VISUAL ATTENTION IN DEVELOPMENTAL COORDINATION DISORDER

LOOKING AND SEEING: HOW DO SCHOOL-AGED CHILDREN WITH AND WITHOUT DEVELOPMENTAL COORDINATION DISORDER INTEGRATE VISION AND ATTENTION DURING VISUOMOTOR PERFORMANCE?

By
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Abstract

This dissertation explores how children with and without developmental coordination disorder (DCD) ‘look’ *and* ‘see’: how they integrate vision and attention to guide arm and hand movements during a visuomotor task.

Chapter 1 provides the thesis context, reviewing the vision and attention literature, outlining the role of these processes in motor performance, and reviewing what is known about vision and attention in children with DCD. Chapter 1 includes a discussion on eye tracking to measure visual attention, and outlines the thesis purpose and objectives.

Chapter 2 focuses on children with DCD, detailing their presentation and clinical management. This chapter serves to increase the reader’s understanding of the difficulties children with DCD experience, and to demonstrate the need for intervention to prevent the profound consequences that can impact their quality of life.

Chapter 3 presents a study that explores how children with and without DCD employ vision and attention to accomplish a visuomotor task in a natural setting, using a novel eye tracking design. Highlighted here are important differences during visuomotor task performance: compared to their peers, children with DCD did not use predictive gaze to attend to relevant task objects, but rather used vision to guide their arm/hand throughout the task.

Chapter 4 outlines lessons learned from using an eye tracker with children with DCD, describing the children for whom eye tracking was not reliable, and discussing equipment and participant factors that impact eye tracker use. Recommendations for future research using eye tracking with the DCD population are provided.

Finally, Chapter 5 discusses the clinical and research implications of the studies conducted here. Insights gained regarding visual attention differences between children with and without DCD are discussed in the context of interventions to improve health outcomes in children with DCD and the design of future eye tracking studies.

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As the saying goes, 'it takes a community to raise a child'. I believe the same (and more) can be said of raising a PhD student! There are many individuals in my 'community' who have been instrumental in helping me along my doctoral journey, and to whom I am very grateful. I am indebted to my thesis advisor, Dr. Cheryl Missiuna, who has always been more than an supervisor to me, but who is also a trusted colleague and friend. A compassionate and understanding mentor with a wonderful ability to encourage me to accept a 'just right' challenge, Cheryl has never ceased to be an inspiration for my work. My sincere gratitude goes also to the members of my exceptional supervisory committee, Dr. Laurie Wishart, and Dr. Timothy Lee, for their guidance and wisdom and for their tireless support and encouragement. It has been my privilege to work with Laurie and Tim and to have benefited from their years of experience and expertise. My thanks go also to the faculty and staff at *CanChild* Centre for Childhood Disability Research, a place where I have always found a home.

My research would not have been possible without the children and families who gave so generously of their time. For their willingness to participant in this project, I am grateful. I would also like to acknowledge the Infant and Child Health Lab (INCH) at McMaster University for sharing their resources and facility. Critical to my research was the support provided by SensoMotoric Instruments in loaning me the eye tracking equipment, without which the success of this project would never have been realized.

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And last, but never least, I thank my friends, and my family, most especially my husband Jim, and daughters Madeleine and Monique for their patience and support, their laughter, and their never-tiring belief in me.

Preface

This preface summarizes all author contributions to each of the manuscripts found in this dissertation.

For the manuscript (book chapter) entitled *"Developmental Coordination Disorder"*:

Lisa Rivard determined the content and organization of this chapter revision, with significant updates to the 3rd edition of this chapter (David, 2006). Lisa re-wrote nearly all the chapter sections, updating to reflect current evidence and to include contemporary theoretical frameworks. She added 10 new sections, and 3 new comprehensive case scenarios. Substantial additions were made to the sections on impairments, role of the physical therapist and clinical assessment tools, as well as intervention approaches. Overall, the update resulted in 10 additional pages of content and 150 additional references. K. David was invited to be a co-author on this chapter version, but did not make additional contributions. She remained as an author on this chapter to acknowledge her previous contributions, and because several of her original tables and figures were retained in the current chapter version. Cheryl Missiuna and Nancy Pollock assisted with details of the clinical case scenarios and provided editorial assistance and feedback on the chapter revision.

For the manuscripts entitled *"Do they 'look' the same? Exploring selective visual attention during visuomotor performance in school-aged children with and without developmental coordination disorder"* and *"Feasibility of using an eye tracker in school-aged children with developmental coordination disorder performing a real-world* *visuomotor task: Lessons learned":* Lisa Rivard formulated the research questions, designed the study, developed the study protocol, completed the ethics approval process, recruited participants and scheduled study appointments, supervised the research project, secured the equipment, hired/managed the research assistants, conducted the experimental testing, completed data collection, analyzed and interpreted the data, and prepared the manuscript. Drs. Cheryl Missiuna, Laurie Wishart, and Timothy Lee assisted with refining aspects of the research questions, study design, and experimental task. They also assisted with interpretation of the study findings and provided editorial assistance with the preparation of the manuscripts.

For the manuscript entitled "Do they 'look' the same? Exploring selective visual attention during visuomotor performance in school-aged children with and without developmental coordination disorder": Dr. Paul Stratford was not a co-author, but was acknowledged for his consultation and assistance with the data analysis for the reliability testing.

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List of Abbreviations and Symbols

APA = American Psychiatric Association

ADHD = Attention Deficit Hyperactivity Disorder

CI = confidence interval

DCD = Developmental Coordination Disorder

DCDQ'07 = Developmental Coordination Disorder Questionnaire

FC = filling cup

fMRI = Functional Magnetic Resonance Imaging

IBM = International Business Machines Corporation

INCH = Infant and Child Health Lab

ICC = intra-class coefficient

KBIT-2 = Kaufman Brief Intelligence Test – 2^{nd} version

MABC-2 = Movement Assessment Battery for Children – 2^{nd} version

OT = occupational therapist

PI = principal investigator

PC = pouring cup

RA = research assistant

SD = standard deviation

SPSS = Statistical Package for the Social Sciences

STATA = Data Analysis and Statistical Software

TD = typically developing

Declaration of Academic Achievement

This dissertation presents original work undertaken by the doctoral candidate. Using an innovative approach resulting from course work completed during the PhD program, the doctoral student designed the studies described herein, and supervised/conducted the experimental testing. The candidate participated in all data collection, analysed the data, and interpreted findings of the work. Collaboration with the thesis supervisor and thesis advisory committee led to refinements in aspects of the study design, experimental task, and analysis performed and reported here. The doctoral candidate is the sole author of this work, and has benefitted from review and feedback from thesis advisors.

Chapter One: Introduction

In Canada, 5-6% of school-aged children have motor coordination difficulties that are significant enough to interfere with their everyday life. These children have developmental coordination disorder (DCD), a little known neurodevelopmental condition that can have profound effects on their daily functioning (American Psychiatric Association (APA), 2013). Children with DCD struggle to participate in the typical activities of childhood and often fall short of reaching their academic potential (Cantell, Smyth, & Ahonen, 1994; Gilberg & Gilberg, 1989; Mandich, Polatajko, & Rodger, 2003; Rasmussen & Gilberg, 2000). Frustrated by repeated failure experiences, they withdraw from physical and social activities, and can be at greater risk of developing obesity, anxiety and depression (Cairney, Hay, Faught, & Hawes, 2005; Pearsall-Jones, Piek, Rigoli, Martin, & Levy, 2011; Pratt & Hill, 2011; Piek et al, 2007).

Although a definitive cause for coordination difficulties in children remains unclear, decades of research provides evidence that children with DCD have difficulty learning motor skills, that their motor skills do not become automatic, and that they are much slower than their peers at completing motor tasks because they rely heavily on visual information (Biancotto et al., 2011; Gueze, 2005; Henderson & Henderson, 2002; Henderson, Rose, & Henderson, 1992; Missiuna, 1994).

Recent cognitive interventions that have demonstrated their effectiveness in assisting children with DCD to learn new motor skills focus specifically on their ability to think through and solve motor problems (Miller, Polatajko, Missiuna, Mandich, & MacNab, 2001; Polatajko & Mandich, 2004; Polatajko, Mandich, Miller, & MacNab, 2001). While effective, we don't yet know the 'active ingredients' to these interventions: What are the essential elements within these interventions? How do they work?

Recent imaging studies examining cortical function in children during motor tasks show that, when performing the same task, children with DCD use different cortical areas than their well-coordinated peers, including areas that receive and interpret visual information and those that are associated with attention (Debrabant, Gheysen, Caeyenberghs, van Waelvelde, & Vingerhoets, 2013; Kashiwagi, Iwaki, Narumi, Tamai, & Suzuki, 2009; Querne et al., 2008; Zwicker, Missiuna, Harris, & Boyd, 2010, 2012). From a clinical perspective, we also know from watching children with coordination difficulties that they concentrate very hard to complete motor tasks. It is possible that, for these children, their ability to pay attention to the relevant parts of a task may influence how well they will ultimately learn and become skilled at that task. To test this hypothesis, it is therefore necessary to examine whether selective visual attention is an essential 'active ingredient' within cognitive interventions. As a first step towards this goal, this thesis examines selective visual attention in children both with and without DCD during a familiar, but novel, pouring task using an eye tracker. Findings from the studies described here provide the groundwork necessary to design future studies examining cueing of selective visual attention as a strategy within cognitive interventions to help children with DCD and their families to manage their difficulties and to ensure their successful participation in daily life activities.

The next sections in this introduction critically appraise and synthesize two complex and intricately related fields of research: vision and attention. The review of literature presented here is not meant to be exhaustive, but rather is intended to be a broad overview of the research conducted in the areas of vision and attention, touching upon the issues most closely related to the purposes and objectives of this thesis. The review begins with a description of the role of vision as it relates to both action and perception. A very brief overview of the vision literature is presented and a description of the anatomical and functional cortical areas that are important for transforming vision into action is provided. Following this, the field of attention is explored; in particular the area of selective visual attention, and the role of attention in visual processing is outlined. Both vision and attention are discussed in the context of motor performance in the section that follows, highlighting the importance of these cognitive processes to the development of skilled motor performance, with examples from sport and everyday life. In order to fully understand the need to intervene clinically with children with DCD, these children are then described, along with their functional difficulties, long-term outcomes, and risk for developing potential profound secondary consequences. The rationale for using a selective visual attention framework in this thesis is supported by the section outlining the role of vision in DCD, and the current state of understanding of selective visual attention in DCD. Finally, this chapter concludes with a brief summary on the use of eye tracking to measure visual attention, the tool used to measure the outcomes important to the purpose and objectives of this thesis.

The Role of Vision: Action and Perception

As human beings, we process and interpret the world around us through our senses. Of all of our senses, vision is arguably one of the most critical, with 70-80% of the incoming information from our environment processed using our eyes (Damyanovich, Baziyan, Sagalov, & Kumskova, 2013). In a single day, we shift our eyes to the objects we want to look at roughly 200,000 times, or 3-4 times in a second. Indeed, by the time we are 80 years old, we will have made 6 billion eye movements (Schiller & Tehovnik, 2005; Snowden, Thompson, & Troscianko, 2012).

In order to interact with everyday objects (reach for, grasp, manoeuver around), vision helps us to identify and select objects. It also assists us in determining their orientation in space, as well as their size, shape, and motion. In addition, vision helps us to locate our bodies in relation to objects in our environment, and to program and monitor our movements to successfully interact with those objects (Schmidt & Lee, 2011; Shumway-Cook & Woollacott, 2012).

It is believed that the processing of visual information is accomplished through two independent, yet connected, functional pathways. These pathways travel in parallel, with each ultimately projecting to different higher cortical areas. One pathway, the ventral stream, thought to be primarily concerned with perception, leads to the inferior temporal cortex. The second pathway, known as the dorsal stream, terminates in the posterior parietal cortex, and is believed to be involved in the visual control of movement, or 'vision for action' (Goodale, 2013; Milner & Goodale, 2008). The role of the dorsal stream is distinct from the ventral stream in that it must transform the visual-spatial coordinates (of both objects and our bodies in visual space) into movement coordinates to develop motor programs for action (Goodale, 2013; Jeannerod, Arbib, Rizzolatti, & Sakata, 1995), and it does so through multiple connections to frontal cortical areas (Rizzolatti et al., 1997). Recently, the increasingly refined measurement of visual function has led to interesting insights with regards to the visual difficulties seen in children with a wide spectrum of neurodevelopmental disorders, introducing the concept of developmental 'dorsal stream vulnerability' (Braddick & Atkinson, 2011, 2013).

The Role of Attention in Visual Processing

One of the difficulties we encounter in everyday life is that our visual world is complex, with a vast array of objects competing for processing and ultimately, cortical representation. Not all of the visual information that we actually 'see' can be processed at once, as we have a limited information processing capacity (Kastner & Ungerleider, 2000; McMains & Kastner, 2011). We are also limited in what we can store in short-term memory (Ballard, Hayhoe & Pelz, 1995). As a result, we must rely on a series of cognitive processes to manage and prioritize the information we perceive from our environment. In particular, we use attention to accomplish this. Attention has been defined as "the ability to deploy the resources of the brain so as to optimize performance towards behavioural goals" (Atkinson & Braddick, 2012, p. 589). Attention is an overarching term that has been used to describe a group of distinct but related cognitive functions that include alerting, orienting, and executive attention, and that involve a complex network of cortical areas (Braddick & Atkinson, 2011; Carrasco, 2011; Corbetta & Shulman, 2002; Scerif, 2010).

It has been theorized that both higher and lower level cortical attentional mechanisms must compete to help us selectively attend to task-relevant objects or object properties (Beck & Kastner, 2009; Desimone & Duncan, 1995). According to this biased competition theory of selective attention, high level, top-down processing mechanisms that are goal-driven compete with low level, bottom-up attentional control processes that are image-driven and highly influenced by salient stimuli (Beck & Kastner, 2009; Hegde, 2008; Kastner & Ungerleider, 2000). Top-down mechanisms include cognitive knowledge, assumptions, expectations, task-requirements, and goals, while bottom-up influences include saliency (loudness, brightness), and danger. Novelty, and 'unexpectedness' may also influence attention (Corbetta & Shulman, 2002).

Selective attention, also known as orienting attention has been referred to as "selection for action" (Braddick & Atkinson, 2011, p. 1597), and relates to an individual's ability to select certain information for processing while ignoring other information. Specifically, selective visual attention is "an internal mechanism for selecting certain visual codes for further processing at the expense of other visual codes" (Hollingworth, Schrock, & Henderson, 2001, p. 296). Selective visual attention literally puts a spotlight on those pieces of information we wish to process further, by determining (via a shift of gaze) which objects are moved on to the fovea, the area of the retina with the greatest resolution and acuity. Selective visual attention serves to highlight very specific visual information at the moment we need it during motor actions (Ballard et al., 1995). From a cortical perspective, it is believed that selective attention (particularly visuospatial attention) is mediated through a network linking the parietal lobe with frontal eye fields and the superior colliculus (Atkinson & Braddick, 2012; Carrasco, 2011; Nobre, 2001). This attention network is well connected to the dorsal stream of visual processing (Atkinson & Braddick, 2012; Braddick & Atkinson, 2011).

Further, visual attention is critically important for developing and maintaining visual memory representations (Hollingworth, 2006; Rensink et al., 2000). Visual short-term memory allows us to briefly store representations of objects and/or spaces to which we allocate our attention (Huebner & Gegenfurtner, 2010). According to visual memory theory (Henderson & Hollingworth, 2003; Hollingworth & Henderson, 2002), as we move our eyes to fixate different locations (thus attending to different bits of visual information), each eye movement encodes information from which we create detailed scene representations. These are stored initially in short-term memory and then later transferred to long-term memory. Visual attention to specific objects and/or locations with subsequent coding and storage of that information in short-term memory provides the mechanism whereby we are able to not only detect changes in our visual environment (Becker, Pashler, & Anstis, 2000; Brady, Konkle, Oliva, & Alvarez, 2009; Liu & Jiang, 2005), but also to direct our eye and hand movements appropriately (Hayhoe et al., 2003).

Vision and Attention in Skilled Motor Performance

Both vision and attention are fundamental to skilled action. Much has been written about the important role of vision as it relates to movement including the control of posture and locomotion, as well as the development and refinement of pointing, reaching, and grasping (Braddick & Atkinson, 2011; Carrico & Berthier 2008; Jeannerod et al., 1995; Land, 2006; Shumway-Cook & Woollacott, 2012). While it is true that not all motor tasks rely solely on vision for their completion, its contributions to skilled movement cannot be overstated (Schmidt & Lee, 2011; Sugden & Wade, 2013; Vickers, 2007).

Evidence highlighting the role of vision as it relates to skilled motor performance can be found in the field of sport. Much of this literature has concentrated on elucidating potential differences between athletes of differing skill levels and has investigated specifically their visual abilities, including their eye movements (Mann, Williams, Ward, & Janelle, 2007; Martell & Vickers, 2004; Vickers, 2011; von Lassberg, Beykirch, Campos, & Krug, 2012). Highly skilled athletes have been noted to differ from athletes of lower skill levels based on their eye movement patterns both while watching videotapes of sport play and while having their eye movements recorded when participating in sports. Faster detection of objects, more efficient visual search strategies, anticipatory gaze, and longer duration of tracking have been some of the features noted to be characteristic of higher-level athletes (Vickers, 2007). Likewise, the 'quiet eye', a gaze pattern studied extensively in sport, speaks to the necessity of vision for optimal motor control and learning (Vickers, 2009; Vine & Wilson, 2011; Wood & Wilson, 2012). The quiet eye is defined as the final gaze directed towards a specific object or location in the visual environment prior to the terminal motor action of a sporting task (Vickers, 1996). It is during the quiet eye phase that important information processing takes place to fine-tune a motor action. A quiet eye that occurs earlier and for longer duration during sporting motor performance is more typical of elite athletes and skilled performers (Mann et al., 2007; Vickers, 2007).

As is the case for vision, the study of attention during skilled motor performance has also concerned itself with differences in expert and novice performance within sporting endeavours (Ille, Selin, Do, & Thon, 2013; Lawrence, Gottwald, Hardy, & Khan, 2011; Lohse, Sherwood, & Healy, 2014; Wulf, 2007). Insights gained through this research have included an understanding of how attention shapes motor control but also how both the degree and target of attentional focus changes with the stage of motor skill learning. More experienced players (sport context) or motor performers (all motor skills) are often more freely able to allocate their attention, including their visual attention, away from the control of their body movements and towards other important aspects of their task goal. Such insights can be readily applied to most athletic endeavours but could just as easily apply to complex skills such as driving a car, playing a musical instrument, or performing surgery.

Developmental Coordination Disorder (DCD)

A significant number of children worldwide struggle to perform everyday motor tasks (e.g. throwing and catching a ball, learning to ride a bicycle, tying shoelaces, handwriting) because of poorly coordinated motor skills (Kadesjo & Gillberg, 1999; Lingam, Hunt, Golding, Jongmans, & Emond, 2009; Tsiotra et al., 2006; Wright & Sugden, 1996). They are recognized as having developmental coordination disorder (DCD), a prevalent neurodevelopmental disorder affecting approximately 5-6% of school-aged children (APA, 2013). By definition, they have no underlying medical or neurological condition to account for their poor coordination and they are of average or above average intelligence (APA, 2013).

Long-term Outcome and Secondary Consequences

The long-held belief that children with DCD would ‘outgrow’ their difficulties has now been refuted by strong evidence that the disorder continues to impact individuals throughout their lives (Cousins & Smyth, 2003; Drew, 2005; Fitzpatrick & Watkinson, 2003; Losse et al., 1991; Rasmussen & Gillberg, 2000). In addition, the primary motor impairment has been shown to adversely affect quality of life for these children (Rivard et al., 2012). Compared with their well-coordinated peers, children with DCD have a greater likelihood of developing depression, anxiety, poor fitness, and obesity, and they are more likely to be bullied, socially isolated, and to become academic underachievers (Gillberg & Gillberg, 1989; Losse et al., 1991; Piek, Barrett, Allen, Jones, & Louise, 2005; Piek, Bradbury, Elsley, & Tate, 2008; Piek et al., 2007; Rivilis et al., 2010; Schoemaker & Kalverboer, 1994; Skinner & Piek, 2001; Smyth & Anderson, 2000). There is a crucial need to intervene with these children in the early years to manage their motor difficulties and prevent secondary impairments (Missiuna, Rivard, & Bartlett, 2003).

Characteristics of DCD

Children with DCD share common movement characteristics. They are slower, use considerably more effort, and are more variable, and less accurate in their motor performance than children their age (Biancotto et al., 2011; Ferguson et al., 2015; Gueze, 2005**;** Henderson, Rose, & Henderson, 1992; Johnston, Burns, Brauer, & Richardson, 2002; Mackenzie et al., 2008; van der Meulen, Denier van der Gon, Gielen, Gooskens, & Willemse, 1991a, b). They have difficulty with motor learning (Gueze, 2005) and are often unable to recognize the similarities between motor tasks; they demonstrate a lack of attention to relevant environmental cues, and have difficulty transferring and generalizing skills to novel tasks with slightly different movement parameters or environmental contexts (Goodgold-Edwards & Cermak, 1990; Missiuna, 1994; Missiuna & Mandich, 2002; Missiuna, Mandich, Polatajko, & Malloy-Miller, 2001).

The Role of Vision in DCD

Despite substantial research investigating the etiology and pathogenesis of DCD, including its potential neural correlates, the cause of the disorder remains elusive (Groenwegen, 2003; Hadders-Algra, 2003; Peters, Maathuis, & Hadders-Algra, 2013; Visser, 2003; Zwicker et al., 2009). Several cortical areas have been implicated as the potential origin of their difficulties and these include the posterior parietal cortex, cerebellum, and basal ganglia, acting either alone or in concert (Debrabant et al., 2013; Geuze, 2005; Gramsbergen, 2003; Groenewegen, 2003; Kashiwagi et al., 2009; Maruff, Wilson, Trebilcock, & Currie, 1999; Peters et al., 2013; van Waelvelde et al., 2006; Wilson et al., 2004; Wilson, Maruff & Lum, 2003; Zwicker et al., 2009). While the underlying cause of DCD is, as of yet, still unexplained, researchers have consistently observed difficulties in how children with DCD use their vision. They have been observed to rely heavily on vision when completing motor tasks (Biancotto et al., 2011; Missiuna, 1994). A meta-analysis conducted by Wilson & McKenzie (1998) revealed difficulties in visual information processing including problems with visuospatial short-term memory, and learning and recall of visual information. A more recent systematic review (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013) presents a similar picture with respect to the visual deficits in DCD. In studies included in this review where either vision alone or both a visual and motor response were required, visuo-spatial difficulties continued to be noted as one of several core deficits in DCD.

Recent neuroimaging studies have furthered understanding of the neurobiology of DCD, specifically as it relates to vision and visual processing, confirming that different brain areas are activated in children with DCD compared to typically developing (TD) children during visuomotor tasks (without or without attention requirements) (Debrabant et al., 2013; Kashiwagi et al., 2009; Querne et al., 2008; Zwicker, Missiuna, Harris, & Boyd, 2010, 2012). In one functional magnetic resonance imaging (fMRI) study employing a visuomotor tracking task using a joystick, children with DCD demonstrated less activation of the posterior parietal cortex, specifically in the left hemisphere, an area the authors note is known for its role in visuomotor control including tool manipulation, and internal models of body positioning and movement (Kashiwagi et al., 2009). Another fMRI study using a similar design protocol and functional task (children were required to trace within a flower trail) showed that children with DCD activated different cortical areas than TD children, in particular those related to visual-motor and visuo-spatial processing, and they activated a greater number of brain areas, including those regulating attentional control (Zwicker, Missiuna, Harris, & Boyd, 2010). It is possible that children with DCD may not be able to 'free up' limited attentional resources to allocate to task-relevant perceptual cues, particularly when a motor response is required (Wilmut, Brown, & Wann, 2007; Wilson & Maruff, 1999). Given these deficits, a prevailing theory suggests that children with DCD may have difficulty developing and/or updating internal (memory) representations of motor tasks, which could then necessitate a dependence on vision over other sources of feedback (Adams, Lust, Wilson, & Steenbergen, 2014; Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Ferguson et al., 2015; Gabbard & Bobbio, 2011; Kagerer, Bo, Contreras-Vidal, & Clark, 2004; Kagerer, Contreras-Vidal, Bo, & Clark, 2006; Maruff et al., 1999; van Waelvelde et al., 2006; Wilmut et al., 2007; Wilson et al., 2004; Wilson et al., 2013).

Visual Attention in DCD

Over the last decade, several researchers have studied visual attention in children with DCD through paradigms investigating covert attention (defined as voluntary shifts of attention without accompanying eye movements) and using computer-generated visual stimuli (Chen, Wilson, & Wu, 2012; Tsai, Pan, Cherng, Hsu, & Chiu 2009; Wilson & Maruff, 1999; Wilson, Maruff, & McKenzie, 1997). This research has demonstrated that children with DCD experience difficulties with the voluntary control of visuospatial attention. As a result of these studies and the work of others (Mandich, Buckolz, & Polatajko, 2002, 2003; Wilmut et al., 2007), it has been further theorized that children with DCD lack the ability to disengage attention and/or inhibit voluntary responses because of slower response times. It has also been observed that the difficulty for children with DCD may lie specifically in the allocation of attention during motor tasks (Wilmut et al., 2007).

On a line of related inquiry, research evaluating a cognitive intervention approach has shown its effectiveness in assisting children with DCD to problem-solve the solutions to motor difficulties by drawing their attention to areas of poor performance (Miller, Polatajko, Missiuna, Mandich, & MacNab, 2001; Polatajko, Mandich, Miller, & MacNab, 2001). It is possible that the success of cognitive interventions with these children is dependent on cueing of their visual attention to assist them in focusing on relevant aspects of motor tasks. In order to test this assumption however, it is first necessary to have a greater understanding of the visual attention of children with DCD during functional motor tasks, a topic of research that is, as of yet, not fully explored. Experimental study designs incorporating the use of mobile eye tracking during motor performance would allow this to be accomplished.

Eye Tracking and Visual Attention

Given the strong link between eye movements and visual attention (Pieters, Rosbergen, & Wedl, 1999; van der Stigchel et al., 2009; Wilmut et al., 2007), eye tracking technology has the potential to reveal more in-depth information regarding visual attention patterns during motor performance as well as to provide further insights on the use of top-down and bottom-up attentional processes. While it is possible to shift attention without moving the eyes (covert attention shift) as has been done in previous empirical work, it is impossible to shift gaze without also making a shift in attention (Ross, Radant, Young, & Hommer, 1994; Snowden et al., 2012). Indeed, the shift in attention occurs prior to the onset of the oculomotor movements needed to shift gaze (Carrasco, 2011). Several types of eye movements can be recorded with great precision using eye tracking methods, the most common of which include saccades and fixations. Saccades are the eye movements made from one location to another when vision is suppressed; gaze fixations are the brief gaps between saccades when the eye is motionless or 'quiet' (Hollingworth & Henderson, 2002; Pieters et al., 1999). A greater understanding of visual attentional processes in children with DCD is necessary before fully exploring its potential role in cognitive interventions designed for this population: the use of an eye tracker with children with DCD may be advantageous in this regard.

Given the current gaps in our understanding of the selective visual attention capabilities of children with DCD, and the desire to maximize the effectiveness of therapy programs that rely on this understanding, the purpose of this thesis is to explore selective visual attention processes in children with and without DCD using a novel eye tracking paradigm. The results of this research will provide the groundwork necessary to design studies investigating the use of verbal attentional cueing of vision within cognitive interventions for children with DCD.

Overview of Thesis Manuscripts

Subsequent chapters in this thesis provide a more comprehensive literature review with regards to what is known about children with DCD (Chapter 2), and describe the design and implementation of two studies (Chapters 3 and 4) aimed at increasing our understanding of selective visual attention in children with DCD. Studies described in Chapters 3 and 4 employed an experimental design using an eye tracker and gaze analysis paradigm. It should be noted that there is very little duplication or overlap between chapters in the thesis. The literature reviewed in Chapter 2 has been further synthesized and condensed in order to incorporate the content into the brief introduction sections found in Chapters 3 and 4. In addition, the methods described in Chapters 3 and 4 are similar, with the description of the procedures significantly shortened from Chapter 3 to Chapter 4. A more detailed description of the content of, and contributors to, Chapters 2 through 4 is found below.

Chapter 2 of this thesis begins by providing a more detailed summary of all aspects of children with DCD. This chapter was published in the text *Physical Therapy for Children (4th Edition)*, under the chapter title "Developmental Coordination Disorder" (Rivard, Missiuna, Pollock, & David, 2012). This text is a leading resource used in the United States for educating entry-level physiotherapists. The chapter is comprehensive, covering all aspects of the presentation of DCD and clinical management, and is linked to electronic media throughout. The content of Chapter 2 (revised by the doctoral student, with review and feedback from co-authors) represents a substantive revision from the 3rd edition (David, 2006), with significant updating of content and re-organization. For the revision, the doctoral student re-wrote a majority of the chapter sections, and substantially updated all sections to reflect current evidence. Over 10 new sections were added, and 3 new comprehensive case scenarios were developed with details of clinical care practice decisions, accompanied by supporting research evidence. The extent of the update is reflected in 10 additional pages of content, and the inclusion of 150 additional references. As some of the chapter content from the 3rd edition was incorporated into the 4th edition, and in order to acknowledge her contributions, K. David was invited to be a co-author on the latter version, but did not make additional contributions. Subsequent to the chapter being developed, the content has informed a comprehensive, evidence-based, online module that is now available electronically to clinicians around the world (Camden, Rivard, Pollock, & Missiuna, 2012). This module contains extensive video clips and additional resources and can be found at dcd.canchild.ca. Finally, the doctoral candidate has just accepted an invitation to remain as senior author on a new edition of this chapter (5th Edition), to be published in 2015. The literature reviewed as part of this doctoral thesis, particularly content related to vision, attention, and internal models, will be incorporated into the 5th edition update.

Chapter 3 of this thesis presents the results of an eye tracking study involving 24 school-aged children, designed to explore and compare selective visual attention in both children with DCD and a comparison group of typically developing children. Comparisons are made across groups of children with respect to gaze fixation durations on important task objects (pouring cups, filling cups) during the performance of a novel pouring task. The innovative approach taken/design of this study was the original work of the doctoral student following doctoral course work. Discussion and collaboration with both the thesis advisory committee and vision researchers led to refinements in aspects of the task and analysis proposed by the student. All data were collected and analysed by the student, with the work being solely written by the doctoral candidate. This manuscript has been submitted to the journal *Human Movement Science* for peer review.

Chapter 4 reviews the eye tracking literature in greater depth and describes a study investigating the feasibility of using this novel method with children with DCD. Text in this section outlines the successes and methodological challenges experienced when using an eye tracker with this population, and provides recommendations for future eye tracking studies in DCD. In addition, this chapter reports specifically on the characteristics of a few children with DCD for whom eye tracking was not a feasible method to measure selective visual attention. This study was designed in collaboration with the thesis supervisory committee; all data collection, analysis, and writing of this chapter were completed entirely by the doctoral student, with feedback provided by the thesis supervisory committee as appropriate. Chapter 4 reports only on the group of children with DCD (Chapter 3 compared children with DCD and TD children). It is anticipated that this manuscript will be submitted for publication to either *Research in Developmental Disabilities* or *Vision Research*.

Finally, Chapter 5 outlines the significance and clinical and research implications of the work presented here, placing the thesis findings within the context of the current DCD literature. This chapter discusses the contributions of the two studies described in this thesis to our current understanding of children with DCD, their selective visual attention, and to the future use of eye tracking methods to measure selective visual attention with this population. In closing, implications for the design of cognitive interventions to maximize the quality of life for children with DCD are explored.

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Chapter Two

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SECTION III Management of Neurologic Impairment

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16 Developmental Coordination Disorder (DCD)

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Pediatric physical therapists evaluate and manage care for children presenting with a variety of motor challenges. They observe children's movement skills and ask key questions about children's motor abilities and development to differentiate among motor behaviors that are characteristic of particular conditions. This differentiation guides their selection of a course of intervention. Some of the children whom physical therapists observe are quite a "puzzle" to figure out. These children frequently trip over their feet and bump into others with clumsy, awkward movements. They may have an unusual gait pattern, or a unique way of "fixing" or stabilizing their joints. Despite these differences, they are often observed to reach their motor milestones within normal age limits. Many of these children appear to have difficulty generalizing learned motor skills across settings or transferring skills to other contexts. Each child with motor difficulties such as these presents a little differently from the others, making it difficult to develop and apply a treatment approach. The children who are captured by this description are those who have developmental coordination disorder (DCD).[4]

Approximately 5% to 6% of school-age children have movement difficulties, unrelated to specific neurologic conditions or cognitive impairment, that limit their potential and affect their long-term academic achievement.[4] Recently, the prevalence rate for the most significantly impaired children in a United Kingdom (U.K.) birth cohort of 6990 children aged 7 to 8 years was close to 2% of the population.[115] These children struggle with everyday functional tasks such as dressing, throwing and catching balls, and learning to ride a bicycle.[10,64,129,135,136] They experience daily frustration with activities that are effortless for their peers, and, as a consequence of their motor problems, they may demonstrate additional difficulties, including poor perceived competence, social isolation, low self-worth, anxiety, and depressive symptoms, even at early ages.[60,163–165,194,195,204,212,217] These difficulties are characteristic features of developmental coordination disorder (DCD), a condition in which poorly developed fine and/or gross motor coordination has a substantial impact on motor skill performance with far-reaching consequences for daily life activities and scholastic achievement.[4] Although it was once believed that these difficulties would diminish with time and maturation, compelling evidence now suggests that DCD is a lifelong condition,[25,39,49,56,119] making this disorder one that warrants significant attention.

Physical therapists have a unique service to offer children with DCD and their families. Therapists' understanding of normal and abnormal motor control, motor learning, and motor development can be used to identify and evaluate the condition, and to plan programs for children with DCD. Through education of children with DCD and their families, teachers, and others in the community, physical therapists can help children with DCD become more active and successful participants in their home, school, and community life.

The information presented in this chapter is intended to increase awareness, recognition, and understanding of children with DCD. The complex nature of DCD and its challenges for clinical management are described. The role of the physical therapist in managing children with this disorder and intervention approaches shown to be effective with children with DCD are explored. Evidence is presented to support the need for a multidisciplinary assessment, and tailored, family-centered intervention with collaborative consultation is emphasized. Three case studies conclude the chapter and serve to illustrate the heterogeneity of the disorder—a factor that greatly influences the decision-making process and strategies employed in the management of a child with DCD. Resources available for children with DCD and their families, as well as health professionals involved in their care, are provided on the Evolve website.

HISTORICAL BACKGROUND

A disorder of "clumsiness" whose key feature is poor motor coordination has been recognized and described for over a century. Much of our current understanding of DCD, however, has resulted from an explosion of research in the field over the past two decades.[124] DCD is a childhood disorder that is of interest to numerous professionals in the medical, rehabilitation, and education fields. Clinicians and researchers, each adopting various perspectives on the condition, have utilized diverse theoretical frameworks in their study of children with DCD. This wide-reaching interest in DCD has provided fertile ground for the development of knowledge about the condition. Historically, however, this diversity in perspectives has also led to a lack of consensus, impacting the progression of research in the field. Different labels have been ascribed to children with DCD, including the clumsy child syndrome,[76] the physically awkward child,[237] developmental dyspraxia,[31] sensory integrative dysfunction,[7] disorder of attention, motor and perception (DAMP),[71] and minor coordination dysfunction,[242] each reflecting the perspectives of professionals who work with these children.[143] In 1994 an international consensus exercise was undertaken,[174] and the term *DCD* was adopted to unify descriptions of children with significant motor incoordination. This decision, in part, was grounded in the recognition that DCD had become an officially recognized movement skills disorder.[3] Recently, a second international consensus conference recommended maintaining use of the term *DCD*.[225] Although *DCD* is the term most widely used in the literature, other terms continue to appear, highlighting the diverse perspectives of researchers who study children with motor difficulties.

DEFINITION AND PREVALENCE

DCD is a chronic condition involving impairment in gross motor, postural, and/or fine motor performance that affects a child's ability to perform the skilled movements necessary for daily living, including the performance of academic and self-care tasks. By definition, DCD is not attributable to a known neurologic or medical disorder.[4] The manifestation of the disorder varies across children, with a spectrum of severity. DCD would be included under the *Guide to Physical Therapist Practice*[2] diagnostic group 5C: Impaired Motor Function and Sensory Integrity Associated With Nonprogressive Disorders of the Central Nervous System—Congenital Origin or Acquired in Infancy or Childhood.

Research performed in many countries around the world has confirmed that large numbers of children are affected by this childhood motor disorder.[58,69,95,102,115,261] Although DCD is highly prevalent in school-age children, it has only recently received worldwide recognition.[4] Attention is increasingly being paid to this disorder because of the impact of children's primary motor limitations on everyday life. The American Psychiatric Association (APA) estimates that DCD affects 5% to 6% of school-age children. Although it is commonly accepted that boys with DCD outnumber girls by a 2:1 ratio,[4] recent population-based studies of children with DCD would suggest that more equal numbers of boys and girls may be affected.[24] The prevalence of DCD appears to be substantially higher than average in preterm populations.[37,43,73,93,251,259] It has also been noted that, over time, preterm/low birth weight infants tend to exhibit poor coordination and many of the physical consequences associated with DCD such as decreased aerobic fitness, strength, and physical activity levels.[190]

DIAGNOSIS

DCD is present when (1) motor impairment and/or motor skill delay significantly impacts a child's ability to perform age-appropriate complex motor activities, (2) adequate opportunities for experience and practice have been provided, and (3) no other explanation can be offered for the motor impairment.[198] In most states and provinces, a diagnosis of DCD can be made only by a physician because it is critical to rule out any other underlying neurologic or medical reasons for the observed motor impairment. Four distinct criteria must be met for a diagnosis of DCD to be given, as outlined in the *Diagnostic and Statistical Manual of Mental Disorders* (Box 16-1)[4]: (A) The motor impairment

Box 16-1 DIAGNOSTIC CRITERIA FOR DEVELOPMENTAL COORDINATION DISORDER (DCD)

- Performance in daily activities that require motor coordination is substantially below that expected, given the person's chronologic age and measured intelligence. This may be manifested by the following:
  - Marked delays in achieving motor milestones (e.g., walking, crawling, sitting)
  - Dropping things
  - "Clumsiness"
  - Poor performance in sports
  - Poor handwriting
- The disturbance significantly interferes with academic achievement or activities of daily living.
- The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, muscular dystrophy) and does not meet criteria for a pervasive developmental disorder.
- If mental retardation is present, motor difficulties are in excess of those usually associated with it.

American Psychiatric Association (APA). (2000). *Diagnostic and statistical manual of mental disorders, fourth edition, text revision (DSM IV-TR)*. Washington, DC: American Psychiatric Association.

must be substantial and discrepant from other abilities, (B) it must have an impact on academic achievement or activities of daily living (ADLs), (C) it must not meet the criteria for a pervasive developmental disorder (PDD) (see Chapter 17 on children with cognitive and motor impairment); and, (D) if accompanied by cognitive difficulties, it must be greater than what would be accounted for by that cognitive impairment.[4] Recently, it has been recommended that if the criteria for diagnosis of PDD are met, both diagnoses should be given.[225] Physical therapists have an important role to play in facilitating a diagnosis of DCD by assisting physicians with confirmation of whether a child meets both criteria A and B of the DCD diagnostic criteria. This will be discussed in greater detail later in this chapter.

DCD usually is not considered to be present if (1) recent head injury or trauma has occurred, (2) progressive deterioration in previously acquired skills is evident, or (3) increased or fluctuating muscle tone is present. DCD also would not be suspected routinely where there is a history of headaches or blurred vision, when evidence of asymmetrical tone or strength is observed, or when musculoskeletal abnormalities or Gowers' sign are present (Box 16-2).[77,138] If children do not show any of these signs but demonstrate uncoordinated movements and motor abilities below those expected for their age, they may have DCD, and it is important for these children to be seen by a physician. A medical practitioner can rule out other possible causes for poor coordination, including genetic causes (e.g., Down syndrome), neurologic disorders (e.g., cerebral palsy), degenerative conditions (e.g., muscular dystrophy, brain tumors), musculoskeletal abnormalities (e.g., Legg-Calvé-Perthes disease), physical impairments (e.g., impaired visual acuity), cognitive impairment (e.g., developmental delay), pervasive developmental disorder (e.g., autism), and head injury (e.g., traumatic brain injury) (Box 16-3).[77,138] See respective chapters in this volume for further information on these other conditions.

Box 16-2 Developmental Coordination Disorder (DCD)—Differential Diagnosis

Coordination difficulties are likely not DCD when a history of any of the following is reported:
- Recent head injury or trauma
- Deterioration in previously learned or acquired skills
- Headaches, eye pain, blurred vision
- Global developmental delays
- Increased muscle tone, fluctuating tone, or significant hypotonia
- Asymmetrical tone or strength
- Musculoskeletal abnormality
- Neurocutaneous lesion
- Avoidance of eye contact, unwillingness to engage socially
- Gowers' sign (difficulty rising to a standing position)
- Ataxia, dysarthria
- Absence of deep tendon reflexes
- Dysmorphic features
- Visual impairment (untreated)

From Missiuna, C., Gaines, R., & Soucie, H. [2006]. Why every office needs a tennis ball: A new approach to assessing the clumsy child. *Canadian Medical Association Journal, 175*, 471–473.

CO-OCCURRING CONDITIONS

Strong associations have been demonstrated between DCD and attention deficit hyperactivity disorder (ADHD), speech/articulation difficulties (specific language impairment [SLI]), and language-based learning disabilities (LDs) (in particular, reading disability).[47,61,89,99,101,166,168,181,230,244] When a child has any of these conditions, the likelihood that DCD is also present is at least 50%. When criteria for more than one disorder are met, more than one diagnosis should be given.[4,225] It is recognized that the presence of co-occurring conditions may increase the probability of negative outcomes.[12,181,204] In particular, children who have DCD in addition to ADHD have a significantly poorer outcome in terms of academic achievement and mental health than children with ADHD alone.[83,181,230] It is important to determine whether or not motor coordination problems are present, and whether they are occurring in combination with another recognized condition. Knowledge of a child's complete profile (including associated conditions) will assist in the identification process and will help to determine intervention and management strategies. The frequently documented association between other developmental disorders and DCD underscores the need for a multidisciplinary assessment.

Box 16-3 Developmental Coordination Disorder

Medical and neurologic disorders that can be associated with motor incoordination must be excluded before a formal diagnosis of DCD is made. These include the following:
- Genetic disorders (e.g., Down syndrome)
- Neurologic disorders (e.g., cerebral palsy)
- Degenerative conditions (e.g., Duchenne's muscular dystrophy, brain tumor)
- Musculoskeletal disorders (e.g., Legg-Calvé-Perthes disease)
- Physical impairments (e.g., impaired visual acuity)
- Cognitive impairments (e.g., developmental delay)
- Pervasive developmental disorders (e.g., autism)
- Injuries (e.g., traumatic brain injury)
- Environmental contaminants (e.g., lead, pesticides)

From Missiuna, C., Gaines, R., & Soucie, H. [2006]. Why every office needs a tennis ball: A new approach to assessing the clumsy child. *Canadian Medical Association Journal, 175*, 471–473.

LONG-TERM PROGNOSIS

Longitudinal research clearly demonstrates that, without intervention, children with DCD do not "grow out of" the disorder. Strong evidence indicates that the motor problems of childhood persist into adolescence and adulthood.[25,39,49,56,119] In fact, children with DCD are at risk of developing serious negative physical, social, emotional, behavioral, and mental health consequences that are not limited to the presenting motor difficulties. Multiple studies have shown that, over time, children with DCD are more likely to demonstrate poor social, academic, and physical competence, social isolation, academic and behavior problems, poor self-esteem, low self-efficacy, victimization, and higher rates of psychiatric and mental health problems.[26,34,53,65,119,163,167,181,194,204,212,217]

Children with DCD engage in less vigorous play and spend significantly more time away from the playground area than their peers.[12] They spend more time alone on the playground and spend less time in formal and informal team play.[217] Many researchers have shown that they are less likely to be physically fit or to participate voluntarily in motor activity, predisposing them to an inactive lifestyle.[12,156,183,241] Their reduced physical activity participation and the associated risks for long-term obesity and poor cardiovascular health are now being documented.[19–22,54,81,207] Although this picture of the numerous consequences associated with motor impairment appears dire, the potential exists for positive trajectories and pathways of resilience.[146] The long-term outcome of the disorder is influenced not only by the severity of impairment and co-occurring conditions, but also by the presence of supportive environments and the strengths of individuals with DCD, including their coping mechanisms. It is possible to "tip the scale" in favor of more positive outcomes,[141] and physical therapists can be instrumental in preventing secondary impairments, which often become areas of greater focus as children mature.

The increased risk for children with DCD of secondary health issues and academic failure highlights the need to identify children with DCD as early as possible.[149] Early identification may facilitate the education of teachers and parents about how to make tasks easier and how to ensure that activities are matched to children's capabilities. In this way, children with DCD can be provided with optimally challenging situations that emphasize mastery and avoid multiple failed attempts.[150]

DESCRIBING CHILDREN WITH DCD

The International Classification of Functioning, Disability, and Health (ICF) provides a useful framework for understanding and describing the difficulties experienced by children with DCD.[260] In the ICF model, observable sensory/perceptual and motor impairments, at the level of body structure and function, can lead to difficulties with skill acquisition, and task performance or activity limitations. These activity constraints, in turn, can place limitations on participation in the many aspects of daily life, conceptualized in the ICF framework as participation restrictions. In addition, personal and environmental factors are seen as important mediating factors at each of these levels (Table 16-1).

BODY STRUCTURE AND FUNCTION

Any description of children with DCD is influenced by the heterogeneity of the condition. The presentation of DCD is somewhat age dependent, is highly variable across children,

TABLE 16-1 **Relationships Among Body Structures and Function, Activity, and Participation for a Child With Developmental Coordination Disorder (DCD)**

Health Condition	Body Structure and Function	Activity Limitations	Participation Restrictions—Environmental Factors	Participation Restrictions—Personal Factors
Unknown/possibly heterogeneous nervous system insult (of prenatal, perinatal, or postnatal origin)	Soft signs: Poor strength Poor coordination Jerky movements Poor visual perception Joint laxity Poor spatial organization Inadequate information processing Poor sequencing Poor feedback and feed forward motor control Poor short- and long-term memory	Awkward, slow gait Delayed and poor quality of fine and gross motor skills, such as hopping, jumping, ball skills, and writing Delayed oral-motor skills	Doors too heavy to open Physical education is competitive and skill oriented Late to class because passing time is too short Time to dress and undress reduces participation in recess and readiness for home and community activities Slow and messy written communication in class limits academic performance Peers don't wait to try to understand conversations	Depression Quit trying to participate, unmotivated Low self-esteem Poor fitness Activities performed without concern for time restrictions Vocational anxiety

TABLE 16-2 **Impairments of Body Structure and Function Identified in Children With Developmental Coordination Disorder (DCD)**

Body Function	Reference
Visual-perceptual, visual-spatial, and visuomotor impairment	Mon-Williams et al., 1999[153]; O'Brien et al., 1988[157]; Wilson & McKenzie, 1998[257]
Inefficient use of visual feedback in fast, goal-directed arm movements	van der Meulen et al., 1991[232]
Impaired visual memory	Dwyer & McKenzie, 1994[52]
More dependent on visuospatial rehearsal to memorize	Skorji & McKenzie, 1997[213]
Difficulty with visual and motor sequencing tasks requiring short- and long-term recall	Murphy & Gliner, 1988[154]
Impairments of size-constancy judgments, spatial position, and visual discrimination	Lord & Hulme, 1987[117]
Slow performance related to reliance on information feedback rather than feed forward programming	Missiuna et al., 2003[149]; Rosblad & van Hofsten, 1994[193]; Smyth, 1991[220]
Slow reaction time and movement time related to impaired response selection	Raynor, 1998[182]; Van Dellan & Geuze, 1988
Prolonged response latency related to the process of searching for and retrieving the correct responses with reliable timing	Henderson et al., 1992[86]
Poor timing, rhythm, and force control	Lundy-Ekman et al., 1991[120]; Volman & Geuze, 1998[236]; Williams et al., 1992[250]
Impaired performance on kinesthetic acuity, linear positioning, and weight discrimination	Hoare & Larkin, 1991[92]
Prolonged burst of agonist activity and delayed onset of antagonist activity	Huh et al., 1998[94]
Reduced power and strength	Raynor, 2001[183]
Reduced ability to successfully inhibit an action	Mandich et al., 2002[125]

and is complicated by the possible presence of co-occurring conditions. This variability in presentation has led investigators to examine multiple sensory and motor processes that contribute to the development of motor coordination. In a recent review of research into possible underlying mechanisms for DCD, primary impairments at the level of body structure and function have been proposed in the sensory, motor, and sensorimotor domains (Table 16-2).[235]

Primary Impairments

Sensory/Perceptual Deficits

Early research on children with DCD focused on possible impairments in visual, kinesthetic, and proprioceptive processing. Children with DCD were shown to have difficulties with visual-spatial processing, including determining object size and position, as well as with visual memory. Children with DCD have also demonstrated a limited ability to use visual rehearsal strategies.[52,257] More recent research suggests that in children with DCD, visual feedback is managed differently and is processed more slowly than in typically developing children.[255,264] Children with movement problems have also shown deficiencies in kinesthetic processing, have poor proprioceptive function,[111,221] and demonstrate a heavy reliance on visual feedback to guide task performance.[86,134,171,263] This predominant use of vision to control movement is observed well beyond the age at which typically developing children would rely on vision.[134,213,219] As a result, children with DCD lack automation in their movements and remain at an early stage of motor learning for much longer.

Because both visual and kinesthetic perceptual deficits have been demonstrated in groups of children with DCD, it has been suggested that the deficit may not be confined to one specific sensory modality, but may be multisensory in nature.[252] This seems plausible given that fluent, coordinated movements require multiple processes to plan, execute, and, when necessary, correct motor activity. Further, the motor impairments could be accounted for by impaired perception-action coupling or poor integration of the senses, including poor "mapping" of visual and proprioceptive information with the motor system.[153,191,210,218,264]

Research examining different profiles, or subtypes, of children with motor impairment has contributed to understanding in the area of possible sensory/perceptual deficits. Although studies have differed on the specific clusters of children identified and the individual characteristics of the subgroups, there appears to be general agreement that there is a group of children who demonstrate a generalized, and often significant, perceptual deficit, including both visual and kinesthetic difficulties.[46,91,122,151] Questions remain, however, in that these specific perceptual deficits have not been shown to be present in all subgroups with motor impairment. This again serves to underscore the heterogeneity of the condition and suggests that different profiles of motor coordination problems may exist in children with DCD with varying sensory/perceptual impairments.

Motor Deficits

Children with DCD move awkwardly and slowly, with a rigid, jerky quality to their movements.[5,103,247] They frequently bump into objects and people and have a tendency to trip and fall.[107] Poor balance, especially pronounced during single-leg stance, and difficulty maintaining postures are often noted (see video of Bill for an example of a child with similar problems).[247] To compensate for their instability, children with DCD may demonstrate many associated movements.[107] On physical examination, decreased muscle tone and neurologic soft signs can often be observed. This constellation of physical signs, combined with the possible sensory deficits outlined previously, have led many to hypothesize that the origins of the motor impairments seen in children with DCD may lie in faulty motor control and motor learning processes.

Motor Control Deficits

Children with DCD demonstrate inappropriate and ineffective neuromuscular strategies, both in muscular activation and in sequencing. This is particularly evident in their use of atypical postural control strategies,[92,247] including when their balance is challenged.[249] An increased level of muscle co-contraction has also been described, in which children with DCD demonstrated a much less effective method of muscular organization than their peers, which did not improve with age.[183] Children with movement difficulties tend to "fix" or stabilize their joints during task performance.[183,209] The deliberate stabilization of their joints in this way leads to lack of fluency in their movements[149] and contributes to their stiff, awkward, and clumsy appearance[209]; it also increases the time it takes them to adapt to changes in their movement environment.[134] Fixing can be thought of as a strategy to control the multiple degrees of freedom of joints and muscles for efficient functioning. Children with DCD who "fix" their joints during task performance are more likely to fatigue[161] and to demonstrate inconsistency in task performance.[134,209] Overall, the postural fixation and atypical muscular activation and sequencing seen in children with DCD result in less efficient movement patterns and reflect a less skilled stage of movement acquisition than is typical of age peers.

When performing reaching tasks, children with DCD use different neuromuscular strategies than their typically developing age-matched peers, contributing to their slower and more variable movement and reaction times, as well as their movement inaccuracy. These findings have been consistently described in the literature.[68,86,97,120,121,221,232,233,236,245,247,250] Children with DCD display gait differences, which have also been suggested to be a result of their movement variability.[197] Decreased and variable force control and difficulties with temporal precision (both movement production and time perception) have also been noted in the motor control literature.[63,86,97,236,245,248,250]

As can be seen from extensive motor control research, in comparison with their typically developing peers, children with DCD demonstrate variations in movement speed, timing, and force across a series of different tasks, resulting in qualitative differences in their movement and motor control patterns.

Motor Learning Deficits

In addition to poorly controlled movements, children with DCD exhibit limited movement repertoires, lacking both adaptability and flexibility in their motor behavior.[110] This, along with the variability and inconsistency seen in their motor performance, suggests difficulties in motor learning processes.[6,68] Evidence from subtyping and other research would suggest that, although some children with DCD exhibit problems primarily in execution and control of movements, others have difficulties related to motor planning processes.[64,67,216,220]

As has been previously described, children with DCD demonstrate movements that are inaccurate and lack fluency, as they are unable to accurately correct their movement patterns through error detection or feedback. Although these children may achieve motor milestones within normal time limits, they have difficulty learning new motor skills.[85,134] They fail to see the similarities between motor tasks and thus are unable to transfer learned skills from one activity to a closely related activity. They also experience difficulty generalizing from one context or situation to another. Both of these processes reflect an early, more cognitive stage of motor learning (see Chapter 4 for more information on motor learning).[72,134,139,140] According to motor learning theory, as skills are learned, feedback requirements lessen and change, with proprioceptive and kinesthetic feedback relied on more than visual input.[55] Children with DCD continue to rely predominantly on visual information, as if they were still in the early stages of motor learning. As a result, their motor performance is sometimes more similar to that of younger children than to that of age peers.[117,118,239]

Children with coordination difficulties have also been described as repeating tasks the same way over and over again, regardless of their success with the task.[85,128] They appear to have difficulty understanding the demands of a task and its component parts, interpreting environmental cues, and selecting the best motor response for a task.[72] As a result, they do not effectively use the feedback originating from knowledge of their past performance to prepare for upcoming actions (anticipatory preparation), and they have difficulty adapting to situational demands.[67,72,134,139] It has been postulated that children with DCD might attend to the wrong cues and not to the more salient aspects of available feedback.[72] Others have suggested that the problem might lie in the failure of children with DCD to use anticipatory control strategies for motor tasks[247]; as a result, they might have to rely heavily on a feedback or closed loop strategy to control movement.[191,193,216]

In summary, children with DCD have difficulties with error detection and movement correction during the execution of motor skills. This is especially evident when motor tasks are complex and involve spatial uncertainty.

Secondary Impairments

Physical

Although slow, awkward movements are typical of children with DCD and are easy to casually observe (e.g., see video of Bill), what is less evident is the extra effort that motor skills seem to require and the struggle that children have in making adaptations and in "fine-tuning" movements.[28] Secondary impairments related to primary motor coordination difficulties are of considerable concern and include lack of energy and fatigue, as well as decreased strength, power, and endurance.[156,183] Children with DCD complain of being tired more easily than their peers and are often exhausted by the end of the day as they must exert more effort during motor-based activities at school and at home.[107] Maintaining their posture for extended periods of time is fatiguing for these children, so they may try to lean against the wall or on other children when standing or may assume a slouched posture when sitting (Figure 16-1). Recent strong empirical evidence indicates a progressive decrease in strength and power in children with DCD over time, which is already apparent between the ages of 6 and 9 years.[183] Obesity in children with DCD and the relationship between their motor difficulties and cardiovascular risk factors have begun to be studied in greater detail.[20,54] As will be discussed later in this chapter, these secondary sequelae are precursors for participation restrictions in sporting and/or leisure activities, reduced opportunities for social interaction, and diminished physical fitness across the life span. Secondary impairments in children with DCD may be preventable and are appropriate targets for physical therapy.

Social/Emotional/Behavioral

Often children with DCD demonstrate associated behavioral problems that become the focus of concern, especially in the classroom.[187] Children with DCD may be quiet and withdrawn at school, with avoidance of schoolwork and frequent "off-task" behaviors.[32,33,136] Alternatively, children may act out in class, disrupting the teacher and/or others.[129] Learning new skills in physical education is a continuous challenge (e.g., see video of Bill), and children may try to avoid these classes with complaints of illness or problem behaviors. Avoidance of written work can result in "behaviors" such as needing to sharpen the pencil multiple times, talking and asking questions, attention seeking, and interference with other children. Low frustration tolerance, decreased motivation, and poor self-esteem are commonly observed.[204,212] Children with movement difficulties give up on tasks easily, which occasionally leads to angry, aggressive classroom behavior. Task initiation and task completion are often major issues, both at home and at school.[136]

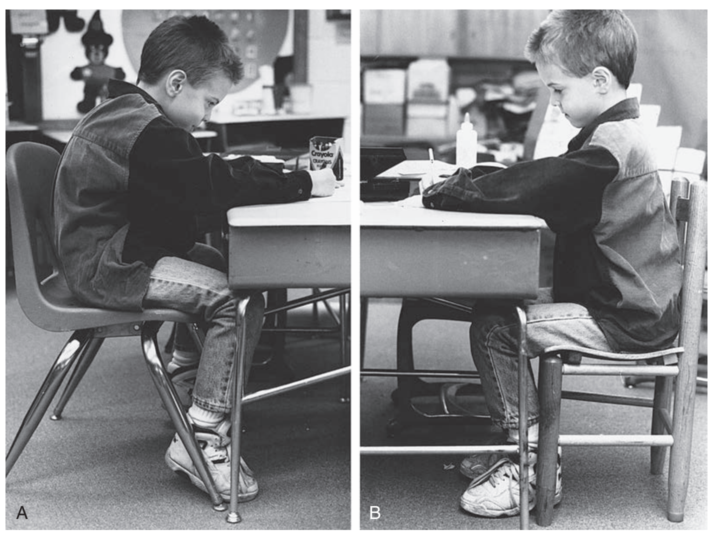

Figure 16-1 **A,** This child demonstrates poor posture that interferes with fine motor classroom activities. **B,** A different desk and chair improve this child's posture and improve the precision of his fine motor activities.

Like the physical impairments outlined previously, these associated social, emotional, and behavioral difficulties can be significant but are not inevitable. All efforts should be made through early identification and management to prevent their occurrence.

ORIGIN AND PATHOPHYSIOLOGY

Although much has been learned regarding the body structure and function deficits of children with DCD and the potential sensory, motor control, and motor learning processes affected, the origin of the disorder remains poorly understood.[235,265] Currently, no specific pathologic process or single neuroanatomic site has been definitively associated with DCD, but many behavioral studies, in particular studies on co-occurring conditions and possible subtypes of DCD, have led researchers to speculate as to the underlying mechanism(s) involved in DCD. Some researchers have postulated that diffuse, rather than distinct, areas of the brain may be affected, resulting in the variable expression of the disorder and the different profiles seen in children with DCD (including co-occurring conditions).[104] This would imply that the specific combination of co-occurring disorders depends on the location and severity of neurologic insult. This theory, however, does not take into account cases where developmental disorders occur alone.[235] Other researchers highlight the strong association between motor, attention, and perceptual processes[70] and point to the possible role of neuroanatomic structures such as the cerebellum and basal ganglia.

Research studies employing a dual-task paradigm indicate a lack of automatization of motor actions in children with DCD when attentional demands increase.[35,113] These findings implicate the cerebellum as a possible site of pathophysiology in children with DCD, given its known role in the automatization and learning of motor tasks.[27,108,200] The thinking behind the interference seen in dual-task paradigms is that performance of one task will be negatively affected by the second if both tasks need to make use of the same "pool" of resources, including visual and cognitive resources. Concurrent work examining motor adaptation, or the ability of children with DCD to adapt their performance to changing environmental contexts, comes to a similar conclusion with respect to the potential role of the cerebellum in children with DCD. In these studies, children with motor difficulties show poor adaptation to gradual changes in environmental stimuli.[13,27] Given the rapid growth and vulnerability of the developing cerebellum to external events in the first year of life, theories regarding the possible link between cerebellar involvement and motor impairments are plausible.[74] Although the proposed link between motor coordination difficulties and the role of the cerebellum appears to be strong,[265] especially in situations of co-occurring conditions,[158,166] testing of causal models will be necessary to confirm these hypotheses.

Another avenue of research includes the investigation of motor imagery deficits in children with DCD. Understanding in this area has led to a proposal that impaired feed forward models could be a potential mechanism underlying DCD (efference-copy-deficit hypothesis).[256,258] In this theory, motor imagery deficits seen in children with DCD are related to difficulties in generating efference copies of motor commands through feed forward models, pointing to the possible involvement of the posterior parietal cortex.[256]

Recently, increasing interest in the possibility of impaired internal models can be seen in the DCD literature.[103] Internal models are neural representations of the visual-spatial coordinates of intended motor actions.[131] It has been hypothesized that children with motor impairment may have inadequate forward modeling of movements and are unable to form, access, or update their internal models, which results in poor "online" error correction and ultimately affects motor learning.[216] It is believed that internal models are located in the cerebellum.[265] Parallel work investigating the role of "mirror neurons" (which are housed in the ventral premotor and posterior parietal cortices) has shed additional light on how motor representations are formed not only during the performance, but also in the observation, of movements.[131,188] Mirror neurons in the posterior parietal cortex may work in concert with internal models in the cerebellum through extensive neural projections between these two brain structures to code and update movement.[131]

Taken together, behavioral studies suggesting involvement of the cerebellum, research investigating motor imagery deficits in children with DCD, and the recent discovery and understanding of the role of mirror neurons suggest that a complex and shared interplay may occur between different neuroanatomic regions of the brain when learning, executing, and correcting movements. Research studies employing neurodiagnostic technologies such as functional magnetic resonance imaging and electroencephalography are becoming more prevalent in the literature investigating possible mechanisms involved in DCD.[159,266] Combined with behavioral research, these experimental studies will likely shed more light on the potential neuroanatomic sites involved in the pathophysiology of DCD.

In the end, why are there so many plausible theories regarding the origin of DCD and so many proposed sites of neurologic abnormality? The production of well-coordinated, smooth motor movements is a complex process requiring multiple levels of information processing, each of which requires different abilities such as sensory acuity, memory, decision making, attention, perception, feedback, and feed forward mechanisms. It is likely that children with DCD may have impairments in one or more of these functions and in related brain areas, and that different groups of children may have abnormalities in different neural correlates.[74,96,265] Other possible influencing factors have already been alluded to earlier in this chapter. The heterogeneity of the disorder and the presence of co-occurring conditions give rise to different profiles of impairment, which may indeed have different underlying neural mechanisms.

ACTIVITY LIMITATIONS

How do the proposed body structure and function deficits manifest themselves in a practical sense? Children with DCD tend to have the greatest difficulty with skills that must be taught. In particular, skills requiring accuracy and refined eye-hand coordination and that require constant monitoring of feedback pose significant challenges for the child with DCD.[140,225] Children with DCD may experience difficulty with fine motor activities, gross motor activities, or both (see video of Bill).[123] These activity limitations are readily observable in the classroom, on the school playground, and at home.[32,136]

Fine Motor Activity Limitations

Self-Care

The ability of children with DCD to perform self-care activities such as doing up snaps, zippers, and buttons, tying shoelaces, opening snack containers, and managing juice boxes is poorer than expected for their age. Tying shoelaces is an example of a skilled activity required at school by the time a student is in first grade. Children with impairments in sequencing skills cannot correctly sequence the steps in shoe tying, even though they may have practiced it many times before. When children with DCD make a mistake in one step of the sequence, they have to start over again rather than simply redo the last step. Or they might omit a different step in the sequence each time they try to tie their shoes (Figure 16-2). At home, parents notice difficulties when children are using cutlery, and there is a tendency to spill liquid from drinking glasses or when pouring from a container. Parents also describe problems with grooming such as bathing, combing hair, and brushing teeth.[129,136,228] At school, children with movement difficulties are often the last to get snowsuits, jackets, and boots on, or to get their knapsacks organized to go home at the end of the day.

Academic

Classroom fine motor difficulties include problems with printing and handwriting (Figure 16-3).[9,132,136] Written work is illegible and inconsistent in sizing and requires great effort.[160,161] Frequent erasures of work, inaccurate spacing of words, and unusual letter formation are evident.[107] Pencil/crayon grasps are awkward, and written work is not well aligned. Pencils may be dropped frequently and pencil leads broken or paper torn as the result of excessive pressure on the page.[28,107] Because of this, teachers and parents often note that children with DCD have difficulty finishing academic tasks, including homework, on time. Children with these difficulties tend to rush through tasks or may be unusually slow (see video of Bill). Academic tasks that have a motor component require extra effort and attentional resources. Children with DCD can become fatigued and frustrated, as they work harder than children their age to complete the same activity. Teachers often describe a large discrepancy between their oral and written work. Copying from the board and other fine motor tasks such as completing puzzles and turning door handles or washroom taps are also affected. Many children with DCD tend to avoid art projects and craft activities that require coloring, cutting, and pasting.[129,142] In addition, they may be intolerant of sensations such as those encountered at rice, sand, and water tables, or during finger painting activities.[105]

Overall, children with DCD, in comparison with typically developing children of the same age, have been noted to require more support and assistance from those around them to complete motor-based self-care and academic tasks at home and at school.[137,228]

Figure 16-2 This 8-year-old boy still cannot independently tie his shoes. His verbal cues were "loop around and go through." He forgot to "loop around" and forgot to make a second loop.

Gross Motor Activity Limitations

Lacking good balance and postural control, children with DCD often have difficulties with the flexibility and adaptability required for gross motor activities. They may show delays each time they learn a novel skill such as riding a push toy, learning to ride a tricycle or bicycle, and pumping a swing.[107,129,136] They demonstrate poorly coordinated running, skipping, hopping, and jumping and may have difficulty managing stairs, especially when they must maneuver around others (Figure 16-4).[9,32,42] Coordination of eyes and hands at a whole body level is problematic, so children with

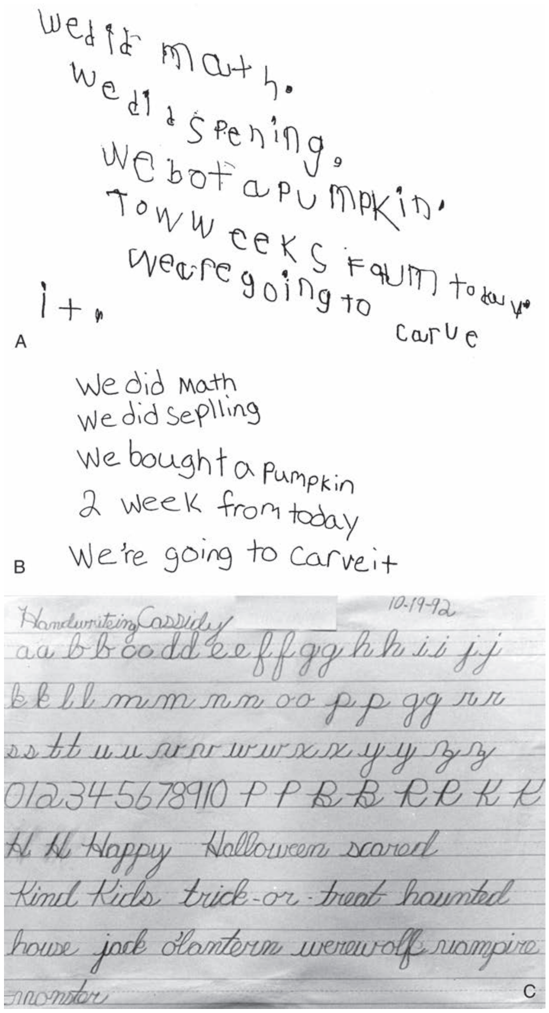

Figure 16-3 **A,** Handwriting sample of a third grade child with developmental coordination disorder and a learning disability. **B,** Handwriting sample obtained for comparison from a randomly selected third grade peer without motor difficulties. **C,** Sample of cursive writing from another peer without motor difficulties demonstrates an even more advanced expectation of third grade students.

DCD have difficulty with throwing, catching, and kicking a ball accurately.[6,27,136] When kicking or throwing a ball, the child with DCD may have trouble judging the amount of force required to throw the ball,[107] with resulting performance on these tasks being more like that of a younger child (see www.cmaj.ca/cgi/content/full/175/5/471, and click on "videos" in right-hand menu; also see video of Bill). Children with DCD have more difficulty with gross motor activities that require constant changes in body position or adaptation to changes in the environment, such as when playing baseball or tennis or jumping rope.[136,226] Activities that require the coordinated use of both sides of the body

Figure 16-4 **A,** Managing stairs can be challenging for children with developmental coordination disorder (DCD), given their difficulties with posture and balance. **B** and **C,** Stair climbing is made more challenging when children with DCD must maneuver around others in a crowded environment.

are difficult (e.g., stride jumps, swinging a bat, handling a hockey stick).[136]

The fine and gross motor activity limitations of children with DCD can be understood in the context of associated body structure and function deficits, according to the ICF model (Table 16-3). An appreciation of the link between underlying deficits and their expression in ADLs can be instrumental when planning effective and targeted interventions.

PARTICIPATION RESTRICTIONS

In the context of the ICF framework, the fine and gross motor activity limitations seen in children with DCD in their school and home environments can lead to participation restrictions that prevent them from having opportunities for optimal physical, social, and cognitive development. When parents of children with DCD are asked what their concerns are, they frequently identify restricted participation.[189,208] As a result of their motor difficulties, children with DCD have reduced interest in physical activities and usually begin to withdraw from, and avoid, motor and sports activities at an early age.[12,29,136,238,241] Because of their difficulties with self-care tasks at school, they are often slow to get to the playground for recess, restricting their physical participation and further diminishing their opportunities for physical and social interactions.

Complicating their physical challenges, children with motor difficulties often do not know how to play physical games, nor do they understand the rules of the game,[107] limiting both physical and social participation with peers. They are often the last to "get picked" for teams and are not sought out to play with others.[129,241] As a result, these children can quickly become isolated from their peer group.[107] Difficulties in relating to their peers have been noted in children with DCD.[107] This may be the result of not being chosen to participate in motor-based activities, or because their clumsy, less predictable movements may disrupt their play with others.[129] Typically, children with DCD tend to watch more than play, preferring to wander the playground periphery or talk to teachers rather than engage in active play with others and socialize with their peers; this may be related to decreased self-confidence.[179] With fewer opportunities for social interaction, they often appear not to have learned the "intuitive" rules of social situations.[107]

PERSONAL FACTORS

Children with DCD often self-impose restrictions on their participation. They perceive themselves to be less competent than their peers and have lower self-worth and greater anxiety.[212] When poor gross motor skills lead to inactivity and avoidance of physically challenging games, the child with DCD becomes less fit and further avoids physical activity. Avoidance of games requiring fine motor skill leads to decreased opportunities for practice, preventing ongoing academic skill development. Parents have reported that the more difficulty their children had with motor skills, the less

TABLE 16-3 **Examples of Activity Limitations and Related Body Structure and Function Deficits in Children With Developmental Coordination Disorder (DCD)**

Activity Limitations	Related Body Structures and Functions
SELF-CARE ACTIVITIES	
Eating:	
Frequent spills, messy eating	Poor body awareness
Leaning on the table	Poor postural tone
Poor use of cutlery when spreading/cutting	Difficulties with in-hand manipulation
Dressing:	Difficulties judging force and distance, targeting
Slow and disorganized	Poor use of dominant-assistant hands
Trouble with fasteners (buttons, zippers)	Poor body awareness and proprioception
Clothes twisted or on backward	Lack of balance
Shoes on wrong foot	Poor finger dexterity and strength
	Difficulties with touch perception, sequencing
ACADEMIC ACTIVITIES	
Printing/handwriting:	Muscle tone and postural issues
Slow, poor legibility	Poor fine motor control
Awkward grasp	Over-reliance on vision
Reduced volume of work	Use of attentional resources to maintain posture
Frequent erasures	Language and learning issues
Avoidance behaviors	Low muscle tone, fatigue
Sitting at a desk/in circle time:	Decreased postural control
Slumped posture	Poor body awareness
Holding head	Need for boundaries, increased sensory feedback
Leaning on others, lying down	Need to move to maintain muscle activity
Wiggling	
Falling out of chair	
SPORTS AND LEISURE ACTIVITIES	
Ball-related activities:	Poor management of multiple degrees of freedom
Miss the ball, get hit by the ball	Timing issues
Slow to react	Difficulties correcting errors, poor generalization
Can't keep up	Difficulties attending to body position
Fatigue	Passivity response a coping mechanism
Passive—watch rather than play	Need to avoid failure, possibility of humiliation
Interact with adults rather than with peers	

willing they were to engage in physical activity.[170] Self-imposed isolation becomes a self-perpetuating cycle of poor skill development, limited skill practice, poor performance, and further isolation.[177]

ENVIRONMENTAL FACTORS

With younger children, the environment tends to be more accepting of motor difficulties because of the wide range of normal variation. Early signs of incoordination may be viewed as part of normal developmental awkwardness or normal but slower maturation. As preschoolers become elementary school children, however, peers, parents, teachers, and/or communities may create unwarranted restrictions, artificial barriers, or rigid expectations.[180] If a physical education class or a community recreation program strictly adheres to performance criteria for group activities such as baseball, basketball, or dance class, a child with DCD can be prevented from participating with peers. If parents restrict their child's outdoor play to certain environments or to certain activities because they are afraid the child will get hurt, then another barrier is established and peer relationships are potentially limited. If a family feels uncomfortable eating out at a restaurant or with relatives and friends because of a child's messy eating and restricts these opportunities to certain environments, social interactions will be unduly limited. Indoor manipulative play can pose just as much of a problem. When limitations exist in fine motor skills of coloring, cutting, and stacking objects, imaginative play with paper, small toy people, or building blocks is very difficult. When children are not allowed to play with modified toys, or when individualized expectations are not acceptable, a child's experiences can be artificially limited.

ROLE OF THE PHYSICAL THERAPIST

Physical therapists are skilled in the observation of gross motor task performance and can help to identify children whose poor motor performance leads to activity limitations and participation restrictions. Physical therapists can observe the lack of adaptive flexibility, the lack of pre-movement organization, and the "fixing" that is so characteristic of children with DCD in the early years.[149] These observations can facilitate early identification, which can help to prevent the development of secondary impairments. Physical therapists can provide education and guidance that will encourage the engagement of children with DCD in the typical activities of childhood, thereby reducing the risks of decreased physical health, as well as decreased self-esteem, self-efficacy, and social participation, that have been noted at an early age.[109]

IDENTIFICATION AND REFERRAL TO PHYSICAL THERAPY

The recognition of DCD will depend on the extent to which physical, social, and attitudinal factors have influenced motor skill acquisition. Although DCD must be considered at least theoretically to be present from birth, children differ with respect to the apparent age of onset, as the developmental progression will vary depending upon the environmental and task demands placed upon the child in the early years. Because DCD is a disorder that has an impact on the development of movement skills, children with motor impairments often do not display the full extent of their functional difficulties until they are of school age. Limitations observed in the preschool years may be seen as "slow development" or temperamental differences. However, poor performance on everyday activities is tolerated less and less as children with DCD reach school age. Their coordination difficulties may not be easy to observe until they reach the point at which they attempt to learn and perform skills that require adaptations in speed, timing, and grading of force. As has been mentioned, the presence of secondary impairments and co-occurring conditions can complicate the identification process.

Typically, children with motor difficulties are identified and referred to physical therapy via one of two principal routes—through the health care system or through the educational system. In the medical pathway, children with motor difficulties may have been investigated for possible musculoskeletal, orthopedic, or neurologic concerns. These may include concerns regarding ligament laxity, low tone, or an unusual gait pattern, or the results of regular monitoring after premature birth or low birth weight.[162] In the education system, referrals are usually made when poor motor performance affects academic functioning. Sources of initial identification within each of these pathways are varied and may include primary care physicians, community and developmental pediatricians, and hospital and infant programs, as well as classroom, physical education, and resource teachers, educational psychologists, and occupational therapists (OTs). Although some children are identified by the health care system, a significant number of the children referred to physical therapy for investigation of motor problems are referred through the educational route.

Although parents are often keenly aware early on of their child's activity limitations and participation restrictions,[1,189] classroom and special education teachers may be the initial source of referral to rehabilitation professionals when they notice poor skill development interfering with classroom work and overall academic performance.[227] Often, the structured demands of the classroom with expectations of increasingly precise motor skills and shorter time frames for performance stress a child with DCD to his or her limit. In fact, children with DCD are commonly underrecognized until academic failure begins to occur[59,77,132,223] and often are not identified before age 5.[132] In addition, teachers have many opportunities to compare the performance of children with poor motor coordination with that of their more typically developing peers. At school age, poor written communication is frequently the first activity limitation that educators identify, so children with incoordination are most often referred to OTs for handwriting difficulties. This is often, however, just the "tip of the iceberg," as children commonly experience other challenges at school, on the playground, and at home. In the school setting, children with motor impairments may be referred to physical therapists for assistance with physical education programming and for safety concerns, as well as for strength and endurance issues. A physical therapist working in an educational setting has the advantage of screening children in natural environments while the children participate in everyday, functional activities. Immediate collaborative consultation with the classroom and/or physical education teacher can occur, to gather information regarding the nature and extent of the motor concerns. After this, an appropriate physical therapy examination allows more comprehensive observation of function and functional difficulties in the classroom, at recess, and in physical education class. When children with possible DCD are referred and examined in a clinic setting, in-depth interviewing of parents and teachers regarding their motor difficulties, as well as observation of functional activities, is needed to accurately identify concerns related to body structure and function and activity limitations.

EXAMINATION AND EVALUATION

Given the heterogeneous nature of DCD, it is important for a physical therapy assessment to utilize multiple sources of information and types of examinations.[144] The *Guide to Physical Therapist Practice*[2] recommends the collection of historical information, including a developmental and medical history (pregnancy, delivery, and past and current health status); results of previous musculoskeletal and neuromuscular examinations; and a history of current functional status from the family and from school personnel. As part of the examination and evaluation process, physical therapists must differentiate the motor behaviors of children with DCD from those of other movement disorders. Children referred in the early years with poor coordination and/or motor delay may have disorders such as cerebral palsy, muscular dystrophy, global developmental delay, or DCD. Physical therapists must make evaluation hypotheses regarding the origin of the coordination difficulties. Some key questions may help therapists focus on differentiating among each of these patterns of motor behavior. In a young child, it would be important to ask these questions: (1) Is there evidence of increased or fluctuating tone? (Observed alterations in muscle tone might be suggestive of a condition such as cerebral palsy.) (2) Are the delays more global in nature, rather than occurring in the motor domain alone—a situation in which global developmental delay might be suspected? (With a preschool- or school-age child, questions might center around the history of the poor coordination.) (3) Have the difficulties been present from an early age? (4) Are the motor concerns appearing to worsen over time? (5) Has there been a loss of previously acquired skills? (If so, this might be suggestive of a condition like muscular dystrophy.) (See chapters in this volume on specific conditions for further information on differential diagnosis.)

The following example suggests the process used in the examination of a young child who is demonstrating movement difficulties. A typical initial referral in a school-based service delivery environment might be made by a physical education teacher regarding a 5-year-old kindergarten student who is falling often. Initial hypotheses concerning why Sarah is falling more often than her peers might include the following: (1) She has mild cerebral palsy, spastic diplegia, or hemiplegia; (2) she has early symptoms of muscular dystrophy; (3) she has DCD; (4) she has characteristic symptoms of ADHD, and as a result she is impulsive and distracted to the extent that she bumps into people and objects; (5) her shoes are too big and she trips over the laces; or (6) she has a perceptual or visual impairment. If hypothesis 4 or 6 seems likely based on physical examination and observation, referral to another health care service provider would be warranted.

Direct observation of Sarah on the playground and during physical education class could rule out falling related to improperly fitting shoes (hypothesis 5) or significant impulsivity and distractibility possibly related to ADHD (hypothesis 4). Additional observation could identify a positive Gowers' sign and large calf muscles, suggesting further medical referral for possible muscular dystrophy (hypothesis 2). Observation of movement patterns during play may suggest typical symmetrical synergies of hip adduction and internal rotation with knee flexion and ankle plantar flexion (more suggestive of cerebral palsy, spastic diplegia; hypothesis 1), or unilateral shoulder retraction, internal rotation and adduction, elbow flexion with forearm pronation, wrist and finger flexion, and hip adduction and internal rotation with knee flexion and plantar flexion (indicative of cerebral palsy, hemiplegia; hypothesis 1). If none of these observations is made, then the likelihood increases that Sarah has DCD (hypothesis 3).

Direct observation of functional activities in naturally occurring situations is an important part of the physical therapy assessment. If observations and examinations must be performed in a hospital or clinic setting, then behavior might have to be observed in a noisy, distracting, fast-paced environment such as a busy waiting room or a children's play area. Putting a coat on while surrounded by 25 other 7-year-old children, all struggling in a small space to get dressed and get outside for recess first, is much different from putting on a coat in a quiet room with one adult giving positive encouragement.

Additional information obtained from parent and teacher interviews is vital. A parent may describe her daughter as having a pattern of general incoordination with delayed speech, messy eating, and general clumsiness present from a young age but without a medical diagnosis related to a neurologic impairment (suggesting hypothesis 3). If you suspect that a child is demonstrating the characteristics of DCD, you might want to ask parents about other developmental concerns (fine motor, self care, leisure). It will be important to inquire whether or not difficulties are observed at home, such as struggling with buttons, using eating utensils, or tying shoelaces. Parents can provide information on the amount of effort required to complete motor tasks and whether their child participates in organized sports or other physical activities. The parent interview combined with information from a teacher can confirm the presence of a significant problem with academic achievement or ADLs—a key diagnostic finding in DCD (again suggesting hypothesis 3). However, if the parent describes a pattern of typical motor development followed by a recent decrease in strength and the loss of ability to climb stairs independently, the hypothesis of muscular dystrophy (2) would be supported.

Direct examination by the physical therapist might identify muscle hypertonicity that increases with faster movements (possible cerebral palsy; hypothesis 1). On the other hand, if direct examination suggests low muscle tone with shoulder, elbow, and knee hyperextension, DCD again becomes a valid hypothesis (3). If muscle testing reveals a weak gastrocnemius and pseudohypertrophy, the hypothesis of muscular dystrophy (2) would be supported. During direct examination, the therapist may be able to relate the most striking activity limitations to difficulties in following directions when asked to perform a motor task or to poor attention to task. Children with DCD often cannot imitate body postures or follow two- or three-step motor commands. Frequent demonstration and actual physical assistance may be needed to accomplish items on standardized tests.

Clinical Assessment Tools for DCD

Initial Screening

To identify children with motor challenges so that early and effective interventions can be implemented, the use of reliable and valid screening instruments is critical. To meet this need, several screening tools have been developed to elicit parent, teacher, and child perceptions of children's motor concerns.

Parent Report

Parents know their children's developmental history, have observed their functioning in multiple environments, and can provide important diagnostic information during screening for potential DCD.[58] The Developmental Coordination Disorder Questionnaire (DCDQ)[254] is a parent-report screening tool (at the ICF activity level) that measures the functional impact of a child's motor coordination difficulties. The DCDQ has recently been revised as the DCDQ'07.[253] Originally intended for use with parents of children 8 to 14 years of age, this 15-item tool has now been extended to include children 5 through 15 years old. Each item of the DCDQ describes tasks that are often of concern with children with motor impairment (e.g., catching a ball, riding a bicycle, writing), and parents are asked to compare their child's coordination to that of children the same age by choosing ratings on a 5-point scale. Percentiles are provided to assist the clinician in determining definite motor difficulties, "suspect" for motor difficulties, and no motor difficulties. The DCDQ is quick to complete and can provide valuable information regarding the impact of motor coordination difficulties on activities of daily life (i.e., Criterion B of the DSM-IV).[4] Research performed on the original version of the DCDQ provides evidence of internal consistency of the test items, construct validity, and concurrent validity with both the Movement Assessment Battery for Children (MABC) test of motor impairment[87] and the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP),[15] as well as high sensitivity and specificity for identification of risk for DCD versus no DCD in populations of children in several different countries.[36,40,75,203,254] The new version of the DCDQ'07 was developed with a population-based sample from Alberta, Canada, and validated with typically developing children, as well as children with, or likely to have, coordination difficulties. The new DCDQ'07 was again noted to have high sensitivity and specificity, as well as construct and concurrent validity.[253] Findings from more recent studies of the criterion-related psychometric properties of the DCDQ are conflicting.[23,116] This may relate, in part, to the fact that the DCDQ measures the functional impact of poor coordination, whereas several of the criterion standards to which the DCDQ has been compared measure difficulties in skill performance directly. The DCDQ'07 is available online at no charge (http://www.dcdq.ca/pdf/DCDQ_Administration_and_Scoring.pdf).

Teacher Checklists

Although teachers identify some children who have DCD, they have been shown to be inaccurate in some cases.[51,100,167] In one study of children 9 to 11 years of age, classroom teachers were able to identify only 25% and physical education teachers identified only 49% of the children with DCD.[167] This discrepancy is partially explained by the different environments on which the two types of teachers based their observations and may also be related to the fact that teachers may not be able to observe all functional tasks included in checklists. The popular teacher checklist (ICF activity level) used in this study, the Movement Assessment Battery for Children Checklist (MABC-C),[87] is also limited as it is somewhat lengthy, making it time-consuming for teachers to complete. With regard to studies of the psychometric properties of this checklist, the results have been mixed. The MABC-C has been shown to demonstrate internal consistency, construct validity, and concurrent validity when measured against the Movement Assessment Battery for Children (MABC)[87] test of motor impairment.[206] However, the checklist has been noted to have poor sensitivity, meaning that many of the children at risk for motor problems may not be identified.[100] The MABC checklist has recently been revised (MABC Checklist-2)[88] and includes fewer items, along with a new standardization sample of 395 children. Determination of the new checklist's psychometric properties will be important to determine whether the issues raised above have been addressed.

Recently, the Children Activity Scale for Teachers (ChAS-T) has been developed for younger children 4 to 8 years of age.[196] In addition, the Motor Observation Scale for Teachers (MOQ-T) (previously known as the Groningen Motor Observation Scale) has been revised and new norms developed.[201] This checklist is intended for use with teachers of 5- to 11-year-old children. Only preliminary work has been conducted to examine the reliability and validity of these tools.[196,202] Until further validation studies have been done on these teacher checklists, caution should be exercised when relying only on the judgment of classroom or physical education teachers to identify children with DCD.

Child Report

The Children's Self-Perceptions of Adequacy in, and Predilection for, Physical Activity Scale (CSAPPA)[80] is a brief 19-item child self-report measure of self-efficacy with regard to physical activity. It is intended for use with children aged 9 to 16 years. Specifically, the CSAPPA is a participation measure of children's perceptions of their adequacy in performing, and their desire to participate in, physical activity. It contains three subscales: perceived adequacy, predilection to physical activity, and enjoyment of physical education class. The CSAPPA uses a structured alternative choice format wherein children choose from two statements the one that best describes them (i.e., "some kids are among the last to be chosen for active games" vs. "other kids are usually picked to play first") and then indicate whether the statement is true or very true for them. The tool has been shown to have high test-retest reliability, as well as predictive and construct validity.[80] The CSAPPA tool has been used in screening large groups of school-age children, primarily for research purposes, and scores on the CSAPPA have compared well with scores on a standardized test of general motor ability.[81] Several research studies suggest that the tool may be useful in the clinical setting for identification purposes.[23,81,82] Although it is possible to use only the subscales when screening for motor impairment, the use of additional sources of information on motor performance has been recommended to increase the specificity of the tool.[23]

Regardless of the type of screening tool used (parent, teacher, or child report), it should be noted that screening tools are just the first step in identifying potential DCD. Children identified through these tools as having possible motor impairment should undergo a more detailed assessment intended for use with children with DCD to confirm their motor difficulties (Criterion A).[225] When multiple measures are employed to confirm motor impairment (such as a checklist or questionnaire for initial screening followed by a test of motor ability), it should also be remembered that different tools may measure different constructs, including a child's capability (what the child can do, as measured by a standardized assessment) and the child's actual performance (what the child does do in everyday life and in multiple contexts or environments).[36] It is important to know a tool's strengths and limitations and to use a tool suited for the examination purpose. Each of these different tools can provide valuable information in understanding the complete picture of a child's difficulties.

Evaluation of Motor Impairment

One of the DSM-IV discriminating criteria for DCD is that motor coordination is markedly below expected levels for the child's chronologic age.[4] To distinguish DCD from a developmental motor delay, standardized tests of developmentally sequenced gross and fine motor items can be used. Currently, there is no widely accepted standard for the assessment of children with DCD,[40,84,104,123,144,254] in part because of the heterogeneous nature of DCD and the frequent presence of co-morbidities. It is important to note that studies have reported inconsistencies in the numbers and types of children identified using different assessment tools specifically designed for children with DCD.[40,123] Without a gold standard to identify these children, researchers have often used more than one assessment tool to confirm the identity of children with movement problems in research study samples.[261] It has been recommended that any examination of children with DCD should include information from a number of sources, including standardized tests, functional task analysis, and examination of tasks in natural environments.[40,123,144] The next sections describe a number of tests that are used with children with DCD. Further information on standardized tests can be found in Chapters 2 and 3.

Young Children

In the early years, identification of children who may be at risk for DCD is critical[148] and can be achieved through the use of descriptive measures designed for this purpose. As has been described previously, when DCD is suspected, it is important to confirm that a motor impairment is present and to determine the impact of that impairment on activity. Standardized assessments developed for very young children often examine activities by measuring the achievement of developmental skills but do not usually focus on impairment in the qualitative aspects of movement. Identification of a motor skill delay in the young child indicates the need for ongoing monitoring, intervention, or an assessment of motor impairment at a later age.[149]

One tool used to assess early motor skills is the Peabody Developmental Motor Scales–Second Edition (PDMS-2).[57] Popular among clinicians, the PDMS-2 is clinically relevant, with high test-retest reliability and internal consistency. The PDMS-2 has been shown to demonstrate construct validity and concurrent validity with the previous version of the tool.[57] A diagnostic and an evaluative measure, the PDMS-2 is an appropriate choice for assessment of the young child with characteristics of DCD. Given that the PDMS-2 has evaluative properties, it could also be used as a preintervention and postintervention measure to evaluate whether change has occurred.

Older Children

Two popular assessment tools used for older children with DCD are the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)[15] and the Movement Assessment Battery for Children (MABC).[87] Both of these assessment tools have been recently revised from their original versions as the BOT-2[16] and the MABC-2,[88] respectively.

The BOTMP (original version) has been reported as one of the most frequently used assessments with school-age children 4½ to 14½ years of age.[17,18,184] It is a standardized, norm-referenced discriminative and evaluative measure of the construct of motor ability (fine motor and gross motor) and is available in short or long form. Of concern for the DCD population, the BOTMP does not measure impairment in terms of quality of movement but, rather, measures only the ability to perform a given activity. It has been shown that children with DCD may achieve performance criteria on an activity but still have such poor quality of movement and reduced speed that their performance is not functional.[144] The diagnostic validity of the original version has previously come under scrutiny in the research literature[18,40,79,229,246,254] with speculation that the BOTMP may fail to identify some children with motor impairment when compared with the MABC.[40,229] This inability to identify children with motor impairment was not alleviated even when more stringent cutoff scores were adopted.[229] The BOTMP became outdated in its normative data and was in need of revision and re-standardization after 25 years.[229]

The newest version, the BOT-2,[16] has an expanded age range from 4 to 21 years, and items have been added and modified. This revision consists of 4 motor area composites (fine manual control, manual coordination, body coordination, and strength and agility), with 2 subtests in each composite, and, like its predecessor, both long and short forms of the test are available. The instructions are less standardized in the newer version, allowing greater flexibility for testing. New norms based on a representative, stratified, random sample of 1520 children and youth in the United States were developed. As reported in the manual, the BOT-2 has good interrater reliability, with evidence of test-retest reliability for the total motor composite and short form (reliability is variable, however, when one looks specifically at the composites and subtests, and a practice effect has been noted).[16] Internal consistency is high for the total motor composite and acceptable for the short form (except in the case of 4- to 8-year-olds) and borderline to high for the subtests. In addition, the developers of the tool indicate that the BOT-2 demonstrates construct validity and concurrent validity with the BOTMP and the PDMS-2.[16] With respect to its clinical use, although the items in the newer version are more functionally relevant and the norms are current, some practical issues and limitations remain.[44] The scoring system is noted to be lengthy and prone to error, and some issues have been noted with regard to the stability or reliability of subtest scores, necessitating that total scores be used. The use of total scores may pose problems in cases where children have poor motor skills in a single area only (e.g., poor gross motor skills but adequate fine motor skills)——a situation that has been known to occur with some children with DCD. Using a total score, these children may score well overall despite having significant difficulties in one area of their motor performance. Because of the inclusion of children with disabilities in the new normative sample, cutoffs previously used with the original version may no longer apply, as using the previous cutoffs may under-identify children with motor difficulties. In addition, the BOT-2 does not assess handwriting—a skill that is frequently problematic for the DCD population. Despite its wide usage, the BOT-2 may not be the most appropriate clinical assessment to identify children with DCD, given these concerns.

The MABC-2[88] is based upon the earlier MABC,[87] which has been translated into several languages and is used internationally to identify children with motor impairment. The MABC-2 is a norm-referenced examination that was normed on a stratified sample of 1172 children representative of the U.K. population. The MABC-2 (ICF activity level) contains three sections, and each section includes eight items for each of three age bands: 3 to 6 years, 7 to 10 years, and 11 to 16 years. Items are divided into manual dexterity (three items), aiming and catching (two items), and balance (three items) and include activities such as threading beads, putting pegs in a pegboard, catching and throwing a beanbag, balancing on one leg, jumping, hopping, and heel-to-toe walking. The total score is used to determine if performance is within normal ranges, if motor performance is borderline or at risk, if a motor impairment is present, and if the motor impairment is significant.

The original version of the MABC has been shown to demonstrate good test-retest reliability and concurrent validity with the BOTMP.[40,41,87] In addition, numerous studies conducted worldwide have demonstrated that the MABC identifies children with DCD at the same prevalence rates as would be predicted,[192,214,261] and the body of evidence examining the use of the MABC has been steadily growing. After a literature review of 176 publications, Geuze and colleagues[66] concluded that the MABC is the best assessment tool for DCD in spite of the fact that it omits tasks related to handwriting—an important task to assess.[225] With regard to the newer MABC-2, two studies undertaken by the test developers demonstrate acceptable test-retest reliability (the tool was less reliable when the younger age band was used); information regarding other forms of reliability, however, is not available.[88] Although recent investigations of pilot versions of the lower and upper age bands of the updated MABC-2 provide some evidence of interrater, intrarater, and test-retest reliability, issues related to translation of the test items into other languages, cross-cultural examination, and use of single bands of the assessment tool in these studies have all been identified as issues influencing these results.[14] To date, evidence of the new tool's construct and concurrent validity has not yet been firmly established.[14] Additional studies regarding these properties are emerging and include research on the concurrent validity of the MABC-2 with the MABC-C and the BOT-2, factor analytic validation, and further investigation of test-retest reliability.[8,215,234]

The MABC-2 has several advantages over other assessment tools. The age bands for this instrument cover from 3-0 to 16-0 years, but testing time is short as the assessor presents only activities appropriate for that child's age. The original version has been shown to identify more children with coordination difficulties than the BOTMP[48] and appears to identify more readily those children who have additional learning or attention problems.[40] One of the key contributions of the tool to the assessment of children with DCD is its inclusion of qualitative descriptors of motor behavior (i.e., impairment level descriptions) that the therapist can focus on during the administration of each test item. The MABC-2 also contains a behavioral checklist that can provide insight into the effects of motivation on assessment results and overall compliance with testing. Each of these unique features of the MABC-2 is of value to the clinician in identifying children with, or suspected of having, motor impairment. Although the MABC-2 demonstrates many clinical benefits, given that the psychometric properties of the MABC-2 have yet to be firmly established, therapists are encouraged to make use of several sources of information, including the MABC-2, in their clinical decision making.[14]

Additional Assessment Tools

Although initial tests of motor impairment can screen for, and confirm the presence of, significant motor difficulties, these tools do not provide a complete profile of a child's motor functioning,[98] an understanding of which is important for program planning and intervention.[243] In addition, the definition of DCD,[4] with its emphasis on the impact of motor coordination difficulties on daily life functioning, implies that a comprehensive assessment of the child with DCD will include some examination of the child's ability to perform functional, everyday tasks in natural environments. Only a few assessment measures are available that include this functional and contextual emphasis, such as the Vineland Adaptive Behavior Scale, Second Edition (VABS).[222] When secondary impairments are also present, it may be important to perform additional examinations at a body structure and function level (e.g., strength, physical fitness measures) to plan interventions to address these secondary issues specifically.[58]

FACILITATING A DIAGNOSIS OF DCD

It is not within the scope of practice of physical therapists to formally diagnose DCD. Nevertheless, physical therapists, through their examination and evaluation of test results, are in an ideal position to recognize the motor and behavioral characteristics of potential DCD, and they can provide useful information to the child's physician regarding Criteria A and B of the diagnostic criteria in particular.[4] Criterion A of the DSM-IV indicates that a significant impairment in motor coordination must be present, which can be difficult to determine in a physician's office.[4] Physical therapists can observe and test for motor impairment and provide information to both the family and the physician. The DSM-IV Criterion B states that the motor impairment must interfere with academic achievement and/or ADLs. The therapist can gather information from parents, teachers, and the child about what tasks are difficult for the child to perform and can relay this information to the physician.

Although health professionals may be hesitant to label the observed difficulties as DCD, a strong case can be made for the need to identify and recognize the disorder and for the role of the therapist in facilitating formal recognition of the motor difficulties.[146] DCD has a significant impact not only on the child, but on the entire family.[141,142,228] Parental concerns are not often heard or acknowledged,[1,189] and parents are often frustrated with the health care and educational systems as they pursue answers to their concerns.[58] Significant family stress can occur regarding daily activities at home and around schoolwork. Parents not only are aware of the difficulties their child experiences from an early age,[1,189] but are searching for answers and access to resources and are often relieved once they have a greater understanding of their children's difficulties. Recent research has shown that in pursuing answers to their concerns, parents are often involved with multiple education and/or health professionals before a diagnosis is made.[1,142]

Facilitating a diagnosis is critically important for the prevention of secondary consequences, in particular, self-esteem issues for the child. A diagnosis can help to initiate education, intervention, and accommodations for the child and allows parents to access resources. Equally important, recognition of the impairment can help to facilitate a long-term relationship with the family's primary care physician. This is critical for follow-up of potential secondary issues that may develop as the child matures and for identifying other developmental conditions that often coexist with DCD (e.g., expressive and receptive language difficulties, attention deficit disorder). Referral to other health care providers for assessment can then be made as appropriate. If DCD is suspected, the physical therapist should encourage the family to have the child seen by their primary care physician.

Referral to Other Disciplines

As has already been discussed in this chapter, it should not be assumed that DCD is an isolated motor problem. An examination performed by any of the following individuals may be needed: (1) a family physician or neurologist when neuromuscular or musculoskeletal concerns are identified; (2) an OT when fine motor, self-help, or motor planning areas need further examination; (3) a speech and language pathologist when speech, oral-motor dysfunction, or possible cognitive-linguistic problems are observed; (4) a psychologist when intellectual or behavioral issues have surfaced; or (5) an adapted physical education teacher when more thorough gross motor skill training is needed.

INTERVENTION

DIRECT INTERVENTION APPROACHES

According to the ICF model, physical therapy interventions can be directed toward remediating impairment, reducing activity limitations, and/or improving participation.[260] In the past, treatment interventions used with children with DCD were aimed primarily at changing body structure and function impairments by trying to improve either the child's sensory processing abilities (vision, kinesthesis) or the difficulties in individual motor components (balance, strength) that were believed to contribute to poor performance. These interventions have been referred to as "bottom-up" interventions, as they tend to address movement problems by emphasizing the building of foundational skills.[126] Examples of bottom-up interventions include perceptual-motor training, process-oriented approach, sensory integration (SI), and neurodevelopmental therapy (NDT). These interventions reflect more traditional theories of motor development and are based on the theoretical belief that, by changing these underlying deficits, task performance will be improved.[126] Some of these bottom-up interventions are still employed by therapists today when working with children with DCD, but several recent and comprehensive systematic reviews on the effectiveness of these approaches have found them to produce minimal change in functional outcomes and to offer no clear advantage of one approach over the other.[58,90,126,152,172,173] When gains are seen after the use of these approaches, the question has been posed as to whether they may be more a function of the skill of the therapists or application of general learning principles than of the treatment itself.[152,211,224] Physical therapists are challenged to re-think the importance of implementing intervention strategies for children with DCD that serve only to change primary impairments.

Dynamic systems theorists have proposed that improvement in functional tasks relies on many variables and tends to be environment-specific.[231] This way of thinking emphasizes that intervention must be contextually based, with intervention occurring in everyday situations and being of significance to the individual child. More recent interventions for children with DCD reflect these beliefs and now tend to emphasize the development of specific skills rather than underlying skill components alone. These have been referred to as "top-down" interventions,[126] which focus on motor learning principles in combination with other theories that emphasize the role of cognitive processes in the learning of new movement skills.[139] Top-down interventions include task-specific interventions and cognitive approaches. See Chapter 4 for more information on motor learning and task-specific intervention.

When selecting an intervention approach for children with DCD, physical therapists need to consider the motor learning difficulties that are particularly evident in this population such as the inability to transfer and generalize skills and learn from past performance. It would seem reasonable from a motor learning perspective that giving feedback at the right stage of learning as well as opportunities to solve movement problems are instrumental guiding principles for interventions with children with movement difficulties.[139] It is likely that interventions that directly target the transfer and generalization of new skills and that emphasize motor learning will be the most successful. Many techniques to foster motor learning can be incorporated into intervention; these include providing verbal instructions, positioning, handling, and providing opportunities for visual or observational learning. Physically demonstrating or modeling movement sequences as well as helping children to learn strategies for managing feedback and organizing their bodies so they can attend to the most salient environmental cues may also be helpful, especially when intervening with young children. The use of frequent practice, practice in variable settings, and consistent provision of feedback should be key elements in any intervention approach for children with DCD. It is important to create practice opportunities in a variety of environments so that each repetition of the action goal becomes a new problem-solving opportunity.[139]

Task-Specific Approaches

A growing body of research demonstrates the value of task-specific interventions.[169,185,211] Movement educators have found task-specific intervention to be a useful way to teach children with DCD specific gross motor skills[185]; they also emphasize its indirect effect in enhancing general participation in physical activity.[110]

Task-specific interventions have as their focus the direct teaching of functional skills in appropriate environments with the intended goal of reducing activity limitations and, by implication, increasing participation levels. Task-specific interventions are individualized approaches that attempt to increase the efficiency of movement by optimizing the way in which skills are performed, given the constraints within each of the several systems that interact during task performance—the child, the task itself, and the environment.[110] As children attempt to solve a movement problem, they may discover several ways to complete a motor task (Figure 16-5). Children explore a variety of solutions to motor problems and are encouraged to experience the resulting effects of using different aspects of their bodies or the environment. The therapist guides the child in choosing which of these different ways of performing represents the most efficient, optimal way for him individually, and in a specific environment.

In task-specific interventions, the therapist is directive, providing verbal instructions, visual prompts, or physical assistance by guiding and directing movement so that children can appreciate the "feel" of efficient movement. Based on tasks that the child needs or wants to perform, the goal of task-specific instruction is to teach "culturally normative tasks in mechanically efficient ways" (p. 238)[110] with the result that children will be less clumsy and will derive more enjoyment from the performance of tasks that were previously performed poorly.[185] Neuromotor Task Training[205] is one example of a task-oriented intervention that emphasizes components of motor learning such as verbal feedback and variable practice. Although there is good evidence that children learn the tasks that are taught through a task-oriented approach (and since they are culturally normative skills, this is important), there is not much evidence for transfer or generalization in this approach.[152,185] The latter are significant considerations when choosing an effective intervention for the child with DCD; more research is needed on how to best achieve these effects.

Figure 16-5 **A,** After many therapy sessions with verbal and physical prompts, this child is still unable to sit on the floor and cross his legs independently. **B,** After being reminded of the verbal cues he needs to say to himself, he now successfully crosses his legs.

Cognitive Approaches

Like the task-oriented approaches described previously, interventions employing cognitive approaches also address activity and participation goals. Cognitive approaches, based on theoretical frameworks from cognitive and educational psychology as well as motor learning principles, use direct skill teaching in their approach but differ in their unique problem-solving framework that attempts to help children develop cognitive strategies, acquire tasks, and generalize from the learning of one skill to the next.[140] Cognitive approaches are based on the premise that children with DCD may be deficient in what has been termed their "declarative knowledge" related to motor tasks, that is, they lack knowledge of how to approach a task, how to determine what is required for the task, and how to develop strategies to use when learning and performing a motor task. Intervention approaches using cognition stress the importance of children learning to monitor their performance and use self-evaluation. Mediation is used wherein children are guided to discover problems, generate solutions, and evaluate their success independently.[150]

Preliminary evidence has been shown for the effectiveness of a cognitive approach known as Cognitive Orientation to Daily Occupational Performance (CO-OP).[176] This approach guides the child in discovering verbally based strategies that help him problem-solve in new movement situations.[127,133,175,199] CO-OP emphasizes a child-centered approach with goals that are ecologically valid and performed in a realistic setting. Practice focuses on the child's ability to select, apply, evaluate, and monitor task-specific cognitive strategies with emphasis on facilitating transfer and generalization of the newly learned strategies (for a more in-depth review of the specific CO-OP protocol and the essential components of this approach, including the development of global and task-specific cognitive strategies, the reader is referred to Polatajko, Mandich, Missiuna, Miller, Macnab, Malloy-Miller & Kinsella, 2001).[176] This cognitive approach was shown to be effective in a research clinic setting and, of note, demonstrated some generalization and transfer of skills in children with DCD.[175] Additional research studies have begun to investigate its suitability for use with younger children in clinical settings.[11,240]

The way in which cognitive intervention approaches are used by physical therapists will depend on the age of the child. For younger children, a participatory or consultative approach may be most effective. Using the principles of motor learning, it is important to provide appropriate feedback to children with DCD and to help them to focus on the salient aspects of a given activity by modeling and/or providing them with verbal guidance as they proceed through it. For older children, direct intervention with a more cognitive approach can be used to encourage them to think independently through motor problems. Whether a direct or consultative method of intervention is used, increasing a child's self-efficacy should be a major aim of therapy.[223]

Tools for Goal Setting and Measuring Intervention Effectiveness

Depending upon the target of intervention, several measures can be used to set collaborative goals and evaluate the efficacy of intervention. Whenever possible, goals should be child- and family-centered, as well as environmentally referenced to a problem related to participation in real-life situations.[58] OTs frequently use the Canadian Occupational Performance Measure (COPM)[114] as both a goal setting and outcome measure, and this tool would be similarly applicable to identifying and measuring physical therapy intervention goals. This semistructured interview is used before intervention to have the child and/or family identify areas of functional difficulty (i.e., activity limitations or participation restrictions) and to rate the child's current performance of, and satisfaction with, each task. After intervention, the rater is asked to reflect upon his performance and satisfaction for each targeted goal, and a change score can be generated. The COPM is best suited for use with children older than 8 or 9 years of age. With children younger than this, the Perceived Efficacy and Goal Setting System (PEGS)[147] may be a more appropriate goal-setting tool. In this pictorial measure, children reflect on and indicate their competence in performing 24 tasks that they need to do every day. They then identify any other activities that are difficult for them and select and prioritize tasks as goals for therapy. Using the PEGS, young children have been shown to be able to rate their competence at performing motor tasks and set goals for intervention.[145,148] The PEGS includes companion questionnaires that can be completed by caregivers and teachers. Research evidence indicates that children's goals often differ from those of their parents and teachers, so the views of both may need to be solicited.[50,145]

Goal attainment scaling (GAS) is increasing in usage as a rehabilitation outcome measure with regard to both program evaluation and assessment of individualized client outcomes.[106] With GAS, five possible levels of specific functional attainment are developed for a child to create a criterion-referenced individualized measurement. To date, its use with children with DCD has been described mainly at a programmatic level. In this population, GAS that focuses on the levels of activity and/or participation, not on primary impairment, is warranted.

A measure that can be used to describe or evaluate activity and/or participation is the School Function Assessment (SFA).[38] The SFA evaluates a child's participation in six school-related settings (Participation Scale) and also examines the amount of assistance and/or the types of adaptations required for the child to perform essential school tasks (Task Support Scale). A third scale is very detailed and focuses on the performance of specific activities. In addition to more typical classroom tasks, a section of this scale focuses on the child's mobility and ability to maintain and change positions, manipulate objects, and move on recreational equipment. The SFA requires observation of functional performance over time, so it is usually completed by the therapist through interview of the teacher and others familiar with the child. The SFA has been used to describe the participation patterns of children with DCD,[262] but its use in a pre- to postintervention study of change has not been reported.

EDUCATION AS INTERVENTION

An important, perhaps even primary, benefit of an evaluation for DCD is the follow-up consultation that allows the physical therapist the opportunity to discuss restrictions in activity and participation with the child, the parents, and school personnel.[48] Education and consultation with the family, school personnel, and the community lessen the impact of environmental and personal-contextual factors that may restrict participation.[58] Family members and school personnel are key players in improving outcomes for children with DCD. The physical therapist should always provide parents and school personnel with information about the disorder and its impact on functional activities, and should provide additional resources regarding DCD tailored to the child's and family's needs, including print and web-based educational materials (see resources provided on Evolve website). After collaborative goal setting and intervention planning, written recommendations for home and school would also be helpful for families and school staff. When working toward the acquisition of specific skills, meaningful learning takes place over time and in multiple environments. Daily environmental modifications and task adaptations are critical for improved performance and motor learning for the child with DCD.[48,69]

Helping parents to understand their child's strengths and limitations is an important component of secondary prevention and risk management.[149] Family and cultural expectations can be inconsistent with a child's motor abilities. Expecting proficiency in competitive sports or dance or valuing perfect penmanship can lead to frustration and stress for everyone. Physical therapists can help families and children match interests and skills with expectations that lead to success. When parents are able to look at a play situation in their neighborhood or community recreation program and understand which motor skills are interfering with their child's ability to participate, the play situation can be adapted to maximize the child's participation and help prevent the imposition of societal limitations on full participation in community activities. Consultation with parents and teachers regarding promoting physical activity participation in children with DCD is addressed specifically in a later section in this chapter.

Communication with other disciplines is also an important component of physical therapy intervention for children with DCD.[58] DCD is a multifaceted disability, and more than one service provider may be involved with a child at any given time. If delays in speech and poor social language skills are associated with developmental incoordination, intervention by a speech/language pathologist may be appropriate. If oral-motor impairment is present, goals may be directed at improving articulation and fluency of speech.

Occupational therapists (OTs) are able to contribute in a variety of ways when children are experiencing difficulties with self-care, academic performance, and social participation. Assessments typically conducted by OTs will provide useful information about diagnostic Criterion B.[146] OTs are frequently asked to assist teachers and to provide assessments and interventions related to handwriting. OTs can also address classroom and home modifications that may remediate problems related to organization and spatial orientation in changing environments.[136]

Adapted physical education teachers can consult with regular physical education teachers to help modify the curriculum so that the child with DCD can participate and experience success. As has been discussed, children with DCD have a lower activity level than their peers,[12] have decreased anaerobic power, and have decreased muscle strength.[156,183] For example, if a child cannot run fast enough or safely without falling, then games such as baseball can be modified so that a designated runner is used or players are grouped into teams for all activities with one person hitting and one person running or one person catching and one person throwing. In addition, peer helpers can be identified to help the child with DCD practice basic motor skills such as hopping, jumping, or skipping .

If distractibility and attending to task are identified problems, a school psychologist can assist the physical therapist in managing disruptive or otherwise negative behaviors that interfere with learning motor skills. When concerns regarding distractibility and hyperactivity arise, a referral to a physician should be considered for evaluation of possible attention deficit disorder, or ADHD. Many children with ADHD but not DCD will appear clumsy. If they attend poorly, they will bump into and trip over objects in their environment. When ADHD is associated with DCD, the term DAMP (dysfunction of attention, motor control, and perception) has been used.[70] If behavioral and/or emotional problems such as poor self-esteem, depression, and anxiety become apparent, follow-up by the child's primary care physician is important. If the level of depression or anxiety is serious, psychiatric intervention, medication, and/or counseling might be needed. Physical and mental health complaints should be taken seriously, and previously unidentified medical conditions should be ruled out before other approaches to deal with the symptoms are implemented.

Recently, innovative service delivery models have begun to be explored, incorporating therapists in primary care settings (physician's office) as part of a multidisciplinary team. These service delivery models have the potential to increase awareness of DCD in the community, facilitating accurate and early identification and referral of children with DCD.[62] These new methods of service delivery provide models to enhance collaboration among the many health care professionals involved in the management of children with DCD.

CONSULTATION REGARDING PHYSICAL ACTIVITY

Task-specific and cognitive approaches target intervention at the level of activity limitation. To increase participation levels, a key role for the physical therapist lies in early consultation with physical educators about strategies for the school environment and education for families about appropriate leisure activities that will likely be most successful for children with DCD.[58] These strategies emphasize participation without the risk of injury and are aimed at preventing the physical effects of inactivity.[9,149] In so doing, it may be possible to prevent many of the detrimental consequences that have been documented in children with DCD, including decreased activity, participation, strength, and fitness as well as poor self-competence and self-esteem.[12,45,112,130,155,156,183,204,252] Although it may not be possible to change or "fix" the primary impairments of the child with DCD (such as low tone), the decrease in strength and fitness that can result from avoidance of physical activity is not inevitable and might be improved through promotion of an active lifestyle at home, at school, and in the community.[177]

Physical Education Class

Although teachers can often modify or adapt academic activities in which motor performance is not the primary focus, it may not be as easy to decrease the motor requirements in physical education class. Strategies can be used, however, to encourage children with DCD to make progress within their own range of abilities, to foster self-esteem, and to promote the value of physical activity for long-term fitness and health. As a general strategy, teachers can learn how to "MATCH" tasks to fit the needs of individual children with DCD to encourage maximal participation.[150] With the MATCH strategy, teachers are encouraged to Modify the task, Alter their expectations, Teach strategies, Change the environment, and Help by understanding. (The reader is referred to the *CanChild* Centre for Childhood Disability website at http://www.canchild.ca for downloadable educator resources by grade level. These resources provide examples of different ways to adjust, i.e., MATCH, a task to improve fit with the abilities of a child with DCD.)

When physical activities are taught to children with DCD, emphasis should always be placed on encouraging fun, effort, and participation rather than proficiency. Noncompetitive games in which goals are measured against one's own performance and not that of other children may be helpful.[178] Another strategy is to divide the class into smaller groups when practicing skills, as fewer obstacles will need to be avoided. When a new skill is taught to the class, children with

DCD can be models while instructions are given so that they have an opportunity to experience the movement in addition to observing.[136] With ball skills, modifying the equipment will decrease the risk of injury and increase the likelihood of successful participation; beanbags, nerf balls, and large balls can all be used effectively.

The School Playground

For outside play, introducing children with movement difficulties to playground equipment on an individual basis and teaching them how to use the equipment when in a relaxed environment will increase their motivation to try independently. Children with DCD often avoid playground apparatus from an early age and have not had the experience of discovering how the equipment can be used.[241] The addition of moving objects (in this case, other children) increases the complexity of the environment significantly. Guiding them toward activities where they are more likely to have success (e.g., running or tag instead of ball games) will foster positive self-esteem and reward participation.

Sports and Leisure Activities

From what is now understood about the specific body structure and function impairments of children with DCD, it is possible to predict those types of functional tasks that are more likely to be problematic and to understand why certain sports and leisure activities may be more or less successful for them. It is important, first, to make the distinction between two types of motor behaviors. Early milestones such as sitting, crawling, and grasping (which are considered basic motor abilities) appear to develop relatively spontaneously in these children without any teaching (although milestones sometimes may be delayed and movement quality may not be optimal). Coordination difficulties appear to be much more evident when skills have to be purposefully learned. These skills include such things as catching or kicking a ball and playing baseball. Children with DCD experience particular difficulty with skills that require greater precision, continuous adaptability, and eye-hand coordination.[139] It is also important to appreciate the requirements of individual tasks. Some require constant monitoring of feedback during task performance, and others, once learned, do not require adaptations in response to environmental feedback. As one might expect, tasks with a heavy reliance on integrating feedback from the senses will be difficult for children with DCD.[139]

The type of task, as well as the degree of teaching involved, need to be taken into account when recommendations about sporting and leisure activities are made for children with DCD. Activities like swimming, skating, skiing, and cycling require some initial teaching of the skill and may pose a challenge for children with DCD during early learning of the skill because all novel skills are difficult for them and they do not generalize easily from previous learning.[186] Without encouragement and individualized attention, children with DCD may express dissatisfaction with these activities. Children with DCD, as well as their parents, can be helped to understand that, because these sports contain a sequence of movements that are very repetitive, and these activities do not require constant monitoring of feedback during their performance, children with DCD can become very successful with these activities.[78,149] These are important "lifestyle" sports that individuals with DCD can continue to participate in throughout their lifetime. As well, since many of these sports tend to be taught through verbal guidance, they may be easier for children with DCD to learn. In contrast, activities such as hockey, baseball, football, and basketball (and other ball-related sporting activities) contain a high level of unpredictability. When the environment is changing or variable, the child not only has to learn the movement but also must continuously monitor the environment to adapt to change. Any time a player is required to hit or catch a baseball, contact a hockey stick to a puck, or move quickly around other players, changes must be made in the direction, force, speed, and distance of the movement. Even when the skill is learned, children must continue to adapt to changes in the environment and their place in it. Activities with a high degree of spatial and temporal uncertainty or unpredictability are likely to be challenging for the child with DCD.[82] The need for ongoing adaptation to changes in the environment is always a consideration; running on a smooth surface like a road or track, for example, will be much easier for a child with DCD than running on a forest trail.[149]

Parents of children with DCD have found that their child's involvement in organized sports is greatly enhanced if coaches are flexible about the child's role (e.g., having the child with DCD be the goalie).[142] Self-esteem is promoted through participation in organized sporting activities, and children appreciate when effort and personal mastery are emphasized.[30] Resources regarding ways to promote increased participation in community sports and leisure activities are available for parents, service providers, coaches, and community leaders on the CanChild website (http://www.canchild.ca).

TRANSITION TO ADULTHOOD AND LIFELONG MANAGEMENT OF DCD

High school classes, learning to drive a car, and vocational exploration present new challenges for the adolescent with DCD. It is now apparent that issues related to DCD are lifelong for many, if not all, individuals with DCD. Physical therapy re-examination needs to include discussion of the prevention of secondary problems in adolescents with DCD. Identification of strategies to prevent impairments in body function from limiting activity or restricting participation can be one of the most important outcomes of physical therapy. Musculoskeletal or neuromuscular problems that would signal the need for future physical therapy care should be discussed, as the changing environment and variables related to growth may place new demands on these systems. Preventive initiatives are needed, as adults with DCD often have decreased strength, experience pain, and have poor aerobic capacity and endurance. Appropriate leisure activities that foster strength, endurance, and joint protection should be encouraged. The physical therapist can assist the individual with DCD to identify and participate in appropriate community fitness programs. Goals for lifelong leisure and recreational activity should be discussed with young adults. Activities should minimize competition and the need for quick motor responses. Swimming is likely to be more fun and more successful than playing tennis, and therefore more likely to provide health benefits. Singing in a community choir may be a better choice than playing in a community basketball league. Riding a bike for exercise and enjoyment would be more appropriate than participating in a volleyball competition. Additional practical suggestions have been outlined in books for adolescents[107] and adults.[49]

Vocational choices are important decisions for individuals with DCD. Jobs that minimize the need for changing motoric and environmental expectations should be emphasized. Based on Henderson and Sugden's four-level categorization of motor skill difficulty, vocations that involve skills in which neither the individual nor the environment is moving or changing would be top choices.[87] Vocations in which the individual is moving and the environment is changing would be more challenging for the young adult with DCD (Table 16-4).

TABLE 16-4 **Examples of Occupations Categorized by Motor Skill Difficulty**

Individual	Environment: Stable	Environment: Changing
STATIONARY	Secondary school and college teaching Managerial occupations Psychologist Data processor Budget analyst	Air traffic controller Preschool and early elementary teaching Taxi driver in urban areas
MOVING	Custodian Mail carrier Gardener Nurse Restaurant waiter	Fire fighter Physical education teacher Athlete in competitive sports

SUMMARY

DCD is a chronic condition affecting approximately 5% to 6% of the regular school-age population. A motor impairment disorder, its impacts are seen in academic underachievement and poor performance of everyday motor-based tasks. The exact origin and pathophysiology are unknown, but DCD appears to have both motor production and cognitive-linguistic components. Physical therapists have an important role to play both in identifying the impairments of body function and the activity limitations associated with DCD and in providing intervention to prevent or minimize the participation restrictions related to the person and the environment that might otherwise occur. DCD is a lifelong disability that presents challenges for adults, as well as for children and adolescents. Physical therapists function as members of the comprehensive team needed to manage the multiple ramifications of DCD and its many associated learning and medical problems.

CASE STUDIES

The case studies that follow describe several typical presentations of DCD. They are presented here to demonstrate the variable nature of DCD and the different challenges that arise for physical therapy management.

"Daniel Dreads School"

Daniel, age 5 years, is in kindergarten. Daniel's school has initiated an evaluation for special education services and, as part of this, has made a referral to you as the school-based physical therapist, indicating "fine and gross motor delay" and requesting assistance for the classroom teacher with physical education programming. A referral has also been made to the school-based OT regarding Daniel's fine motor concerns. Daniel's parents have provided permission for you to observe and evaluate Daniel in the classroom and have provided input to the school-based team that is assessing the need for special education services.

Physical Therapy Examination

School Concerns

You use the MABC checklist to guide your interview with Daniel's classroom teacher in identifying specific classroom concerns. When you speak with the teacher, the teacher reports that Daniel slouches when sitting at a table, and when participating in circle time, he tends to lean on nearby walls or classmates and sometimes lies down on the floor. The teacher notes that when printing his name, his work is labored and that he struggles with cutting and pasting activities.

Continued

CASE STUDIES—cont'd

Daniel is usually the last one to get ready for recess or to organize his backpack to go home. In physical education class, he is able to throw a tennis ball with direction, but cannot catch one that is thrown to him (see video of Bill for an example of a child with similar problems). Daniel is able to hop only twice on one foot before losing his balance, and tends not to participate in activities that the class is doing (see videos Skip, Hop, Gallop, Jump, and Hopping Strategy Development in a 6-year-old child from Chapter 2 for comparison with typical development of hopping).

Family Concerns

Daniel's parents report that Daniel seems reluctant to go to school, often complaining that his stomach hurts. Getting dressed is always a struggle, so his mother ends up helping him to get him to school on time. On days that he is at home, he is far happier, preferring solitary play with books or on the computer. Daniel's parents are worried that something is wrong. Although they don't feel that anything has deteriorated in his development, they haven't seen much progress or have noted very slow progress in his motor skills. Daniel's parents are also concerned that Daniel's younger brother is catching up to him and worry about how Daniel will feel about himself if his brother overtakes him.

Developmental History

Daniel's birth and early childhood health history are unremarkable. He achieved motor milestones at the expected age, and his parents describe him as an easy child with a gentle temperament. When Daniel started to attend preschool, his parents noticed that he seemed to be a bit behind the other children in self-help skills and did not enjoy some preschool activities. His teachers encouraged them to spend time at home on fine motor activities to encourage Daniel, but he was fairly resistant to working on these tasks, preferring to watch TV, look at books, and play with his robot toys. These play patterns have persisted and strengthened as he has become older.

Medical History

Daniel's hearing and vision have been tested and are normal. At his mother's request, Daniel has been seen by the family doctor for investigation of the family's concerns. Although the doctor does note slightly decreased muscle bulk overall with low postural tone, he is not overly concerned about Daniel's health or his development. He assures Daniel's parents that Daniel will eventually grow out of his difficulties.

Observation at School

You observe that Daniel likes sharing stories with his teacher and class and playing at the sand and water centers. You notice that he has trouble using scissors and avoids drawing or printing letters. Daniel seems to like listening to the teacher when reading books, but often has difficulty sitting quietly at circle time; he usually ends up getting in trouble, as he leans on other children or lies down on the floor. In outdoor play, Daniel is cautious and frequently spends time walking around the perimeter of the playground or walking and talking with the teachers. You spend some time talking with Daniel about things he likes to do and about things he would like to learn how to do. Daniel shares with you that he wants to learn how to catch a ball, as his peers are often engaged in playing catch at recess and lunch time and he is starting to feel left out because he has trouble joining in. You observe Daniel's throwing and catching abilities and you note that he demonstrates immature catching and throwing patterns (see www.cmaj.ca/cgi/content/full/175/5/471; click on "videos" in the right-hand menu).

Standardized Examination

You ask Daniel's parents to complete the Developmental Coordination Disorder Questionnaire (DCDQ'07) to obtain some initial screening information about Daniel's motor difficulties (see Examination Decision in Evidence to Practice Box). You use the framework of the Movement Assessment Battery for Children Checklist (MABC-C) to guide your interview with the teacher to determine the nature of concerns about Daniel at school. You complete a standardized assessment (the Movement Assessment Battery for Children [MABC-2]) to document the nature and extent of Daniel's difficulties. For a summary of Daniel's scores on the MABC-2, see Table 16-5.

TABLE 16-5 **Summary of MABC-2* Scores for Case Study "Daniel Dreads School"**

Component	Component Score	Standard Score	Percentile
Manual dexterity	9	3	1
Aiming and catching	12	5	5
Balance	19	6	9
Total test score	40	3	1

**MABC-2,* Movement Assessment Battery for Children, 2nd edition (Henderson & Sugden, 2007).

CASE STUDIES—cont'd

EVIDENCE TO PRACTICE 16-1

CASE STUDY "DANIEL DREADS SCHOOL": EXAMINATION, EVALUATION, AND PLAN OF CARE DECISION MAKING

Examination Decision: Parents' perspectives are critical when gathering information related to motor difficulties. Parents can provide useful information about the impact of motor coordination problems on functional, everyday tasks—a necessary diagnostic criterion for the identification of developmental coordination disorder (DCD). The decision to use the Developmental Coordination Disorder Questionnaire (DCDQ'07) is supported by its strong psychometric properties, including its ability to differentiate between children with and without coordination difficulties. The newest version of the questionnaire is appropriate for a child 5 years of age.

Evaluation Decision: Although physical therapists are in an ideal position to observe movement impairments characteristic of DCD, it is not within the scope of practice of physical therapists to formally diagnosis DCD. Other underlying medical or neurologic causes for the motor impairment may be present, and when DCD is suspected, it is important that the child be seen by his primary care physician to rule out other explanations for the motor difficulties. Where it would be appropriate (given local regulations), referral directly to a neurologist or physiatrist with expertise in DCD may be beneficial.

Plan of Care Decision: When goals for intervention are set, a collaborative approach is recommended. This approach emphasizes gathering child, parent, and teacher perspectives on priorities for goal setting. The Perceived Efficacy and Goal Setting System (PEGS) facilitates the setting of goals that are child- and family-centered and is environmentally referenced to real-life situations. Using the PEGS, young children with movement impairment have been shown to be able to judge their performance on everyday tasks and are capable of planning appropriate intervention goals.

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Physical Therapy Evaluation, Diagnosis, and Prognosis

Results of your examination indicate that Daniel seems to be demonstrating motor difficulties that would be characteristic of DCD (see American Physical Therapy Association [APTA] Guide to Physical Therapist Practice Pattern 5C—Impaired Motor Function and Sensory Integrity Associated With Nonprogressive Disorders of the Central Nervous System—Congenital Origin or Acquired in Infancy or Childhood2). Daniel is experiencing significant motor difficulties, and the impact of his motor challenges is already apparent, as his teacher and family report both his dislike of school and his avoidance of physical activity. You are concerned about the development of additional secondary consequences, both physical and social/emotional. You would like to have input from Daniel's physician to rule out any other possible reasons for his difficulties (see Evaluation Decision in Evidence to Practice Box). In addition, you feel it would be important to provide some services to Daniel and assistance to the teacher with physical education programming, and you outline your evaluation recommendations to the school team.

Plan of Care/Intervention

The team has reviewed your evaluation recommendations and has decided that special education services are needed; an individual

Continued

CASE STUDIES—cont'd

education plan (IEP) is developed. As part of the IEP, you have indicated that you will do the following:

- Provide general and tailored information/resources on children with motor difficulties to people involved with Daniel at home and in school.
- Encourage Daniel's parents to follow up with their primary care physician regarding motor concerns at home and in the classroom, and/or initiate a direct referral to other health care professionals such as a neurologist or a physiatrist familiar with the disorder (if appropriate within local regulations).
- Establish some tasks that Daniel wishes to accomplish by having Daniel complete the Perceived Efficacy for Goal Setting system (PEGS) (see Plan of Care Decision in Evidence to Practice Box).
- Encourage the teacher and parents to complete the PEGS to identify tasks for work on generalization of function within the classroom and at home; collaboratively set goals for intervention.
- Work on acquisition of Daniel's chosen tasks to build initial success using motor learning principles and modeling combined with verbal guidance to develop strategies (e.g., "helper hand, doer hand" strategy for tasks that require dominant/assistant use of upper extremities).
- Identify tasks at home and school for transfer and generalization of the strategies ("helper hand/doer hand" is a useful strategy for catching a ball [one of Daniel's goals], holding paper while cutting with scissors [teacher's goal], and using a knife and fork to cut food [parents' goal]); encourage home and school to use mediation techniques to help Daniel develop his problem-solving abilities.
- Make recommendations to Daniel's parents about activities within the community in which he is likely to be successful, and discuss the importance of promoting physical activity and building overall strength for long-term health.
- Make recommendations to the classroom teacher regarding accommodations for the classroom, the physical education class, and the playground.

Outcome

To determine whether any functional gains have been made in Daniel's chosen goals (and to see whether gains have been sustained), you re-administer the PEGS in 6 months' time with Daniel, his teacher, and his parents. You discuss strategies for long-term management with Daniel's teacher and parents, encouraging them to continue to use a mediational approach when new motor problems are identified and to foster Daniel's independence in using problem-solving strategies. You also encourage the use of accommodations and adaptations of the environment to reduce participation restrictions whenever possible.

"Katie Can't Keep Up"

Katie is an 8-year-old girl who was referred by her family physician to the local children's treatment center where you work because of concern regarding her gross motor difficulties.

Physical Therapy Examination

Family Concerns

Katie's parents are concerned about her lack of strength, endurance, and overall coordination. In particular, she seems to have trouble participating in, and sustaining, physical activities. When she and her family go out for a hike, they often have to come back early because she complains of being physically tired. Katie's parents report that at school Katie has trouble sitting on the floor for long periods without something to lean on and has difficulty carrying her knapsack to school. Her parents have also noted Katie's tendency to lean on her desk while doing her homework. She has difficulty with her balance, especially when she is required to stand on one foot, including while dressing (pants in particular) and in managing stairs. Katie's parents note that she was delayed in achieving some of her milestones and has not yet learned to ride a bicycle. Katie's lack of endurance has caused her parents to wonder if perhaps she is anemic. She has difficulties with bowel control, which also concerns her parents. Hoping to improve her overall strength and endurance, her parents enrolled her in dance lessons. Katie was so frustrated with regular dance classes that her parents decided to register her in a musical theater class. Katie is often anxious and her parents are worried about the effect that her incoordination is having on her overall motivation and self-esteem.

Developmental History

Katie is an only child, and she is reported by her parents to have been slower in her motor development than other children of her age. They report that she was a "floppy" child in infancy. Her gross motor skills were acquired slowly, and they had hoped that she would outgrow her delays. A review of Katie's chart indicates that the pregnancy, birth, and developmental history are unremarkable, other than the delays evident in gross motor development.

Medical History

Katie's physical and neurologic exams are unremarkable, with the exception of mildly decreased tone in the extremities and trunk. Overall, Katie shows decreased strength in all extremities. Katie is slightly overweight for her age. Medical investigations regarding the issue of incontinence and lab (bloodwork) results were all normal.

Observation

Katie attends your treatment center. You observe Katie performing several gross motor skills (e.g., throwing and catching, running and skipping) on an informal basis. Her movements are generally slow,

CASE STUDIES—cont'd

and she appears somewhat stiff when moving, particularly when running. She has limited success in catching a small ball and is unable to skip rope (see www.cmaj.ca/cgi/content/full/175/5/471; click on "videos" in right-hand menu). Katie appears to be shy and reserved during the visit and needs quite a bit of encouragement to try the activities.

Standardized Examination

You administer the MABC-2 to Katie and her total score is at the 2nd percentile, with an equal distribution of impairment scores across categories (see Examination Decision in Evidence to Practice Box). Katie moves very slowly during the manual dexterity items, and although she completes the tasks, she takes too long. During the ball skill activities, you notice that she does not use any consistent patterns of movement, but instead changes her strategy with every trial and never really finds a successful strategy. Her balance difficulties are most evident in the static balance item (see video of Bill for an example of a child with similar problems). She comments a few times during the testing that she is "kind of a klutz."

EVIDENCE TO PRACTICE 16-2

CASE STUDY "KATIE CAN'T KEEP UP": EXAMINATION, EVALUATION, AND PLAN OF CARE DECISION MAKING

Examination Decision: Young children observed to have movement difficulties may be demonstrating characteristics of developmental delay or motor impairment. To determine if motor impairment is present, it is important to use a standardized tool intended for this purpose. The Movement Assessment Battery for Children-2 is a norm-referenced examination that incorporates test items that are difficult for children with development coordination disorder (DCD) (manual dexterity, ball skills and balance). Studies of the psychometric properties of the MABC-2 are emerging. The original version of the MABC is believed to be a valid and useful tool that has several advantages over other assessment tools, including the wide age range it covers and its ability to identify children with DCD and co-occurring learning or attention problems. The test also includes qualitative descriptors of motor behavior and a behavioral checklist, both of which would be extremely helpful to the physical therapist.

Evaluation Decision: Strong evidence suggests that children with motor difficulties do not outgrow the condition and that, over time, they are at significant risk of developing numerous negative secondary consequences unrelated to their primary impairment. When a physical therapist observes movement impairment that is suggestive of DCD, it is important to encourage the family to follow up with their primary care physician. Facilitating this relationship is critical, as the primary care physician can monitor for the development of physical, social, emotional, and behavioral difficulties and can initiate referrals to other health care providers as appropriate. Children with movement difficulties may also have unrecognized co-occurring conditions. Early identification of these difficulties can lead to appropriate interventions and may reduce the potential for negative long-term outcomes.

Plan of Care Decision: Adoption of a task-based intervention approach to address Katie's difficulties is supported by the research literature. Task-specific intervention is ecologically valid because it involves the direct teaching of functional tasks in natural environments. The approach fits well with contemporary thinking about motor development and performance and has been shown to be a successful way to teach children with DCD specific motor skills that they need or want to perform in their everyday lives. In turn, the skills acquired through a task-based approach can enhance physical and social participation, both of which are particularly important for children with DCD. Children with DCD tend to withdraw from physical activity at an early age, limiting their physical and social interactions.

See also Chapter 4 on task-based motor learning programs.

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CASE STUDIES—cont'd

EVIDENCE TO PRACTICE 16-2—cont'd

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Physical Therapy Evaluation, Diagnosis, and Prognosis

Clinically Katie is showing a movement impairment pattern that is suggestive of developmental coordination disorder (see APTA Guide to Physical Therapist Practice Pattern 5C—Impaired Motor Function and Sensory Integrity Associated With Nonprogressive Disorders of the Central Nervous System—Congenital Origin or Acquired in Infancy or Childhood). Although your professional expertise allows you to identify the motor and activity limitations that Katie has, it is not within your scope of practice to diagnose the medical condition (see Evaluation Decision in Evidence to Practice Box). You believe it is important to have additional medical input regarding the clinical issues you are observing to rule out alternative diagnoses (e.g., see Box 16-3). Katie has a motor coordination impairment that is affecting her ability to participate fully in activities of daily living, a condition that can be addressed with physical therapy. She is at high risk for physical, emotional, and social problems as secondary consequences of her movement difficulties.

Plan of Care/Intervention

- Discuss your findings with the parents to help them understand the role that DCD is likely playing in Katie's difficulties.
- Talk with Katie about DCD, using child-friendly language so she has an understanding of why she is struggling.
- Encourage Katie's parents to return to the family physician for further diagnostic workup and to develop a bowel management program.
- Provide individualized task-based physical therapy procedural interventions to address Katie's performance difficulties with an additional focus on building core skills such as strength, endurance, balance, and stability (see Plan of Care Decision in Evidence to Practice Box). Establish baseline strength and fitness measurements preintervention for future comparison to evaluate change. Have Katie complete the COPM to establish child-centered goals for intervention and to measure progress.
- Provide consultation to Katie's parents regarding ways to incorporate/transfer and generalize tasks learned during intervention to daily activities and how to encourage Katie's participation in regular physical activities, including those available within the community.
- Encourage Katie's parents to share with her dance teacher educational materials designed for community leaders and coaches (http://www.canchild.ca).
- Speak to the parents about making a referral to the center-based OT to assess potential fine motor difficulties.

Outcome

As you progress toward achieving Katie's goals, you re-administer the COPM and repeat measurements of strength and overall fitness. As necessary, you make modifications to your intervention, including progressing strengthening activities as necessary. You have a follow-up visit with Katie's teachers in a few weeks to see how things have been working at school and provide additional information/resources to the teacher as necessary. You continually monitor Katie's progress and goals to establish or revise intervention frequency and duration.

"Aidan Acts Out"

Aidan is a 13-year-old boy who has ADHD and a history of behavior problems at school. You have a pediatric private practice and receive a call from Aidan's family. Aidan's parents think something is not "quite right" but can't seem to pinpoint the specific origin of his difficulties.

Physical Therapy Examination

Family and School Concerns

Aidan's parents are aware and have been dealing with his ADHD since kindergarten, but believe there is more going on with him. He is

CASE STUDIES—cont'd

frequently in trouble and sent to the office and has been suspended from school several times. Aidan's parents indicate that he is currently receiving special education services at his school and has an IEP. He has very poor written expression, rarely completes tasks independently, and is disruptive in class. Homework completion is a huge problem and is placing a lot of stress on the family. He is taking medication, which has helped with his attention, but teachers report that he continues to act out, particularly during physical education class and when he is expected to write. He has recently been given greater access to assistive technology for writing, and this has been a positive step, but the school has expressed concerns about his readiness for moving on to high school, and staff members also wonder if they aren't missing something. Aidan's mother describes him as awkward-looking and "gangly" and says that he covers up his difficulties by clowning around. Aidan's mother reports a history of withdrawal from organized physical activities, with frequent sign-ups and then dropouts. He tends to spend all his time at home on the computer. Recently, Aidan's parents have become increasingly concerned about Aidan being socially rejected by his friends, especially given some issues with bullying in the earlier grades. Aidan is spending most of his time alone, and his parents can see his mood deteriorating.

Developmental History
Aidan was born prematurely but has had few health concerns since. His development was monitored at regular intervals because of his prematurity. Although Aidan often seemed slow in his development, he did manage to meet all of his motor milestones in a timely fashion. He was diagnosed with ADHD in his early school years.

Medical History
Aidan does not have any current health issues and takes medication for his ADHD.

Observation
You observe Aidan informally and notice that his movements are awkward and have a rigid quality to them. His ability to jump, hop, and maintain balance are less than what you would expect for his age. Aidan is reluctant to demonstrate his motor skills to you, and you observe frequent "off-task" behaviors during your assessment.

Standardized Examination

You have Aidan complete the CSAPPA to get more information about Aidan's perceptions of his abilities (see Examination Decision in Evidence to Practice Box). You also administer the MABC-2, which suggests that Aidan has motor difficulties in addition to his attention difficulties (see video of Bill for an example of a child with similar problems).

EVIDENCE TO PRACTICE 16-3

CASE STUDY "AIDAN ACTS OUT": EXAMINATION AND PLAN OF CARE DECISION MAKING

Examination Decision: The Children's Self-Perceptions of Adequacy in, and Predilection for, Physical Activity Scale (CSAPPA) provides information regarding a child's self-efficacy toward physical activity. Use of this scale is supported by the research evidence and would be particularly helpful in this case scenario. The tool is age-appropriate and would provide valuable information about Aidan's desire, and his perceived ability, to participate in physical activity. He is reluctant to demonstrate his motor abilities. The CSAPPA can provide information about his physical participation levels, which can be useful to you as you plan intervention. As he has already begun to withdraw from participation, you hope to focus your intervention on physical activities in which he can achieve success and build his confidence, and that he can continue for his lifetime. The CSAPPA has demonstrated construct validity, and it has been suggested it may be useful to clinicians in screening for motor impairment.

Plan of Care Decision: Children with developmental coordination disorder (DCD) can become successful participants in physical activity and receive the long-term health and social benefits that regular physical activity provides. The key to encouraging participation in children with DCD lies in matching children's abilities with activities that promote success. Consultation with children, family, and others about activities that are likely to be successful in children with DCD is an important role for the physical therapist and should be part of the intervention process. Parents, teachers, and others in the community can be helped to understand the role of physical activity participation for positive social and physical health.

Plan of Care Decision: Children with DCD may have difficulties in both fine and gross motor skills, leading to activity limitations and participation restrictions. Consultation and collaboration with other health care providers may be necessary, as a variety of motor performance issues may need to be addressed with the child with DCD. Each health care provider brings area-specific expertise and can be instrumental in facilitating appropriate environmental accommodations and adaptations for success at home and in the classroom.

Continued

CASE STUDIES—cont'd

EVIDENCE TO PRACTICE 16-3—cont'd

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Physical Therapy Evaluation, Diagnosis, and Prognosis

You believe that Aidan's poorly developed motor abilities may be consistent with developmental coordination disorder, and that these difficulties are present in addition to his attention issues (see APTA Guide to Physical Therapist Practice Pattern 5C—Impaired Motor Function and Sensory Integrity Associated With Nonprogressive Disorders of the Central Nervous System—Congenital Origin or Acquired in Infancy or Childhood). You are concerned about Aidan, given his motor difficulties, his co-occurring ADHD, and the fact that he is already demonstrating physical and social participation withdrawal.

Plan of Care/Intervention

- Help Aidan to understand the nature of his attention and motor difficulties and the combined impact that these are having on his physical and social participation.
- Speak to Aidan's parents and obtain permission to observe Aidan in the classroom and meet with school personnel; coordinate with general education personnel at Aidan's school and the special education teacher. Determine if Aidan has a school-based physical therapist currently working with him at school, and coordinate services as appropriate.
- Consult with Aidan's parents and teachers by providing resources and information; suggest some physical activities that might "MATCH" his abilities and interests, and promote his physical participation both at school and in the community (see Plan of Care Decision in Evidence to Practice Box).
- Discuss with school personnel and Aidan's parents upcoming high school courses that might be challenging (e.g., music, shop); make recommendations/provide input for his IEP regarding possible accommodations and/or adaptations that could be put in place.
- Reinforce the need for accommodations regarding writing assignments and access to a laptop at school.
- Suggest a referral to OT for any additional recommendations regarding writing issues (see Plan of Care Decision in Evidence to Practice Box).

Outcome

You plan to continue to assist Aidan and his family as they make the transition to high school. You help Aidan and his parents to proactively problem-solve as new issues arise. You follow up with Aidan and his family several months after he has settled in to high school, monitoring the need for referral to other health care service providers for social, emotional, and behavioral issues.

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Chapter Three

Title of Paper: Do they 'look' the same? Exploring selective visual attention during visuomotor performance in school-aged children with and without developmental coordination disorder

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Abstract

Developmental coordination disorder (DCD) is a prevalent condition, for which a definitive pathophysiology remains elusive. However, research suggests that children with DCD depend on vision during motor tasks, possibly related to poorly developed internal models. Their over-reliance on vision may mean they fail to attend to relevant task information critical to motor learning. Recently, cognitive interventions have been effective in helping children with DCD learn motor tasks; however, the cognitive mechanisms involved are unknown. Neuroimaging studies also confirm that children with DCD differ from their typically developing (TD) peers, utilizing networks associated with attention, and visual-motor/-spatial processing to complete motor tasks. The contributions of visual attention and attentional cueing to cognitive intervention success have been hypothesized but not yet studied. Using a novel eye tracking design, we explored gaze in school-aged children with and without DCD during a functional pouring task. Twenty-four children (12 DCD, 12 TD), aged 7-15 years, participated. Gaze overlay videos provided measures of gaze fixations. Between group ANOVAs, and Mann-Whitney

U/Kruskal-Wallis Tests detected group and age-related differences. We found that children with DCD fixated longer on their pouring arm/hand, and on the pouring cups while pouring than TD children; TD children fixated longer on task-relevant pouring/filling cups. Compared to older children (9-10 and > 11 year olds), 7-8 year olds fixated for a shorter time on the filling cups before pouring. Our results suggest that children with DCD used vision to monitor their arm/hand position, rather than to focus on important aspects of a motor task. It appears they may not benefit from predictive visual fixations, providing some support for the internal model deficit hypothesis.

Keywords: developmental coordination disorder, school-age, selective visual attention, eye tracking, visual difficulties, internal models

Introduction

Developmental coordination disorder (DCD) is a highly prevalent, but poorly recognized, neurodevelopmental condition of childhood affecting 5-6% of the school-aged population (American Psychiatric Association (APA), 2013). Due to their poor motor coordination, children with DCD have significant difficulties engaging in daily life activities, with far-reaching consequences for their academic potential and quality of life. Without intervention, they have a greater likelihood of developing serious secondary issues including academic problems, anxiety, depression, and social isolation (Rivard, Missiuna, Pollock & David, 2012). It is well documented that children with DCD have difficulties learning motor skills (Henderson & Henderson, 2002; Missiuna, 1994; Missiuna & Mandich, 2002). As a result, they tend to withdraw from physical activities at an early age, putting them at increased risk of obesity, decreased physical fitness, and poor cardiovascular health (Rivilis et al., 2011). Children with DCD present with complex rehabilitation issues for the practicing clinician, making this disorder one that warrants significant attention (Barnhart, Davenport, Epps, & Nordquist, 2003). The benefits that children with DCD could realize from early identification, effective intervention, and long-term management cannot be over-stated (Missiuna, Rivard, & Bartlett, 2003).

While the mechanisms and potential neural correlates underlying DCD remain poorly understood (Peters, Maathuis, & Hadders-Algra, 2013; Visser, 2003; Zwicker, Missiuna, & Boyd, 2009), it has been noted that children with DCD rely heavily on vision to complete motor tasks (Biancotto, Skabar, Bulgheroni, Carrozzi, & Zoia, 2011; Missiuna, 1994) and it is suspected that they do so because they have poorly developed or poorly integrated internal (memory) representations of motor tasks (Adams, Lust, Wilson, & Steenbergen, 2014; Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Ferguson, Duysens, & Smits-Engelsman, 2015; Gabbard & Bobbio, 2011; van Waelvelde et al., 2006; Wilson et al., 2004; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). This over-reliance on vision as compensation may mean that children with DCD fail to attend to, and integrate, other relevant information from the environment that is critical to motor learning. In other words, they may not have sufficient attentional resources available to allocate to task-relevant perceptual cues, especially during motor tasks (Wilmut, Brown, & Wann, 2007; Wilson & Maruff, 1999). This line of thinking may, theoretically, help to explain why a cognitive intervention approach that helps children to problem-solve the solutions to motor difficulties by drawing their attention to areas of poor motor performance has been successful (Miller, Polatajko, Missiuna, Mandich, & MacNab, 2001; Polatajko, Mandich, Miller, & MacNab, 2001). While effective, the specific cognitive mechanisms that promote success with this intervention are not yet fully understood. It is possible that the success of cognitive interventions is dependent on the verbal cueing of visual attention to assist children in focusing on relevant aspects of motor tasks. There have been several studies investigating selective visual attention in children with DCD (Chen, Wilson, & Wu, 2012; Mandich, Buckolz, & Polatajko, 2003; Tsai, Pan, Chang, Wang, & Tseng, 2010; Tsai, Pan, Cherng, Hsu, & Chiu 2009; Wilmut et al., 2007; Wilson & Maruff, 1999; Wilson, Maruff, & McKenzie, 1997) but none of these studies have examined selective visual attention in relation to the performance of a functional motor task performed in a natural setting. Recent neuroimaging findings confirm that children with DCD show differential brain activation in relation to their same-aged counterparts (Debrabant, Gheysen, Caeyenberghs, van Waelvelde, & Vingerhoets, 2013; Kashiwagi, Iwaki, Narumi, Tamai, & Suzuki, 2009; Querne et al. 2008; Zwicker, Missiuna, Harris, & Boyd, 2010, 2012). In particular, one study demonstrated that, during a trail-tracing task, children with DCD used primarily those cortical networks associated with attentional control, and visual-motor/-spatial processing. TD children performing the same task tended to activate both fewer, and different brain areas including those used during spatial processing, motor control/learning, and error detection (Zwicker, Missiuna, Harris, & Boyd, 2010). The contributions of selective attention and cueing to these processes, and to the success of cognitive interventions with this population, have to date only been hypothesized. A greater understanding of visual attentional processes in both TD children and children with DCD; specifically where, when, and for how long children visually fixate objects that are important to the successful performance of a task is necessary before fully exploring the potential role of selective visual attention and attentional cueing in cognitive interventions designed for use with the DCD population.

A research method that holds promise in measuring visual attention that has not yet been fully explored during functional tasks in DCD/probable DCD is eye-tracking (Wilson, Miles, Vine, & Vickers, 2012). With this technique, eye movements including gaze fixations and saccades are used as indirect or proxy measures to infer selective visual attention processes. Researchers examining other pediatric clinical populations have readily adopted the use of eye tracking (Damyanovich, Baziyan, Sagalov, &

Kumskova, 2013; Falck-Ytter, von Hofsten, Gillberg, & Fernell, 2013; Green et al, 2009; Karatekin, 2007; Munoz, Armstrong, Hampton, & Moore, 2003; Norbury, 2013; Wilkinson & Light, 2014). It is not yet known whether this technique could be a reliable and valid way to measure selective visual attention in children with DCD.

The purpose of this research study was to examine selective visual attention during motor performance in children with and without DCD employing an eye-tracker and gaze analysis paradigm. The aims of this study were to: 1) measure gaze fixation during three phases of a familiar fine motor task in a natural setting, and 2) investigate potential group and age differences in gaze fixations between TD children and children with DCD.

Specifically, the following research questions were addressed: During a pouring task, do school-aged TD children and children with DCD visually fixate for:

1) a similar duration (total) on pouring/filling cups, and their pouring arm/hand?
2) a similar duration (proportion of total time) on pouring/filling cups?
3) a similar duration (average) on pouring/filling cups within specific task phases?

Methods

Ethics

The Hamilton Integrated Research Ethics Board (HIREB) at McMaster University in Hamilton, Canada approved this study. Parents/caregivers provided their signed consent; children provided their signed assent to participate.

Design

This research study used an experimental design in a naturalistic setting. An eye tracker and novel gaze analysis paradigm were used.

Recruitment

We recruited a sample of children, aged 7 to 14 years who demonstrated the clinical characteristics of DCD (APA, 2013; Blank, Smits-Engelsman, Polatajko, & Wilson, 2012) (DCD group). Children were recruited through occupational therapists (OTs) at a local private pediatric therapy organization and from a DCD parent group. Children in the DCD group were sex- and age-matched (within 6 months) with a convenience sample of TD children (TD group). All families interested in participating received a letter of information describing the study along with consent/assent forms.

Inclusion/exclusion criteria

Prior to testing, caregivers of all interested participants were contacted by phone to complete a brief general health and development questionnaire to ensure inclusion/exclusion criteria were met. Children whose movement difficulties were not attributable to neurological or medical disorders, and who had normal or corrected to normal vision, as per parent report, were invited to come to the Infant and Child Health Lab (INCH Lab) at McMaster University (Hamilton, Ontario) to complete the experimental task.

Procedure

All testing was completed at the INCH Lab, during a single session lasting approximately 45-60 minutes for each child. Testing occurred over the school's winter break, during either the morning or afternoon, when it was most convenient for families. Parents were reimbursed for mileage and parking costs. Children were given a gift card honorarium to thank them for their participation.

Study Measures

Parent-Completed Questionnaires

Parents completed the 45-item Conners' 3-P [S] measure of attention (short-form, parent version) (Conners, 2008). Using this tool, parents provided ratings of their children's behaviours regarding different aspects of attention (e.g. inattention, hyperactivity/impulsivity, learning difficulties, executive functioning). The Conners-3 P [S] has been shown to be reliable and valid for the school-aged population (Wilding & Cornish, 2012). Parents also completed the Developmental Coordination Disorder Questionnaire (DCDQ'07) (Wilson et al., 2009). The DCDQ'07 has sound psychometric properties and is known for its ability to screen effectively for DCD in children of this age (Rivard, Missiuna, McCauley, & Cairney, 2012; Wilson et al., 2009).

Occupational Therapist Assessment

A registered OT with experience working with children with DCD completed additional measures. To categorize children's motor coordination and to adhere to international recommendations regarding satisfying the criteria for DCD (APA, 2013; Blank et al., 2012), two study measures (in addition to the DCDQ'07 completed by parents) were used. The OT administered the Movement Assessment Battery for Children-2 (MABC-2) (Henderson, Sugden, & Barnett, 2007), a reliable and valid tool frequently recommended for the assessment of coordination difficulties for both research and clinical purposes (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). The OT was blinded to group status, had been previously trained in the use of the MABC, and had administered this measure in a previous study (Cairney, Missiuna, Veldhuizen, & Wilson, 2008). The OT was also previously trained in the use of the Kaufmann Brief Intelligence Test-2 (KBIT-2) and completed this testing with the children. The KBIT-2 is an easy to administer, valid, and reliable tool for measuring cognitive abilities (Kaufman & Kaufman, 2004). Children were randomly assigned to complete either the experimental task or the study measures first, to balance testing order between the two groups.

Room, Equipment, and Task Set-Up

Children were seated facing a rectangular table in a quiet, well-lit room. They sat in a chair without arms (so as not to impede forward reach) and additional seat cushions were used to adjust the child's positioning as needed to ensure approximately 90 degrees of hip and knee flexion. Two small step stools were available and were selected and placed to ensure children's feet were flat when performing the task.

Mobile Eye Tracking Glasses

Children wore lightweight, mobile eye tracking glasses (SensoMotoric Instruments (SMI), version 1.0, sampling rate 30Hz) consisting of 2 separate recording devices (Figure 1): one camera facing outwards to record the scene directly in front of the child, and two small cameras pointing towards each pupil to record gaze direction (images from both eyes were averaged). Nose pieces were used to adjust the glasses to fit the children and attempts were made to place eye tracking glasses directly over corrective eyeglasses where necessary (as recommended, L. Richardson, personal communication, October 31, 2013).[1]

Eye Tracking Calibration

Using the eye tracking equipment calibration software, the Principal Investigator (PI) calibrated the eye tracking glasses for all children using a 3-point fixation calibration, with fixation points marked on the wall in front of the child at a distance of 2 m, as per the manufacturer's instructions. To ensure proficiency in calibration and recording, as well as extraction of data using the analysis software, the PI completed trials with 12 school-aged children not involved in the study, using the same instructions and task set-up (collected data were not analysed for this study). During the formal study trials, the eye tracking equipment was calibrated on the1st trial only, unless the glasses required re-

[1] Note: All 4 children with DCD who wore glasses had to remove them for testing as the eye tracker would not calibrate. We spoke with the child/caregivers prior to the task to inquire as to the reason for the glasses (near or far distance wearing) and to determine whether the child could still complete the task. For 1 child with DCD (near-sighted), the calibration points were adjusted slightly to enhance visual contrast. No further accommodations were required. Any information provided regarding vision was noted in the study charts, as was the decision to remove the glasses, to assist with data analysis as needed.

calibration during the trials/blocks (i.e. glasses slipped from their initial position, child lifted the glasses or rubbed his/her eyes).

Task Set-Up

Two trays placed on the table in a horizontal orientation were lined up against one another in the middle of the table (Figure 2). Beneath the trays a non-slip surface was adhered to the table. On each of the trays was an additional non-slip surface.

Three plastic coloured filling cups (red, yellow, and blue) were placed on the left-sided tray on a diagonal, down and to the left, equidistant from one another, with stickers beneath the cups on the tray marking their locations (note: this was a right hand-dominant set-up; filling cups were placed on the right-sided tray for all left-handed children). Numbers (1 through 3) identified filling cups, with numbers and a fill line marked in black on the outside and inside of cup approximately half way up the cup. Cups were placed such that the numbers were easily visible to the child.

Three glass 250 mL pouring cups were placed on the right-sided tray with handles facing towards the child, placed on a diagonal down and to the right, equidistant from one another, again with their position on the tray marked by stickers (note: pouring cups were placed on the left-sided tray for left-hand dominant children). Three small square coloured cardboard cards matching the colours of the filling cups were affixed to the outside of the pouring cups and matching numbers were written on the cards.

Prior to the first trial, and following every 3rd trial when changes to filling cup order were made, a large cardboard box concealed the task materials (see notes on specific trials below).

The table, trays, and cups remained in the same measured locations for all participants. To accommodate children's specific body size (height, trunk girth, arm length/reach, leg length), we adjusted chair and step stool position/(size) as well as cushions to ensure children were able to touch the ground with feet flat, and to ensure a shoulder position of neutral flexion/extension with a 90 degree angle at the elbow.

Task

A graduate student research assistant (RA) with experience with experimental testing, naive to group status, completed the experimental trials with the children. Children poured water from the pouring cups into the colour-matched filling cups to the marked fill line until all 3 cups were filled in sequence.

Prior to beginning the task, the RA gave verbal instructions and provided a demonstration of the task using identical pouring and filling cups to those used in the task to ensure understanding. Children were instructed regarding task start and end position (fists placed on the table in front of them, shoulder width apart with thumbs facing upwards, on location stickers affixed to the table just in front of the trays). The RA indicated that there would be 3 pouring and 3 filling cups in the task, that the pouring and filling cups would have different colours, that they were to begin pouring from the red pouring cup first (always first in the pouring cup sequence), and that they were to continue pouring until all filling cups had been filled before they stopped. The RA instructed the children to move only the pouring cups as needed. All location stickers were pointed out to the children and reminders/cues to replace the pouring cups on their stickers were given during the task as needed. Children were also told that they would have as much time as they wanted to look at all of the pouring and filling cups once the cardboard box had been removed before they actually began the task. Children did not practice the task (to avoid potential task learning) and they were not informed that the order of the filling cups would be altered during the trials. They were encouraged to ask questions or request further clarification as needed prior to engaging in the task, and/or between task trials. The RA was instructed to encourage the children during the task to ensure participation, motivation, and attention but otherwise not to engage the children in conversation so as not to distract them.

Following calibration with the eye tracker, the RA revealed the task materials. At that time, children surveyed the task materials for as long as they needed, and asked any additional questions about the specifics of the task. Once the child indicated that he/she was ready to begin, the child was instructed to fix his/her gaze on the final calibration point and maintain their gaze on that point until the RA signaled the start of the trial. Eye tracking recording began at the point when the child re-fixated on the final calibration point and ended once the blue pouring cup was returned to its location sticker.

Task Trials

Children completed 12 trials (4 blocks of 3). A single trial consisted of children pouring the water from all 3 pouring cups into the corresponding filling cups. Children performed 3 trials in each block - Trial 1: no additional instructions (self-paced), Trial 2: ‘as fast as you can’, and Trial 3: ‘as carefully as you can’. The RA monitored cup position following each trial, adjusting where necessary to ensure the task was standardized. Individual trials lasted 30 to 60 seconds with a short break between trials to record task fidelity (described below), and to replace water in the pouring cups.

There were 4 blocks in total - for the 1st block (‘compatible’ condition: red/yellow/blue), corresponding pouring cups and filling cups were placed directly across from one another (i.e. red pouring cup across from red, etc). Prior to beginning the 2nd block (‘mirror’ condition: blue/yellow/red), the cardboard box was replaced so children could not see the task materials and changes were made to the filling cup order. The location of the red and blue filling cups were switched. The cardboard box was then removed and children had as much time again to survey the task materials. Eye tracking for the 2nd block began as it had in the 1st block once children indicated they were ready to begin and following re-fixation on the final calibration point and signal from the RA. The 3rd (‘reversal 1’ condition: red/blue/yellow) and 4th blocks (‘reversal 2’ condition, yellow/red/blue) proceeded in a similar manner. Throughout the 12 trials, the pouring cups remained in their same positions; only the order of the filling cups was altered. There was a short break between trial blocks to change filling cup locations. An entire set of 12 trials lasted 15 to 30 minutes, depending on how the child attended to, and engaged in, the calibration process, and the task.

Data Collection

Task Fidelity

For each trial, the RA completed an observational checklist to examine task performance fidelity, recording the amount of water transferred from each pouring cup to the corresponding filling cup. It was not the intent of this study to specifically examine this data, except to ensure children performed the task as they had been instructed.

Video Export

We exported the recorded data from the eye tracking glasses using dedicated software (BeGaze Mobile Video Analysis software, version 3.4 (SMI)) to create gaze overlay videos with the eye gaze cursor superimposed on the scene image (Figure 3).

Data Coding

We developed, tested, and refined an eye-tracking video observation scoring sheet, along with operational definitions to assist in scoring items. The development and testing process is detailed further, along with the early version of the scoring sheet and guidelines, in Appendix A. The final scoring sheet (Table 1) consisted of 9 scoring items (scoring guidelines found in Appendix A) and demonstrated excellent intra-rater reliability (intra-class coefficients (ICCs) for total item scores ranging from 0.92 to 0.99, with the exception of 1 item: filling cup prior to pour, which had an ICC of 0.67. The ICC for this item total resulted from an estimate of 0 for one of the pouring/filling cup combinations, with all children scoring 0 on this item. As such, there was no variability in scores, resulting in an estimate of 0. This particular item was reviewed, discussed with the study team and retained, as it was still deemed important for the analysis; a slight change was made to the definition of the pouring and forward transport phases. These changes did not impact the actual items). Scored items included item 1: total trial time; items 2-7: time spent fixating (for each of the pouring/filling cup combinations) on the: pouring cup prior to forward transport, pouring cup during forward transport, filling cup prior to pour, filling cup during pour, pouring cup during pour, and pouring cup during back transport/set down/release; item 8: time spent fixating on pouring arm/hand (any phase, across all cup combinations); and item 9: total scored time.

Video Scoring

A second graduate student RA who demonstrated good intra-rater reliability scored the Trial 10 video recordings for all children in the study sample. For those children who were unable/did not maintain at least 1 second of gaze fixation on the final calibration point, items 2 through 9 on the scoring sheet were not scored. Data from the scoring sheets was then entered into Excel and transferred to SPSS Statistics Software, Version 22 (IBM Corporation).

Outcome Variables

We computed 10 outcome variables from the 9 scored items to address the 3 study research questions. For Research Question 1 these included: 1) the sum of item totals 2, 3, 6, 7 (time fixating on pouring cups across all task phases); 2) the sum of item totals 4 and 5 (time fixating on filling cups across all task phases); and 3) item 8 total (time fixating on pouring arm/hand (any phase)); for Research Question 2: 1) item 9 minus item 8 total / item 1 x 100% (proportion of total time fixating on pouring/filling cups); for Research Question 3: individual averages of each of the 5 item totals related to pouring and filling cups only (average time fixating on either pouring or filling cups within each task phase). In addition, for age analyses, we divided the sample into 3 age groups: 7 to 8 years (n=9), 9-10 years (n=7), and > 11 years (n=8).

Statistical Analysis

Descriptive statistics and plots were generated for all 10 outcome variables, (mean, SD, median, range, skewness, kurtosis, Kolmogorov-Smirnov and Shapiro-Wilk tests of normality, histograms, and boxplots). We inspected the data and removed outliers and extreme outliers for each outcome variable (outliers were defined as those data points 1.5 box-lengths from the edge of the box in a box plot; extreme outliers were 3 box-lengths from the box edge). We then re-analysed the descriptive statistics and plots, and continued this process until no outliers remained. Levene's test of equality of error variances, and tests of homogeneity of variances were also performed. Two-way between-groups ANOVAs were calculated to explore the impact of group and age on the outcome variables. Where assumptions for ANOVA were not met, we conducted Mann-Whitney U (group differences), and Kruskal-Wallis tests (age differences).

Results

Participants

DCD Group

Of the original sample of children recruited to the study, one child enrolled but did not provide consent to participate, another child was excluded as his developmental history and clinical assessment of his difficulties indicated that his motor concerns might be other than DCD (i.e. potential learning disability <u>not co-morbid</u> with DCD), and two children who were recruited for the TD group were re-allocated to the DCD group based on low MABC-2 scores. The final DCD group was comprised of 12 children (11 M, 1 F), with a mean age (SD) of 10.5 years (2.3) (range 6.7). Table 2 summarizes their demographic and clinical information. Half of the children (n=6) had a formal DCD diagnosis given by pediatrician (n=4), family physician (n=1), and neurologist (n=1). Nine children were right-handed; 3 left-handed. Five children wore corrective eyeglasses (far-sighted (n=3), near-sighted (n=1), and poor depth perception and bilateral astigmatism (n=1)).

TD Group

Of the children without motor coordination difficulties recruited to the study (sex- and age-matched to the DCD group), one child enrolled but was unable to participate due to scheduling, and 2 children were re-allocated to the DCD group based upon low MABC-2 scores. The final TD group was comprised of 12 children (10 M, 2 F), with a mean age (SD) of 9.7 years (1.9) (range 6.9) (Table 2). Ten were right-handed; 2 left-handed. Two children wore eyeglasses (both were near-sighted). Two were red/green colour blind.

Task Fidelity

Data collected indicated that all children performed the task as they were instructed.

Missing Data

We excluded cases where data was missing for the entire video trial (n=2 TD) due to equipment failure. For 3 children with DCD, we did not score items 2 through 9 of the scoring sheet, as the children were unable to maintain gaze fixation on the final calibration point for at least 1 second.

Study Findings

The major findings from this study are:

- <u>Group differences:</u>

  Compared to TD children, children with DCD fixated longer on their pouring arm/hand (as measured across all task phases) and longer on the pouring cups while pouring. Compared to children with DCD, TD children fixated for a longer proportion of time on task-relevant pouring/filling cups.

- <u>Age differences:</u>

Compared to older children (both 9-10 and > 11 year olds), 7-8 year olds fixated for a shorter time on the filling cups before pouring.

Each of these findings is described in more detail below.

Question 1:

Do TD and children with DCD visually fixate for similar total durations on:

1) pouring cups?

Yes. Both groups fixated for similar total durations on pouring cups when combined across all task phases (all effects were non-significant).

2) filling cups?

Yes. Both groups fixated for similar total durations on filling cups when combined across all task phases (all effects were non-significant).

3) pouring arm/hand?

No. Children with DCD spent significantly longer fixating on their pouring arm/hand (as measured across all task phases and all cup combinations) than TD children. There was a statistically significant main effect for group ($F(1,9)=7.5$, $p<.05$). The effect size was large (partial eta squared=.46). The group by age interaction and main effect of age were non-significant.

Question 2:

Do TD and children with DCD visually fixate for the same proportion of TOTAL time on all objects of importance (pouring/filling cups)?

No. TD children fixated for a significantly longer proportion of the total trial time on pouring/filling cups than DCD children. A Mann-Whitney U test revealed a significant group difference between TD children (Md=79.9, n=8) and children with DCD (Md=63.3, n=9), U=11.0, z=-2.41, p<.05, r=.58). There was no significant difference among the three age groups.

Question 3: Do TD and children with DCD visually fixate <u>for similar average durations</u> on:

1) pouring cups within specific phases?

No. The DCD group fixated for a significantly longer average duration on pouring cups during pour than TD children. A Mann-Whitney U Test revealed a significant group difference between TD children (Md=0.00, n=9), and children with DCD (Md=0.04, n=9), U=16.5, z=-2.33, p<.05, r=.56). There was no significant difference among the three age groups.

In addition, there were no significant group by age interactions, or group or age differences for items related to fixations on pouring cups*:* 1) prior to forward transport, 2) during forward transport, or 3) during back transport/set down/release.

2) filling cups within specific phases?

Yes. Both groups fixated on filling cups both before and during pour for similar average fixation durations (all interaction and group main effects were non-significant).

Interestingly, younger children (7-8 yr olds) fixated for significantly shorter average fixation durations on the filling cups prior to pour compared to older children (both 9-10 and >11 yr olds). There was a statistically significant main effect for age ($F(2,12)=8.98$, $p <.01$), with a large effect size (partial eta squared=.60). Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the 7-8 yr old group ($M=.66$, $SD=.14$) was significantly less than the 9-10 yr olds ($M=.96$, $SD =.16$) and the > 11 yr olds ($M=1.02$, $SD=.11$); the 9-10 yr olds and > 11 yr olds did not differ significantly from one another. The main effect of group was non-significant.

Discussion

Group differences found with respect to selective visual attention in our study suggest that children with DCD and TD children do not 'look' the same. Our findings confirm previous literature indicating that children with DCD predominantly use vision to complete motor tasks (Biancotto et al., 2011; Missiuna, 1994) and would further suggest that, in children with DCD, vision is being allocated specifically to control their upper body movements. During a functional pouring task performed in a natural setting, children with DCD spent more time visually fixating on, or attending to, their pouring arm/hand than TD children, as measured across all task phases. This finding highlights the important role that vision plays for children with DCD in monitoring their upper body position during motor performance, a pattern that is atypical. A review paper by Land (2009) provides evidence that, for adults performing complex tasks such as tea- or sandwich-making, gaze fixations are never made to the hands. In fact, in these instances, even with task objects, gaze shifts away from the objects as soon as the hands have manipulated them. Land (2009) further suggests that this pattern underscores the need to disengage vision, allowing proprioception and touch senses to be used instead, so that vision can be employed elsewhere.

Fixation on the arm/hand during the task also suggests that children with DCD in our study performed as if in an earlier motor learning stage than their same-aged counterparts, a finding that has been previously noted (Rivard, Missiuna, Pollock, & David, 2012). This skill-focused visual attention, whereby children with DCD are selectively directing their visual attention to their body and/or movement coordination, rather than aspects of the task, is more typical of novice learners, and has been noted to lead to slower, more inefficient movements (Wulf, 2007).

Our findings, taken together with the literature, provide some support for the notion that cueing of visual attention to aspects of a task that are critical to performance (i.e. pouring and filling cups) might lead to improved motor performance in children with DCD. Indeed, in our study, children with DCD spent a shorter proportion of the total trial time on the task-important pouring and filling cups compared to TD children. While some of the difference in proportional fixation time found between the groups can be accounted for by time spent fixating on the pouring arm/hand by children with DCD, this explanation is incomplete. Examination of the gaze overlay videos indicates that, throughout the task phases, children with DCD frequently demonstrated a greater number of gaze shifts than TD children. For example, when shifting gaze from the pouring cup towards the corresponding filling cup, TD children would typically use a single gaze shift (most often without visualization of the pouring arm/hand), whereas children with DCD would use several gaze shifts. On occasions, these gaze shifts served as a way to track the pouring arm as it approached the filling cup. On other occasions, this was not the case, with children with DCD using several eye movements where TD children might only use a single shift of gaze.

In children with DCD, the need to visually control their motor movements throughout a task may reduce their ability to ‘free up’ their visual attention for objects important to the overall task. It is therefore possible that an intervention that helps children with DCD to shift from an internal (movement-based) to an external (task/environment-based) focus of attention may improve motor task performance. Such assistance may also facilitate graduation to more autonomous stages of motor learning. It is unclear at this time whether guidance to alter the foci of attention during motor performance could be one of the processes contributing to the success of cognitive interventions. The use of an external focus of attention has just begun to be studied in the DCD literature (Jarus et al., 2014) and needs to be tested further under varying task demands and conditions.

While both groups of children appeared to fixate pouring and filling cups somewhat equally when averaged over the total time spent fixating these objects, when analyzed by task phase, children with DCD spent a greater amount of time fixating the pouring cups during pour. This pattern again suggests a need for children with DCD to monitor upper body movements (the pouring cup and pouring hand forming a unit). Their TD peers seemed to adopt a pattern whereby they fixated the pouring cup as they prepared to grasp it and/or during the early phases of transport to the filling cup. However, very soon after, they allocated their visual attention to the filling cup where their attention remained during the pour phase. TD children did not tend to look back at the pouring cup, concentrating on the filling cup during the pour. They performed as if the spatial coordinates of the pouring cup, their pouring arm/hand, and its relation to the pouring cup had been previously determined and these coordinates translated into a motor program. Children with DCD, in comparison, did not appear to use similar 'look ahead' visual fixations to locate/identify the filling cup, typical gaze patterns that have been described in the literature (Hayhoe, 2009; Hayhoe & Ballard, 2005; Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Land, Mennie, & Rusted, 1999; Pelz & Canosa, 2001), and which indicate movement planning prior to actual execution (Mennie, Hayhoe, & Sullivan, 2007). The lack of predictive, or feedforward motor control in DCD has been noted by other researchers (Adams et al., 2014; Debrabant, Gheysen, Caeyenberghs, van Waelvelde, & Vingerhoets, 2013; Fergsuon, Duysens, & Smits-Engelsman, 2015; Wilmut & Wann, 2008). It is possible that the pattern of selective visual attention seen in DCD may be the result of poorly developed internal representations of motor tasks, as has been suggested (Adams et al., 2014; Bo et al., 2006, Ferguson et al., 2015; Gabbard & Bobbio, 2011; Kagerer et al., 2004, Kagerer et al., 2006). Alternatively, perhaps it is the continued used of atypical gaze patterning, over the course of development and prompted by a primary need to control body movement, that has given rise to an internal model deficit.

Finally, developmental differences found in our study whereby younger children fixated for less time than older children on the filling cups prior to pour seems to underscore further the influence of developmental stages of motor learning, which are presumed to advance with maturation and age (Shumway-Cook & Woollacott, 2012). It may be that younger children in both groups have not yet developed the internal memory representations of tasks that are seen in older children and that are required for quick and efficient movement. It is unclear from our study why differences were seen only for one of the task phases. It could be that children were fixating locations other than those measured and deemed to be important to the task (pouring and filling cups). Interestingly, a group by age interaction related to the fixation duration on the filling cups during pour trended towards significance, suggesting that there may be additional group differences (mediated by age) worth exploring further.

There were several limitations to this study that limit its generalizability. The study may not have been sufficiently powered to detect all group and age differences and therefore may underestimate the findings detailed here. In addition, as the DCD participants were recruited primarily from clinical samples that had been referred for therapy, the children had more significant coordination difficulties (reflected in both their MABC-2 scores and the early age of formal DCD diagnosis for several children). The heterogeneity of the sample was also a limitation that impacted the analyses (i.e. exclusion of some participants from analysis because their scores were outliers from the group). It is quite possible that important and meaningful differences were therefore not noted. Documented co-morbidities, including attention and learning issues among the children with DCD may have also affected overall task performance and study results (Karatekin 2007; Munoz et al., 2003). In addition, anxiety is known to affect motor performance (Vine & Wilson, 2011; Wulf, 2007), has been noted in children with DCD (Pearsall-Jones, Piek, Rigoli, Martin, & Levy, 2011; Pratt & Hill, 2011; Skinner & Piek, 2001), and might certainly be present due to potential perceived testing pressure in our study.

Conclusions

Study findings suggest that, during a pouring task performed in a natural setting, school-aged children with DCD, in comparison to their TD peers, do not 'look' the same. Results of this study suggest that the pattern of selective visual attention differs between these groups, with children who have motor coordination difficulties allocating more gaze time to monitor their body movements rather than task-relevant objects. These findings provide some support for the notion of an internal model deficit. Further studies employing larger samples and statistical designs and methods that permit analysis of factors such as motor coordination severity and co-morbidities that may impact the results seen here will be useful to further explore selective visual attention in DCD as well as the verbal cueing of attention. Greater understanding of these processes may in turn lead to more effective cognitive interventions used with this population.

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Appendix A: Development and Testing of Eye Tracking Video Coding Scheme

Frame-by-Frame Analysis

To develop the video coding scheme (video observation scoring sheet and guidelines), the Principal Investigator (PI) systematically reviewed 12 eye tracking videos (8 TD, 4 DCD) using manual frame-by-frame analysis to identify important visual gaze behavior outcomes. (For a list of all videos used in the frame-by-frame analysis, as well as those used for subsequent testing as described below, please see the end of this Appendix). An iterative process was used whereby the PI reviewed the Trial 1 video from a TD 11 year old child. This child was chosen in particular because 1) his age was in the mid-range of the ages of the children in the study, 2) the literature suggests that eye movements are stable (and adult-like) by this age, and 3) this child was observed by the PI to have excellent eye tracking (stable, well-calibrated). Summary impressions on eye movement patterns were recorded and scoring definitions developed (determination of start and end of trial, definition for a shift of gaze, etc). The PI then used the same process to review this same child's Trial 10 recording, making note of any changes in eye movement patterns between the trials, with further summary impressions developed. The PI then reviewed Trial 1 from a TD 9 year old child. The same process was followed - review of Trial 1, followed by review of Trial 10, noting any changes between the trials and, in addition, any age-related differences. This process was then repeated with 2 more TD children – first a 14 year old and then a 7 year old, to ensure the PI was well familiarized with the eye movement patterns for TD children of several ages. An overall summary of impressions from the TD videos was generated, and scoring definitions were further refined. The PI then reviewed Trials 1 and 10 for 2 children with DCD using an identical process. From the summary findings of all of the children, the PI developed a video observation scoring sheet and scoring guidelines. The other members of the research team reviewed the scoring sheet and guidelines to identify any missing items or definitions and their feedback was incorporated.

Outcome Variables

The video observation scoring sheet included 24 variables: 1) the total time (in seconds) taken to perform the task, 2) the number of shifts of gaze, 3) whether the child maintained stable gaze fixation during calibration (yes/no), 4) whether the child demonstrated visual scanning of the task environment prior to the task (yes/no), and 5) 20 additional visual gaze behaviours organized by task phase. Five functional task phases were identified and included: 1) reach/grasp/lift, 2) forward transport, 3) pour, 4) backward transport, and 5) set down/release. In total, the scoring sheet contained 62 items: the 4 variables noted above, and 20 visual gaze behaviours across all 3 pouring cup/filling cup combinations, with the exception of 2 variables (related to shifting or maintaining gaze during the set down/release phase) which were not applicable for the blue pouring cup/blue filling cup combination.

Video Scoring Training (1 rater)

As a first step to ensuring reliable coding with the video scoring sheet, and to train the Research Assistant (RA) in the use of the scoring sheet and guidelines, the PI and RA met to review and discuss the scoring sheet and guidelines in detail, with the PI reviewing all definitions, task phases, and providing examples as necessary. Together the RA and PI reviewed 2 eye tracking videos (Trial 4 for a TD child and a child with DCD) discussing the items and guidelines, and then they each scored the videos independently. The RA was blinded to the child's group status (the PI was not). Trial 4 was chosen because it was most similar to the trial that would be used for the final analysis (Trial 10). Trial 4 is the 1st trial in the 2nd block of trials and was therefore performed in the same manner (the task is initially hidden from view, the children are instructed to perform the task as they usually would), with the only difference being the order of the filling cups (in the case of Trial 4 it was Blue/Yellow/Red, or the 'mirror' condition). It should be noted that these children were both part of the final study sample but their Trial 4 recordings were not part of the analysis reported in this study. As with the initial development of the coding scheme, and for the reasons mentioned above, the children whose recordings were used for this stage were approximately 11 years old (11 years 11 months (TD); 12 years 4 months (DCD)). These children were not the same participants whose recordings were used to develop the coding scheme. This was done specifically to highlight any difficulties/concerns with either the coding scheme or the scoring guidelines that were not discovered during the development stage. There was general agreement between the PI and RA regarding the estimates of total trial times as well as the number of shifts of gaze. In addition, the responses to the dichotomous items 'maintains stable gaze on final calibration point' and 'visually scans to extract relevant information' were found to be consistent between the raters. Small discrepancies between the raters in the number of observations for the visual behaviours by task phase were discussed with subsequent modification of the scoring sheet and guidelines. Changes included re-wording of some items, and deletion of items that were redundant or not mutually exclusive. The PI and RA then used the revised scoring sheet and guidelines to independently re-score the same 2 videos, this time scoring only the 20 visual behaviours, as there was good agreement on the other items. Following independent scoring, the RA and PI met again to discuss any discrepancies. Most discrepancies found on this occasion were not in the numbers of observations, but rather in the determination of which phase to score an observation. Discussion followed to ensure appropriate interpretation of the beginning and end of each phase. No revisions were made to the scoring sheet items or guidelines. The RA and PI then independently scored 2 new videos (Trial 4 for 1 child with DCD and 1 TD child) with good agreement across items.

Video Scoring Training (2 additional raters)

As the study sample size was small, and only a small sub-sample of participants were to be included in the formal reliability testing, it was determined (through consultation with a statistician (P. Stratford, personal communication, March 26, 2014)) that using a total of 4 raters would increase the likelihood of meaningful (and interpretable) reliability estimates. Two additional raters (1 graduate student, 1 undergraduate student) were therefore also trained to score the videos. They were provided with 2 new practice videos (Trial 4 for 1 DCD and 1 TD) along with the scoring sheet and guidelines, and they independently scored the videos. (NB: although previous scoring revealed that Trial 4 was likely the most difficult task (‘mirror’ condition), and perhaps more prone to scoring discrepancies, the decision was made to continue to use Trial 4 for training with the additional raters (rather than Trial 7) in order: 1) to be consistent and 2) because further concerns could be highlighted and then addressed. The 4 raters met together to discuss the videos, to review in detail the scoring sheet and guidelines, and to mutually agree on scoring procedures. Two new practice videos were provided to all 4 raters to score independently, with a follow-up meeting to examine rater agreement and discuss any questions or concerns. No changes were made to the scoring sheet or guidelines and rater agreement was felt to be adequate to continue to the formal reliability testing.

Reliability Testing: Inter-Rater Reliability (4 raters)

Inter-rater reliability testing was then performed with the 4 raters, all of whom independently coded 2 videos (Trial 1 and Trial 10) from each of 4 children (2 DCD, 2 TD) for a total of 8 eye tracking videos each. The 3 student raters were naive to both group status and trial number (although the trial number could be deduced from the placement of the filling cups). The PI could not be blinded to group status given the PI’s involvement in the administration of the eye tracking. Children whose recordings were used in this stage were chosen randomly from the final sample (n=24), following division by group (with the exception of 2 TD children who were removed from the randomization process as they did not have eye tracking data). The order in which individual recordings were viewed by each of the raters followed a 4x4 Greco-Latin square to minimize any artifact due to order. In this approach, raters viewed all Trial 1 recordings prior to the

Trial 10 recordings for each of the children (as this was to replicate the pattern that would be used when rating all of the videos in the final sample). However, within a set of trials, the order in which the raters viewed the videos differed. Data from the video coding was entered into Excel, and using STATA statistical software, Version 13 (StataCorp), intra-class correlation coefficients (ICCs) were calculated to determine inter-rater reliability.

Reliability Testing: Trial 1 Recordings

Overall, for the Trial 1 recordings, the inter-rater reliability estimates for the 62 items were quite poor, with approximately one third (20) of the items having an estimate that was either 0 (there was no variability in scores) or undefined (an estimate could not be calculated). The majority of the remaining items appeared to have somewhat better point estimates but, on closer inspection, these were actually found to be unreliable as the estimates had very wide confidence intervals (CIs) (often ranging from 0 or near 0 to 0.9). In the end, only 5 of the 62 items demonstrated satisfactory reliability (>0.8), although these still had moderately large CIs, and these included: total trial time, shifting of gaze during reach/grasp/lift (for the red and blue pouring cups only), and for the blue pouring cup only, maintenance of gaze on pouring cup during reach/grasp/lift and shifting of gaze to upper extremity.

Reliability Testing: Trial 10 Recordings

A similar pattern was seen with the Trial 10 recordings. Again, more than one third (24) of the items had reliability estimates that were 0 or undefined. As with the Trial 1 recordings, most of the remaining items were found to be unreliable (moderate estimates but very wide CIs). Five items had reliability estimates ≥ 0.8 (with moderately large CIs): total trial time, visually scans environment, shifts gaze during reach/grasp/lift (red pouring cup), shifts gaze to pouring cup on back transport (red pouring cup), shift gaze to objects/locations beyond task (red pouring cup). When comparing Trials 1 and 10, the only items that overlapped with respect to good reliability were total trial time, and shifting of gaze during reach/grasp/lift (red pouring cup).

To improve the reliability estimates, the scores of all raters were examined more closely to look for potential outliers among the raters. Reliability coefficients were re-calculated but only modest improvements were found. It had been the original intent to have all 4 raters score the remaining videos but, given the poor inter-rater reliability, the decision was made to have a single rater score all the videos, following intra-rater reliability testing with this single rater. In addition, following further review of the data, as well as consultation with the research team, it was decided that the removal of items demonstrating the poorest reliability as well as the summing of scores across pouring cups (with calculation of the reliability of the summed scores) might increase the reliability overall.

Revision of Video Coding Scheme

Prior to establishing intra-rater reliability of the video scoring sheet, the PI consulted with a visual neuroscience researcher (D. Giaschi, personal communication) to discuss the study findings. Following this, the PI decided to go back and review several videos again using frame-by-frame analysis, which led to a further revision of the video coding scheme using a slightly different approach. A new scoring sheet with fewer items that focused on the length of gaze fixations on important objects within the scene (pouring cups, filling cups only) (rather than on the frequencies of fixations) was then developed (see Table 1, this chapter). The scoring guidelines were revised to incorporate new definitions where necessary (see the end of this Appendix).

Reliability Testing: Intra-rater reliability (1 rater)

One of the raters (graduate student) was invited to participate in the intra-rater reliability testing. The RA scored 2 new practice videos (Trial 4 for 1 TD and 1 DCD) with the new scoring approach and guidelines and then met with the PI to discuss. Minor discrepancies were resolved with discussion and clarification only. No changes were made to the scoring sheet or the scoring guidelines. As the rater had participated in earlier practice scoring, and the new scoring approach was somewhat similar to the previous version, no further practice/training was deemed necessary.

For the formal intra-rater reliability testing, the RA scored 8 videos in total (4 videos, twice each, separated by a 1 week interval). Trial 10 recordings from 2 children with DCD and 2 TD children were used, as scores from these recordings (2nd week scores) would then be used in the final study analysis.

Results of the reliability estimates using the new scoring approach were much improved from previous, particularly at the individual item level (estimates ranging from 0.92 to 0.99). The most problematic item (reliability estimate of 0.67) was ‘time spent fixating filling cup prior to pour’. In consultation with the rater, as well as the study team, the decision was made to alter slightly the definition of the pour phase (which then altered slightly the definition of the forward transport phase). These changes did not alter the actual items in the scoring sheet.

For the children whose videos were part of the intra-rater reliability testing, these videos were not re-scored, rather, the second of each of the 4 videos (scored at the later date) became part of the final study sample results.

List of Videos Used for Coding Scheme Development, Rater Training, and Inter-/Intra-Rater Reliability

Purpose	***# of Raters***	***Trial #***	***Participant Number***	***Method used to choose***
Development of coding scheme (1 rater – LR)	1	1	ETS-27 (11y) (TD)	Purposeful (12)
	1	10		
	1	1	ETS-22 (9y) (TD)	
	1	10		
	1	1	ETS-26 (14y) (TD)	
	1	10		
	1	1	ETS-24 (7y) (TD)	
	1	10		
	1	1	ETS-6 (11y) (DCD)	
	1	10		
	1	1	ETS-15 (9y) (DCD)	
	1	10		
1st Practice Training (1 rater-KW) 2 videos	2	4	ETS-1 (DCD)	Purposeful (2)
	2	4	ETS-8 (TD)	
2nd Practice Training (1 rater-KW) 2 videos	2	4	ETS-14 (DCD)	Purposeful (2)
	2	4	ETS-23 (TD)	
1st Practice Training (3 raters- KW, RM, SKD) 2 videos	3	4	ETS-15 (DCD)	Purposeful (2)
	3	4	ETS-22 (TD)	
2nd Practice Training (3 raters - KW, RM, SKD) 2 videos	3	4	ETS-3 (DCD)	Purposeful (2)
	3	4	ETS-26 (TD)	
Inter-rater reliability (4 raters- LR, KW, RM, SKD)	4	1	ETS-4 (DCD)	Random following group (8)
	4	10		
	4	1	ETS-16 (DCD)	
	4	10		
	4	1	ETS-7 (TD)	
	4	10		
	4	1	ETS-12 (TD)	
	4	10		
1st Practice Training New Approach, (1 rater - SKD)	2	4	ETS-1 (DCD)	Purposeful (2)
	2	4	ETS-8 (TD)	
Intra-rater reliability (2 raters – LR, SKD)	2	10 (twice)	ETS-2 (DCD)	Random following group (with stable gaze fixation) (4 x 2=8)
	2	10 (twice)	ETS-11 (DCD)	
	2	10 (twice)	ETS-8 (TD)	
	2	10 (twice)	ETS-22 (TD)	

EARLY VERSION: Eye Tracking Video Observation Scoring Sheet
(use the EARLY VERSION Eye Tracking Video Observation Scoring Guidelines)
Participant ID: ____________ Trial #: _______________ Dominant hand: __________

	Start of Trial (sec): End of Trial (sec): Total Trial Time (sec):
	# Shifts of Gaze:
	Maintains stable gaze on final calibration point: YES NO (circle)
	Visually scans to extract relevant information: YES NO (circle)

BEHAVIOURS OBSERVED	**# Observations**			
	RPC	**YPC**	**BPC**	**Total**
REACH/GRASP/LIFT				
1. Shifts gaze from PC to corresponding FC during reach/grasp/lift (*circle*)				
2. Maintains gaze on PC throughout reach/grasp/lift				
FORWARD TRANSPORT				
3. Shifts gaze from PC to corresponding FC				
4. Tracks PC initially, then shifts gaze from PC to corresponding FC				
5. Tracks PC throughout transport				
6. Shifts gaze from FC *back* to PC				
POUR				
7. Shifts gaze from FC to water flow/PC spout				
8. Maintains gaze on water flow/PC spout throughout the pour				
9. Shifts gaze from water flow/PC spout to fill line				
10. Shifts gaze from fill line *back* to water flow/PC spout				
BACK TRANSPORT				
11. Shifts gaze towards PC placement sticker				
12. Tracks PC initially, then shifts gaze to PC placement sticker				
13. Tracks PC throughout transport				
14. Shifts gaze from placement sticker *back* to PC				
SET DOWN/RELEASE				
15. Shifts gaze from PC to next PC during set down/release (*circle*)			N/A	
16. Maintains gaze on PC throughout set down/release			N/A	
OTHER				
17. Gaze cursor disappears from scene camera range				
18. Shifts gaze to any part of dominant or non-dominant U/E				
19. Shifts gaze to other objects/locations on task surface				
20. Shifts gaze to objects/locations beyond task surface/materials				
TOTALS				

EARLY VERSION Eye Tracking Video Observation Scoring Guidelines

ACRONYMS:
PC = pouring cup (i.e. RPC = red pouring cup, etc)
FC = filling cup (i.e RFC = red filling cup, etc)
U/E = upper extremity

DEFINITIONS *(listed in the order that they occur in the Video Observation Scoring Sheet):*

Dominant upper extremity: the extremity that the child uses most often for printing/writing, as identified by the parent (with the non-dominant extremity being the opposite extremity)

Gaze cursor**:** the coloured circular cursor superimposed on the video recorded from the eye tracking glasses that represents the position of the child's gaze during the task

Final calibration point**:** located on the wall directly in front of the participant, the lowermost "X" where the participant fixates their gaze prior to the start of each trial

Start of Trial: the time (recorded in seconds) when the gaze cursor is ***first seen*** to shift ***away from*** the final calibration point (towards the task surface (this should occur simultaneously with the tester's auditory prompt to begin the trial but may not always do so))

NOTE:

1) the start of the trial will always occur *after the child has completed his/her initial visual scan (following box removal)*, and has been asked to fix on the calibration point
2) if unsure of precisely when the trial started because the child:
    a. did not/was unable to maintain their gaze on the final calibration point OR
    b. did not attend well generally to the instructions to maintain their gaze

   use the time (in seconds) when the gaze cursor first disappears from the final calibration point to determine the start of the trial

End of Trial: the time (recorded in seconds) when the child has completely set down the BPC, and begins to move his/her eyes away from the BPC (NB: at this point, they may not yet have released their grasp on handle of the BPC)

Total Trial Time (seconds): the ***start of trial*** time subtracted from the ***end of trial*** time

Shift of gaze: a shift/displacement of the gaze cursor from an object or location to another object or location within the scene camera, regardless of time spent attending to the object or location

***Shifts of Gaze*:** a frequency count of the total number of times the gaze cursor shifts from an object or location to another object or location within the scene camera, regardless of time spent attending to the object or location

Stable gaze: gaze remains fixed on an object or location for a period of time (NB: gaze cursor may move very slightly (in any direction) away from the object or location as long as it does not shift to another object or location) (Example: 1) gaze is fixed on calibration point and moves slightly up and down but does not move from the calibration point itself to another location beyond the calibration point on the wall; 2) gaze is fixed on the water fill line, and may move in any direction near/close to the water fill line, as long as it does not move to the another location such as the PC spout or water stream or another meaningful location, in which case it would be considered a shift of gaze)

Visually scans to extract relevant information: During initial visual scan of the task (following box removal) prior to the start of the first trial in a block of trials, appears to purposefully extract relevant/useful visual information (i.e. scans positions of PCs and FCs with intent, fixating on PCs/FCs at least once and possibly up to several times)

\# ***Observations***: a frequency count of the total number of times the observation was observed during the performance of the task

Reach/Grasp/Lift Phase: The phase of the experimental task beginning with the moment in time when the pouring arm/hand is first viewed in the scene camera to be reaching towards a PC and ending when the FC has been fully lifted from the task surface (includes the child grasping the PC) (NB: all task phases including this phase are described with reference to actions performed with the PCs)

Forward Transport Phase: The phase of the experimental task beginning with the moment in time when the child, having fully lifted the PC, begins to turn and/or move the PC towards the corresponding FC and ending with the point in time when the child turns/tips the PC to begin to pour (NB: The turn of the PC may occur as the child is lifting the PC but as soon as the PC begins to move towards the FC, this is considered to be the beginning of the Forward Transport Phase; also the turn of the PC may occur at any point during the transport phase and/or just prior to the Pour Phase, and in some instances, the child may not turn the PC at all)

Tracks: gaze moves along with a moving object (i.e. a PC) in a horizontal direction (NB: gaze may follow or 'lag' behind the PC or precede the PC; what is important to note is that the gaze **moves with** the PC rather than shifting gaze ahead or back to another object/location); ***gaze must track the object for a minimum of 3 frames to be considered tracking***

Pour Phase: The phase of the experimental task beginning with the moment in time when the child first turns/tips the PC to initiate pouring and ending with the flow of water being stopped

Fill line: Black line on FCs (marked on both inside and outside) indicating where water is to be filled and located approximately half-way up the FCs

Placement sticker**:** the stickers located on the left and right trays upon which the PCs and FCs are placed, and upon which the PCs are to be re-placed during the task

Back Transport Phase: The phase of the experimental task beginning with the moment in time when the PC is turned to be upright (after the pouring is complete) and ends after the child has moved the PC towards the tray placement sticker but before the PC is set down

Set Down/Release Phase: The phase of the experimental task beginning with the moment in time when the child sets the PC down on the tray and ending with the grasp being released from the PC

Scene camera: The forward facing camera located in the eye tracking glasses that captures/records the scene directly in front of the participant (including as the participant's head turns)

Scene camera range: The horizontal and vertical range of the scene camera/area visible directly in front of the child, and determined by the child's head position during the task

Gaze cursor disappears from scene camera range: This refers to periods of time (***minimum of 3 frames***) during which:

1) the gaze cursor cannot be located in the range of view of the scene camera, AND
2) when gaze *would be expected* to be either locating/fixating objects (shifting gaze) or guiding movement (tracking)

During these disappearances it is not reasonably clear/evident where gaze is being oriented - such disappearances could be due to: 1) eye blinks, 2) prolonged eye closing, or 3) gaze shifted elsewhere out of range of the scene camera

NOTE: this does NOT include those situations where the scene video is 'blurred' and gaze appears to precede head and U/E movement (i.e. gaze is 'out of range' of the scene camera and the head is in motion); these situations become apparent when viewing the subsequent video frame where the gaze cursor is seen to be fixated on an object/location that was initially out of the video scene range; in these situations it is reasonably clear that the gaze was shifted just prior to, or during, head movement

Upper extremity: includes the shoulder, upper arm, elbow, forearm, wrist, hand, fingers on either the dominant or non-dominant side

Task surface: table surface directly in front of the child upon which the task materials (trays, PCs, FCs) are placed

Shifts gaze to other objects/locations on task surface: gaze shifts to objects/locations on the task surface *other than* the PCs/FCs/placement stickers, and NOT including either dominant or non-dominant U/E

Shifts gaze to objects/locations beyond task surface/materials: gaze shifts to objects/locations *other than* the task surface and/or materials, and within the room/testing environment (e.g. could include gaze shifts to the examiners, or testing equipment (cameras, shelf directly in front of the participant etc))

Other: this space is for noting any additional observations not listed on the scoring sheet and is not specific to any phase (score these if observed in any phase, making note of the specific phase(s) where observed); blank space left for additional observations in this section – note here any additional *gaze* variables, as well as observations noted re *posture*, *task performance*, *learning*, *attention, etc* (e.g. mistakes made in carrying out the task instructions, could also be noted here)

FINAL VERSION Eye Tracking Video Observation Scoring Guidelines

1) Total Trial Time (calculated as previous – use Early Version Eye Tracking Video Observation Scoring Guidelines)

2) Length of time *fixating gaze* in a single location ('calibration point') **prior to initiation of task** regardless of*:*
    - *where* they fixated, as long as gaze remains approximately in the same location during the single fixation episode
    - *when* they fixated prior to the task (i.e. does not need to be *immediately preceding* the task, can occur at any point prior to task)
    - whether or not they are calibrated exactly on the terminal calibration point and
    - as long as the gaze cursor can be viewed

   Also
    - child is permitted to shift his/her gaze away from their initial fixation point as often as they want and for any length of time that they want and return back to their initial gaze fixation point
    - time calculated is *total time spent* in a single episode of fixating

   If time spent fixating gaze in single location is less than 1 second, DO NOT proceed to score items in lower table. (NB: as long as one episode of fixating prior to task is longer than 1 second, can proceed to the lower table)

   Items in the lower table are initially calculated for each different colour of pouring cup and then time is later combined across all pouring cups:

3) Length of time *fixating pouring cups* **prior to forward transport**, including:
    - fixating during *any or all of* reach/grasp/lift;
    - fixating *anywhere near pouring cup location*;

   (NB: the child can shift to/from PC and to/from any location; time calculated is total time spent during fixation ONLY, and doesn't include time spent shifting to/from PC)

4) Length of time *fixating pouring cups* **during forward transport** (as above, child can shift to/from PC and to/from any location; time calculated is total time spent during fixation ONLY, and doesn't include time spent shifting to/from PC)

5) Length of time *fixating filling cups* **prior to pour** including:
    - time spent in *any and all fixations* prior to the pour (including immediately following fixation on initial calibration point),

- shifts in gaze to and/or from PC to FC at any point prior to pour
- fixating anywhere near filling cup location
- small (< 1 cm) shifts of gaze away from FC in any direction

6) Length of time *fixating filling cups* **when pouring** regardless of where on the filling cup they fixate

7) Length of time *fixating pouring cups* **when pouring** regardless of where on the pouring cup they fixate

8) Length of time *fixating pouring cups* **during back transport, set down and release**

9) Length of time *fixating dominant and/or non-dominant U/E*
    - must be deemed to be a deliberate fixation on U/E and not a shift of gaze passing by U/E on the way to another location
    - child can fixate any part of the extremity

ADDITIONAL NOTES:
Calculating length of fixations: Record the time when the child first fixates on an object right up until the first frame *AFTER* the gaze is no longer on that object (will help to ensure that shorter length fixations are counted)

Absent gaze cursor: Record only the time spent fixating on an object *when the gaze cursor can be seen* (i.e. do not include blinks/looking away when the gaze cursor cannot be seen; need to subtract this time from the total time calculation)

Water flow: Time spent fixating on the water flow is included as part of the time spent fixating on the PC

Placement sticker: When the child is setting the PC down on the placement sticker, record *any* time spent fixating on the PC, even if you think he/she is looking at the placement sticker *through the PC*

Table 1: FINAL VERSION Eye Tracking Video Observation Scoring Sheet
(use the FINAL VERSION Eye Tracking Video Observation Scoring Guidelines)

Child ID: _______________ Trial #: ____________ Dominant hand: ______

OUTCOME	TIME (seconds)
Start of Trial	
End of Trial	
Total Trial Time	
Time spent fixating gaze in one location prior to initiating task **(***if time spent = < 1 second, DO NOT score table below)**	

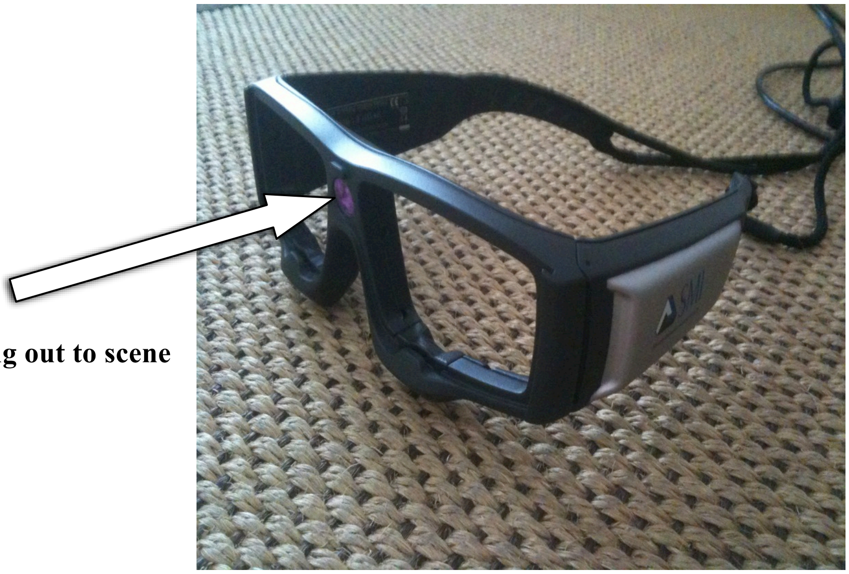
OUTCOME	TIME (seconds)			
	RED	YELLOW	BLUE	TOTAL
Time spent fixating POURING CUP *prior to* **forward transport**				
Time spent fixating POURING CUP *during* **forward transport**				
Time spent fixating FILLING CUP *prior to* **pour**				
Time spent fixating FILLING CUP *during* **pour**				
Time spent fixating POURING CUP *during* **pour**				
Time spent fixating POURING CUP *during* **back transport/set down/release**				
Time spent fixating *dominant U/E*				
TOTAL SCORED TIME				

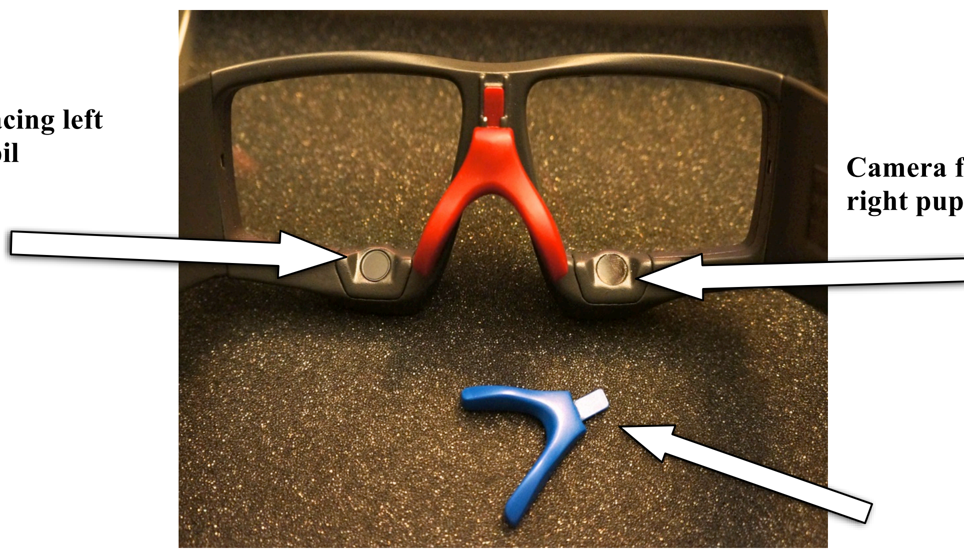
Table 2: Demographic and Clinical Characteristics of Children with and without Developmental Coordination Disorder (n=24)

Gender	Age[a] (yrs)	MABC-2[b] (%ile)	DCDQ'07[b] (Total score)	KBIT-2[a] (IQ Composite)	Conners 3-P[S] (T-scores) Inattention[b]	Hyperactivity Impulsivity[c]	Executive Function[c]	Learning[c]
DCD Group (n=12) (11M, 1F)								
M	8.2	1.0	36.0	110.0	73.0	66.0	82.0	77.0
M	8.2	5.0	73.0	112.0	54.0	53.0	44.0	42.0
F	8.3	0.5	35.0	93.0	73.0	54.0	64.0	87.0
M	8.5	0.5	37.0	86.0	63.0	50.0	85.0	70.0
M	8.8	2.0	39.0	98.0	48.0	69.0	76.0	48.0
M	9.7	0.5	28.0	108.0	65.0	58.0	56.0	49.0
M	10.3	5.0	54.0	93.0	69.0	83.0	67.0	58.0
M	11.0	0.5	25.0	94.0	65.0	45.0	78.0	49.0
M	11.2	1.0	27.0	103.0	54.0	62.0	49.0	76.0
M	12.3	2.0	71.0	99.0	60.0	46.0	63.0	42.0
M	14.1	5.0	19.0	118.0	68.0	90.0	48.0	68.0
M	14.9	9.0	27.0	121.0	62.0	58.0	56.0	45.0
Mean (SD)	**10.5 (2.3)**	**2.7 (2.7)**	**39.3 (17.7)**	**102.9 (10.9)**	**62.8 (7.8)**	**61.2 (14.0)**	**64.0 (13.9)**	**59.3 (15.7)**
TD Group (n=12) (10 M, 2F)								
M	7.3	25.0	67.0	99.0	49.0	45.0	49.0	43.0
F	7.8	25.0	66.0	110.0	46.0	48.0	41.0	43.0
M	8.2	63.0	71.0	114.0	51.0	53.0	54.0	45.0
M	8.9	63.0	64.0	97.0	54.0	60.0	69.0	56.0
M	9.0	75.0	74.0	89.0	54.0	47.0	60.0	48.0
M	9.2	63.0	72.0	109.0	61.0	52.0	47.0	52.0
M	9.5	37.0	70.0	131.0	56.0	43.0	54.0	48.0
M	9.7	16.0	74.0	99.0	56.0	52.0	57.0	52.0
M	9.9	63.0	75.0	97.0	61.0	57.0	47.0	42.0
M	11.3	16.0	73.0	94.0	40.0	70.0	40.0	41.0
F	11.9	50.0	75.0	128.0	40.0	48.0	51.0	42.0
M	14.2	37.0	66.0	88.0	56.0	42.0	53.0	45.0
Mean (SD)	**9.7 (1.9)**	**44.4 (20.9)**	**70.6 (3.9)**	**104.6 (14.1)**	**52.0 (7.1)**	**51.4 (8.0)**	**51.8 (8.0)**	**46.4 (4.8)**

DCD = Developmental Coordination Disorder; **TD** = Typically Developing
MABC-2 = Movement Assessment Battery for Children-2 (Henderson, Sugden, & Barnett, 2007); **DCDQ'07** = Developmental Coordination Disorder Questionnaire (Wilson et al., 2009); **KBIT-2** = Kaufman Brief Intelligence Test-2 (Kaufman & Kaufman, 2004); **Conners 3-P[S]** = Conners-3 Parent Rating Scales of Attention (Short Form) (Conners, 2008)
Between group differences: [a]non-significant; [b]significant, $p < .01$; [c]significant, $p < .05$

Figure 1: Mobile Eye Tracking Glasses[2]





[2] ™ SensoMotoric Instruments (SMI), Boston, MA

Figure 2: Set-up of Experimental Task

Task Covered: Start of Each Trial Block **Task Set-Up (Right Hand Dominant)**

Task From Participant Perspective: Right Hand Dominant Set-Up

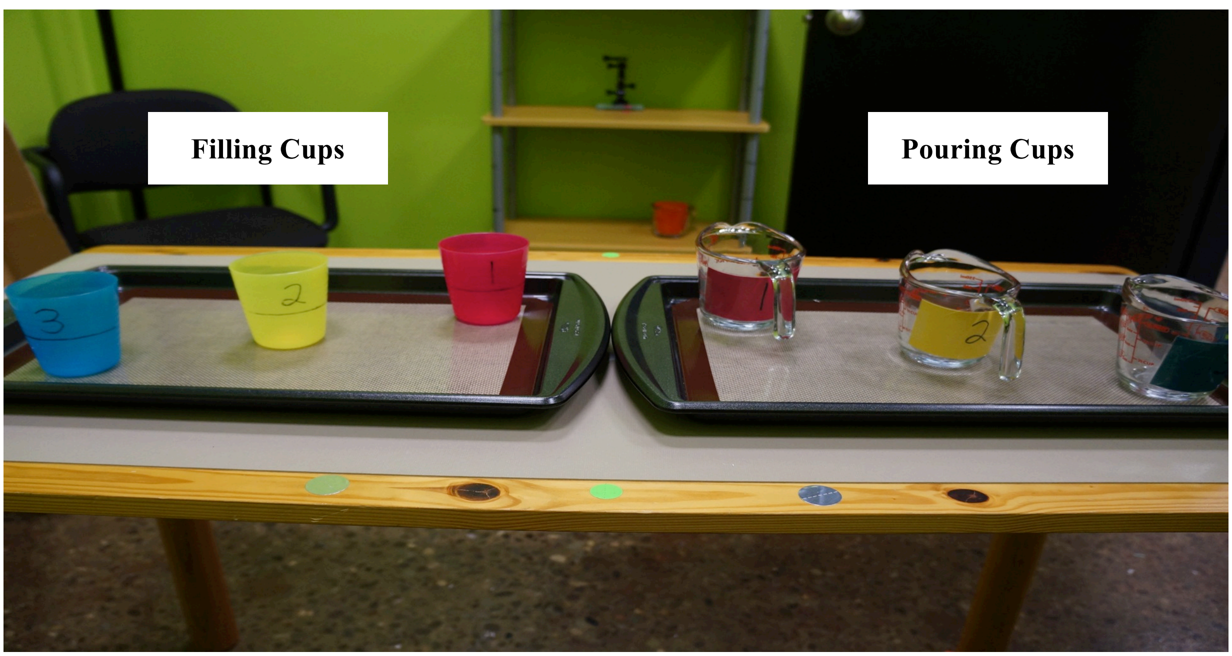
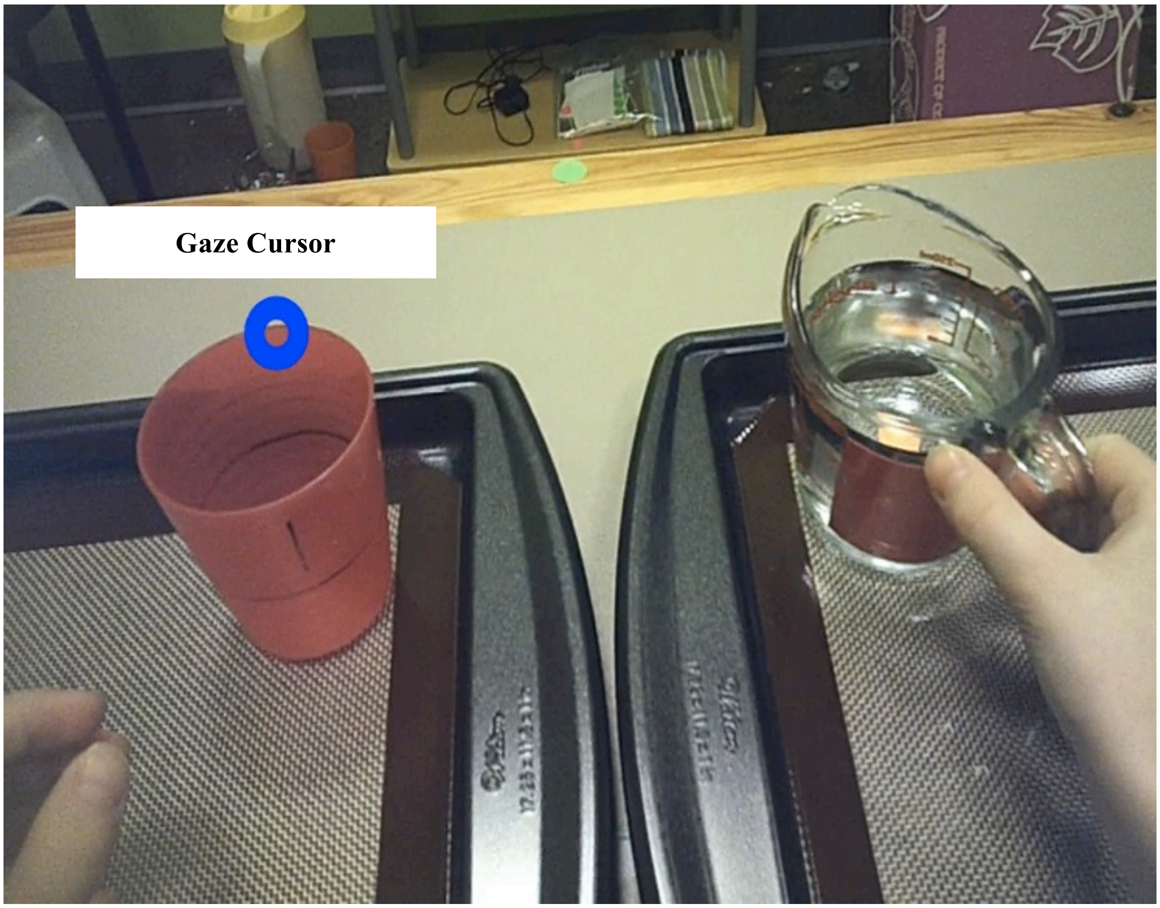


Figure 3: Exported Gaze Overlay Video



Experimental Task 'Scene' as Viewed from Right-Handed Participant Perspective

Chapter Four

Title of Paper: Feasibility of using an eye-tracker in school-aged children with developmental coordination disorder performing a real-world visuomotor task: Lessons learned

Authors: Lisa Rivard, Laurie Wishart, Timothy Lee, Cheryl Missiuna
Complete citation: Rivard, L.M., Wishart, L.R., Lee, T.D., & Missiuna, C. (to be submitted). Feasibility of using an eye-tracker in school-aged children with developmental coordination disorder performing a real-world visuomotor task: Lessons learned. *Research in Developmental Disabilities*.

Abstract

While eye tracking has been used to measure cognitive processes in children with neurodevelopmental disorders, this method has been employed infrequently with children with developmental coordination disorder (DCD). Children with DCD have motor coordination difficulties that are significant enough to impact their everyday life, academic achievement, and social/emotional functioning; early identification and effective intervention are critical to prevent secondary sequelae. Eye tracking may be useful to further understanding of the cognitive processes that influence motor performance in DCD; however, it is not yet known whether this is feasible during a functional task in a natural setting. The purpose of this study was to investigate the feasibility of using an eye tracker with children with DCD performing a real-world visuomotor task. As part of a larger study investigating selective visual attention, 12 children with DCD (11 M, 1F; mean age (range): 10.5 yrs (6.7)) wore a mobile eye tracker while pouring water from 3 pouring cups into 3 colour-matched filling cups sequentially (single trial). Children performed 12 trials of increasing difficulty (filling cup position was re-arranged on every 3rd trial). Parents completed the DCDQ'07 and the Conners-3 Parent Rating Scales of attention. Children's motor impairment was assessed using the Movement Assessment Battery for Children-2 (MABC-2). Following task completion, gaze overlay videos were extracted and analysed. For the majority of children with DCD (75%), eye tracking was feasible and reliable, and highlighted atypical gaze patterns during motor performance that might not have otherwise been captured. However, methodological challenges experienced in this study related to the nature and heterogeneity of DCD, as well as the eye tracking equipment suggest that multiple factors need to be considered when choosing eye tracking equipment and designing studies to investigate their use. These include eye tracker specifications, the experimental task, and potential co-occurring conditions (visual impairments, attention difficulties). Recommendations regarding equipment choice, task design, and study sampling may assist with the successful implementation of eye tracking studies with the DCD population.

Keywords: developmental coordination disorder, eye tracking, feasibility, visuomotor coordination, comorbidity, attention

Introduction

An old English proverb, often attributed to William Shakespeare states that the eyes are the window to your soul. Could they be the window to your mind as well? Many researchers believe this to be true and have been using eye trackers to record and quantify eye movements and, by inference, the neurological processes that underlie them (Bekkering & Neggers, 2002; Land, Mennie & Rusted, 1999; Kowler, 2011; Pelz & Canosa, 2001). Indeed, eye trackers have the potential to further our understanding of not only what the eyes 'see', but what objects we selectively shift our attention to, and also perhaps to understand how we think and what we are (subjectively) feeling.

The use of eye trackers has been documented for over 100 years, although early designs were basic and often intrusive (Holmqvist et al., 2011). Eye trackers have been used to assess literacy and related abilities (McDonald & Shillcock, 2003), determine direction of gaze while reading advertisements (Fischer, Richards, Berman, & Krugman, 1989), and to measure a variety of cognitive processes such as attention (Duc, Bays, & Husain, 2008), working memory (Park & Holzman, 1993; Hannula et al., 2010), language processing (Trueswell, Sekerina, Hill, & Logrip, 1999), and social perception (van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002). Historically, eye trackers were used primarily with animals, and then later adults, including both healthy and clinical populations such as Parkinson's disease (Shibaski, Tsuji, & Kuroiwa, 1979), Huntington's disease (Blekher, et al., 2006), and Tourette syndrome (Dursun, Burke, & Reveley, 2000). It is only more recently that eye trackers have come to be used more frequently with typically developing infants, children and adolescents (Aslin, 2009, 2012;

Corbetta, Guan, & Williams, 2012; Franchak & Adolph, 2010; Franchak, Kretch, Soska, & Adolph, 2011; Gredeback, Johnson, & von Hofsten, 2010; Yoshida & Smith, 2008). This is perhaps, in part, owing to the fact that eye tracker design has evolved over time becoming not only less invasive but also more flexible, permitting their use even with small infants.

Eye trackers have the capacity to measure distinct eye movements simultaneously including saccades, fixations, and smooth pursuit tracking. Saccades have been described as ballistic eye movements and are the small ‘jumps’ that occur when vision is inhibited; gaze fixations take place between the saccades. During these periods the eye remains relatively stationary or ‘quiet’ (Hollingworth & Henderson, 2002; Pieters, Rosbergen, & Wedel, 1999). In addition, pupillary dilation can be measured, and visual exploration of scenes and/or faces tracked and mapped (Karatekin, 2007). Specifically, with respect to saccades, the nature of the task can be altered to measure direct visual orientation, or alternatively, predictive or memory-guided processes. Tasks requiring an individual to look towards, or away from, an object or stimulus have been used to measure the ability to orient or inhibit saccadic eye movements. Subsequently, eye movement data have been used to infer information about underlying cognitive processes and neural substrates (Anderson & Rees, 2011). This has come about as a result of researchers having now mapped out in much greater detail the specific brain areas controlling the various types of eye movements including the superior colliculus and frontal eye fields (Atkinson & Braddick, 2012; Carrasco, 2011; Nobre, 2001).

As mentioned, eye tracking has become a more common method used in studies investigating eye movements in typically developing children. Recently, these methods have been extended to children with various neurodevelopmental disorders, with eye tracking becoming an innovative technique for measuring cognitive processes and associated neurobiological substrates, as well as to create developmental trajectories in children. The majority of the clinical eye-tracking studies have been conducted in the area of autism spectrum disorder/speech language impairment (Falck-Ytter, von Hofsten, Gillberg, & Fernell, 2013; Norbury, 2013; Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014), but studies have also been conducted with children with learning disabilities (Jones, Obregon, Kelly, & Branigan, 2008), Down Syndrome (Wilkinson & Light, 2014), Fragile X syndrome (Benjamin et al., 2014), Williams syndrome (Kirk, Hocking, Riby, & Cornish, 2013), dyslexia (Kunert & Scheepers, 2014), attention deficit hyperactivity disorder (Damyanovich, Baziyan, Sagalov, & Kumskova, 2013; Munoz, Armstrong, Hampton, & Moore, 2003) fetal alcohol spectrum disorder (Green et al., 2009), and children at risk for schizophrenia (Kumra et al., 2001). To date, this method has been employed infrequently with children with developmental coordination disorder (DCD), children whose poor motor coordination impacts their everyday life, academic achievement, and social/emotional functioning, and for whom early identification is paramount (Rivard, Missiuna, Pollock, & David, 2012).

Over the last several decades, only a few studies have investigated eye tracking in children with DCD (or probable DCD), with examination of smooth pursuit eye movements (Langaas, Mon-Williams, Wann, Pascal, & Thompson, 1998; Robert et al., 2014), eye-hand coordination during pointing or reaching/grasping (Wilmut, Wann & Brown, 2006; Wilmut & Wann, 2008), the allocation of attention (Wilmut, Brown, & Wann, 2007) and the 'quiet eye' during catching and throwing (Wilson, Miles, Vine, & Vickers, 2012). It is possible that the tracking of eye movements might provide a window into the neurobiological impairment in DCD, which would guide interventions used with this population. Specifically, eye tracking may be a useful method to improve understanding of the cognitive processes that influence the performance and learning of a functional motor task in DCD. However, it is not yet known whether this is feasible, especially when the occurrence of comorbid conditions may impact the reliable use of eye trackers with this population. In addition, with the exception of the research conducted by Wilson et al. (2012), studies employing eye tracking in children with DCD have used laboratory-based tasks. Everyday motor tasks have not yet been incorporated into these eye tracking studies, perhaps owing to the fact that everyday motor tasks are more complex, and that paradigms investigating eye movements for these naturalistic tasks have not yet been standardized. From what is known about the nature of attention, and how it differs based on the cognitive processes involved in task goals (Beck & Kastner, 2009; Hegde, 2008; Kastner & Ungerleider, 2000), it is important to understand eye movements in children with DCD in the context of natural tasks if we are to further our understanding of how these children allocate vision (and attention) during everyday motor performance.

As part of a larger study investigating selective visual attention in school-aged children with DCD performing a real-world visual motor task (pouring) (Rivard, Lee, Wishart, & Missiuna, submitted), the purpose of this study was to determine the feasibility of using an eye tracker with children with DCD. This manuscript outlines the successes, challenges, and lessons learned during this study, and provides recommendations for the use of eye tracking in future studies with this population.

Methods

Ethics

We obtained ethics approval from the Hamilton Integrated Research Ethics Board (HIREB) at McMaster University in Hamilton, Canada.

Recruitment

We recruited children with DCD from a private pediatric therapy organization and a local parent group. Families of the children received a letter of information describing the study along with consent/assent forms. Parents provided signed informed consent and children provided their signed assent to participate. Prior to testing, we contacted parents by phone prior to testing to complete a brief general health and development questionnaire to ensure children met DCD inclusion/exclusion criteria, including the absence of neurological or medical problems, and parent report of normal or corrected to normal vision.

Participants

Twelve children with DCD (11 M, 1F) participated. Their mean age (range) was 10.5 (6.7) years; their demographic characteristics are presented in Table 1.

Study Measures

Children and families attended the Infant and Child Health Lab (INCH) at McMaster University (Hamilton, Ontario), where testing was completed over a single 45-60 minute session for each child, in the morning or afternoon, at the family's convenience. Parents' costs to attend the session were reimbursed and a gift card honorarium was given to all children participating.

Parents and an experienced occupational therapist (OT) completed several study measures to ensure participants met criteria for DCD (APA, 2013). Parents completed the 45-item Conners-3 Parent Rating Scales of Attention (Conners, 2008) as well as the Developmental Coordination Disorder Questionnaire (DCDQ'07) (Wilson et al., 2009). Both the Conners-3 and the DCDQ'07 have well-established psychometric properties (Wilding & Cornish, 2012; Wilson et al., 2009). The OT assessed children's coordination using the Movement Assessment Battery for Children-2 (MABC-2) (Henderson, Sugden, & Barnett, 2007), recommended for motor coordination assessment (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). In addition, the OT completed the Kaufmann Brief Intelligence Test-2 (KBIT-2), a test used to provide information on children's problem-solving abilities and demonstrating sound psychometric properties (Kaufman & Kaufman, 2004). Results of the study measures can be found in Table 1.

Experimental Task

Children wore lightweight, mobile eye tracking glasses (SensoMotoric Instruments (SMI), version 1.0, sampling rate 30Hz) that recorded their eye movements and the task scene in front of them while they poured water from 3 glass pouring cups into 3 colour-matched plastic filling cups sequentially (single trial) (see Rivard, Lee, Wishart, & Missiuna, submitted). Children performed 12 trials (4 blocks of 3 trials) of increasing difficulty [on subsequent trials within a block, children were required to be accurate (trial 2), and quick (trial 3) while pouring]. The position of the filling cups was altered after every 3rd trial to change the colour order (red, yellow, blue order was changed to blue, yellow, red (mirror condition), then reversal 1 (red, blue, yellow) and then reversal 2 (yellow, red, blue)). Single trials lasted 30-60 seconds; total testing time was 15-30 minutes.

The first author completed all calibration and eye tracking. A graduate student research assistant (RA) conducted the experimental task. Once children were ready to commence individual trials, they were instructed to maintain their gaze on the final calibration point until the RA signaled the start of the trial. Following task completion, gaze overlay videos were extracted and analysed using eye tracking software (BeGaze Mobile Video Analysis software, version 3.4 (SMI)). Further details on the data coding process, video scoring, and outcome variables can be found elsewhere (Rivard et al., submitted).

Feasibility

For 9 children with DCD (75%), eye tracking was feasible and reliable, and highlighted subtle and important gaze patterns during the pouring task that might not have otherwise been captured. Use of the eye tracker demonstrated that children with DCD tended to use their vision quite specifically during the pouring task to guide and monitor their pouring arm/hand, rather than task-relevant objects including the pouring and filling cups (Rivard et al., submitted), suggesting a lack of predictive eye movements and confirming what has been previously found in the literature.

However, despite the successes with using the eye tracker, there were some methodological issues that needed to be overcome, and which, on occasion, impacted data collection and analysis. These related to both equipment and participant factors. Equipment factors included camera scene range and fit; participant factors included calibration challenges and heterogeneity. Each of these challenges is described below in more detail.

Methodological Issues: Equipment Factors

Camera Scene Range

One of the design limitations of the eye tracker we chose to use in our study was that it was only possible to capture the location of the child's visual attention when the gaze cursor appeared within the frame of the eyeglasses. If the child visually fixated on a location beyond the range of the glasses (perhaps using their peripheral vision), without also moving their head, his/her gaze position could not be identified. A similar situation would arise if the child blinked (especially during slow or prolonged blinking), causing the gaze cursor to disappear momentarily. When the gaze cursor disappeared for a few recording frames (i.e. up to 3 frames), and then re-appeared in the same location on subsequent frames, it could be reasonably ascertained that the child had likely been blinking. However, for some children, the gaze cursor disappeared for multiple frames within a single trial (in some cases up to several seconds), and on more than one instance. When the gaze cursor did not re-appear in a similar location, indicating the child's gaze had been diverted elsewhere during those frames, this meant that, during these times, the location of visual attention could not be precisely determined. This did prove challenging initially for reliable data coding, but a re-design of the approach to video coding and scoring ensured that the data from a maximum number of children could be analysed. Further, it must be noted that, while the data coding issues appear to have been related to the eye tracking equipment, the challenges might also have been related to the nature (i.e. heterogeneity) of DCD as difficulties occurred only with a few children with DCD. Such gaze interruptions may represent important observations distinguishing some children with DCD from the DCD group overall. However, with the current data, changes in gaze location in these instances could not be well detailed. It is only possible to say with certainty that, for a few children with DCD, gaze was diverted for long periods away from the task scene when it would not have been expected.

Eye Glasses Fit

Age was not previously presumed to be a limiting factor, as it was reported that the glasses had been worn successfully with children as young as 7 years of age.

However, small head size was noted as a limitation of the equipment (M. Mento, SMI, personal communication, October 12, 2011). For several children in our study, the glasses did not stay in place well throughout the trials, requiring the glasses to be re-adjusted between trials and occasionally requiring re-calibration. Despite these issues, however, data collection and analysis were not impacted by these factors.

Methodological Issues: Participant Factors

Calibration Challenges

Reliable calibration of the eye tracker was completed for 9 children with DCD (75%). However, for 3 children (25%), steady gaze fixation for calibration was challenging, and led to exclusion of some of their data. Even with reliable calibration for the 9 children with DCD, several observations were made that are quite intriguing. Some children appeared to have difficulties ‘landing’ their gaze on the calibration point (i.e. either overshooting or undershooting the target), and required several tries to do so. Others were readily able to visually ‘find’ the calibration point initially, but then seemed to struggle to maintain a steady fixation.

Heterogeneity

<u>Vision/Use of Corrective Eyewear</u>

Five children with DCD (42%) wore corrective glasses; 1 child did not bring his glasses to the testing session, as he used them for reading only. For the 4 children who wore glasses throughout the day, we were unable to calibrate the eye tracking equipment without removing their corrective glasses (this was noted as a limitation in pre-testing trials as well). Where needed (1 child who was near-sighted), the calibration points were adjusted slightly to enhance/maximize visual contrast until the child indicated that he could see them well. No further accommodations were required. With their eyeglasses removed, 3 out of the 4 children (75%) had insufficient (< 1 second) steady gaze fixation during calibration, limiting the scoring of their data. It is unknown whether they would have performed similarly had they been able to wear their corrective eyeglasses with the eye tracker. It is interesting to note that 1 child who wore glasses (but had them removed for the testing) was able to demonstrate stable gaze for calibration.

Attention

As described above, parents completed the Conners-3, a measure of attention. Two of the 12 children (17%) had a formal diagnosis of ADHD in addition to DCD. Five other children (42%) did not have a formal diagnosis, but parents noted concerns regarding attention in the general health and development questionnaire. To examine the issue of attention further, children were divided into 2 groups based on their ability to maintain steady gaze fixation for calibration. Characteristics of the 2 groups are found in Table 2, including MABC-2 scores, and 4 relevant sub-tests from the Conners-3 scores. Children with poorer gaze fixation during calibration all had visual difficulties requiring corrective eyeglasses. In addition, they had significantly lower MABC-2 percentiles (M=0.67 (0.29)) than the group without calibration difficulties (M=3.33 (2.86);

$t(10)=2.75$, $p < .05$). However, the 2 groups did not significantly differ in attention-related behaviours, as measured by the Conners-3.

Sensory Challenges

Four children (33%) appeared to have some tactile hypersensitivity to wearing the eye tracking glasses and expressed sensory complaints. Over the course of the trials, they did not tolerate the glasses well, often complaining that the glasses fit too tightly on their nose, or that they just didn't like the way the glasses felt. As a result, they would frequently adjust, and/or remove the eye tracking glasses from their head, necessitating re-calibration several times throughout the set of trials, hindering efficient data collection. While the children expressed complaints, with much encouragement, they successfully completed the trials so no data were lost.

Posture/Fatigue

Head and overall body posture impacted the use of the eye tracking glasses for 6 children (50%). As children relaxed during the trials, they often assumed a slumped posture, which had the effect of altering their head position and therefore the previously calibrated final fixation point. We gave children frequent reminder cues to 'sit tall' but they often resumed alternate postures. Interestingly, this was less evident with the older children with DCD who independently assumed a more upright posture once a new trial was to begin. However, the majority of children appeared to fatigue as the trials progressed and they would frequently lean on the table both during and in between trials.

Fatigue during the experimental task for children who completed the study measure testing first was not anticipated to be a concern, as individual trials lasted only a minute. We gave frequent breaks between trials, and total testing (including the assessment measures) was completed within a half hour; however, for some children with DCD fatigue was noted to be an issue, with 1 child requiring a much longer break of 10 minutes in order to continue the testing.

Lessons Learned

Despite the methodological challenges encountered in this feasibility study of eye tracking in children with DCD performing a visuomotor task, this study successfully demonstrated that, for the majority of children with DCD, eye tracking is a feasible method to investigate eye movements during the performance of a functional task. This study highlights the importance of eye tracking methods in revealing subtle nuances in the gaze patterns of children with DCD, which would otherwise not be apparent. Lessons learned from the implementation of this study that have implications for the design of future eye tracking studies with this population will now be discussed and include equipment choice, task deign, and study sampling.

Equipment Choice

The eye tracker used in this study was chosen specifically for its unique design. It was lightweight, which was deemed essential for children with DCD. As children with DCD tend to fatigue easily (Hands & Larkin, 2002), even without added equipment constraints, the eye tracking glasses were chosen over other head-mounted designs that require substantial head and neck muscle control and endurance during wearing, and which could cause children with DCD to fatigue. In addition, the eye tracking glasses are intended to allow children to move their head freely, a feature that was essential to the nature of our experimental task, while at the same time offering a secure fit to ensure initial calibration remained steady. Despite these provisions, for some of the children with DCD, the contact made with the glasses elicited sensory responses sufficient enough for them to need much encouragement to keep the glasses in place, and to complete the trials. Overall, this had the effect of slowing the experimental testing down because of the need to re-calibrate, which then made the sessions longer; however it should be noted that, no data was lost as a result. The repeated calibrations could have contributed to the overall fatigue that was observed in the children, although it is also likely that fatigue would have been a factor, even without such challenges. Combined with the issue of poor fit on some children with smaller head sizes, it is possible that the design of eye tracker chosen was not the most compatible for all children with DCD in our study. As there are a number of eye trackers available on the market to choose from, each with different features, the challenges noted during our study highlight important considerations for the choice of eye tracker in future designs. Indeed, eye movements can be measured in a number of ways, beyond head-mounted designs, or eye tracking glasses, and different designs offer advantages over others. The choice depends upon the objectives of the study and what eye movements are to be recorded. A recent study in DCD employed electro-oculography to measure blinks and saccades although this option may be more invasive compared to video-based eye tracking models (Tsai, Pan, Cherng, Hsu, & Chiu, 2009); a study of very young typically developing infants used a very lightweight head-mounted version that may be useful, or could be adapted, especially for smaller head sizes (Franchak et al., 2011). The use of scanning laser opthalmascopy is another option that could be considered (D. Giaschi, personal communication, June 7, 2014; Roorda, 2010). Each of these options has been designed with different features to address recognized barriers in eye tracker use; in future, these eye tracking designs should be explored to determine if they would be better choices for use with children with DCD.

Task Design

Another important aspect to consider when designing an eye tracking study in children with DCD is nature of the task itself. Ideally, the task and eye tracker should be matched to optimize the data that can be collected without sacrificing the elements of the task that are deemed important to the overall study objectives. Given the functional, real-world nature of our task, the 'looking area' was not defined to a space directly in front of the participant. To visually locate the pouring/filling cups placed to the far left or right (the 3rd pouring and filling cups in the line, respectively), children could utilize their peripheral vision, without also moving their head. In these situations, their eye movements would then be outside of the camera scene range, and therefore not recorded. Due to the design of the eye tracking glasses we chose, it was not possible to determine when a child was using his/her peripheral vision in an appropriate manner versus when they were blinking/closing their eyes momentarily, or, alternatively, when they were neither locating peripheral objects or blinking, but rather fixating elsewhere. In fact, it was difficult to determine whether this was the result of a mismatch between eye tracker design and experimental task, or an important finding distinguishing the gaze pattern of children with DCD. In certain cases, as in situations when the gaze cursor disappeared for a lengthy time and re-appeared in locations unimportant to the goals of the task itself, it was readily obvious that the gaze fixations were unusual. Unfortunately, we were unable to qualify this difference by determining precisely where gaze was located during the disappearances. Having said that, however, the atpyical gaze patterns are still an important finding that must be explored in future studies. Research is emerging (M. Farmer, personal communication, November 12, 2014) that would suggest that the ocular fixations of children with DCD are, in fact, somewhat unusual and that the gaze disappearances found in our study are also being found in other experimental work. Combining eye tracking with neuroimaging may help further to test hypotheses around the causes of atypical fixation patterns.

Sampling of Participants

Vision

Five children (42%) wore corrective eyewear. This had implications firstly for fitting the eye tracking glasses. All 5 children had to remove their glasses to complete the experimental testing. Secondly, the influence of their visual impairment on their data could not be described. It is unclear whether or not their results would be different, had they been able to wear their glasses during the task. In fact, 3 of the 5 children (60%)

demonstrated poor fixation for calibration purposes. While we did verify with parents of children who wore glasses that they would be able to complete the task without their corrective glasses, and made accommodations on one occasion only, we do not know whether the poor fixation resulted from their uncorrected visual impairments. Visual difficulties including poor binocular vision, refractive error, and ocular alignment have recently been demonstrated in a large sample of children with DCD, particularly among children who have the most pronounced coordination difficulties (Creavin, Lingam, Northstone, & Williams, 2013). Children in our study had significant motor difficulties, with 6 children (50%) at or below the 1st percentile on the MABC-2, including 4 of those (67%) wearing glasses. In future studies, it may be necessary to either exclude children with visual impairment, or to use eye tracking technology that permits the wearing of corrective glasses. As an alternative, with larger study samples, it may be possible to incorporate methodology that permits analyses that take co-morbid visual impairments into account.

Attention

It is well known that DCD is highly associated with the presence of Attention Deficit Hyperactivity Disorder (ADHD) (Rasmussen & Gillberg, 2000; Tervo, Azuma, Fogas, & Fiechtner, 2002), with as many as 50% of children with DCD reported as also having attention difficulties (Kadesjo & Gillberg, 1998, 1999). In our study, 3 children (25%) had co-occurring ADHD that was formally diagnosed, and, for an additional 6 children (50%) without such a diagnosis, parents noted some concern regarding attention.

It has been observed in studies of children with ADHD that they can have difficulties with stable fixation, which would make calibration with an eye tracker more challenging (Damyanovich et al. 2013; Munoz, Armstrong, Hampton, & Moore, 2003). Difficulties inhibiting ‘intrusive saccades’ have been noted in children with ADHD, along with a greater number of saccadic intrusions when they are required to fixate for longer periods (Munoz et al., 2003). This may help to explain, in part, the observations seen in our study regarding poor gaze fixation that resulted in exclusion of some data due to unreliable calibration (2 of the 3 children with poor fixation for calibration had attention difficulties), and perhaps also to the difficulties of some children when attempting to ‘land’ their eyes on the visual calibration target, when calibration was otherwise successful. Interestingly, Munoz et al. (2003) point out that saccadic control continues to improve with age for children both with and without ADHD into the adolescent years, and note the coincident timing with the maturation of other cortical areas including the frontal lobe and basal ganglia. It may be that co-morbid attention challenges rather than motor coordination difficulties alone impact gaze fixation in some children, especially those who are younger.

Alternatively, the ‘quiet eye’ phenomenon may also help to explain unsteady gaze in children with DCD. This gaze behaviour has only just begun to be studied (Wilson et al., 2012). Findings from this research using catching and throwing as the motor tasks suggest that children with DCD have shorter timeframes during which their eye remains motionless or ‘quiet’, the time during which movement planning is believed to occur

(Vickers, 2011). It is not known how many children with DCD in the study by Wilson and colleagues (2012) might have also had co-occurring ADHD.

Taken from different but related vantage points, current understanding of eye movement control in adults indicates that dysmetric eye movements, inaccurate/poorly coordinated eye movements that either 'overshoot' or 'undershoot' a visual target, can result from cerebellar impairment (Krauzlis, 2005), an area often implicated in the pathophysiology of DCD. Similarly, the ability to sustain gaze and suppress unwanted saccades has been studied in autism, related to a cerebellar role in these proceses (Nowinski, Minshew, Luna, Takarae, & Sweeney, 2005).

Insights from the research reviewed above and the current study have several implications. Firstly, it is critical when sampling children with DCD, to include assessments of any co-morbid conditions, particularly, attention issues and visual impairment. Secondly, there is a need for future studies, using real-world tasks, that investigate the impact of the coordination difficulties of DCD occurring alone or with other co-morbidities as possible underlying reasons for differences in gaze fixation stability, before generalizations about eye movements in children with DCD can be made. Study designs which control for heterogeneity will further our understanding of visual processes including selective visual attention in children with DCD, with or without co-morbid conditions, will allow generalization of those findings, and may help clinicians tailor interventions for these children.

Recommendations

The following are recommendations that arise from this study for overcoming challenges in eye tracking research with children with DCD:

- consider characteristics of DCD such as challenges with postural control and endurance, and possible tactile hypersensitivity, as well as potential co-morbid difficulties in attention and vision when choosing an eye tracking tool
- collaborate with vision scientists/others with expertise in eye tracking study design and eye tracker use to maximize the match between the study task and choice of eye tracker
- whenever possible, match task characteristics, study objectives, and eye movements to be recorded with selection of eye tracker design
- consider DCD co-morbidities, especially visual impairments and attention difficulties when sampling participants, designing eye tracking studies, and analyzing and interpreting results; whenever possible, include analyses of co-morbid conditions

Conclusions

Eye tracking technology opens up a window of possibilities, allowing the measurement of an array of eye movements during real-world functional motor tasks. This study found that eye tracking was a feasible approach to use with most children with DCD during a functional task. However, the nature and heterogeneity of DCD, as well as practical equipment challenges suggest that researchers should consider multiple factors when choosing eye tracking equipment and designing eye tracking studies. Eye tracker specifications, the experimental task, along with potential co-occurring conditions, including visual impairments and attention difficulties, all need to be taken into consideration. Recommendations made regarding equipment choice, task, design, and participant sampling may assist with the successful implementation of future eye tracking studies with the DCD population.

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Table 1: Demographic and Clinical Characteristics of Children with Developmental Coordination Disorder (n=12)

Gender	Age (yrs)	MABC-2 (%ile)	DCDQ'07 (Total score)	KBIT-2 (IQ Composite)	Conners 3-P[S] (T-scores)			
					Inattention	Hyperactivity Impulsivity	Executive Function	Learning
DCD Group (n=12) (11M, 1F)								
M	8.2	1.0	36.0	110.0	73.0	66.0	82.0	77.0
M	8.2	5.0	73.0	112.0	54.0	53.0	44.0	42.0
F	8.3	0.5	35.0	93.0	73.0	54.0	64.0	87.0
M	8.5	0.5	37.0	86.0	63.0	50.0	85.0	70.0
M	8.8	2.0	39.0	98.0	48.0	69.0	76.0	48.0
M	9.7	0.5	28.0	108.0	65.0	58.0	56.0	49.0
M	10.3	5.0	54.0	93.0	69.0	83.0	67.0	58.0
M	11.0	0.5	25.0	94.0	65.0	45.0	78.0	49.0
M	11.2	1.0	27.0	103.0	54.0	62.0	49.0	76.0
M	12.3	2.0	71.0	99.0	60.0	46.0	63.0	42.0
M	14.1	5.0	19.0	118.0	68.0	90.0	48.0	68.0
M	14.9	9.0	27.0	121.0	62.0	58.0	56.0	45.0
Mean (SD)	**10.5 (2.3)**	**2.7 (2.7)**	**39.3 (17.7)**	**102.9 (10.9)**	**62.8 (7.8)**	**61.2 (14.0)**	**64.0 (13.9)**	**59.3 (15.7)**

DCD = Developmental Coordination Disorder
MABC-2 = Movement Assessment Battery for Children-2 (Henderson, Sugden, & Barnett, 2007); **DCDQ'07** = Developmental Coordination Disorder Questionnaire (Wilson et al., 2009); **KBIT-2** = Kaufman Brief Intelligence Test-2 (Kaufman & Kaufman, 2004); **Conners 3-P[S]** = Conners-3 Parent Rating Scales of Attention (Short Form) (Conners, 2008)

Table 2: Corrective Eyewear, & Coordination and Attention Scores of Children with Developmental Coordination Disorder Based on Gaze Fixation Stability During Eye Tracker Calibration

Unstable gaze fixation (< 1 second) (n=3)						
Participant	MABC-2 (%ile)[a]	Glasses	Conners 3-P[S] (T-scores)			
			Inattention	Hyperactivity/ Impulsivity	Executive Functioning	Learning
1	1.0	Y	54.0	62.0	49.0	76.0
2	0.5	Y	73.0	54.0	64.0	87.0
3	0.5	Y	65.0	45.0	78.0	49.0
Mean (SD)	**0.7(0.3)**	**N/A**	**64(9.5)**	**53.7(8.5)**	**63.7(14.5)**	**70.7(19.6)**
Stable gaze fixation (>= 1 second) (n=9)						
1	2.0	N	60.0	46.0	63.0	42.0
2	5.0	N	69.0	83.0	67.0	58.0
3	2.0	N	48.0	69.0	76.0	48.0
4	1.0	Y	73.0	66.0	82.0	77.0
5	5.0	Y	54.0	53.0	44.0	42.0
6	5.0	N	68.0	90.0	48.0	68.0
7	0.5	N	63.0	50.0	85.0	70.0
8	0.5	N	65.0	58.0	56.0	49.0
9	9.0	N	62.0	58.0	56.0	45.0
Mean (SD)	**3.3(2.9)**	**N/A**	**62.4(7.7)**	**63.7(14.9)**	**64.1(14.6)**	**55.4(13.3)**

DCD = Developmental Coordination Disorder
MABC-2 = Movement Assessment Battery for Children (2nd ed.) (Henderson, Sugden, & Barnett, 2007)
Conners 3-P[S] = Conners-3 Parent Rating Scales of Attention (Short Form) (Conners, 2008)
SD = Standard deviation
[a]Significant difference in means, $p < .05$

Chapter Five: Discussion

The purpose of this dissertation was to explore visual attention in children with DCD. This work was designed to further understanding of the cognitive processes underlying the success of clinical interventions used with the DCD population. This discussion section begins by reviewing the major study findings, outlining the significance of the work, and placing it in the context of the DCD literature. Clinical and research implications of the results are discussed throughout.

Chapters 1 and 2 outlined the prevalence of DCD, characteristic presentation, and limitations in our understanding of a definitive etiology. These chapters synthesized the empirical evidence calling for identification and intervention to prevent long-term secondary consequences, including poor physical, social/emotional, and mental health. In addition, this review highlighted the necessity of gaining a better understanding of the 'active ingredients' in cognitive interventions to maximize their effectiveness. Through a review of this research it is apparent that, while cognitive interventions help children with DCD learn and transfer motor skills, we do not yet fully understand the reasons why. A working hypothesis presumes that selective visual attention may play an important role in the success of such interventions, based on neuroimaging research and clinical observations. However, the literature reviewed in Chapters 1 and 2 underscores our limited understanding of visual attention processes in children with DCD.

The studies presented in Chapters 3 and 4 represent the next steps towards increasing our knowledge of visual attention in DCD. These studies, modeled after research conducted with adults, were initiated to uncover possible relationships between visual attention and motor performance in children with DCD, with the long-term goal of informing clinical interventions. The contributions of these studies to current DCD knowledge, along with the clinical and research implications of the findings, are discussed in more detail in the sections that follow.

Findings from Chapter 3 confirm and add to the growing body of work demonstrating support for the internal model deficit hypothesis (Adams, Lust, Wilson, & Steenbergen, 2014; Bo, Contreras-Vidal, Kagerer, & Clark, 2006; Ferguson et al., 2015; Gabbard & Bobbio, 2011; Kagerer, Bo, Contreras-Vidal, & Clark, 2004; Kagerer, Contreras-Vidal, Bo, & Clark, 2006; Maruff et al., 1999; van Waelvelde et al., 2006; Wilmut, Brown, & Wann, 2007; Wilson et al., 2004; Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013). This theory speculates that children with DCD may not develop or update their internal representations of motor tasks during motor performance and learning. In the study presented in Chapter 4, children with DCD, compared to their typically developing peers, demonstrated a lack of predictive gaze during a real-world visuomotor pouring task, confirming research showing a decreased ability to use predictive motor control in DCD (Adams et al., 2014; Debrabant, Gheysen, Caeyenberghs, van Waelvelde, & Vingerhoets, 2013; Fergsuon et al., 2015; Wilmut & Wann, 2008). This study was unique, employing an innovative eye tracking methodology. It is one of the few studies in the DCD literature on visual attention to incorporate an everyday task performed in a natural setting. In future, the novel gaze analysis paradigm developed and tested within this study may provide a useful template upon which to build DCD eye tracking studies utilizing functional tasks.

While the comparison study described in Chapter 3 revealed group similarities, visual attention differences found between TD children and children with DCD suggest that they do not 'look the same'. Study results increase our understanding of DCD, highlighting subtle nuances in gaze patterns between the DCD and TD groups that might not otherwise have been detected. While we know from previous studies that children with DCD rely heavily on vision during laboratory-based motor tasks (Biancotto, Skabar, Bulgheroni, Carrozzi, & Zoia, 2011; Missiuna, 1994), our results now extend those findings to complex tasks performed in a natural setting. Eye movement recordings indicate that, when children with DCD are unrestrained in the performance of an everyday task, (i.e., they can choose where to allocate their visual attention based on task goals), they use vision to guide and monitor their movements. They do so rather than looking ahead to visually locate, and develop visual codes for task objects, a pattern that was typical of children without coordination difficulties in our study, and which has been demonstrated in adults (Hayhoe, 2009; Hayhoe & Ballard, 2005; Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Land, Mennie, & Rusted, 1999; Mennie, Hayhoe, & Sullivan, 2007; Pelz & Canosa, 2001). So while children with DCD do not voluntarily deploy attention to non-relevant, highly salient objects (as might be hypothesized given possible co-morbid attention difficulties), it does appear as if they are unable to deploy their attentional resources to objects of task importance, due to a need to visually attend to their body movements. From this, one could reasonably argue that, during the performance of a motor task, detailed representations of the coordinates of task relevant objects (e.g., the filling cup) are developed much later on in the movement sequence, if at all. This would have the overall effect of slowing down the movement process, as the child must continually locate, or even re-locate, task objects. Indeed, the use of computationally heavy (from a cortical standpoint) visual processing in the absence of attention to, and processing of, other forms of feedback, may contribute to the slowness of movement seen in children with DCD. However, while these assumptions may be accurate, it is still possible that co-occurring global attention difficulties could also contribute in some way to the findings observed. This emphasizes the importance of considering co-morbid attention issues in the design and methodology of DCD eye tracking studies.

Children with DCD spent the same amount of time as TD children fixating on the pouring and filling cups when time was summed across all task phases. Nevertheless, when examined in relation to the total time spent visually engaged in the task, children with DCD spent less time fixating on the task relevant cups. Due to the study design and eye tracker characteristics, definitive conclusions could not be drawn regarding the period of time during which children with DCD attended to locations other than the task scene. Even so, this finding may guide the development of new hypotheses that can be tested in future studies. Specifically, global attention and/or anxiety, either alone or in combination, may play a role in the motor task performance in DCD.

Further, study observations point to the use of an internal focus of attention in children with DCD, whereby they attended to their movements (pouring arm/hand, pouring cup while pouring) rather than to the outcome of their movements (water filling the cup). Although an internal focus of attention may be most appropriate for new learners, shifting to an external attentional focus at some point during motor practice and learning is necessary to move to more automatic, proficient motor learning stages (Schmidt & Lee, 2011; Wulf, 2007). Subsequent studies investigating cueing of visual attention in DCD within clinical interventions could incorporate cueing of both internal and external visual foci to test whether this research finding holds true for children with DCD, and if so, whether there is generalization across other meaningful tasks.

The feasibility study in Chapter 4 provides evidence that eye tracking measures can be completed reliably with most children with DCD. This study provides further insights into the heterogeneity of DCD and possible sub-types, as some, but not all children with DCD, had difficulties with stable gaze fixation. Results of this study call for the thorough assessment of co-morbid visual conditions that may impact eye movement recordings during eye tracking studies. A more detailed description of the characteristics of children who have co-occurring visual impairments, along with comparisons with those who do not, may reveal finer subtleties inherent in the visual processing abilities of children with DCD. In fact, such studies might further our understanding of internal models that are reliant upon accurate visual information for proficient motor performance. It will be increasingly important for our understanding of selective visual attention processes in DCD, and motor performance and learning in these children generally, that we are able to identify their visual impairments with greater specificity. While it is hypothesized that the mechanisms of cognitive interventions involve, and rely upon, visual attention cueing for their success, it is possible that such interventions have different effects on children with DCD. In other words, intervention success may relate to the presence or absence of visual attention difficulties, which may in turn be related to visual impairment. Studies incorporating children with DCD with varying levels of visual impairment, and whose visual impairments have been thoroughly described, may allow rigorous analyses of cueing of visual attention to further test these assumptions.

The work conducted in Chapter 4 also underscores the necessity of including detailed descriptions of concomitant attention difficulties in all clinical DCD intervention studies, especially those with an emphasis on cognition. It is unclear from the current study whether children with associated motor, visual, and attentional difficulties may benefit to a greater or lesser extent than children without co-occurring conditions from interventions directed at improving visual attention. The fact that some children had severe motor difficulties, visual impairment, attentional difficulties, and unstable gaze fixation means that such factors ought to be taken into consideration when designing future eye tracking studies.

Finally, while it may be premature to make substantial changes to current evidence-based therapies for children with DCD based on the results of the 2 studies presented here, there are several clinical implications inherent in this work. It will be important for clinicians to consider the impact that visual and attention impairments may have on motor performance and learning, both when teaching functional tasks to children with DCD, and when consulting with families to encourage physical participation. From the work presented here, it appears that strategies commonly used to manage attention (visual and global) could be used to great benefit. Further, greater collaboration between clinicians and other health service providers, in particular those who assess and manage visual and attention issues should be encouraged.

In sum, through a comparison study of visual attention in TD children and children with DCD, and an eye tracking feasibility study, this thesis work has laid the foundation to guide the development of future DCD eye tracking studies. Insights gained here can now be used to advance clinical research studies examining the use of cueing of visual attention in cognitive interventions for children with DCD. Such clinical studies are desperately needed to prevent secondary consequences, and maximize interventions that promote quality of life and full participation in children with DCD.

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