps, anterior tibialis and gastrocnemius muscle groups. The EMG signal was sampled at 1,000Hz, and the raw signal was sent unfiltered to the workstation. These data were collected to provide select information about coordination of muscular activation within each leg’s segments (intralimb coordination) as well as between the two legs (interlimb coordination).

Prior to testing, each participant was asked to remove his/her shoes and socks and to change into his/her bathing suit in a private area, with the parent assisting as needed. Anthropometric measurements (i.e. arm length, leg length, overall height, weight) were
taken for each child prior to marker preparation. The markers and EMG leads were then placed on the appropriate anatomical landmarks (see Figures 1a and 1b). The approximate total preparation time was 10 minutes.
Figure 1a. Schematic of anatomical marker placement.

Figure 1b. Schematic of trunk deviation angle.
**Gait Evaluation Tasks**

*Stance Task (calibration).* The participants were asked to stand with their feet hip-width apart while looking forward for 30 seconds while standing on a force plate. This task allows for the participant’s calibration of the gait analysis system.

*Walking Task (baseline).* The participants were asked to walk at their preferred pace along a 10 meters long walkway for 2 trials, without any additional task demands. This task provided a baseline measure of the child’s natural self-selected walking.

*Walking with Directionality Task.* A picture of a bird was projected on a screen located at the end of a walkway in the lab. The location of the pictured bird was pre-assigned to either the right or left side of the screen (2 trials). The participant was asked to walk towards the bird and touch it. This task served to demonstrate both the child’s understanding of location of target as well as the ability to pre-plan his/her movement to walk in the appropriate direction. The EPrime system was integrated with this task and served to provide the projected goal task (picture of bird), and was used to collect data related to time of full task completion (from start of trial until ‘bird’ was touched).

*Dual Attention and Walking Task A: Voice Response.* The computer-based ‘find the dog’ attention task, as described above, was projected on a screen at the end of the walkway. Four randomly interspersed attention shifting (right, left) and disengagement (right, left) trials were presented with counterbalancing across participants. The participant was instructed to start walking down the walkway while focusing on the
centralized cue, and to then say ‘dog’ when he/she sees the dog on either the right or left side of the screen, while continuing to proceed down the walkway. Reaction time from onset of target to verbal response was measured. The EPrime system was integrated with this task and served to provide the projected goal task (‘find the dog’), and was used to collect data related to time of full task completion (from start of trial until participant said ‘dog’).

_Dual Attention and Walking Task B: Touch Response_. During these trials the computer based ‘find the dog’ attention task, identical to Task A, was projected on a screen at the end of the walkway. Four trials with random and counterbalanced presentation of attention shifting (right, left) and disengagement (right, left) trials were presented with the instruction given to the child to physically touch the dog at the end of the walkway. The experimenter initiated the projection after the participant had taken 3 steps forward to ensure duality of task, while allowing for sufficient time for a motor response to be implemented. This task differed from the voice response task in that it required the participant to plan his/her movement on-line based on the information that he/she received while walking. The EPrime system was integrated with this task and served to provide the projected goal task (‘find the dog’ game), and was used to collect data related to time of full task completion (from start of trial until ‘dog’ was touched).

_Dual Attention and Walking Task C: Barrier and Touch Response_. For these trials a foam filled 61cm cube barrier was placed at the 2/3 mark (~ 7 meters from the starting point) on the walkway which, given its size, required the child to modify his or her
trajectory to walk around the barrier in order to reach the screen. During these trials the computer based ‘find the dog’ attention task, similar to the prior two dual attention tasks, was projected on a screen at the end of the walkway. Four trials with random and counterbalanced presentation of attention shifting (right, left) and disengagement (right, left) trials were presented with the instruction given to the child to touch ‘dog’. This task also required on-line motor planning, but constrained the child’s movement as it did not allow for the possibility of last minute adjustment of directionality. The experimenter initiated the projection after the participant had taken 3 steps forward to ensure duality of task, while allowing for sufficient time for a motor response to be implemented. The EPrime system was integrated with this task and served to provide the projected goal task (‘find the dog’ game), and was used to collect data related to time of full task completion (from start of trial until ‘dog’ was touched).

Walking Task (assessment of fatigue). Following the dual task trials, the participants were asked to walk at their preferred pace along the 10 meters long walkway for 1 trial, without any additional task or barrier demands. This trial assessed the effects of fatigue, and is standard practice in gait analysis studies.

Rest Periods. Rest periods were provided to each subject as needed throughout the gait evaluation session.
Incorporation of Retrospective Neonatal Infant and Toddler Data

Retrospective neonatal and early toddler data, including physiological measures of early brain stem function and behavioral measures of attention, previously collected in the infant follow-up study on the same participants, will be compared to data from the current study, to determine if there is a relationship between early behaviors and performance with the experimental tasks tested in this study.
CHAPTER III. DATA PREPARATION/ANALYSIS/RESULTS

III.1 Standardized Tests and Questionnaires

In order to corroborate the participants’ objective performance as observed on the MABC-2, the scores from this standardized test were compared to the subjective information about their functional ability, as reported by the parents using the DCDQ, CPQ and Conners’ questionnaires. Pearson correlation analyses were performed to relate the total percentile score on the MABC-2 with the raw score of the DCDQ, with the derived quotients for participation diversity, intensity, independence, enjoyment and parent satisfaction from the CPQ and with the raw scores of the cognitive inattention, ADHD, hyperactivity and oppositional categories on the Conners’ Parent Rating Scale (See Table 3). Consistent with previous reports, positive correlations were found between performance on the MABC-2 and parent report on the DCDQ, r=.53, p=.04, (Wilson, et al., 2009) and the participation diversity measure of the CPQ, r=.54, p=.04, (Liberman, Ratzon, & Bart, 2013). This suggests that the children with lower percentile scores on the MABC-2 also present with reduced functional ability and participation deficits relative to their peers. A negative correlation was found between performance on the MABC-2 and the Conners’ cognitive inattention, r= -.46, p=.02 and ADHD, r= -.40, p=.04 subsections, indicating an inverse relationship between these children’s motor performance and their behaviors related to attention. The children with lower percentile scores on the MABC-2 have a greater number of behaviors reported related to decreased attention.
Table 3. Pearson Correlation Analyses Between Standardized Motor Test and Questionnaires

<table>
<thead>
<tr>
<th>MABC-2 Total %</th>
<th>DCDQ Raw score</th>
<th>CPQ Diversity</th>
<th>CPQ Intensity</th>
<th>Conners’ Cognitive Inattention</th>
<th>Conners’ ADHD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation Sig. (2-tailed)</td>
<td>.530</td>
<td>.538</td>
<td>.463</td>
<td>-.460</td>
<td>-.403</td>
</tr>
<tr>
<td>N</td>
<td>.035*</td>
<td>.038*</td>
<td>.082</td>
<td>.018*</td>
<td>.041*</td>
</tr>
</tbody>
</table>

* p < .05 Note. (DCDQ= Developmental Coordination Disorder Questionnaire, CPQ= Children’s Participation Questionnaire, ADHD= Attention Deficit and Hyperactivity Disorder)
III.2 Computerized Attention Task

**EPrime Generated Data Preparation.** Practice trials were not included in any of the analyses. The two blocks of 8 test trials per task type (voice and button press response) were reduced to 8 test trials. Invalid trials (experimenter error) were found for one trial with two participants, and these data points were imputed with values representing the individual’s average performance for that task type. Behavioral video analysis of the participants’ performance during this task revealed that one subject did not actively participate in this testing, refusing to respond to the cues until the final 4 trials. This participant’s data was eliminated from all analyses related to this task resulting in one removed participant from the young, no risk group leaving an N=26 for all analyses related to the computer attention task.

Consistent with De-Marchis, (2013), the response time data for the button press and voice response mode tasks were transformed to allow for comparison of response times between tasks. A McCall’s T-test transformation ($(z\text{score}*10)+50$) was used. It should be noted that the analyses using the raw data had the same outcome as the analyses with the transformed data. However, since this transformation was necessary to allow for analysis of reaction time between this computerized attention task and the dual tasks (reported later), the transformation was maintained for these analyses. For ease of interpretation the raw score means are reported.

**Computerized Attention Task Data Analysis and Results**

*Reaction Time.* It was predicted that: 1) Overall (independent of group), there would be a longer reaction time during the disengagement trials (kaleidoscope central cue
preserved) as compared to the shifting trials (kaleidoscope central cue disappears); 2) Independent of risk group, younger children would have a longer reaction time than the older children for all trial types; 3) Children at risk for DCD (risk group) would have longer reaction time than the no-risk group for the button press task because it is a dual task; 4) The children in the risk group will demonstrate a different developmental trend (slower or faster, both are plausible) for response time as compared to children in the no-risk group (risk x age interaction).

Preliminary analyses revealed that there were no differences between groups for Side of stimulus presentation, and this variable was subsequently removed for all additional analyses. Reaction time was analyzed using a 2 x 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (voice response and button press) x Trial (shift and disengagement) mixed design repeated measures GLM with a Huynh Feldt adjustment in SPSS. Means reported reflect the raw data with a unit of milliseconds (ms). A significant main effect was found for Age, F (1,22) = 3.75, p = .07m (young M; 830.35ms, old M: 729.13ms), and a significant two-way interaction was found between Task and Risk F(1,22) = 5.84, p=.02 (voice no-risk M: 706.79ms, voice risk M: 893.04ms, button press no-risk M: 840.88ms, button press risk M: 919.32ms), both of which are qualified by a marginal three-way interaction between Age, Risk and Task, F(1,22) = 3.16, p=.09m (young no-risk voice M: 819.74ms, young risk voice M: 1019.69ms, young no-risk button press M: 863.48ms, young risk button press M: 978.50ms, old no-risk voice M: 577.71ms, old risk voice M: 820.67ms, old no-risk button press M: 815.05ms, old risk button press M: 885.50ms). In order to isolate the locus of this three way interaction, separate post hoc t-tests were analyzed. Independent t-tests showed a significant
difference in Reaction Time during the Voice response Task between the younger and older children, in that the older children were faster than the younger, t (24) = 2.73 \( p = .01 \) (young M: 699.19ms, old M: 886.39ms). An independent t-test analyzing the no-risk group only demonstrated that this Age related difference was within this group of children, t (13)= 3.31, \( p = .01 \) (young no-risk M: 816.13ms, old no-risk M:575.43ms). A paired t-test demonstrated that within the risk group there was a marginally significant difference in Reaction Time between Tasks, with faster Reaction Time during the voice response task, t (10) = 1.88, \( p = .09m \) (voice M: 642.09ms, button press M: 919.45ms), and an independent t-test analyzing the young group only demonstrated that it was only the young children in the risk group who were faster than the no-risk group of children during the Voice response Task, t (10)=2.26, \( p = .05 \) (young no-risk M: 816.13ms, young risk M: 645.00ms). This three-way interaction describes a differential developmental trend between the risk and no-risk groups between Tasks (see Figure 2). In the button press response task, the participants in the risk group demonstrated a similar developmental improvement as the participants in the no-risk group, with the older participants responding faster than the younger ones. However, in the voice response task, the younger participants in the risk group respond faster than the young participants in the no-risk group, but while there is developmental improvement observed with the older participants in the no-risk group, there is none observed in the risk group. While these risk children appear to start at an advantage at a young age, they don’t improve over time, and at the older age perform slower than their peers in the no-risk group.
Figure 2. 3-Way Age x Risk x Task Interaction: Response Time.
**Accuracy.** It was predicted that 1) Independent of Risk category, younger children (3-to 5) would demonstrate less accuracy than the older children for all trial types; 2) Risk group would demonstrate less accuracy than the no-risk group for the button press task.

The accuracy measure was scored using dichotomous variables of 0 (inaccurate) and 1 (accurate), so non-parametric statistics were used for analysis. The Wilcoxon Signed Ranks Test was used to assess differences in Accuracy between voice and button press response type tasks, and between attention disengagement and attention shifting Trial types, irrespective of Age or Risk groupings. Overall, the participants were more accurate during the voice task as compared to the button press task (p=.034, z-score -2.12 Voice M: 1.00 Button Press M: .98), and they were marginally more accurate during the attention shifting trials as compared to the attention disengagement trials (p=.074, z-score -1.79 Shifting M: .995 Disengagement M: .985).

In order to compare performance between groups, the Mann Whitney U Test was used to compare Accuracy across all Trial types for Age and Risk groupings. Across Task type, Trial type and Side of presentation, no group differences for accuracy were observed (Risk: p=.97, z-score = -.038, Age: p=.11, z-score = -1.613).

**Inhibition.** Response inhibition was defined as the ability to wait for the appearance of the target stimulus prior to initiating a response. Off-line behavioral video analysis of all computerized attention task trials was used to code behaviors indicative of decreased inhibition. For the voice task trials, a participant saying ‘dog’ prior to the presentation of the target stimulus was coded as an incidence of decreased inhibition, and
for the button press task trials, a participant raising his/her hand off of the blue pad prior to presentation of the target stimulus was coded as an incidence of decreased inhibition. Frequency counts were tabulated, with higher numbers indicating higher incidence of decreased inhibition.

It was predicted that 1) younger children would demonstrate less inhibition than the older children and that 2) the risk group would demonstrate less inhibition as compared to the non-risk group.

This data set consisted of categorical data, requiring non-parametric statistical analyses. The Mann Whitney U Test was used to compare inhibition across both Task types for Age and Risk groupings. Overall, the younger children demonstrated a marginally higher frequency of decreased inhibition as compared to the older children, p= .07; z-score =-1.83. (younger: M: 2.17, SD: 2.82, older: Mean: .86  SD: 2.11). Upon further examination of the data, this was found to be related to their performance on the voice task, p=.063; z-score = -1.92. (younger : M: 1.17, SD: 1.70, older: M: .29, SD: .83), and not the button press, p=.338; z-score= -1.10. Across task types, there was no difference in inhibition between the risk and non-risk groups, p= .42; z-score= -.84.

### III.3 Gait Evaluation

**Kinematic Analysis.** One of the participants chose not to have the reflective markers placed on her, so she did not perform any of the walking experimental tasks (n=26). Participants were instructed to stand in a centered position at the start of the walkway, and, when cued, to walk towards the end of the walkway using their regular pattern of walking. Participants walked without additional task constraints for two trials.
at the start of the gait data acquisition, and then for one additional trial following all other gait data acquisition trial types. As a general rule, the first walking trial and the walking trial performed at the end of the entire gait session were chosen for analysis, and the second walking trial was used only when one of the others did not have full representation of data points. T-test analyses between the two trials demonstrated a general reduction in walking velocity (meters/second m/s) across all participants, with decreased average velocity between the first and final walking trial of the session, F(1, 20) = 6.14, p = .03 (walk first trial: M: .91 m/s SD: .44; walk final trial: Mean: .56 m/s, SD: .90). However, this reduced velocity (interpreted as fatigue) was non-differential across age and risk groups.

Variables assessed for this task include the walking Velocity across the entire trial (mean and standard deviation), degree of Elbow Flexion (a measure related to balance preservation), and Jerk (a measure related to smoothness of movement). A brief description of each of these variables will be provided here, followed by the analyses and results.

**Velocity.** For this baseline measure ‘walking only’ task, average velocity of the trajectory along the pathway (m/s) was intended to reflect the individual’s typical self-selected speed. The standard deviation of the average velocity was analyzed as a separate variable (unitless) to assess how continuous a path the participants sustained during the trial (e.g., did the participant pause, slow down or speed up). Since variation in participants’ height is a potential confound when comparing velocity across shorter and taller individuals, participant height was held as a covariate for these analyses (gait speed normalized to height, see Shumway-Cook and Woollacott, Fourth Edition page 418)
**Elbow Flexion.** In typical development, new walkers maintain an elevated upper extremity posture (known as ‘high guard’), and following ~ 3 months of practice and experience the arm posture lowers and reciprocal arm swing, in synchrony with the legs, develops (see Lebedt, 2000). A similar posture had been noted in individuals with various neurological diagnoses including cerebral palsy, stroke and Parkinson’s disease (see review by Meyns, Bruijn and Duysens, 2013), and is often associated with maintaining or supplementing posture or balance. In healthy experienced walkers this posture often reappears when new motor skills are attempted or when walking on uneven or treacherous surfaces. The elbow flexion variable in this study reflects the degree of arm elevation, with a greater degree of elevation considered as a marker for a less practiced or mature gait, particularly in dual task trials. This measure in the single ‘walking only’ task was intended to be a baseline measure of each individual’s maximum arm flexion with normal arm swing, with no difficulty expected between groups for this well practiced motor skill.

**Jerk.** Jerk, as defined by the rate of change of acceleration, is reported in units of meters/seconds$^3$ (m/s$^3$), and represents a jolt, or surge in movement, that might render an overall movement to be less smooth. Others have reported that children with DCD demonstrated more jerk with upper extremity movements during a visuomotor drawing task as compared to age matched typically developing peers (Pangelinan, Hatfield, & Clark, 2013). Pangelinan and colleagues’ research showed that children with DCD demonstrated differential cortical activation patterns, as seen with EEG recordings, but had similar behavioral performance as compared to their typically developing peers. The
exception to this behavioral performance was with the amount of jerk observed, indicating less smoothness of movement during the task.

For this study, the jerk was calculated based on the trajectory of movement collected from the reflective marker on the sacrum, as this best approximated the participants’ center of mass and was postulated to best represent the smoothness of movement for the entire system, as opposed to an individual limb. The data set presented with a positive skew, so a log transformation (10 log) was applied. For this baseline walking task, which is a well-practiced motor task across all participants, no differences between risk groups were predicted.

**Results for Walking Only Task.** For this ‘walking only’ task it was predicted that: 1) No difference in mean Velocity would be found between groups (Age or Risk); 2) No difference in standard deviation of Velocity would be found between groups (Age or Risk); 3) no difference in amount of Elbow Flexion would be found between groups (Age or Risk); 4) No difference in Jerk (smoothness of trajectory) between the risk and no-risk groups would be found; 5) Older children would demonstrate less Jerk (smoother trajectories) than younger children.

Each of the walking variables (mean Velocity, standard deviation of Velocity, Elbow Flexion and Jerk) was analyzed with a 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Trial (Walking Trial 1 and Walking Trial 2) mixed design repeated measures GLM with a Huynh-Feldt adjustment in SPSS. As predicted, no difference was found for Age or Risk for average Velocity (m/s), with height held as a covariate. A between groups difference for the standard deviation of average Velocity was found for
Age, $F(1, 22) = 4.34, p = .05$, with the older participants varying their speed more than the younger participants (young M: .24, old M: .38). No statistical difference was found for the standard deviation of Velocity for Risk. No statistical difference was found for degree of Elbow Flexion for Age, but a trend was noted with the risk group demonstrating more elbow flexion than the no-risk group, $F(1,22)= 3.09, p = .09$, (no risk M: 148.72 degrees, risk M: 140.45 degrees). The analysis for Jerk revealed no statistically significant differences for Age or Risk.

### III.4 Dual Tasks

**Kinematic Analysis.** Directionality task: Two trials were administered for this task; one with the picture of a bird presented on the right side of the screen, and the other with the picture on the left side, and both trials were included for analysis. The purpose of this task was to ensure that all participants were able to understand that a goal had been added to the task of walking, and it served as a criterion for participation in the successive dual task trials. This task also served as a basis of comparison for the subsequent dual tasks to assess for compensatory balance strategies when changing direction towards the target stimulus.

Voice, Touch, and Barrier Dual Tasks: While participants engaged in four trials of each of these tasks, only the first right and the first left trials were chosen for analysis. The remaining two trials served as buffers if one of those first two trials were missing data points.

For directionality, voice, touch, and barrier task trials, the gait events of interest were defined by the image onset (IO) and change of direction (CD). Change of direction was
defined as the first step following the participant’s deviation from the initial trajectory. If the participant started the trial by walking in a specific direction (towards or away from the projected image), as opposed to changing direction mid-way, then change of direction was defined by the first step in the trial. Each step was defined by a heel strike (when foot lands on ground following swing phase).

The gait evaluation tasks were chosen, within the dual-task paradigm, to challenge the normally well-practiced movement pattern of basic walking in children. The tasks provide increasing demands on cognitive processes while in motion, with the Barrier Task expected to require the highest level of attention and vigilance. However, individual differences are anticipated, illuminating a number of strategies employed by both the risk and no-risk groups. Children might modify their trajectory or respond to the required change of direction by a) slowing down (Velocity variable); b) showing heightened arousal (Elbow Flexion variable); c) changing the orientation of their trunk (Trunk Deviation variable); d) decreasing the smoothness of their transition (Jerk variable); or e) demonstrating other gait modifications in anticipation of the task (anticipation error). While the results of these individual variables will be treated separately in the results section, they will be viewed as a multi-faceted dynamic and interactive pattern of complex movements in the discussion section, similar to the framework of Dynamic Systems Theory forwarded by Thelen and Smith (2007).

The following dependent variables were considered with individual sets of analyses run for each variable. Age and Risk group were the between factor variables that were included in each analysis.

1. Mean of average Velocity across the trial (reported in meters/second: m/s)
2. SD of average Velocity across the trial
3. Elbow Flexion at image onset (degrees)
4. Elbow Flexion at change of direction (degree)
5. Degree of Trunk Deviation from upright (angle between the 3D vector Sacrum – C7 and the horizontal vector) during change of direction (degree), See Figure 1b.
6. Distance between the subject and the obstacle during the Image Onset (meters, m)
7. Distance walked between image onset and change of direction (meters, m)
8. Reaction Time between image onset and change of direction (seconds, s)
9. Jerk at image onset (meters/second$^3$, m/s$^3$)
10. Jerk at change of direction (meters/second$^3$, m/s$^3$)

For the dual task kinematic analyses the predictions were: 1) Across groups, as compared to the baseline walking task, there will be greater variability of walking speed during the dual task trials; 2) The risk group will demonstrate more variability in velocity during the dual tasks as compared to the non-risk group; 3) The younger and risk groups will demonstrate more elbow flexion during image onset of the voice, touch and barrier tasks, as compared to their baseline; 4) The younger and risk groups will demonstrate more elbow flexion during change of direction as compared to during image onset for touch and barrier tasks; 5) The younger and risk groups will demonstrate more trunk deviation during change of direction as compared to the other groups during the touch and barrier tasks; 6) Younger children will have a less smooth trajectory of walking during the barrier trials than the older children; 7) Risk group will demonstrate a less smooth trajectory in the barrier trials as compared to the no-risk group.
Each of the walking variables was analyzed using repeated measures GLM with a Huynh-Feldt adjustment in SPSS.

**Velocity.** The average Velocity (average walking speed) across the entire trial was compared between the walking only, and dual task (voice, touch and barrier response) trials, with the child’s height held as a covariate. For these analyses, results are reported in units of meters/seconds (m/s). No difference in walking speed was found between these Task types, and no statistical difference was found for Age or for Risk, indicating that the children did not differentially utilize speed of walking as a strategy to approach the various tasks. In order to assess the variability in walking speed between groups, the mean of the standard deviation of Velocity across the entire trial was compared between these same task types. No difference in variability between Task type was found. A between-groups effect was found for Age, F (1, 21) = 7.62, p=.01, with the older participants demonstrating more variability in speed across the different trial types as compared to the younger participants (young M: .27, old M: .40). This might reflect an ability to use modulation of speed as a strategy to adapt to the task demands. No between groups effect was found for Risk.

**Elbow Flexion.** The degree of Elbow Flexion was analyzed using a 2 x 2 x 3 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Baseline (Walking or Directionality)), Touch and Barrier) x Event (image onset and change of direction) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. Means reported reflect a unit of angular degree (deg), with higher numbers indicating more Elbow
Flexion. Main effects were found for Task, $F(2, 30) = 4.92, p = .014$ (Baseline M: 37.13 deg, Touch M: 42.30 deg, Barrier M: 39.29 deg) and for Event, $F(1, 30) = 3.81, p = .07m$ (Image Onset M: 37.43 deg, Change of Direction M: 42.14 deg). These main effects, as well as a statistically significant two-way interaction for Task and Event $F(2,30)= 3.76, p = .04$ (Baseline image onset M: 33.28 deg, Baseline change of direction M: 38.11 deg, Touch image onset M: 38.35 deg, Touch change of direction M: 47.75 deg, Barrier image onset M: 38.82 deg, Barrier change of direction M: 37.71 deg) were qualified by a significant three-way interaction for Task, Event and Risk, $F(2, 20) = 5.47, p = .01$ (Baseline IO no-risk M: 31.84 deg, Baseline IO risk M: 34.32 deg, Baseline CD no-risk M: 40.71 deg, Baseline CD risk M: 36.21 deg, Touch IO no-risk M: 41.19 deg, Touch IO risk M: 36.28 deg, Touch CD no-risk M:46.48 deg, Touch CD risk M: 47.75 deg, Barrier IO no-risk M: 43.07 deg, Barrier IO risk M: 35.73 deg, Barrier CD no-risk M: 38.55 deg, Barrier CD risk M: 37.10 deg); (See Figure 3). In order to isolate the locus of this three way interaction, separate post hoc t-tests were analyzed. A paired t-test revealed a statistically significant difference for Elbow Flexion between the Baseline and Touch tasks, $t (18) = 3.37, p < .01$, with more Elbow Flexion seen during the Touch Task (Baseline M: 35.70deg, Touch M: 42.78deg). This difference held true for the children in the risk group $t (7) = 2.52, p = .04m$ (Baseline M: 39.88deg, Touch M: 50.40deg) and the no-risk group, $t (10) = 2.50, p = .03$(Baseline M: 32.65deg, Touch M: 37.24deg). An independent t-test revealed that the risk group demonstrated more Elbow Flexion during the Touch Task as compared to the no-risk group, $t(22) = 1.87, p = .08m$ (no-risk M: 37.67deg, risk M: 48.78deg). Paired t-tests revealed that within the Baseline Tasks, overall the children demonstrated more Elbow Flexion during the change of direction.
event as compared to the image onset event, t(20) = 2.33, \( p =.03 \). (Baseline IO M: 33.96deg, Baseline CD M: 40.30deg) however further analysis revealed that this held true for the no-risk group only, t (11) =2.34, \( p =.04 \) (Baseline IO M: 30.89deg, Baseline CD M: 39.81deg). A paired t-test revealed a moderately significant difference between the image onset and change of direction events within the Touch Task, with more Flexion seen during change of direction, t= (23), \( p =.07 \) (Touch IO M: 39.19deg, Touch CD M: 45.40deg), and further analysis revealed that this difference was only demonstrated by the risk group, t (9) = 2.37, \( p =.04 \) (Touch IO M: 42.06deg, Touch CD M: 55.50deg). No between Event difference was found for the no-risk group during the Touch Task, however during the Barrier Task, the no-risk group demonstrated more Elbow Flexion during the change of direction event, t(14) = 1.87, \( p =.08 \) (Barrier IO M: 33.77deg, Barrier CD M: 38.62deg). Additionally, within each Event for the Touch and Barrier Tasks, differences were found between risk and no-risk groups. During the Touch change of direction event, the risk group demonstrated more Elbow Flexion than the no-risk group, t (23) = 2.22, \( p =.04 \) (no-risk M: 39.20deg, risk M: 55.50deg) and this was further demonstrated to be related to the older risk group, t (10) = 1.96, \( p =.08 \) (old no-risk M: 34.59deg, old risk M: 59.31deg). For the Barrier Task, it was during image onset that the risk group demonstrated more Elbow Flexion as compared to the no-risk group, t(23) = 2.12, \( p =.05 \) (no-risk M: 33.77deg, risk M: 46.63deg), and this was further revealed to be related to the young no-risk group, t(11) = 1.92, \( p =.08 \) (young no-risk M: 37.08deg, young risk M: 54.75deg).
Figure 3. Differences in Elbow Flexion Strategy between Touch and Barrier Tasks during Image Onset and Change of Direction: Risk.
These results illuminate the differential strategies that were used across Tasks and Events between the no-risk and risk groups of participants. As compared to the Baseline Task, all of the participants had more Elbow Flexion during the Touch Task. This appears to reflect an elevated state during this task, perhaps related to the anticipation of the stimulus (image onset) and related perturbation of having to change direction. Within this task, however, only the risk group demonstrated more Elbow Flexion during the change of direction event than during image onset, indicating that they also utilized this balance strategy to compensate for the actual perturbation of having to change direction. This is different than what is seen in the Barrier Task. For the Barrier Task, the no-risk group utilizes additional Elbow Flexion when changing direction, whereas the risk group does not. In fact, the risk group uses more Elbow Flexion during image onset as compared to what they utilize when changing direction, indicating they pre-set their arm elevation to a greater degree than they actually require for the perturbation.

Trunk Deviation. The absolute degree of Trunk Deviation from upright, defined by the vector between the sacrum and C7 and the horizontal angle (see Figure 1b.), was calculated during change of direction of the Touch and Barrier Task types. This measure reflects a reactive compensatory balance response to the perturbation of changing direction, and is numerically reported in a unit of degrees, in which a larger number represents more trunk deviation from midline. Trunk Deviation was analyzed with a 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Touch and Barrier) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. A significant between subjects effect was found for Risk, F (1, 19) = 5.522, p=.03 (no risk M: 2.95
deg, risk M: 4.32 deg). Although a Task x Risk interaction did not reach statistical significance, it appears that the risk group demonstrated more Trunk Deviation during the Barrier task as compared to the Touch task (see Figure 4).
Figure 4. Difference in Trunk Deviation Strategy between Touch and Barrier Tasks: Risk
Jerk. It was hypothesized that the participants in the risk group would demonstrate greater amount of Jerk than those in the no-risk group, specifically as related to the Events of image onset and change of direction during the Barrier Task. It was also hypothesized that for both the Touch and Barrier Tasks, the younger children would demonstrate more Jerk than the older children. This data set presented with a positively skewed distribution, so a log transformation (10 log) was applied.

The magnitude of Jerk was analyzed using a 2 x 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Touch and Barrier) x Event (image onset and change of direction) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. Although the analyses were run using the transformed data, the raw data means, reflecting a unit of meters/second$^3$, are reported for ease of interpretation, with higher numbers reflecting more Jerk. A marginally significant Task by Event by Age three-way interaction was found, $F(1,20) = 3.27$, $p=.09$ (young Touch IO M: $275.98 \text{ m/s}^3$, young Touch CD M: $347.11 \text{ m/s}^3$, young Barrier IO M: $208.10 \text{ m/s}^3$ young Barrier CD M: $300.70 \text{ m/s}^3$, old Touch IO M: $325.64 \text{ m/s}^3$, old Touch CD M: $135.35 \text{ m/s}^3$, old Barrier IO M: $333.23 \text{ m/s}^3$, old Barrier CD M: $156.23 \text{ m/s}^3$), and this was qualified by a significant four-way Task by Event by Age by Risk interaction, $F (1,20) = 4.63$, $p=.04$ (young no-risk Touch IO M: $127.95 \text{ m/s}^3$, young risk Touch IO M: $609.06 \text{ m/s}^3$, young no-risk Touch CD M: $234.95 \text{ m/s}^3$, young risk Touch CD M: $599.46 \text{ m/s}^3$, young no-risk Barrier IO M: $108.47 \text{ m/s}^3$, young risk Barrier IO M: $432.36 \text{ m/s}^3$, young no-risk Barrier CD M: $394.94 \text{ m/s}^3$, young risk Barrier CD M: $88.65 \text{ m/s}^3$, old no-risk Touch IO M: $388.61 \text{ m/s}^3$, old risk Touch IO M: $262.68 \text{ m/s}^3$, old no-risk Touch CD M: $134.31 \text{ m/s}^3$, old risk Touch CD M: $136.21 \text{ m/s}^3$, old no-risk Barrier IO M: $437.46 \text{ m/s}^3$ old risk Barrier IO M: $437.46 \text{ m/s}^3$
228.97 m/s$^3$, old no-risk Barrier CD M: 83.53 m/s$^3$, old risk Barrier CD M: 228.94 m/s$^3$). In order to identify the locus of this four-way interaction, separate post hoc t-tests were analyzed. An independent t-test revealed a moderately significant difference in Jerk at image onset between Risk groups, with the risk group demonstrating more Jerk than the no-risk group (no-risk M: 236.14 m/s$^3$, risk M: 355.77 m/s$^3$), $t(23) = -1.82, p = .08$. A paired t-test revealed that the older group of children demonstrated more Jerk during image onset as compared to change of direction during the Touch Task, $t(10) = 2.03, p = .07$ (Touch IO M: 332.89 m/s$^3$, Touch CD M: 135.35 m/s$^3$). Additionally, an independent t-test revealed that the older risk group demonstrated more Jerk during the change of direction event in the Barrier Task as compared to the older no-risk group, $t(10) = 2.34, p = .04$ (old no-risk M: 83.53 m/s$^3$, old risk M: 228.94 m/s$^3$). An independent t-test revealed that the young risk group demonstrated more Jerk during the image onset event in the Touch Task as compared to the young no-risk group, $t(11) = -1.89, p = .09$ (young no-risk M: 127.95 m/s$^3$, young risk M: 609.06 m/s$^3$). During the image onset event of the Touch Task, the older children had more Jerk than the younger, but the young risk group demonstrated more Jerk than the young no-risk group. During the Barrier Task, the older risk group demonstrated more Jerk at change of direction.

Implementation Strategies in Concert with Change of Direction Adjustments.

Additional analyses were run to assess other strategies that were potentially used by the participants between image onset and change of direction. It is possible that some participants waited an extended period before making any adjustments, and this could potentially have affected their attempt to change direction. The first strategy relates to the
spatial component, and the Distance that the participant traversed from the time of the appearance of the target stimulus until they changed direction. The unit of this variable is meter (m), with a larger number indicating a longer distance. Due to the nature of the environmental constraints of the tasks, it was hypothesized that this Distance would differ between Touch and Barrier Task types between the Age and Risk groups.

Distance walked between image onset and change of direction was analyzed with a 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Touch and Barrier) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. For this analysis participant height was added as a covariate to ensure that this did not interfere as a confound, similar to what was done for the Velocity analyses. This analysis revealed a statistically significant two way interaction between Task and Age, F(1, 20) = 4.85, p=.04 (touch: young M: 1.76 m, old M: 1.43 m, barrier: young M: .49 m, old M: .89 m) and a statistically significant two way interaction between Task and Risk, F (1,20)= 7.923, p=.01 (touch: no-risk M: 1.41 m, risk M: 1.77 m, barrier: no-risk M: .81 m, risk M: .58 m). In order to identify the locus of the interaction between Task and Age, separate post-hoc t-tests were analyzed. Paired t-tests revealed that the younger children walked a lesser Distance prior to changing direction during the Barrier Task as compared to the Touch Task, t(12) = 5.48, p<.001 (Touch M: 1.60m, Barrier M: .59m), and the older children demonstrated the same pattern, t(11)= 5.30, p<.001 (Touch M: 1.54m, Barrier M: .87m). An independent t-test revealed a statistically significant difference in Distance walked between Age groups during the Barrier Task, with the younger group walking a lesser Distance before changing direction than the older group, t(23) = -3.17, p<.01 (young M: .59m, old M:.87m). While all children had a smaller Distance walked prior to
change of direction during the Barrier Task, the younger group appeared to rely on their perception of the available distance more than the older group.

In order to identify the locus of the interaction between Task and Risk, separate post-hoc t-tests were analyzed. Paired t-tests revealed that both the no-risk and risk groups of children walked further Distance until change of direction during the Touch Task as compared to the Barrier Task, no-risk $t(14) = 4.16$, $p=.001$ (Touch M: 1.43m, Barrier M: .79m), risk $t(9) = 8.91$, $p<.001$ (Touch M: 1.78m, Barrier M: .62m).

Independent t-tests revealed that during the Touch Task, the risk group walked a further Distance until change of direction as compared to the no risk group, $t(23) = -2.00$, $p=.06$ (no-risk M: 1.43m, risk M: 1.78m). The pattern of response for the no-risk group looks like the response seen with the older group, and the pattern of response seen with the risk group looks similar to that of the younger participants, with possible reliance on their perception of the available distance (see Figure 5).
Figure 5. Difference in Distance Covered between Image Onset and Change of Direction: Task x Risk
The time analogue of the distance covered variable, is the temporal variable of reaction time, which was defined as the period of time between image onset and change of direction. Reaction Time was analyzed with a 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Touch and Barrier) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. For this analysis participant height was added as a covariate to ensure that this did not interfere as a confound, similar to what was done for the Velocity analyses. Means reported reflect a unit of seconds (s).

A significant two way interaction was found for Task and Age, F (1, 20) = 13.497, p<.01 (Touch: younger M: 2.08s, older M: .92s, barrier: younger M: .51s, older M: .93s). In order to identify the locus of this interaction, separate post-hoc analyses were performed. Paired t-tests revealed that the young group had a faster reaction time for the Barrier Task as compared to the Touch Task, t(12)=3.96, p<.01 (Touch M: 1.71s, Barrier M: .59s), and that this was true for the older group as well, t(11)=2.59, p=.03 (Touch M: 1.26s, Barrier M: 1.02s). Independent t-tests revealed that during the Touch Task, the older group had a faster Reaction Time than the younger group, t (14.61) = 1.91, p=.08m (Touch young M: 1.71s, Touch old M: 1.26s), but during the Barrier Task the younger children had a faster Reaction Time than the older group, t (-2.13) =13.24, p=.05 (Barrier young M: .59s, Barrier old M: 1.02s).

A significant two way interaction was also found for Task and Risk, F (1, 20) = 7.829, p=.01 (touch: no-risk M: 1.35, risk M: 1.65, barrier: no-risk M: .95, risk M: .49). In order to identify the locus of this interaction separate post-hoc analyses were conducted. A paired t-test revealed that the no-risk group had a faster reaction time for the Barrier Task than the Touch Task, t(14) = 2.52, p=.03 (Touch no-risk M: 1.39s,
Barrier no-risk M: .92s), and that this was true for the risk group as well, t(9) = 3.25, p=.01(Touch risk M: 1.66s, Barrier risk M: .61s).

**EMG Analysis.** The EMG data, reported as microvolts, was filtered using a combination of low pass and high pass filters, allowing for frequencies between 10Hz (to minimize movement artifact) and 450Hz (to allow full frequency spectrum of muscle firing) (See Standards for Reporting EMG Data, Website of International Society of Electrophysiology and Kinesiology http://www.isek-online.org/standards_emg.html). After filtering, the signal was rectified (converting negative values into positive values) and normalized relative to the maximum value collected during each walking trial. This allowed the entire EMG to be represented as a percentage of the maximum contraction. By normalizing, it is possible to compare not only the muscle activity between muscle groups in a single participant, but also between the participants. The data reported below represent the root mean square (RMS) of the amplitude, indicating that the raw EMG signal has been smoothed, filtered and rectified across a specific time interval. The RMS is an expression of magnitude, reflecting both amplitude (strength) and duration (length) of the muscle contraction.

The EMG data was available for a subset of 12 out of the 26 participants who engaged in the walking tasks. This reduced number of participants is attributable to the occasional lack of hardware availability, occasional software error in integrating the EMG with the kinematic data collection, and, in one case, participant reluctance to don the leads. In order to assess if a valid signal was collected from the EMG leads, a power spectrum analysis was run for each trial to be included in the analysis. This power
spectrum analysis provided an array of signal frequencies obtained during the data collection, and was visually inspected for a range of frequencies with discrete peaks in the distribution, as an indicator of validity.

In an attempt to provide information about strategies employed by the participants distal from the arms and trunk, analysis of ankle muscle activation was chosen at this time. Power spectrum analysis revealed that the signal from the lead used for one of the left ankle muscles was consistently invalid, indicting hardware malfunction. Of the 12 participants with EMG data, 9 had valid EMG signals for both muscle groups across the right ankle (right anterior tibialis and right gastrocnemius), and these were further analyzed for differences between tasks and between groups (see Table 4 for subset participant breakdown). Due to the small number of participants included in this analysis, only an initial exploration of the EMG data was undertaken with a measure of total ankle effort (sum RMS of right anterior tibialis and gastrocnemius muscle groups for each participant) for the first barrier trial. Time periods sampled and compared include: Barrier trial :1. Time period between first step in trial until onset of target stimulus (Pre-stimulus); and 2. Time period between onset of target stimulus to change of direction (Post-stimulus).
Table 4. Subset Participant Breakdown

<table>
<thead>
<tr>
<th></th>
<th>No-Risk</th>
<th>Risk</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>n=3</td>
<td>n=0</td>
<td>3</td>
</tr>
<tr>
<td>Old</td>
<td>n=3</td>
<td>n=3</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>n=6</td>
<td>n=3</td>
<td>9</td>
</tr>
</tbody>
</table>
Predictions included: 1) Participants will demonstrate more ankle activity during post-stimulus as compared to pre-stimulus in the barrier trial; 2) There will be age group differences in ankle muscle activity during pre- and post-stimulus of the barrier trial and 3) There will be risk group differences in ankle muscle activity during pre- and post-stimulus of the barrier trial.

The Total Ankle Effort was assessed with a 2 x 2 x 2 Age (young and old) x Risk (no-risk and risk) x Time (pre-stimulus and post-stimulus) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS. This analysis revealed a significant main effect for Time, $F(1,6) = 10.026$, $p=.02$, with more Total Ankle Effort observed during post-stimulus as compared to pre-stimulus across both Age and Risk groups (Pre-stimulus M: 117.32 uv, Post-stimulus M: 150.70 uv). The number of participants in each of the Risk groups was not sufficient for a significant interaction between Risk and Time, however a non-significant trend, $F(1,6) = 2.05$, $p=.20$ was noted. Since the prediction related to differences in ankle strategy and Risk was considered an important one for this study, separate t-tests were conducted to further investigate this relationship. A paired t-test revealed that during the Barrier Task the risk group exerted more Total Ankle Effort post-stimulus as compared to during pre-stimulus, $t(2) =-10.52$, $p=.01$ (pre-stimulus M: 115.22uv, post-stimulus M: 171.81uv). The risk group of children utilized an ankle strategy when responding to the stimulus and the no-risk group did not require this adjustment (See Figure 6).
Figure 6. Total Ankle Effort Pre and Post Stimulus During the Barrier Task: Risk
Dual Task: Attention (EPrime data)

Walking with Directionality Task. Upon analysis of the EPrime generated response time data associated with the directionality task, many inconsistencies were noted, with response times recorded that exceeded the expected range of 3-8 seconds for task completion. Video analysis revealed that during this task there was malfunction of the software, in that even when the end of the task was triggered by the experimenter, the time was not recorded as such. Experimenter error was noted on a few isolated trials as well, with failure to trigger the end of the task. Analysis of the attention task related to this part of the walking assessment was therefore not performed.

Dual Attention and Walking Task A: Voice Response. Upon analysis of the response time data associated with the voice response dual task, many inconsistencies were noted with response times recorded that were either much shorter or much longer than the expected range of 3-8 seconds. These inconsistencies are attributed to design issues related to coordination of hardware and software, and software malfunction issues. The first 12 participants’ voice responses to this task were recorded by the experimenter pressing a designated key that indicated a response. The following 14 participants’ voice responses were recorded by a wireless microphone that was integrated with the software program to indicate a response. On many occasions the wireless microphone was too sensitive and registered the sound of a footfall as a response, which explains the very short response times. On other occasions even when the experimenter pressed the key to indicate a verbal response, the end of task was not recorded, accounting for the longer
than expected trials. Considering the many inconsistencies of this dataset, no analyses were performed for this task.

**Dual Tasks B and C: Touch and Barrier.** Video-based behavioral analysis of the touch trials revealed 11 invalid trials (out of 104 total trials), one each for 9 participants, and two trials for 1 participant (related to experimenter error, and on one occasion participant behavior). Video-based behavioral analysis of the barrier trials revealed 12 invalid trials (out of 104 total trials), one each for 6 participants, and two invalid trials each for 3 participants (related to experimenter error, and participant behavior). These data points were imputed with values representing the individual’s average performance for that task type. All response time/task completion data, as defined by amount of time calculated by EPrime between start of trial and end of trial (triggered when participant touched target stimulus on screen at end of walkway) for the touch and barrier tasks were transformed using a McCall’s T-test transformation (= (zscore x 10) + 50). Although analyses were run with transformed data, the means reported relate to the raw data for ease of interpretation with an associated unit of milliseconds (ms).

Preliminary analyses of Trial Type (attention shifting and attention disengagement) and Side (right and left) were non-significant, and were therefore removed from subsequent analyses. The task Completion Time was analyzed using a 2 x 2 x 2 (Age (young and old) x Risk (no-risk and risk) x Task (Touch and Barrier) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS, n=26. A marginally significant main effect for Age was found, F (1, 22) = 3.72, p<.07,
indicating that the older children completed the tasks faster than the younger children (young M: 3801.23ms, old M: 3138.31ms). A marginally significant two way interaction was found for Age and Risk, F (1, 22) = 3.624, p=.07m (young no-risk M: 4013.56ms, young risk M: 3323.50ms, old no-risk M: 2988.67ms, old risk M: 3266.57ms). In order to identify the locus of this interaction separate post-hoc analyses were performed. An independent t-test revealed that during the Touch Task and within the no-risk group the older children had faster completion times as compared to the younger children, t(13) =3.31, p=.01 (young M: 4257.33ms old M: 2683.50ms). This indicates that during the Touch Task there was a developmental improvement in completion time for the children in the non-risk group, but no developmental improvement was seen for the children in the risk group. (See Figure 7; comparison to Figure 2b should be noted and will be discussed in more detail in discussion section).
Figure 7. Task Completion Touch and Barrier Tasks: Age x Risk
III.5 Integration of Attention Data between Computerized Attention Task and Dual Tasks

The Reaction/Completion Time (as calculated by EPrime) across the computer-based and walking dual tasks was analyzed to investigate if across tasks and environments (sitting/computer-based and walking/dual task based) there would be consistency of performance between groups. Reaction/Completion Time was analyzed with a 2 x 2 x 4 Age (young and old) x Risk (no-risk and risk) x Task (Computer Voice, Computer Button, Dual Touch, Dual Barrier) mixed design repeated measures GLM with Huynh Feldt adjustment in SPSS, N=25. The analysis was run using the transformed data (as previously described), and since the raw scores for the Dual Tasks are much higher than those for the Computer Tasks, the transformed means are reported. A significant main effect for Age was found, F (1,21) = 5.92, p=.02 with the older children demonstrating faster reaction/completion times than the younger children across all task types (young M: 52.68, old M: 47.29; See Figure 8).

A marginally significant two way interaction for Task and Risk was found F (3,63) = 2.26, p=.09 (Button: no-risk M: 47.25 risk M: 53.74, Voice: no-risk M: 52.04 risk M: 47.79, Touch: no-risk M: 49.54, risk M: 48.41, Barrier: no-risk M: 50.98, risk M: 46.57). In order to identify the locus of this interaction separate post-hoc analyses were run. A paired t-test revealed that the risk group was faster with the Voice Response Task as compared to the Button Press Task, t(10) = 2.41, p=.04 (Voice M: 48.28, Button Press M: 52.66; See Figure 9). This finding is contrary to the initial hypotheses, as it was expected that the risk group would be slower for all task types.
Figure 8. Integrated Task Analysis: Age
Figure 9. Integrated Task Analysis: Risk
III.6 Incorporation of Neonatal, Infant, and Toddler Data

The reported findings indicate that children at risk of DCD demonstrate differential abilities to regulate their motor performance when the task complexity increases. In line with the driving hypotheses of this study that there is an underlying deficit in the attention regulation systems in these children that manifests itself in diminished motor performance, it was postulated that these children would have behaved differentially when tested for other behaviors requiring attention regulation in their neonatal and toddler stages, and that specifically, differences would be found in motor behavior performance at these younger ages. Pairwise Pearson correlation analyses were performed between the categorical risk variable (risk/no risk) and select variables related to the participants’ qualitative performance during the most difficult experimental task in this study, the barrier task, (including the full trial average Velocity, and Jerk, Trunk Deviation, and Elbow Flexion during change of direction), and 1. Physiological markers of neonatal brain insult; 2. An arousal modulation of attention (looking) task, tested at birth, one month, and 4-months of age; 3. The Rapid Neonatal Neurobehavioral Assessment at birth and 1-month 4. The mental and motor scales of the Bayley Scales of Infant Development, Second Edition, tested at every 3-months between the ages of 4-months and 25-months.

The first set of archival data that was examined included the physiological markers of neonatal insult (auditory brainstem response, and cranial ultrasound; see Gardner, Karmel and Flory, 2003) and the Risk groupings and performance on the experimental tasks from this current study. It was hypothesized that there would be a positive correlation between degree of neurological insult and risk classification. Pairwise
Pearson correlations revealed no relationship between these functional and structural measures of neonatal brain insult and the risk groupings or performance variables.

The arousal modulated attention looking task has previously been described in this paper. Neonates are shown flashing lights at varied frequencies (Hz), both pre- and post-feeding. At young ages (0 and 1 month) infants who did not sustain brain insult and who have not been exposed to teratogens, such as cocaine, prefer to look at higher rates of stimulation when they are less aroused (post-feeding), and at lower rates of stimulation when they are more aroused (pre-feeding, or with additional pre-stimulation) reflective of modulation of arousal that is dependent on both exogenous and endogenous conditions, and which is mediated by brainstem function (Gardner, Karmel, & Magnano, 1992). However, at 4 months this is no longer seen in healthy infants, as along with increased cortical connectivity, their attentional systems are no longer tethered to their internal states of arousal. At young ages, infants who sustained early brain insult tend to seek less stimulation regardless of their internal state of arousal, and cocaine exposed infants tend to seek more stimulation regardless of their internal state of arousal. Additionally, babies with history of insult tend not to transition to the mature regulation state at 4-months, rather they continue to demonstrate a preference for greater or lesser amounts of stimulation (see Gardner & Karmel, 1995). A pairwise Pearson correlation revealed a negative relationship between the Risk grouping variable and the participants’ earlier performance on this test at newborn age ($r = -.568$, $p = .003$, $N = 25$), in that those in the risk group were more likely to demonstrate a negative slope post-feeding, or they preferred to look at slower rates of stimulation post feeding, similar to what is seen in the population of infants post brain injury. Additionally, a positive correlation was found between Jerk
and the participants’ performance on the looking task at 4 months (r=.494, p=.017, N=23), in that the children who demonstrated more Jerk during change of direction in the barrier task, did not demonstrate the expected maturation of no preference to stimulation rate at the age of 4 months. As was previously noted, in this current study it was the older risk group of children who demonstrated more Jerk during the change of direction event of the Barrier Task. These results are consistent with what is being reported with other neurodevelopmental disabilities, such as autism spectrum disorders (Karmel, Gardner, Swenson, Meade, et al., 2010), and indicate that despite not demonstrating a difference in physiological measures of brain insult as neonates, when they were 1- and 4-months-of-age the at risk of DCD group behaved similar to infants who had sustained a brain insult.

The Rapid Neonatal Neurobehavioral Assessment (RNNA: (Gardner et al., 1990; 2001)) assesses a number of behaviors seen in neonates, including visual and auditory attention, extremity muscle tone, head and trunk muscle tone, organization of spontaneous movements, and state control. This test is scored by providing individual item scores for each behavior observed, and a composite score related to number and severity of abnormalities is assigned as well. It was hypothesized that there would be a positive correlation between the composite scores at 0- and 1-month-of-age and the participants’ current classification of Risk. It was hypothesized that participants in the risk group would have previously demonstrated specific abnormalities in the items related to attention and motor organization. A pairwise Pearson correlation analysis found a positive relationship between risk classification and composite score on the RNNA at the newborn age (r=.58, p=.002, N=26), indicating that the at risk of DCD group in the current study had more abnormalities on this behavioral assessment than the no-risk
group. Additionally, performance on the individual head control and extremity tone items at both 0- and 1-month correlated with the various qualitative measures of performance on the barrier task, indicating that early measures of head control related to differential balance responses at older ages. Specifically, at the newborn age, greater difficulty with head control and muscle tone in the arms related to a greater amount of Trunk Deviation at change of direction during the Barrier Task (head control: $r=.477$, $p=.018$, $N=24$; arm tone: $r=.428$, $p=.037$, $N=24$), and at the one month age, greater difficulty with head control related to greater amount of Trunk Deviation ($r=.425$, $p=.038$, $N=24$).

The Bayley Scales of Infant Development, Second Edition (Bayley, 1993) is subdivided into three performance scales, including the mental, motor and behavior scales. As young infants and toddlers the participants of this current study had previously been tested on these scales every three months between the ages of 4-months and 25-months. It has previously been demonstrated that infants who have not sustained neonatal brain insult have a stable index score on the mental and motor scales over time, but infants who have sustained brain insult show a decrement of performance over time, differentiating from their non-injured peers as they get older (Gardner, Karmel, Freedland, et al., 2006). A plot of the mean scores on the mental and motor scales at each age of administration for the risk and no-risk groups depicts how the children at risk of DCD in this study had a similar trend of decreasing performance to the below average range at 19-months (See Figure 8).
Figure 10. Mean Scores on Motor and Mental Scales of BSID-2 for risk and non-risk groups. Note: Dark line at 100 mark indicates average performance; Arrows indicate most significant change in performance trajectory for risk group.
In order to assess if the risk of DCD and no-risk groups differentiated from one another at the last time of administration, a Pearson correlation analysis was performed using the index score obtained when the participants were between 19 and 25 months (last obtained scale score used in analysis). Using these variables, a negative correlation was found between the categorical Risk grouping variable and performance on the mental scale ($r = -.415, p=.035, N=24$), indicating that the children in the risk group performed worse on the mental scale at the older ages as compared to the participants in the no-risk group. No relationship was found between the risk grouping and the motor scale. No relationship was found between performance on the Bayley scales and the qualitative performance variables related to the experimental task.
CHAPTER IV. DISCUSSION

IV.1 Computerized Attention Task Discussion

The goal of the computerized attention task was to provide a baseline measure of how children at risk of DCD differentially perform on an attention task across age groups both when it is not coupled with a gross motor task (voice response mode) and when it is coupled with a gross motor task (button press response mode). As previously noted, it might have been better to have implemented a single button press task in place of the voice response task for consistency of mode of response, however transformation of the data enabled comparison between the tasks.

Although both age groups performed the tasks with equal accuracy, the older children performed faster than the younger children across task types, providing ecological validity to the task and indicating that the task was appropriate at each age. The risk group demonstrated differential performance on the voice response task as compared to the button press task. During the voice response task, the younger children at risk had a faster response time as compared to the non-risk group, but while the no-risk group demonstrated an expected developmental trend of improved response time with age, this was not seen with the risk group. Perhaps children with DCD have longstanding difficulty integrating their motor and attention systems, and they adaptively become more skilled with other systems, but maximize their abilities on this at an early age, with little developmental improvement noted. It is important to consider that for this measure the young risk children appeared to be performing in a superior manner as compared to the young no-risk children, and if this is true in other tasks, it may explain why it has been difficult to identify younger children at risk of this disorder.
Previous reports indicate that children with DCD have increased difficulty during attention task trials when the central cue persists requiring them to first disengage from the central cue prior to shifting their attention to the target stimulus (Wilmut et al., 2007). In this study we did not find any statistically significant differences for trial type between the no-risk and risk group. It is possible that the difference in magnitude of this effect between studies relates to the dependent variables used. Wilmut and colleagues (2007) measured saccade latency, as a direct measure of attentional focus, and in this study the reaction time of a voice or button press mode following a shift in attentional focus was used as the dependent variable. It is possible that the more conscious effort of the response modes used in this study had associated greater amounts of variability.

IV.2 Single Walking Task Discussion

By the ages of 3-8 years, walking is a well-practiced motor skill, and while there continues to be slight developmental refinements of some aspects of gait between these ages, (e.g. narrowing of the base of support, increased arm swing; see Shumway-Cook and Woollacott, 2012 chapter 13), overall the qualitative aspects of gait are well established. In this study the older children demonstrated greater variability of velocity when walking as compared to the younger group, indicating adjustment of speed during the trial. No other age differences were found. No significant difference between the risk and no-risk groups was found.
IV.3 Dual Walking Task Discussion

The directionality task was developed as a baseline measure to investigate how children adjusted to changing direction when they were able to plan the entire trajectory at the outset of the trial, and were not reliant on information provided on-line while walking. It is the touch and barrier tasks then that are most informative of the larger questions that this thesis set out to investigate, with much of the analyses and discussion focusing on these tasks. During the touch and barrier dual tasks we see differences across age groups that reflect differences in balance, planning and perception of task. For example, the older group of children demonstrates more jerk during image onset as compared to change of direction during the touch task. The younger children plan for the available time and space in a task specific way while the older children use a general mid-way approach to handle varied situations. In order to be successful using this generalized approach, the older children tend to vary their speed to accommodate for their position.

Separate from these developmental results, as compared to the walking only task, in which no significant differences were found between risk and no risk groups, the risk groups differentially planned and reacted to the balance perturbations associated with changing direction across ages and across the touch and barrier tasks. Similar to the younger children, the participants at risk of DCD seemed to rely on their perceptual feedback of the environment when planning the time and distance needed to change direction, allowing for a longer distance to be traversed for the touch task and responding relatively quickly during the barrier task. This reliance on visual feedback has previously been described in this population. Deconinck and colleagues (2006) found that when
children with DCD walked with ambient light, their velocity was the same as their typically developing peers, but when the lights were dimmed, only the children with DCD slowed down, indicating a greater reliance on visual information for walking than in typically developing children.

Both the no-risk and risk groups of children demonstrated a heightened state during the touch task as compared to the baseline task. The children in the no-risk group use a steady amount of elbow flexion strategy throughout the touch task, and in the barrier task demonstrated an increase of elbow flexion when changing direction. The children at risk differentially used this strategy. For the touch task, they utilized this strategy in response to the stimulus, when changing direction. However, the barrier task seemed to present a different level of challenge for them, as they pre-set an elevated arm position in anticipation of the stimulus presentation, only to lower their arms during change of direction. For the risk children the touch task is a challenging motor task, but one that they expect to be able to compensate for. The barrier task is much more daunting to them, and they pre-set with elbow flexion.

Understanding how the children in the risk group differentially utilized elbow strategies for the events associated with the touch and barrier tasks may explain why no differences were found in the amount of elbow flexion between the directionality (baseline change of direction task) and the barrier (most difficult change of direction task) tasks. During the directionality task, they didn’t require a balance response as they did not experience much of a perturbation, and with the barrier task, they experienced a much greater perturbation requiring a different level of response all together.
In place of using elbow flexion to compensate for balance perturbations during change of direction in the barrier task, the children at risk of DCD used alternate strategies, including trunk movements. These trunk deviations indicate a larger perturbation requiring a full-bodied response. Similar to the younger children, the perception of difficulty for the barrier task was inflated for the risk group, which led them to pre-set their elbow flexion, and also to respond relatively quickly to change direction. This quick change could have provided a larger perturbation than necessary, resulting in greater trunk deviations.

As compared to the non-risk group of children, the children at risk of DCD had more jerk from the outset (at image onset) of both touch and barrier tasks. Additionally, the risk group of children demonstrates differential amounts of jerk between the events associated with the touch and barrier tasks. During the touch task, the older risk children demonstrated more jerk at image onset as compared to change of direction, and during the barrier task they demonstrated more jerk during change of direction as compared to image onset. This pattern is the opposite from what was seen with utilization of the elbow flexion strategy, and may indicate that when these older risk children are not compensating for balance perturbations with arm elevation, their quality of movement is less smooth. The EMG data related to the total right ankle effort corroborate these findings, as the risk children demonstrated more ankle effort during the change of direction in the barrier tasks as compared to the children in the no-risk group.

In addition to the behaviors analyzed that differentiated between children at risk of DCD and those not at risk of DCD, the data also illuminated variability in behavior that reflects the broad range of normative strategies that children use, and errors that they
make, related to individual differences and not related to developmental coordination disorder. The numerous dual tasks were conceptualized to provide different controls and different levels of difficulty to the walking task. The voice response dual task was intended to serve as the easiest level of the dual tasks. It was posited that this task would illuminate how children were able to respond to an attention task while walking, in a manner that would not require making a decision related to side or execution of a response that would necessitate alteration of the walking trajectory. However, video analysis of this task revealed that in some ways the voice response dual task appeared to be more difficult than the other dual tasks, and the participants seemed to react to it differentially from the other tasks. During the voice dual task, many of the children demonstrated task confusion, requiring them to strategize ways to execute the task in a serial fashion as opposed to blending the components to perform them in parallel. Some children would not walk until they had seen the image and could say ‘dog’ first, some children would start walking for the trial, but at image onset would stop walking to say ‘dog’, with a subset of these participants not resuming to walk the rest of the walkway and some continuing on after saying ‘dog’, and yet others walked until the end of the walkway prior to saying ‘dog’. All of these strategies served to accomplish the same thing, in that they were able to fulfill the task requirements in a serial fashion. A total of 11 participants demonstrated this behavior for a total of 14 occurrences, with no differences found in frequency between age or risk groups.

It is possible that these observed strategies relate to the input-output interference found with incompatible modalities. It has been reported that for visual stimuli a manual response is compatible, and for an auditory stimulus a vocal response is compatible.
When these pairings are not adhered to there is greater dual cost, or task error (see Stelzl and Schubert, 2011). In the voice response dual task a visual stimulus was presented requiring a vocal response (incompatible pairing) and the participants were also asked to continue walking while generating this response, providing additional interference. For the touch and barrier dual tasks, the stimulus was visual, and the response required was manual (walking). Not only is this a compatible response type, but the walking task was integrated into the response and did not add any additional interference. The dependent variables used in this study did not sufficiently account for this apparent task confusion so this task type did not contribute to the overall story. However, this task would be useful for future explorations.

During the directionality, touch, and barrier tasks there were a number of children who started walking in one direction from the start of the trial prior to stimulus presentation, requiring them to make adjustments, such as a side step, at the end of the trial to enable them to touch the dog on the appropriate side. While no difference in frequency between age or risk groups was evident, the number of times that this strategy was employed in each of the task types provides a measure of internal validity to the intended ramping of level of difficulty from the directionality to the touch to the barrier tasks. In the directionality task, 6 of the participants demonstrated this strategy for a total of 8 times, for the touch task, 3 of the participants demonstrated this strategy for a total of 3 times, and for the barrier task only 1 participant demonstrated this strategy for a total of 2 times. This seems to indicate a trend of greater vigilance to respond to the cue related to side of stimulus when greater task constraints were implemented.
During the barrier trial other unique errors were observed including bumping into the barrier, and going around the wrong side of the barrier, with a total of 8 participants demonstrating these errors for a total of 14 occurrences. No difference in frequency of these errors was evident between age and risk groups. It is important to note that all of the strategies and errors described above that are non-differentiating for clinical group are just as important to know about as those that are differentiating for clinical status, to understand what represents normative versus non-normative development.

**IV.4 Dual Task: Completion of Attention Task Discussion**

Similar to the findings related to the computer based attention task, overall for both the touch and barrier tasks, the older children had faster completion times than the younger children. Also in line with what was observed during the voice response computer task, a differential developmental trend as related to task completion time was observed between the no-risk and risk groups and the dual touch and barrier tasks. Whereas the no-risk children demonstrated a developmental improvement (hastening) with task completion time, with the older no-risk children performing faster than the younger no-risk children, this trend was not found with the risk group of children. The young children at risk of DCD don’t demonstrate developmental improvement as they get older.

**IV.5 General Discussion**

The first aim of this research project was to identify stable underlying features of DCD in the context of how deficits in attentional capacity affect motor planning and
coordination of gait across development. This was operationalized by developing a dual task paradigm in which the participants’ abilities would be assessed on a stand-alone attention task, on a stand-alone walking task, and then during dual-tasks with the attention and walking components integrated with one another. The children’s performance on each of the stand-alone tasks could then be compared to their performance on the dual-tasks to identify how the children respond to the increased challenges to their attentional capacity, and which elements of the tasks would suffer an expression of dual cost. Although the sample size in this study (27) was relatively small, and many analyses considering both risk and age had limited power to achieve significant findings, differences for age and risk were illuminated.

An integrated analysis of the transformed reaction/task completion times across the computer and dual tasks revealed a robust age effect that was independent of complexity of environment. Across computer and walking tasks, a consistent developmental increase in speed of response/task completion time was found, providing ecological validity to the task, and indicating that the task was appropriate and of sufficient difficulty across ages. Additionally, because this age effect was established, the effects seen between risk and no-risk groups, independent of this age effect, can be considered meaningful.

Across all of the attention tasks (button press, voice response, touch and barrier), the most salient finding for the risk group, was a consistent difference in developmental trend between the no-risk and risk groups of children. Whereas the older children in the no-risk group demonstrated increased speed of response time or task completion time as compared to the younger children in the no-risk group, this trend was not consistently
found for the risk group. During the computer-based and dual tasks the young children in the risk group tended to demonstrate faster response or task completion time as compared to the young no-risk children, but they did not improve their performance as they got older. In fact, at the older ages, the no-risk group’s response time was faster than for the children at risk. It is possible that the fast response time seen early on reflects decreased modulation between task demands and response, with a less thought out and planned response. At the younger ages this presents as an advantage as compared to their no-risk peers, but at older ages it becomes apparent that this poorly modulated approach persists. A ‘respond as fast as possible’ approach does not provide opportunities for learning over time about what worked and what didn’t work. The children in the no-risk group learned how to succeed at these types of tasks, but with limited opportunity for learning on the part of the risk group, their performance stagnated.

An analysis of reaction/task completion time across the tasks between the no-risk and risk groups revealed that the button press task was unique from the others, and statistically different from the computer voice response task. The button press task was the only task during which the children at risk of DCD were slower than their no-risk peers. The button press task was a very fast forced choice task that required consideration of side when executing a response, as well as inhibition to prevent oneself from pressing the wrong button, and the difficulty of integrating all of these demands appeared to affect the risk group. Although the walking dual tasks also required a side related choice, there was relatively more time for the participant to respond, and there were other motor adjustments that could be made to compensate for their difficulty. For these tasks the risk children were able to achieve task completion at a comparable speed as their no-risk
peers, but their qualitative performance in the motor domain was compromised. In essence, it appears that the voice response computer task was the only true stand-alone attention task, and the button press response task was a dual task. During this very fast task with a simple gross motor response, the behavioral ramification was seen with response time. With the dual walking tasks, the ramifications were with motor/postural adjustments, with greater deviations seen during the barrier task which inherently provided greater time-related demands, as change of direction had to be completed before they bumped into the barrier.

The motor adaptations during the touch and barrier tasks seen in the risk group were reflective of the increased demands with which each of the tasks presented. As compared to the children in the no-risk group, the children at risk of DCD differentially planned the timing of their trajectories for each of the task types, differentially pre-set their postures as the motor tasks became more difficult (i.e. elbow flexion), and they differentially responded to balance perturbations as the motor tasks became more difficult (i.e. elbow flexion, trunk deviation, jerk and total ankle effort). During the most challenging dual task, the barrier task, the children at risk of DCD had more elbow flexion pre-setting, and they responded to the stimulus faster, with more jerk, more trunk deviation and greater ankle effort as compared to the children in the no-risk group. In some instances, the risk group demonstrated similar planning and adjustments as the younger children. For example, walking for relatively shorter distance between image onset and change of direction following stimulus presentation in the barrier task is a similar strategy as was used by the younger participants (across risk groups). For older children at risk to continue using this strategy, it suggests that they have not learned
alternate and more effective strategies to plan their movement in different environments, and, at these older ages, they demonstrated a more effortful and qualitatively messy performance.

These findings that suggest more difficulty learning with experience and more effortful performance are consistent with the literature. It has previously been reported that while achieving a similar level of accuracy or success at tasks, children with DCD demonstrate more variability between trials (e.g. Cantin et al., 2007), more behavioral jerk (Pangelinan, et al., 2013), and overall exert greater amounts of effort (Zwicker et al., 2010) as compared to their typically developing peers. This study supports assertions that have been repeated in the literature since originally posited in 1970 by Dare and Gordon, that children with DCD have difficulty with automatization of skill learning, and that there is a deficit in their perceptual system. Our findings suggest that decreased automatization may result in continued reliance on perceptual information leading to greater postural perturbations and differential quality of movement as compared to their peers.

In other research studies related to Developmental Coordination Disorder, the participants had already received a diagnosis of DCD, indicating that a concern had been expressed, either by a teacher or a parent, and the child had subsequently gone through the diagnostic testing process. Prior to this current study, none of the participants had a diagnosis of DCD. Rather, we hypothesized that since a high percentage of children who require stay in the NICU as neonates present with motor dysfunction later on (see Williams, Lee & Anderson 2009 and Hemgren & Persson, 2004), if a group of children from this population was sampled it would be likely that a percentage of them would
present with the criterion for DCD. Using the MABC-2 to test motor proficiency, this is in fact what was found; out of 27 children tested, 11 (41%) met the first criterion for DCD, with a score at or less than the 16th percentile. Of those who scored at or below the 16th percentile, 7 were in the age range at which DCD is currently diagnosed, 6-8-years-old. The question is, why hadn’t these children’s low motor performance abilities been previously identified? One possibility relates to the second criterion of diagnosing DCD, in that there needs to be an associated academic or functional consequence of the poor motor performance. This is typically quantified using a parent or teacher-report questionnaire, such as the DCDQ. By applying the criterion provided by the questionnaire’s manual none of the 11 children met the threshold to be classified as being at risk of DCD. However, when the raw scores on the questionnaires were compared to the children’s performance on the MABC-2, a positive correlation was found, indicating that more concern reported by the parent related to lower performance on the standardized motor proficiency test.

It could be that children who perform on the lower end of the motor performance spectrum, but for whom the functional ramification is not significant enough, should not qualify for a diagnosis of DCD. However, it is also possible that the questionnaires currently used don’t provide a sensitive enough cutoff to indicate risk. Considering that parents are poor reporters of children’s activity (e.g., Basterfield et al., 2008), relying on a specific threshold of parental report may result in rendering children who are having significant motor deficiency without classification or services. If the former is in fact true, then performance on experimental tasks that do not include test items similar to those found on standardized motor tests, but that challenge other areas of difficulty found
in this population, should not differentiate between groups formed based on the standardized test alone. In this study, we found that, in fact, performance on the experimental tasks was differentiated by risk classification, indicating that the latter is true; the questionnaires are either not sensitive enough to indicate risk, or parents or teachers are not sufficiently cued into motor deficits at these early ages.

An insufficient awareness of motor deficits may be especially relevant when they present in isolation of other attention and learning problems. Considering that there is at least a 50% rate of co-occurrence between DCD and other developmental disabilities, such as ADHD, RD and ASD, it is possible that when DCD presents alone, there is less concern, with resultant under-testing. It should be noted that the old criterion set in the DSM-IV made it difficult to diagnose DCD when a child presented with an intellectual disability or with an autism spectrum disorder, as those diagnoses took precedence. Consistent with the literature, in our sample of children, we found a negative correlation between the scores on the cognitive inattention and ADHD subscales of the Conners’ and performance on the MABC-2, in that greater deficit in attention was related to decreased performance on the motor tasks. However, only one of the children in our sample had a score on the Conners’ that suggested that he may be in the clinical range for ADHD, and in fact, this child had a diagnosis of ADHD. It is possible that motor deficits in isolation are not sufficiently concerning to parents and teachers when the children are at these young ages, with subsequent under-identification.

This current study adds to the current knowledge base, as we have demonstrated that children at risk of DCD present with differential performance on tasks that are independent of the tests used to diagnose this disorder and that are more ecologically
valid than the standardized tests used, and that differences can be seen between risk and no-risk groups of children at earlier ages than children are currently diagnosed. Additionally, our exploratory study comparing the findings from the current experimental study and data related to measurements taken when the participants were young infants and toddlers, suggests that differences between children at risk of DCD can be seen at much younger ages.

In addition to investigating the regulatory abilities of children at risk of DCD to perform in dual tasks at the ages of 3-8, it was hypothesized that DCD is a disorder that should be identifiable at much earlier ages related to regulatory abilities in the neonatal and toddler ages. While others (e.g. Hua, et al., 2014) have reported a relationship between neonatal demographics (i.e. birth weight, fetal stress during delivery) and later diagnosis of DCD, there have not been any reports of specific neonatal and toddler behaviors that might be predictive of this disorder. In our exploratory study we found that although the children at risk of DCD did not demonstrate structural or functional measures of brain insult as measured by cranial ultrasound and auditory brainstem response testing at birth, their performance on neonatal, infant, and toddler behavioral measures is similar to that of children for whom structural or functional evidence of brain insult was present. Specifically, as newborns, the children in the risk group had demonstrated an interest in looking at higher frequencies of stimulation even when they were more aroused (hungry), and they demonstrated a greater number and severity of atypical behaviors on the neurobehavioral assessment, specifically related to head control and extremity tone. Differences in head control persisted at 1-month, and at 4-months, these children did not demonstrate a mature system of arousal modulated attention on the
looking task. Additionally, similar to what is seen in children with brain insult, serial
testing on the BSID-2 revealed a decline in performance on both the mental and motor
scale for the at-risk group by 19-months, with a greater relationship between risk
classification and poor performance on the mental scale as opposed to the motor scale at
the later ages. Analysis of the items tested at the later ages revealed that at these ages, the
motor scale tests qualitative aspects of fine motor control but concentrates primarily on
gross motor skills. The mental scale tests many items requiring fine motor dexterity in the
context of problem solving, which can possibly be viewed as dual motor and attention
task testing.

The relationships found between the participants’ performance at ages 3-8 and
their performance as neonates, infants and toddlers, provide important insight about the
disorder. First, while there was no evidence of structural or functional brain insult using
the measures of cranial ultrasound and auditory brainstem response testing, these children
differentiate behaviorally at the newborn age similar to children who did sustain a fetal or
neonatal neurological insult. This indicates that these children are starting with an altered
system. There are many neurodevelopmental disorders that present with similar profiles
at such young ages and how the trajectories will vary over time is a multifactorial and
complex phenomenon related to intrinsic and environmental factors (see Thelen and
Smith, 2007). Recall the extensive literature review previously described related to the
search for the impaired brain region or system that could explain the deficits seen in
children with DCD. Our study suggests that there may not be a specific brain region or
system that is implicated; rather, there is an atypical organization of the systems related
to an early insult that will present itself over development in different behaviors. When
an insult occurs during the fetal or neonatal periods the way that it is expressed is
different than when an insult occurs in a mature system. This idea is well elaborated on
by Karmiloff-Smith (2013), as she describes the fallacy of using an adult model of
neurological disorder when describing neurodevelopmental disorders. When a poorly
defined insult occurs in a developing system the emerging relationships within the neural
system, that is within the developing infant and child that is within an environmental and
social context, it will be expressed differentially over time in ways that are different than
a more 1:1 regionally specific ramification that might be seen following insult to a mature
system. Since many neurodevelopmental disorders present with a similar risk profile
early on, it will be important to continue this line of research to investigate if more
specific profiles can be found for DCD to differentiate it from other disorders at early
ages. An important implication of differential behavioral expression of a disorder over
the course of development is that in the endeavor to diagnose DCD at younger ages, the
behaviors to consider are not necessarily those that one would expect.

At this time DCD is diagnosed using standardized tests that assess isolated motor
skills with adjunctive parental reports. However, across ages, there are behaviors related
to underlying processes, such as regulation of attention, that require more sensitive
assessment than standardized tests can provide. In our study, for example, at 4-months
the children at risk in our sample did not perform differentially from their peers on the
BSID-2 at 4-months, but at that same age they did not demonstrate appropriate maturity
related to the arousal modulated attention task. Additionally, while the categorical
measure used for classification of risk based on performance on the MABC-2 correlated
with some earlier behaviors, the experimental measures independently correlated with
these same behaviors and with others. Additionally, while it might be expected that at early ages children with DCD would differentiate from their peers on standard motor scales, with our sample we found that children at risk differentiated at 19-25 months on the standard mental scales. There have been other reports of insufficient sensitivity using standardized tests with children with DCD. For example, Deconinck and colleagues (2008) reported that in double limb stance, boys with DCD demonstrated greater postural sway and greater reliance on visual information for postural control than their typically developing peers, and that these same children had scored in the normal range on the balance items on the MABC-2.

An additional point to consider is, in line with the Dynamic Systems Theory of development as put forth by Thelen and Smith (2007), is that although the underlying neural system has been altered, and there are specific processes that may not develop as in typically developing children, the behavioral expression of these deficits is not obligatory and hard wired. In our study, we measured a host of variables related to motor adaptation of walking following a perturbation in the context of increased attentional load. It would be inappropriate to conclude that children with DCD react to this scenario in a prescribed way of increased elbow flexion, or increased muscular effort at the ankle. Rather, it could be viewed that the stability of the state of the children’s walking when other attentional demands are placed on them is more fragile than the stability of their no-risk peers. Across risk groupings all of the children demonstrated some errors and fluctuations in their postural strategies, as is, and in fact required for successful walking in varied contexts. However, the children at risk of DCD were more affected by this task and demonstrated greater postural deviations and adjustments than their peers. The
compensatory behaviors that the children at risk of DCD demonstrated reflect self-organization required at that moment with that perturbation. In summary, it is not that elbow flexion or jerk in of themselves are indicative of this disorder, rather it is the finding that challenges to the attentional systems while walking created a greater disturbance to the system for these children and not for the others.

As discussed at the onset of this paper, the myriad of behavioral deficits that children with DCD experience culminate in an inability to participate with their peers, with consequences including obesity and limited participation in moderate-vigorous physical activity (Beutum, et al., 2013) and psychosocial disorders, including depression (Lingam et al., 2012). One would think then, that the overarching goal for clinicians would be to assess how the deficits present in contextualized environments, similar to those from which they are precluded participation, and that intervention would be directed towards improved performance within those same contextualized environments. One can imagine, for example, a child wanting to join his/her peers in a group sports activity, such as a soccer game. Some of the motor skills required to play this group sport include kicking a ball with appropriate force and aim, running, and maintaining balance while standing on one leg to achieve a kick. The current standard of testing children with DCD includes motor tests, like the MABC-2, that assess each of these tasks in isolation of any context. The current standard for treating children with DCD includes explicit training of motor skills, again, in a decontextualized way (e.g. see Ferguson et al., 2013). Considering this task specific training, it follows that this type of intervention will result in improved performance on the standardized test. However, while it is true that children with DCD have deficits in specific skills, testing and training these skills in
decontextualized environments does not provide the information or remediation required
to get the child on the field with their peers. As reported in this study, for the children at-
risk of DCD, even a well-practiced motor task in which they did not differentially
perform from their no-risk peers (walking) fell apart when contextualized in an
environment that required regulation of attention from other sources of information at the
same time (i.e. stimulus, barrier). Consider again which skills the child actually needs to
be able to perform in order to join his/her peers in a group sport such as soccer. Not only
does he/she have to kick a ball with appropriate speed while balancing on one leg and
running quickly in rapidly changing environments, but he/she has to do all of that while
simultaneously maintaining vigilant attention about all of the other players’ positions on
the field, the trajectories of their movements, the position of the ball, and so on. Improved
ability to kick a ball will not translate to improved ability to participate.

In conclusion, this study demonstrated that children between the ages of 3- and 8-
years-old who are at risk of DCD have greater difficulty than their peers with dual tasks
requiring increasing attentional demands and differential motor responses. Additionally,
depending on the context, the decrement in performance is differentially expressed.
Although these children were able to demonstrate similar walking abilities to their peers,
when their attention systems were challenged they experienced a greater perturbation
than their peers, highlighting their deficits both with regulating multiple sources of
attentional demands, and with their stability of walking as a state. Furthermore,
relationships were found between performance on this task and classification of risk at
these ages and behavioral performance at neonatal, infant and toddler ages. The findings
of this study support the notions of early identification, more ecologically valid and
sensitive testing and more ecologically valid intervention.

This study suggests a number of directions in which a dual-task paradigm can be integrated into the pediatric clinical setting. Future research efforts will work towards developing low-tech assessment methods to dually challenge the motor and cognitive/attention systems in young children to illuminate processing difficulties and differences in movement strategies. Further work will strive to develop tasks that are appropriate across a range of ages, including both crawling and walking tasks, to assist with early identification. Additionally, further research efforts will work towards development of intervention programs. Specifically, the question of whether attention training in isolation can positively affect motor performance in contextualized environments for children diagnosed with DCD will be investigated.
Appendix A:  List of Acronyms Used

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABR</td>
<td>Auditory Brainstem Response</td>
</tr>
<tr>
<td>ACC</td>
<td>Anterior Cingulate Cortex</td>
</tr>
<tr>
<td>ADHD</td>
<td>Attention Deficit Hyperactivity Disorder</td>
</tr>
<tr>
<td>ASD</td>
<td>Autism Spectrum Disorders</td>
</tr>
<tr>
<td>CBSF</td>
<td>Compromised Brainstem Functioning</td>
</tr>
<tr>
<td>CNS</td>
<td>Central Nervous System</td>
</tr>
<tr>
<td>COP</td>
<td>Center of Pressure</td>
</tr>
<tr>
<td>CT</td>
<td>Computed Tomography</td>
</tr>
<tr>
<td>DCD</td>
<td>Developmental Coordination Disorder</td>
</tr>
<tr>
<td>DCDQ</td>
<td>Developmental Coordination Disorder Questionnaire</td>
</tr>
<tr>
<td>DSM</td>
<td>Diagnostic and Statistical Manual of Mental Disorders</td>
</tr>
<tr>
<td>EEG</td>
<td>Electroencephalogram</td>
</tr>
<tr>
<td>fMRI</td>
<td>Functional Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>IPC</td>
<td>Inferior Parietal Cortex</td>
</tr>
<tr>
<td>IQ</td>
<td>Intelligence Quotient</td>
</tr>
<tr>
<td>MABC</td>
<td>Movement Assessment Battery for Children</td>
</tr>
<tr>
<td>MFC</td>
<td>Middle Frontal Cortex</td>
</tr>
<tr>
<td>NYS DOH</td>
<td>New York State Department of Health</td>
</tr>
<tr>
<td>OCD</td>
<td>Obsessive-Compulsive Disorder</td>
</tr>
<tr>
<td>PDDBI</td>
<td>Pervasive Developmental Disorder Behavioral Inventory</td>
</tr>
<tr>
<td>PPC</td>
<td>Posterior Parietal Cortex</td>
</tr>
<tr>
<td>RD</td>
<td>Reading Disabilities</td>
</tr>
<tr>
<td>SPECT</td>
<td>Single-Photon Emission Computed Tomography</td>
</tr>
</tbody>
</table>
APPENDIX B: Means Tables
Table A. Computerized Attention Task Means Table

<table>
<thead>
<tr>
<th>Reaction Time (ms)</th>
<th>Young</th>
<th>Old</th>
<th>No-Risk</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td><strong>Button</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disengage/R</td>
<td>893.02</td>
<td>245.10</td>
<td>70.75</td>
<td>799.93</td>
</tr>
<tr>
<td>Disengage/L</td>
<td>929.13</td>
<td>170.39</td>
<td>49.19</td>
<td>863.88</td>
</tr>
<tr>
<td>Shift/R</td>
<td>908.38</td>
<td>205.25</td>
<td>59.25</td>
<td>867.41</td>
</tr>
<tr>
<td>Shift/L</td>
<td>876.77</td>
<td>174.53</td>
<td>50.38</td>
<td>869.89</td>
</tr>
<tr>
<td><strong>Voice</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disengage/R</td>
<td>793.61</td>
<td>231.99</td>
<td>66.97</td>
<td>596.16</td>
</tr>
<tr>
<td>Disengage/L</td>
<td>758.94</td>
<td>297.80</td>
<td>85.97</td>
<td>699.19</td>
</tr>
<tr>
<td>Shift/R</td>
<td>762.33</td>
<td>276.10</td>
<td>79.70</td>
<td>575.62</td>
</tr>
<tr>
<td>Shift/L</td>
<td>720.64</td>
<td>274.01</td>
<td>79.10</td>
<td>560.95</td>
</tr>
<tr>
<td><strong>Total Means:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Button</td>
<td>901.82</td>
<td>169.37</td>
<td>48.89</td>
<td>850.28</td>
</tr>
<tr>
<td>Voice</td>
<td>886.39</td>
<td>500.98</td>
<td>144.62</td>
<td>699.19</td>
</tr>
<tr>
<td>Disengage</td>
<td>875.54</td>
<td>164.32</td>
<td>47.43</td>
<td>739.79</td>
</tr>
<tr>
<td>Shift</td>
<td>817.03</td>
<td>139.66</td>
<td>40.32</td>
<td>741.79</td>
</tr>
<tr>
<td>Right</td>
<td>839.34</td>
<td>129.87</td>
<td>37.49</td>
<td>733.10</td>
</tr>
<tr>
<td>Left</td>
<td>853.23</td>
<td>155.58</td>
<td>44.91</td>
<td>748.48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracy (1 =100%)</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
<th>M</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Means:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Button</td>
<td>.97</td>
<td>.07</td>
<td>.02</td>
<td>1.00</td>
<td>.02</td>
<td>.00</td>
<td>.99</td>
<td>.03</td>
<td>.01</td>
<td>.97</td>
<td>.08</td>
<td>.02</td>
</tr>
<tr>
<td>Voice</td>
<td>1.00</td>
<td>.00</td>
<td>.00</td>
<td>1.00</td>
<td>.00</td>
<td>.00</td>
<td>1.00</td>
<td>.00</td>
<td>.00</td>
<td>1.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>Disengage</td>
<td>.98</td>
<td>.04</td>
<td>.01</td>
<td>1.00</td>
<td>.02</td>
<td>.00</td>
<td>.99</td>
<td>.03</td>
<td>.01</td>
<td>.98</td>
<td>.04</td>
<td>.01</td>
</tr>
<tr>
<td>Shift</td>
<td>.99</td>
<td>.04</td>
<td>.01</td>
<td>1.00</td>
<td>.02</td>
<td>.00</td>
<td>.99</td>
<td>.02</td>
<td>.01</td>
<td>.98</td>
<td>.04</td>
<td>.01</td>
</tr>
<tr>
<td>Right</td>
<td>.98</td>
<td>.04</td>
<td>.01</td>
<td>1.00</td>
<td>.02</td>
<td>.00</td>
<td>.99</td>
<td>.01</td>
<td>.00</td>
<td>.99</td>
<td>.04</td>
<td>.01</td>
</tr>
<tr>
<td>Total</td>
<td>.98</td>
<td>.04</td>
<td>.01</td>
<td>1.00</td>
<td>.01</td>
<td>.00</td>
<td>.99</td>
<td>.01</td>
<td>.00</td>
<td>.99</td>
<td>.04</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Young</td>
<td>Old</td>
<td>No-Risk</td>
<td>Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>------------------------</td>
<td>----------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Inhibition</strong></td>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
<td><strong>SE</strong></td>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
<td><strong>SE</strong></td>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
<td><strong>SE</strong></td>
<td><strong>M</strong></td>
<td><strong>SD</strong></td>
<td><strong>SE</strong></td>
</tr>
<tr>
<td><strong>Means:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Button</td>
<td>.92</td>
<td>1.50</td>
<td>.42</td>
<td>.57</td>
<td>1.34</td>
<td>.36</td>
<td>.33</td>
<td>.49</td>
<td>.13</td>
<td>1.27</td>
<td>2.05</td>
<td>.62</td>
</tr>
<tr>
<td>Voice</td>
<td>1.08</td>
<td>1.66</td>
<td>.46</td>
<td>.29</td>
<td>.83</td>
<td>.22</td>
<td>.47</td>
<td>1.36</td>
<td>.35</td>
<td>.91</td>
<td>1.38</td>
<td>.42</td>
</tr>
<tr>
<td>Total</td>
<td>2.00</td>
<td>2.77</td>
<td>.77</td>
<td>.86</td>
<td>2.10</td>
<td>.56</td>
<td>.80</td>
<td>1.57</td>
<td>.41</td>
<td>2.18</td>
<td>3.34</td>
<td>1.01</td>
</tr>
</tbody>
</table>

*Note.* (M = Mean, SD = Standard Deviation, SE = Standard Error, ms = milliseconds)
Table B. Walking Only Task Kinematic Data Means Table

<table>
<thead>
<tr>
<th></th>
<th>Young M</th>
<th>SD</th>
<th>SE</th>
<th>Old M</th>
<th>SD</th>
<th>SE</th>
<th>No-Risk M</th>
<th>SD</th>
<th>SE</th>
<th>Risk M</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1 Velocity (m/s)</td>
<td>.90</td>
<td>.21</td>
<td>.06</td>
<td>.94</td>
<td>.57</td>
<td>.16</td>
<td>.97</td>
<td>.18</td>
<td>.05</td>
<td>.85</td>
<td>.63</td>
<td>.19</td>
</tr>
<tr>
<td>W2 Velocity (m/s)</td>
<td>.38</td>
<td>.89</td>
<td>.25</td>
<td>.76</td>
<td>.90</td>
<td>.27</td>
<td>.59</td>
<td>.82</td>
<td>.22</td>
<td>.51</td>
<td>1.05</td>
<td>.33</td>
</tr>
<tr>
<td>Total M Velocity</td>
<td>.64</td>
<td>.47</td>
<td>.13</td>
<td>.87</td>
<td>.67</td>
<td>.19</td>
<td>.80</td>
<td>.45</td>
<td>.12</td>
<td>.70</td>
<td>.74</td>
<td>.22</td>
</tr>
<tr>
<td>W1 SD of Velocity</td>
<td>.22</td>
<td>.11</td>
<td>.03</td>
<td>.34</td>
<td>.20</td>
<td>.06</td>
<td>.25</td>
<td>.19</td>
<td>.03</td>
<td>.32</td>
<td>.22</td>
<td>.07</td>
</tr>
<tr>
<td>W2 SD of Velocity</td>
<td>.27</td>
<td>.14</td>
<td>.04</td>
<td>.42</td>
<td>.34</td>
<td>.09</td>
<td>.39</td>
<td>.31</td>
<td>.08</td>
<td>.28</td>
<td>.18</td>
<td>.05</td>
</tr>
<tr>
<td>Total SD Velocity</td>
<td>.24</td>
<td>.09</td>
<td>.02</td>
<td>.38</td>
<td>.21</td>
<td>.06</td>
<td>.32</td>
<td>.19</td>
<td>.05</td>
<td>.30</td>
<td>.16</td>
<td>.05</td>
</tr>
<tr>
<td>W1 Elbow Flexion (deg)</td>
<td>31.99</td>
<td>12.38</td>
<td>3.43</td>
<td>34.83</td>
<td>14.32</td>
<td>3.97</td>
<td>29.01</td>
<td>10.46</td>
<td>2.70</td>
<td>39.41</td>
<td>14.61</td>
<td>4.40</td>
</tr>
<tr>
<td>W2 Elbow Flexion (deg)</td>
<td>39.82</td>
<td>14.35</td>
<td>3.98</td>
<td>32.47</td>
<td>15.36</td>
<td>4.26</td>
<td>33.55</td>
<td>14.59</td>
<td>3.77</td>
<td>39.68</td>
<td>15.61</td>
<td>4.71</td>
</tr>
<tr>
<td>Total Elbow Flexion</td>
<td>35.91</td>
<td>12.20</td>
<td>3.38</td>
<td>33.65</td>
<td>13.76</td>
<td>3.82</td>
<td>31.28</td>
<td>11.36</td>
<td>2.93</td>
<td>39.55</td>
<td>13.62</td>
<td>4.11</td>
</tr>
<tr>
<td>W1 Jerk (m/s$^3$)</td>
<td>311.64</td>
<td>504.47</td>
<td>139.92</td>
<td>181.22</td>
<td>162.49</td>
<td>45.07</td>
<td>276.52</td>
<td>461.94</td>
<td>119.27</td>
<td>205.39</td>
<td>214.88</td>
<td>64.79</td>
</tr>
<tr>
<td>W2 Jerk (m/s$^3$)</td>
<td>118.56</td>
<td>116.96</td>
<td>32.44</td>
<td>217.93</td>
<td>385.14</td>
<td>106.82</td>
<td>64.04</td>
<td>59.20</td>
<td>15.28</td>
<td>310.35</td>
<td>396.77</td>
<td>119.63</td>
</tr>
<tr>
<td>Total Jerk</td>
<td>215.10</td>
<td>252.78</td>
<td>70.11</td>
<td>199.57</td>
<td>184.02</td>
<td>51.04</td>
<td>170.28</td>
<td>233.08</td>
<td>60.18</td>
<td>257.87</td>
<td>191.17</td>
<td>57.64</td>
</tr>
</tbody>
</table>

*Note.* (M = Mean, SD = Standard Deviation, SE = Standard Error, W1 = first walking trial, W2 = second walking trial, m/s = meters/second, deg = degrees)
Table C. Dual Task Kinematic Data Means Table

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th></th>
<th>Old</th>
<th></th>
<th>No-Risk</th>
<th></th>
<th>Risk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Mean Velocity (m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>.64</td>
<td>.47</td>
<td>.13</td>
<td>.87</td>
<td>.67</td>
<td>.19</td>
<td>.80</td>
<td>.45</td>
</tr>
<tr>
<td>Voice</td>
<td>.87</td>
<td>.25</td>
<td>.07</td>
<td>.83</td>
<td>.61</td>
<td>.18</td>
<td>.89</td>
<td>.21</td>
</tr>
<tr>
<td>Touch</td>
<td>.99</td>
<td>.22</td>
<td>.06</td>
<td>.99</td>
<td>.69</td>
<td>.20</td>
<td>1.05</td>
<td>.23</td>
</tr>
<tr>
<td>Barrier</td>
<td>.87</td>
<td>.21</td>
<td>.06</td>
<td>.74</td>
<td>.51</td>
<td>.15</td>
<td>.89</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SD Velocity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>.24</td>
<td>.09</td>
<td>.03</td>
<td>.38</td>
<td>.21</td>
<td>.06</td>
<td>.32</td>
<td>.19</td>
</tr>
<tr>
<td>Voice</td>
<td>.24</td>
<td>.08</td>
<td>.02</td>
<td>.40</td>
<td>.20</td>
<td>.06</td>
<td>.32</td>
<td>.18</td>
</tr>
<tr>
<td>Touch</td>
<td>.31</td>
<td>.17</td>
<td>.05</td>
<td>.39</td>
<td>.20</td>
<td>.06</td>
<td>.36</td>
<td>.21</td>
</tr>
<tr>
<td>Barrier</td>
<td>.30</td>
<td>.17</td>
<td>.05</td>
<td>.41</td>
<td>.18</td>
<td>.05</td>
<td>.34</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow Flexion (deg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk IO</td>
<td>35.91</td>
<td>12.20</td>
<td>3.38</td>
<td>33.65</td>
<td>13.76</td>
<td>3.82</td>
<td>31.28</td>
<td>11.36</td>
</tr>
<tr>
<td>Voice IO</td>
<td>49.67</td>
<td>20.79</td>
<td>5.77</td>
<td>33.24</td>
<td>10.63</td>
<td>3.07</td>
<td>42.52</td>
<td>18.95</td>
</tr>
<tr>
<td>Touch IO</td>
<td>42.46</td>
<td>13.79</td>
<td>3.98</td>
<td>35.93</td>
<td>13.86</td>
<td>4.00</td>
<td>37.15</td>
<td>13.92</td>
</tr>
<tr>
<td>Barrier IO</td>
<td>42.51</td>
<td>16.93</td>
<td>4.70</td>
<td>35.03</td>
<td>14.72</td>
<td>4.25</td>
<td>33.77</td>
<td>11.94</td>
</tr>
<tr>
<td>Direction CD</td>
<td>44.60</td>
<td>20.37</td>
<td>6.79</td>
<td>37.07</td>
<td>14.97</td>
<td>4.32</td>
<td>39.81</td>
<td>21.44</td>
</tr>
<tr>
<td>Touch CD</td>
<td>44.59</td>
<td>14.22</td>
<td>3.94</td>
<td>46.95</td>
<td>24.48</td>
<td>7.07</td>
<td>39.20</td>
<td>18.50</td>
</tr>
<tr>
<td>Barrier CD</td>
<td>40.94</td>
<td>14.08</td>
<td>3.90</td>
<td>38.27</td>
<td>15.50</td>
<td>4.47</td>
<td>38.62</td>
<td>16.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trunk Deviation (deg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Touch CD</td>
<td>3.39</td>
<td>2.72</td>
<td>.75</td>
<td>3.09</td>
<td>1.94</td>
<td>.59</td>
<td>2.84</td>
<td>2.30</td>
</tr>
<tr>
<td>Barrier CD</td>
<td>4.16</td>
<td>2.00</td>
<td>.55</td>
<td>3.41</td>
<td>2.16</td>
<td>.65</td>
<td>3.10</td>
<td>1.80</td>
</tr>
<tr>
<td></td>
<td>Young</td>
<td>Old</td>
<td>No-Risk</td>
<td>Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td><strong>Jerk (m/s²)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk IO</td>
<td>215.10</td>
<td>252.78</td>
<td>70.11</td>
<td>199.57</td>
<td>184.02</td>
<td>51.04</td>
<td>170.28</td>
<td>233.08</td>
</tr>
<tr>
<td>Touch IO</td>
<td>275.98</td>
<td>527.26</td>
<td>146.23</td>
<td>325.64</td>
<td>404.32</td>
<td>116.72</td>
<td>232.21</td>
<td>397.01</td>
</tr>
<tr>
<td>Touch CD</td>
<td>347.11</td>
<td>566.85</td>
<td>157.22</td>
<td>135.35</td>
<td>102.92</td>
<td>31.03</td>
<td>199.01</td>
<td>271.04</td>
</tr>
<tr>
<td>Barrier IO</td>
<td>208.10</td>
<td>366.02</td>
<td>101.51</td>
<td>333.23</td>
<td>634.24</td>
<td>183.09</td>
<td>240.07</td>
<td>571.06</td>
</tr>
<tr>
<td>Barrier CD</td>
<td>300.70</td>
<td>446.69</td>
<td>123.89</td>
<td>156.23</td>
<td>143.96</td>
<td>41.56</td>
<td>270.38</td>
<td>420.06</td>
</tr>
<tr>
<td><strong>Distance (m)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barrier Distance IO</td>
<td></td>
<td></td>
<td></td>
<td>1.94</td>
<td>.33</td>
<td>.09</td>
<td>1.91</td>
<td>.26</td>
</tr>
<tr>
<td>Touch and CD</td>
<td>1.60</td>
<td>.55</td>
<td>.15</td>
<td>1.53</td>
<td>.37</td>
<td>.11</td>
<td>1.43</td>
<td>.56</td>
</tr>
<tr>
<td>Barrier: IO and CD</td>
<td>.59</td>
<td>.25</td>
<td>.07</td>
<td>.87</td>
<td>.18</td>
<td>.05</td>
<td>.79</td>
<td>.16</td>
</tr>
<tr>
<td><strong>Reaction Time (s)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Touch</td>
<td>1.71</td>
<td>.80</td>
<td>.22</td>
<td>1.26</td>
<td>.26</td>
<td>.07</td>
<td>1.39</td>
<td>.71</td>
</tr>
<tr>
<td>Barrier</td>
<td>.59</td>
<td>.72</td>
<td>.20</td>
<td>1.02</td>
<td>.16</td>
<td>.05</td>
<td>.92</td>
<td>.28</td>
</tr>
<tr>
<td><strong>EMG (uv)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk Pre</td>
<td>104.89</td>
<td>6.54</td>
<td>3.77</td>
<td>147.98</td>
<td>39.49</td>
<td>16.12</td>
<td>129.65</td>
<td>47.16</td>
</tr>
<tr>
<td>Barrier Pre</td>
<td>128.32</td>
<td>20.28</td>
<td>11.71</td>
<td>111.83</td>
<td>11.11</td>
<td>4.54</td>
<td>118.37</td>
<td>17.10</td>
</tr>
<tr>
<td>Barrier Post</td>
<td>140.15</td>
<td>30.11</td>
<td>17.38</td>
<td>155.98</td>
<td>29.68</td>
<td>12.12</td>
<td>140.15</td>
<td>27.76</td>
</tr>
<tr>
<td>Walk TA Pre</td>
<td>59.81</td>
<td>16.93</td>
<td>9.78</td>
<td>87.18</td>
<td>30.40</td>
<td>12.41</td>
<td>77.17</td>
<td>35.33</td>
</tr>
<tr>
<td>Walk G Pre</td>
<td>45.07</td>
<td>11.41</td>
<td>6.59</td>
<td>60.80</td>
<td>18.45</td>
<td>7.53</td>
<td>52.48</td>
<td>15.24</td>
</tr>
<tr>
<td>BarrierTA Pre</td>
<td>68.49</td>
<td>11.36</td>
<td>6.56</td>
<td>59.82</td>
<td>14.33</td>
<td>5.85</td>
<td>65.33</td>
<td>15.9</td>
</tr>
<tr>
<td>BarrierG Pre</td>
<td>59.83</td>
<td>26.43</td>
<td>15.26</td>
<td>52.00</td>
<td>17.82</td>
<td>7.28</td>
<td>53.04</td>
<td>21.35</td>
</tr>
</tbody>
</table>

*Note.* (M = Mean, SD = Standard Deviation, SE = Standard Error, m/s = meters/second, deg = angular degrees, IO = image onset, CD = change of direction, m = meters, s = seconds, uv = microvolt, TA = tibialis anterior, G = gastrocnemius, Pre = pre-stimulus, Post = post-stimulus).
<table>
<thead>
<tr>
<th>Completion Time (ms)</th>
<th>Young</th>
<th>Old</th>
<th>No-Risk</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Touch</td>
<td>4001.77</td>
<td>1071.46</td>
<td>297.17</td>
<td>2973.31</td>
</tr>
<tr>
<td>Barrier</td>
<td>4787.77</td>
<td>831.93</td>
<td>230.73</td>
<td>4393.46</td>
</tr>
<tr>
<td>Disengage</td>
<td>4415.73</td>
<td>966.65</td>
<td>268.10</td>
<td>3630.73</td>
</tr>
<tr>
<td>Shift</td>
<td>4373.55</td>
<td>747.34</td>
<td>207.27</td>
<td>3735.82</td>
</tr>
<tr>
<td>Right</td>
<td>4285.13</td>
<td>738.55</td>
<td>204.84</td>
<td>3665.63</td>
</tr>
<tr>
<td>Left</td>
<td>4504.16</td>
<td>1035.27</td>
<td>287.13</td>
<td>3700.92</td>
</tr>
</tbody>
</table>

Note. (M = Mean, SD = Standard Deviation, SE = Standard Error, ms = milliseconds)
Table E. Selected Neonatal, Infant and Toddler Data

<table>
<thead>
<tr>
<th></th>
<th>Young</th>
<th>Old</th>
<th>No-Risk</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Neuro Insult</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.23</td>
<td>.83</td>
<td>.23</td>
<td>1.84</td>
</tr>
<tr>
<td>Arousal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Modulated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Attention</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>newborn</td>
<td>.25</td>
<td>.11</td>
<td>.03</td>
<td>.13</td>
</tr>
<tr>
<td>4-month</td>
<td>.08</td>
<td>.07</td>
<td>.02</td>
<td>.01</td>
</tr>
<tr>
<td>RNNA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head</td>
<td>1.38</td>
<td>.65</td>
<td>.18</td>
<td>1.23</td>
</tr>
<tr>
<td>Extremity</td>
<td>1.38</td>
<td>.51</td>
<td>.14</td>
<td>1.08</td>
</tr>
<tr>
<td>Composite</td>
<td>1.23</td>
<td>1.48</td>
<td>.41</td>
<td>.77</td>
</tr>
<tr>
<td>Head</td>
<td>1.38</td>
<td>.65</td>
<td>.18</td>
<td>1.31</td>
</tr>
<tr>
<td>1-month</td>
<td>1.08</td>
<td>.28</td>
<td>.08</td>
<td>1.23</td>
</tr>
<tr>
<td>Extremity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-month</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite</td>
<td>.85</td>
<td>.15</td>
<td>.41</td>
<td>1.23</td>
</tr>
<tr>
<td>BSID-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor 19</td>
<td>101.20</td>
<td>11.45</td>
<td>5.12</td>
<td>97.00</td>
</tr>
<tr>
<td>Motor 25</td>
<td>103.38</td>
<td>13.16</td>
<td>4.65</td>
<td>97.67</td>
</tr>
<tr>
<td>Mental 19</td>
<td>96.20</td>
<td>5.89</td>
<td>2.63</td>
<td>96.08</td>
</tr>
<tr>
<td>Mental 22</td>
<td>95.82</td>
<td>17.22</td>
<td>5.19</td>
<td>97.23</td>
</tr>
<tr>
<td>Mental 25</td>
<td>103.88</td>
<td>15.78</td>
<td>5.58</td>
<td>104.33</td>
</tr>
</tbody>
</table>


time researches: A comparison in low conflict tasks. Computers in Human Behavior,

Physical & Occupational Therapy in Pediatrics, 20:2, 5-27.


Ferguson, G.D., Jelsma, D., Smits-Engelsman, B. C.M. (2013). The efficacy of two task-
oriented interventions for children with Developmental Coordination Disorder:
Neuromotor Task Training and Nintendo Wii Fit training. Research in Developmental
Disabilities, 34, 2449-2461.

coupling in infancy and attention problems in childhood. Developmental Medicine &
Child Neurology, 47, 660-665.


Luce R.D. (1986). *Response times: Their role inferring elementary mental organization,* New York: Oxford University Press.


