Ball catching strategies in children with and without developmental coordination disorder

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Review of the Literature

In every gymnasium and playground there are children with a variety of different physical abilities. Some children find sport skills natural and easy to acquire, while other children have difficulty on the playing field. Today, children experiencing movement difficulties are labeled as having a "Developmental Coordination Disorder" (DCD). Children with DCD do not have an intellectual or neurological dysfunction (Gubbay, 1975) or cerebral palsy; they are simply regular children in regular schools who appear to have no other disability other than on the playing field. They typically display awkward, clumsy movements, have poor coordination (Dewey & Wilson, 2001; Sangster, Beninger, Polatajko, & Mandich, 2005), and often have a history of delayed motor milestones (Polatajko, 1999). As a consequence, children with DCD are often ridiculed and socially isolated from their peers (Bouffard, Watkinson, Thompson, Causgrove Dunn, & Romanow, 1996; Mandich & Polatajko, 2003; Schoemaker & Kalverboer, 1994; Wall, 1982, Wall, McClements, Bouffard, Findlay, & Taylor, 1985; Wilson, 2005). Thus, it is not surprising that these children avoid moving and interacting with the environment and often withdraw from participation in play or sport activities (Bouffard et al., 1996; Wall et al., 1985). The avoidance of physical activity results in a lack of practice, which inhibits skill development and heightens the performance differences that already exist between children with movement difficulties and their peers (Bouffard et al., 1996; Wall, 1990; Wall, 2004).

Recent reviews suggest that children with DCD have limited motor repertoires (Astill & Utley, 2006; Missiuna, Rivard, & Bartlett, 2003); move differently compared to younger typically developing children and their same-age peers (Van Waelvelde, De

Weerdt, De Cock & Smits-Engelsman, 2004), and have unstable patterns of coordination (Utley & Astill, 2007). However, there is little empirical evidence to support this. This review will provide an overview of DCD and will highlight some of the important theories that guide research studies and interventions. In addition, this review will provide information pertinent to ball catching, a skill that has been shown to pose particular difficulty for children with DCD (Hoare, 1994; Wall et al., 1985). The literature review will then be followed by an empirical study on the ball catching strategies in children with and without DCD.

Overview of DCD

History and Terminology

Coordination difficulties have been recognized for many years, but it wasn't until 1962 that the first article to appear in the British Medical Journal entitled "Clumsy Children" marked the beginning of published works that adopted a scientific approach to the disorder (Sugden & Wright, 1998). In 1975, Gubbay used the term "clumsy child syndrome" to describe children of normal intelligence who had normal findings on conventional neurological examinations, but had difficulties in coordination that interfered with academic performance and socialization. In 1982, Wall described "children without known neuromuscular problems who fail to perform culturally normative motor skills with acceptable proficiency". For example, most children in North America acquire culturally normative skills such as playing hockey, basketball or baseball and gain proficiency with age.

The children with pronounced motor difficulties without a known intellectual or neurological dysfunction (Gubbay, 1975), have been labeled clumsy, physically awkward, maladroit, dyspraxic and uncoordinated (Wright, 1996). These children have been termed as having "perceptual-motor dysfunction" (Laszlo & Bairstow, 1985),"Minimal Brain Dysfunction" (MBD, Kalverboer, 1978), or more recently, Developmental Coordination Disorder (American Psychiatric Association, 1994). The term DCD first appeared in the revised third edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-III-R, American Psychiatric Association, 1987). The term was retained in the fourth edition (DSM-IV) with very little change in the diagnostic criteria (Magalhães, Missiuna, & Wong, 2006). Today, the term DCD is well established in the research literature, in part due to the international consensus in 1994 on children and clumsiness, held in London, Ontario, Canada. The International Classification of Diseases (ICD-10, 1992), the World Health Organization (WHO) provides a similar description of a "Specific Developmental Disorder of Motor Function" (SDDMF) that is very similar to DCD.

Both the DSM-IV and the ICD-10 include the term developmental in describing the condition (Henderson & Henderson, 2002). Within DCD research, the term refers to the sequential change in physical and cognitive ability, which is influenced by the interactions of the body's systems within the individual and the interactions between the individual and the environment. Rates of development can differ among individuals of the same age, which is the case between children with DCD and their typically 'developing' peers. The DSM-IV definition for DCD also includes the term *coordination*, which encompasses all the issues of intentionality, spatial and temporal organization of actions, actions involving the sequencing of movements and actions having to fit the coordinates of the environment (Henderson & Henderson, 2002).

Diagnostic Criteria

There are four diagnostic criteria for DCD; two are inclusive (the criteria must be met for diagnosis to be assigned), and two are exclusive (meeting criteria results in rejection of the diagnosis). The DSM-IV defines DCD as "a marked impairment in the development of motor coordination" (Criterion A). This may be evident by clear delays in achieving motor milestones (i.e., walking), poor athletic ability, or poor handwriting. The first criterion indicates that a child's test score on a standardized motor test, such as the Movement Assessment Battery for Children (MABC, Henderson & Sugden, 1992) or the Bruininks Oseretsky Test of Motor Proficiency (BOTMP, Bruininks, 1978) must be below that expected given their chronological age (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). However, these movement assessments usually provide a record of the quantitative level of performance for a child (i.e., number of balls caught) and not the qualitative aspects of performance (i.e., how the ball was caught). Secondly, the diagnosis for DCD is made only if the coordination problems interfere significantly with activities of daily living and/or academic achievement and/or performance (Criterion B). Criterion B implies a causal relationship between the disturbance in Criterion A, in that there must be an impact of the movement difficulties on a child's school performance or activities of daily living (Geuze et al., 2001). A developmental history of a child given by a parent or teacher is needed for proper diagnosis. Thirdly, the disturbance cannot be due to any other known medical disorder, such as cerebral palsy or pervasive developmental disorder (Criterion C). Therefore, children with motor difficulties due to a specific medical condition should be excluded. Lastly, IQ should be excluded from primary diagnosis of DCD, but if cognitive impairments are present, the motor difficulties must be greater than would be expected for the child's mental age (Criterion D).

Underlying Mechanisms

Research efforts have attempted to identify the primary problems associated with the movement difficulties in DCD. Hulme and Lord (1986) asked children to reproduce the same movements in a line-matching task using either visual or kinesthetic perception. They concluded that poor visual perception, particularly of spatial information might contribute to movement difficulties seen in children with DCD. Dwyer and McKenzie (1994) reported a visual memory deficit since children with DCD had difficulty remembering visual geometric patterns over a brief time lapse. Lord and Hulme (1988) discussed feedback and motor programming differences since children with DCD were poorer performers (i.e., slower processors) when time on target was considered in a rotary pursuit-tracking task. Differences in speed of decision making was reported by Rosblad and von Hofsten (1994), who found slowness and variability of responses in children with DCD use of visual information in goal directed movements. Geuze and Kalverboer (1994) suggested a problem of timing since children who were clumsy showed a slightly increased variability across all tapping tasks in which hand, speed and rhythm of tapping were manipulated.

After completing a meta-analysis, Wilson and McKenzie (1998) concluded that children with DCD perform worse in comparison to control children on almost all investigated information processes (i.e., visual and kinesthetic perception, sensory integration, response selection and motor programming), which suggests a "mild and non-specific performance deficit associated with motor impairment" (Van Waelvelde et al., 2004). There are some fundamental movement impairments, which seem to be quite common across this population. Compared to their typically developing peers, children with DCD are described as having both slower reaction and movement times (Henderson, Rose & Henderson, 1992; O'Brien, Williams, Bundy, Lyons, & Mittal, 2008; van der Meulen, van der Gon, Gielen, Gooskens, & Willemse, 1991). Children with DCD rely more heavily on vision to control their movement, as if in the early stages of learning and appear to behave similarly to younger children (Missiuna, 1994; Missiuna et al., 2003). Children with DCD also seem to have difficulty selecting a motor response that would be appropriate for a given situation (Van Dellen & Geuze, 1988, 1990), are unable to generalize to new situations or adapt to changes in external task demands (Missiuna, 1994) and tend to persist during a task, performing the same way whether or not they are successful (Astill & Utley, 2006; Geuze & Kalverboer, 1987; Marchiori, Wall, & Bedingfield, 1987; Van Waelvelde et al., 2004). In all the above studies, it is clear that children with DCD do not use feedback from task performance, and do not automate movements in the same way as children who are typically developing (Missiuna et al., 2003).

Identification and Prevalence

Problems arise when it comes to diagnose DCD. There are no pathological positive signs that can reliably be detected. In other words, there lacks a distinct set of features for DCD that can clearly distinguish it from other developmental disorders (Henderson & Henderson, 2002). Also, children who are physically awkward form a largely heterogeneous group (Dewey & Wilson, 2001) with difficulties in gross motor activities, fine motor activities, and activities of daily living. Some children may have particular difficulty with gross motor performance involving balance and coordinated movements such as running, jumping, hopping, and ball related activities (Hoare, 1994). Other children may have difficulties with activities of daily living, for example dressing, using a knife and fork, folding clothes, tying shoelaces, and doing up buttons and zippers. Others have fine motor difficulties, which include cutting with scissors, printing or handwriting (Barnhart, Davenport, Epps, & Nordquist, 2003).

Several studies support the notion of heterogeneity within DCD samples (Hoare, 1994; Dewey & Kaplan, 1994; Miyahara, 1994; Wright & Sugden, 1996). These studies used cluster analysis to detect subgroups of children with DCD; an approach in which a set of measurements is acquired and participants are grouped together on the basis of the profiles of their scores on these measurements (Visser, 2003). However inconsistencies exist between the Subtypes identified. Hoare (1994) used measurements of visual perception, visuomotor integration, manual dexterity, kinesthetic acuity, balance, and running speed and identified five different subtype profiles of DCD. Dewey and Kaplan (1994) and Miyahara (1994) used different measurements in each study and both found four different subtypes. However, the emergence of a subtype characterized by difficulties in all sensorimotor measures was common among all the studies, which suggest that such a subtype will show up regardless of the specific sensorimotor variables used in the study (Visser, 2003). Wright and Sugden (1996) also used cluster analysis on a set of Movement ABC data and grouped children with general movement problems, or with problems within a particular subsection of the Movement ABC (i.e., manual dexterity, ball skills, balance).

The DSM-IV acknowledges that the symptoms associated with DCD can also be found in children with learning disabilities (LD) and attention deficit hyperactivity disorder (ADHD) (Kaplan, Wilson, Dewey, & Crawford, 1998), which adds to the confusion of defining DCD. Some researches have chosen to adopt more specific terminology such as, deficits in attention, motor control, and perception (DAMP) to describe children with both DCD and ADHD (Gillberg, Rasmussen, Carlström, Svenson, & Waldenström, 1982; Landgren, Kjellman, & Gillberg, 1998), while others have coupled the movement difficulties with deficits in attention, dyslexia and language impairments (Dewey, Kaplan, Crawford, & Wilson, 2002). These conditions frequently share co-morbidity, which suggests that the overlap between DCD and other disorders may not constitute a distinct syndrome (Kaplan et al., 1998). In other words, DCD may be both a symptom of another disorder and a distinct disorder (syndrome) in and of itself. Therefore, in order to begin to understand DCD it would make sense to include only those children who meet all defining features in the DSM-IV.

There is also no "gold standard" assessment instrument for the identification of children with DCD, which causes problems for comparison between and within individuals. As a result, the children in the research classified with DCD may exhibit varying levels of movement problems depending on the measure used (Dewey et al. 2002) causing discrepancies in the prevalence rates, which range from 4% to 15% of school aged children (Maeland, 1992; Gubbay, 1975). Current prevalence rates are estimated to be between 6% and 10% of school-aged children (APA, 1994) with more boys diagnosed than girls (Barnhart et al., 2003; Missiuna, 1994).

Geuze et al. (2001) conducted a review and found that the most commonly used standardized motor tests are the Movement ABC (Henderson & Sugden, 1992), Gubbay's test (Gubbay, 1975), the McCarron test (McCarron, 1982), the Bruininks-Oseretsky test (Bruininks, 1978) and the Southern California Sensory Integration Tests (Ayres, 1980). The most frequently used test for the identification of children with DCD is the Movement ABC (Geuze et al., 2001). It is a test designed to assess motor skills and motor development problems in children between the ages of 4 and 12. It measures skills within three domains: manual dexterity, ball skills, and static and dynamic balance for four age bands (4-6 years old, 7-8 years old, 9-10 years old, and 11-12 years old). Results are converted into percentiles; scores below the 5th percentile indicate definite motor problems and scores between the 6th and 15th percentile identify children who are at risk (i.e., borderline motor functioning). Geuze et al. (2001) suggest that the 15% cutoff can be used for research purposes.

In the past, parents, teachers, and physicians believed that children could outgrow their clumsiness. However, there is now strong scientific evidence that rather than improving over time, the motor difficulties persist throughout adolescence and adulthood. There are several follow-up studies in this area. Geuze and Borger (1993) examined children aged 11-17 years who had taken part in a study five years earlier when aged 6-12 years and who were originally classified as clumsy. Difficulties with manual dexterity and ball skills were shown to persist in at least 50% of the adolescents. A similar study by Losse, Henderson, Elliman, Hall, Knight and Jongmans (1991) had children complete a battery of assessments 10 years after being identified as having poor motor coordination at age six. The results suggested that the clumsy group continued to have motor coordination difficulties during adolescence. Cantell, Smyth and Ahonen (1994) also reported that 46% of adolescents still differed in motor performance ten years later. They had fewer social hobbies and past-times and lower academic achievement.

Perceptions of athletic competence strongly influence a child's decision to participate in physical activities (Weiss & Horn, 1990). It is not surprising that children and teenagers with movement difficulties tend to avoid physical activity and are prone to a number of secondary impairments. In a society where sport skills are highly valued, awkward movements are open for criticism (Wall, 1982, 1990). Social comparison, used predominantly among boys often occurs in the gym and on the playing field where evaluation and competition against others is at the heart of most sporting endeavors (Duda, 1987). Skinner and Piek (2001) compared the psychosocial variables of children and adolescents with and without DCD using Harter's theory of competence motivation. Results revealed that those with DCD perceive themselves as less competent and having less social support in several domains (i.e., not only in the athletic domain). In addition, those with DCD had lower self-worth and higher levels of anxiety than the control groups.

Other studies have found that children with movement difficulties lack self-confidence (Kalverboer, 1990), have low self-esteem (Henderson, May, & Umey, 1989), and report lower self-efficacy toward physical activity (Cairney, Hay, Faught, Mandigo, & Flouris, 2005). Cairney et al. (2005) found that children with DCD minimize exposure in areas they lack competence by withdrawing from participation in organized and recreational play activities and sports. Bouffard et al. (1996) described a cycle of inactivity, called the "Activity Deficit Hypothesis," that could begin and then feed on itself due to lack of physical skill. A study by Thompson, Bouffard, Watkinson and Causgrove Dunn (1994) supports the "Activity Deficit Hypothesis" after reporting that children with movement difficulties in physical education class were less active and stressful in motor activities. In addition, Thompson et al. (1994) suggest that the lack of success experienced by those children may become frustrating, which can lead to avoidance and/or withdrawal. These studies stress the importance of early identification and intervention.

Theoretical Viewpoints

Dynamic Systems Perspective

Motor coordination problems are often expressed as the inability to adequately adopt one's behavior to varying environmental constraints (Deconinck et al., 2006). A dynamic systems approach provides an alternative to the traditional neuro-developmental perspective and accommodates the heterogeneous nature of motor difficulties (Hammond, 2005). According to this theoretical framework, movement and coordinated behavior emerge as a result of a dynamic interaction between perceptual, cognitive, and motor systems (Thelen, Schoner, Scheier & Smith, 2001), and from the interaction between the individual, environment and tasks within a context (Haywood & Getchell, 2005; Van Waelvelde et al., 2004).

Therefore, learning a motor action involves the complex and collaborative interaction between the various systems of the body and constraints (i.e., individual, task, and environment). Variability in movement is driven by the interaction of constraints on action (i.e., changing the constraint may change the movement) and enables functional movement solutions to be found during activity (Davids, Shuttleworth, Button, Renshaw,

& Glazier, 2004). However, as previously noted, children with DCD lack both adaptability and flexibility in their motor behavior (Astill & Utley, 2006; Geuze & Kalverboer, 1987; Marchiori et al., 1987; Utley, Steenbergen, & Astill, 2007; Van Waelvelde et al., 2004). A study by Astill (2007) examined the effect of manipulating task constraints on the nature and extent of inter and intra-limb coupling during two-handed catching in children with and without DCD aged 7 to 10 years. Ten children with DCD and 10 age-matched controls (AMC) attempted 10 two-handed catches in three 3 different conditions: to the midline, to the left and to the right shoulders. Flight characteristics were standardized by means of a ball-machine. Children with DCD had a mean score of 3 (i.e., the ball was missed, but made contact with the hands) in all three conditions. The constraint of catching the ball projected to the left and right side was found to be the most difficult for children with DCD.

Some researchers use developmental sequences as an assessment tool for a number of fundamental skills (Utley & Astill, 2007; Haywood & Getchell, 2005). Developmental sequences describe the level or stages of coordination for a motor skill when they appear in developmental time. From a dynamic systems perspective, development is a self-organizing process and movement emerges from the interaction between constraints (individual, environmental, task). Therefore, movement patterns can change because of constraints placed on the body and the changes occurring within the body's systems (Utley & Astill, 2007). However, there is a narrowing of possible movement solutions to a few patterns, which become more stable and reliable with practice (Roberton, 1977). Clearly, times of instability are permitted for exploration of alternative movement solutions.

According to Roberton (1977), a component stage of a skill is considered stable if at least 50% of all trials are classified at the same developmental level. Unstable movement patterns may be indicative of a child with DCD. Utley and Astill (2007) used the developmental sequences for two-handed catching to evaluate the movement patterns of children with and without DCD, aged between 7 and 8 years old. Children attempted to catch 30 tennis balls two-handed, which were projected from a ball machine. The researchers looked at each component action (arm, hand, body) of a catch separately and then together as a whole, to create a "developmental profile." The results showed that children with DCD display less advanced movement patterns of the arm and body. For example, they display little movement to adapt to the ball's flight. In addition, their developmental profiles are immature and unstable, whereas the AMC children select more appropriate movement patterns that afford task success. This finding indicates that children with DCD are still in an exploration stage of learning and have not developed accurate and consistent performance.

Cognitive Approaches

Information processing perspective. According to this perspective, the brain acts like a computer; inputs information, processes it, and then outputs a response as a result of external or environmental cues. The information-processing approach is used to study motor development in children including studies on memory, attention, effects of feedback and sensory and perceptual abilities. Concepts such as stimulus-response (S-R, O'Brien et al., 2008) and the role of feedback in children are highlighted within this perspective. Difficulty with or delayed processing of sensory input may result in poor motor planning, which in turn may lead to awkward movements (O'Brien et al., 2008).

The meta-analysis conducted by Wilson and McKenzie reported that children with DCD perform worse on almost all information processes, with a particular disturbance in visual perception (Wilson & McKenzie, 1998). In a ball-catching study conducted by Lefebvre and Reid (1998), children with DCD required more time to determine which cues were useful for their decision-making process. Similarly, Missiuna et al. (2003) found that children with DCD rely primarily on vision for feedback and exhibit limited motor repertoires. O'Brien et al. (2008) gained insight into the central nervous system (CNS) processing and the related motor coordination difficulties of children with DCD by exploring patterns of choice reaction time (RT) to visual, auditory and vibrotactile stimuli. The children with DCD performed worse as the tasks became more complex. The results also suggest a developmental nature to sensory processing given that younger children had slower RTs than the older children for all sensory modalities.

Deconinck et al. (2006) conducted a study on the control processes during one-handed catching. In addition, the researchers also changed ball speeds to study the adaptive abilities of boys with and without DCD. Participants attempted to catch a ball released from a pendulum while seated in two conditions. In the first condition, one ball speed was used while the second condition had three random ball speeds. The adaptations to the varying ball speeds did not differ between groups. However, boys with DCD performed similarly in both conditions; they opened their hand less and had a slower maximal closing velocity compared to their peers. The authors suggest that the coordination problems are situated more at the level of execution than at the level of information processing or planning.

Knowledge-based approach. Wall et al. (1985) developed an approach to motor development that stressed the importance of knowledge about action, which can be useful in studying children with DCD. There are five types of knowledge about action a person develops with sport expertise: (a) declarative knowledge, (b) procedural knowledge, (c) affective knowledge, (d) metacognitive knowledge, and (e) metacognitive skill.

Declarative knowledge is the factual information about a skill. It includes the rules of a game, specific contextual and strategic cues, and goal-related tactics that are stored within the memory and influence motor development and performance (Wall, 1986). In the motor domain, an individual's declarative knowledge base includes information about the body and its constraints and the interaction between the person, the environment and the task (Wall, 1990). Declarative knowledge is gained with experience and its development is facilitated through the use of language (i.e., the use of words used to define, describe and label skills). However, children with DCD cannot articulate as well as their typically developing peers due to a limited vocabulary about movement (Wall et al., 1985, Lloyd, Reid, & Bouffard, 2006). Children with DCD also have difficulty understanding the demands of a task, and are unable to vary motor behavior during problem-solving situations, which are both key elements of declarative knowledge about action.

Procedural knowledge underlies all aspects of an action; it is 'knowing how' to execute a skill. Procedural knowledge represents the repertoire of physical skills that one possesses. This type of knowledge reflects the accuracy, consistency, and automaticity of movement. However, children with DCD appear to be in an early stage of motor learning since they exhibit limited motor repertoires and lack both adaptability and flexibility in their performance (Missiuna et al., 2003). According to Gentile (2000), movement consistency appears only at later stages of skill acquisition

Affective knowledge refers to the subjective feelings a person stores about action. Physical self-efficacy beliefs can positively or negatively affect a person's ability to learn and perform in sport settings. Many children with DCD lack competence and motivation, and tend to withdraw from participation in physical activity (Watkinson et al., 2001). Therefore, positive self-concept, sport confidence, and motor competence all play a vital role in the development of affective knowledge and skilled action.

Metacognitive knowledge, also known as self-awareness is a higher-level form of declarative knowledge. This form of self-knowledge refers to knowing one's physical limitations and having the ability to adjust movement in a given situation. Metacognitive skills are a higher-level form of procedural knowledge and allow a person to strategically plan and control their own learning and performance. For example, a person possessing metacognitive skills has the ability to pick up on patterns, learn from his/her previous mistakes and can discuss strategies for improvement. However, children with DCD have difficulty with the flexibility and adaptability required for activities such as catching and tend to persist in error (Marchiori et al., 1987).

Martini, Wall, and Shore (2004) used a think-aloud protocol during a ball-throwing task to compare the active use of metacognition in boys of varying athletic ability (highly skilled, average, and DCD). Although there was no difference in the frequency of metacognitive concepts verbalized between the groups, the children with DCD were found to use inappropriate or inaccurate concepts and need help to planning and evaluating their performance. Lloyd et al. (2006) also found no difference in the quantity of knowledge utterances in boys with and without DCD during hockey shots and a peg solitaire game. However, there was a difference in the verbalization quality. These studies support the cognitive approach to intervention, which focus on teaching children to use self-talk and problem-solving strategies to plan and evaluate performance.

DCD and Intervention

Traditional "bottom-up" approaches to the treatment of DCD have been based in neuromaturational theories, which assume that the developmental of prerequisite skills is necessary to improve performance in motor tasks (Sangster et al., 2005). Some approaches include perceptual-motor training, sensory integration (SI), and process-oriented training, yet there is no evidence to suggest that one approach is superior to the other. These approaches believe in underlying component deficits (i.e., eye-hand coordination, balance), which are grounded in hierarchical models (Mandich et al., 2001; Sangster et al., 2005). However, there has been a paradigm shift in the literature of motor learning to the use of a more cognitive approach during intervention and therapy in dealing with DCD (Mandich, Polatajko, Macnab & Miller, 2001). In this "top-down" approach to intervention, therapists become teachers who guide children in the process of learning motor skills (Niemeijer, Smits-Engelsman, Reynders, & Schoemaker, 2003). Researchers have explored the use of *cognitive strategies* defined as "an individual's approach to a task when it includes how a person thinks and acts when planning, executing and evaluating performance on a task and its outcomes" (Lenz, Ellis, & Scanlon, 1996, p.5).

Goodgold-Edwards, Beshere, Murphy, MacNeil, and Daoust (1997) suggested that children with developmental disabilities often lack movement experiences upon which to build a repertoire of useful cognitive strategies for learning motor skills. The researchers conducted a study on cognitive strategies during a reciprocal tapping task in an attempt to understand the influences of cognitive strategies on performance and to help guide therapists in designing programs that enhance skill acquisition. Goodgold-Edwards et al. (1997) suggest that therapists help children identify a clear goal to guide performance and help them understand the nature of the task. Therapists should also help children understand the affordances of the environment, and should allow them to problem-solve during motor activities.

Cognitive Orientation to daily Occupational Performance (CO-OP) is a cognitive approach to intervention that was developed to promote skill development (Polatjko et al., 2001). The main idea behind CO-OP as a vehicle for DCD intervention is not an issue of neuromaturation, rather is an issue of learning. CO-OP is a verbally-based approach where children with DCD learn to generate effective cognitive strategies using the framework of Goal, Plan, Do, and Check for successful performance, which results from an optimal match between the person, the environment and the task (Goodgold-Edwards, et al., 1997; Sangster et al., 2005). Each stage of Goal-Plan-Do-Check facilitates metacognitive thinking. For instance, a child learns to ask questions, to monitor, observe, and evaluate performance. In addition, this framework leads to the discovery of domain specific strategies that will enhance performance (Polatajko et al., 2001). However, children with DCD often have a lack of knowledge about how to approach a task and how to analyze the demands of a task. Therefore, from a cognitive perspective, the movement difficulties experienced may in part be due to an inability to generate effective problem-solving strategies (Mandich et al., 2001; Polatajko et al., 2001; Sangster et al., 2005).

A study by Bernie and Rodger (2004) explored the differences in cognitive strategy use during handwriting in two younger and two older children with DCD when engaged in ten one-hour CO-OP sessions. Videotapes of the intervention sessions were observed and behavior was analyzed and coded based on the strategies described by Mandich and colleagues (2001). Results supported the use of CO-OP with children less than 7 years of age and illustrated that younger children appear to use verbal-based strategies more frequently than older children. Sangster et al. (2005) conducted a pilot study to investigate the use of cognitive strategies in children with DCD and to determine whether CO-OP improves cognitive strategy use. Eighteen school-aged children identified with DCD participated in either 10 individualized sessions of CO-OP or Contemporary Treatment Approach (CTA). All children were videotaped and posed questions during pre- and post-test sessions as well as during 1 or 2 treatment sessions. The researchers devised a coding sheet with 12 potential strategies to guide their observations of the children's responses. Results indicated that children with DCD can generate cognitive strategies, however this is when provided with a structured intervention program delivered by a trained therapist.

During physical activity research has shown that children with DCD do not perform as well as their typically developing peers on almost all motor tasks (Wilson & Mckenzie, 1998) and are slower to improve even with extended practice (Marchiori et al., 1987). More recently, studies using kinematic analysis (Astill, 2007; Astill & Utley, 2006) and the description of movement patterns (Utley & Astill, 2007; Van Waelvelde et al., 2004) have revealed movement strategy selection differences during motor tasks between children with and without DCD.

For example, Van Waelvelde et al. (2004) conducted a study on the ball catching performance in children with DCD. A modification of the ball catching item of the TGMD (Ulrich, 1985), was used to evaluate the strategies used to catch the ball. Overall, children with DCD had poorer ball catching performance than their same-age peers. Compared to younger children, it was suggested that children with DCD use different movement strategies including less elbow flexion and arm extension, and less bending of the elbows to absorb the force of the ball. It was also suggested that children with DCD continue longer to use the same catching strategies following failure, whereas their peers seem better able to adjust their movement strategy in the next trial.

Astill and Utley (2006) and Utley, Steenbergen and Astill (2007) also observed poorer movement performance in children with DCD compared to age-matched control children (AMC) when catching a ball two-handed. Both studies explored how DCD and AMC children form synergies or couple the limbs when catching a ball two-handed. Eight participants with DCD between 7 and 8 years of age and their AMC were asked to catch a ball 30 times, delivered in three blocks of 10 trials. Balls were projected by means of a ball machine and aimed at participant's chest. Kinematic analyses showed that children with DCD appear to place restrictions on their movement system (i.e., smaller ranges of motion); they appear rigid and show little variability in their upper limbs when catching a ball two-handed. In contrast, the AMC children demonstrate greater release of degrees of freedom (DOF), which allows them to explore the space for alternative movement strategies. Thus, the ability to vary motor behavior in problem solving situations appears to be limited in children with DCD. These results could have detrimental effects on their motor skill acquisition.

Ball Catching

As previously mentioned, the movement characteristics of children with DCD are diverse. However, many struggle to perform interceptive actions, which form an essential part of activities of daily living, sport, and leisure activities (Missiuna et al., 2003). In these activities, children are required to constantly observe their surroundings and adjust their bodies in response to changes in their environment. Ball catching is one such skill that has been found to pose particular problems for children with DCD (Hoare, 1994, Wall et al., 1985). It is a skill that develops from an early age. Initially, children attempt to catch with very little force absorption, the hands and arms are held rigidly and the ball is trapped against the body (Haywood & Getchell, 2005). During initial stages of learning, children often show an avoidance reaction (i.e., close their eyes or turn their heads), which may be learned from earlier failures. Usually, as children mature and gain more experience they develop proficient catching patterns. However, it takes six to eight years before children have gained enough skill to participate in simple catching games (Williams, 1992). The ability to deploy one's limbs adaptively and spontaneously to complete a motor task successfully is a mark of higher proficiency, as is catching with one hand. The act of one handed catching begins to develop at age 5 and reaches mastery by age 12 (Fischman, Moore, & Steele, 1992).

The ability to catch a ball embraces a wide range of possible movement behaviors dependent upon what is moving; the person, the target, or both (Estil, Ingvaldsen, & Whiting, 2002). Catching a ball requires coordination between a) the limbs, which enables the performer to produce an appropriate movement pattern, and b) between the motor action and the environmental and task constraints (Mazyn, Lenoir, Montagne, & Savelsbergh, 2007). For example, the size of the ball may influence a person to catch with the hands if it is small, or to trap it against the body if it is very large in relation to the hands. However, it is more efficient to catch an object in the hands than to trap it against the body (Haywood & Getchell, 2005). The direction and trajectory of the ball in relation to the catcher can vary widely. The ball may be thrown directly to the catcher, to the side, up high or may have a flat trajectory. High trajectories are typically more difficult for young inexperienced catchers than flat trajectories (Haywood & Getchell, 2005). Other factors that influence catching performance include: the distance the ball travels before it is caught, the method of projecting the ball, the speed of the ball, the amount of vision and viewing time, as well as the knowledge and experience one possesses in catching.

Several research studies have looked at the effect of varying task constraints on catching behavior. Isaacs (1980) studied the effects of ball size, ball color and preferred color on catching in children between 7 and 8 years of age. The smaller 6-in. ball resulted in a more mature form of catching (i.e., use of the hands), whereas children regressed to a more primitive style of catching with the larger 10-in. ball. Although ball color had no significant difference on performance, children caught balls of preferred color better than those of non-preferred colors. Payne and Koslow (1981) also studied the effects of varying ball size on catching ability of children in kindergarten, first and second grades. Children attempted to catch 28 balls, seven trials per ball size (i.e., 6, 8.5, 10, and 13 in. diameters) that were rolled down a ramp. The quality of catching performance improved with grade level and the larger ball sizes produced better catching scores than the smaller balls.

Payne (1982) examined the effects of distance of projection and ball size on catching ability of children in the first grade. Trials were evaluated using a 5-point scale devised by Payne and Koslow (1981). Only ball size was shown to affect catching performance. Children had more catching success with the largest ball (10 in.) compared to the 8.5- or the 6-in ball, however the authors did not provide any data on the quality of ball catching performance.

McConnell and Wade (1990) investigated the effects of lateral movement on the quality and quantity of catching in children from Kindergarten through Grade 4. Children attempted to catch 15 balls, which traveled down a ramp into one of five different locations (i.e., the center of the ramp, 1ft. and 2ft. on either side). The quality of performance increased with grade and the locations 2ft. from the center produced significantly poorer quantity of performance.

Kay (1969) studied the catching actions of three children aged 2, 5 and 15 years. It was observed that the two-year-old maintained a static position, had delayed movement and focused solely on the thrower. Change in strategy was observed in the five-year-old who anticipated more during the ball's flight, who focused on the thrower and its own hands, but whose movements were slow. A clear developmental change was observed at 15 years; the catcher was able to predict the ball's flight and the movements were smooth to intercept the ball and grasp it with the fingers. The movement components (arm, hand and body) for a two-handed catch were initially hypothesized by Harper (1979), modified by Roberton and Halverson (1984), investigated by Strohmeyer, Williams, and Schaub-

George (1991), and reported in current form by Haywood and Getchell (2005). The components are divided into developmental levels and are hierarchically arranged from least to most advanced. The hand component deals with the grasp phase of the action; the arm component represents the positioning phase of catching; and the body component has elements of both the shaping and positioning phases. Strohmeyer et al. (1991) conducted a pre-longitudinal investigation of these proposed sequences on a cross section of children between 5 and 12 years old. Balls were thrown directly at the chest, at or slightly above the head and to the left or right of the catcher. Developmental levels increased as age increased, however even some of the youngest children were able to use more advanced patterns to catch. The sequences suggest that proficient catching involves: catching with hands that "give" with the ball and absorb force; the ability to move the body to intercept ball; and the ability to adjust the hands to the location of the catch. However, the preparatory hand positions for catching a ball change depending on the point of contact. At chest level, forearms are slightly pronated with the fingers pointed forward and upward; above the head, the hands should be raised to that level; and at or below the waist, forearms are supinated, with fingers pointed downward (Wickstrom, 1983). Utley and Astill (2007) conducted a cross-sectional study to investigate the developmental characteristics within the three body components (arm, hand, and body), which showed that the hypothesized sequences met the pre-longitudinal screening criteria. Utley and Astill (2007) then used the developmental sequences to evaluate the movement patterns of children with without DCD during two-handed catching. Children with DCD displayed less advanced developmental sequences for the arm and body action components, and overall, exhibited less advanced and unstable developmental profiles compared to AMC children.

Variations in task characteristics influence both the product and process of performance used in the task (Haywood & Getchell, 2005). Therefore, ball catching can be evaluated in quantitative and qualitative terms and is a useful tool for evaluating motor impairment in children (Van Waelvelde, De Weerdt, De Cock, & Smits Engelsman, 2003). It is a skill included in most standardized movement assessments: the BOTMP (Bruininks, 1978), the Movement-ABC (Henderson & Sugden, 1992), the Test of Gross Motor Development (TGMD; Ulrich, 2000), and the Peabody Developmental motor scales (Folio & Fewell, 2000).

Van Waelvelde et al. (2003) developed a short and long version of a ball-catching test for children between 7 and 9 years of age based on the ball-catching items of these standardized motor tests. The long ball catching test consisted of catching 10 consecutive tennis balls in eight different series by means of a ball machine. The protocol manipulated the method of catching the ball: both in a pouch of various diameters (17 or 21cm in diameter), using two hands and using one hand. The direction of the ball was also changed by 5° to the left and right as well as the distance between the child and the ball machine (4 or 7 meters). The short ball catching test consisted of 5 series of 10 manually thrown balls. The degree of difficulty changed by catching the ball with both hands, then one hand, and by increasing the distance. In 2004, VanWaelvelde and colleagues used the long ball catching test and a modified item of the TGMD (Ulrich, 1985) to compare the quality of ball catching performance of children with DCD to the performance of same-age and younger typically developing children. Children with DCD were paired with typically developing children based on gender and age (±6 months), and younger typically developing children based on gender, a minimum age difference of one year, and on skill level (a similar number of caught balls in the long ball catching test). Results of this study indicated that children with DCD performed more poorly both quantitatively and qualitatively compared to same-age typically developing peers. Compared to younger typically developing children, children with DCD were not only delayed in ball-catching, but appeared to use different movement strategies.

Fischman and Schneider (1985) conducted a study on the relationship between skill, vision, and proprioception in simple one-handed catching. Skilled baseball and softball players and novice catchers attempted to catch slowly moving tennis balls where sight of the catching hand was prevented during half the trials. Results revealed that more balls were dropped when vision of the hand was occluded for both experienced and novice catchers. However, novice catchers showed a greater number of positioning errors and relied more heavily on vision. Therefore, it was argued that sight of the hand is necessary for successful one-hand catching.

Mazyn et al. (2007) studied changes in performance and kinematics during the acquisition of a one-handed catch in 8 women during a 2-week training program (1440 trials). Balls were projected by means of a ball machine at three speeds from a distance of 8.4 meters. Participants were then subjected to three test sessions that consisted of 30 trials (ten trials in each of the three ball-speed conditions). Catching performance improved across practice sessions and execution became more consistent, however there was variability among participants. This observation indicates that the learning process for one individual is different from another and cannot be compared. Results from the kinematic analysis concluded that a successful catch depends on forward displacement of the hand and the dynamics of the hand closure. Moving the hands toward the ball in catching is an advanced strategy used by those with more experience.

Williams (1992) observed both the visual attention and movement strategies in 28 children aged 4 to 10 years during one- and two-handed ball catching. Williams examined the catching trials of each child from a frontal view of the catcher to see the participants' line of sight relative to the thrower and the ball, and described the movements of the limbs during the time of the catch. Three distinct modes of visual attention (i.e., retrospective, concurrent, predictive) and limb movement (i.e., cradling, clamping, grasping) spaced along a maturity continuum were observed. Success in two-handed catching improved exponentially with age, however success with one hand was about half as frequent as with two. Exclusive coupling between the visual and motor strategies was only witnessed in the 10-year-old participants. It seemed that participants adopted a less mature, and perhaps more secure strategy after a failed attempt.

Summary

Van Waelvelde et al. (2004) have already established that children with DCD perform more poorly both quantitatively and qualitatively compared to their same-age typically developing peers, and are not only delayed in ball catching, but appear to use different movement strategies compared to younger typically developing children. However, the criteria for ball catching in the TGMD (Ulrich, 1985) provide only the most mature movement pattern for the upper limbs while coordinated movement for a catch must include arms, hands and body. In addition the TGMD does not include developmental sequences (Haywood & Getchell, 2005), only criteria for the most mature form of the catch. Van Waelvelde et al. also suggested that typically developing children seem to learn from the experiences of previous catches and therefore are better able to switch their strategy to a more efficient one to catch a ball. However, the study did not address the stability of their performance (i.e., whether children with DCD continue to use the same movements patterns throughout performance). In addition, the long ball-catching test consisted of catching a ball in eight different series by means of a ball machine. The researchers indicated that children with DCD used different strategies than their peers and younger children, such as less elbow flexion and less arm extension in preparation for ball contact. However, they did not provide the differences in strategy use to the changing task constraints.

Utley and Astill (2007) expanded on the work of Van Waelvelde et al. (2004) by using the developmental sequences for catching (Haywood & Getchell, 2005) to examine how children with DCD coordinate their actions and how their qualitative performance differs to that of their typically developing peers. The authors reported immature levels of ball control in the arms and body component actions of catching, and unstable developmental profiles in children with DCD. However, the researchers did not manipulate any task constraints (e.g., the task involved catching 30 tennis balls directed to the chest), nor did they include a developmentally matched younger control group. Without the use of a younger control group, the question of whether the development of children with DCD is different or delayed cannot fully be answered.

Therefore, the purpose of this research was to expand on the work of Van Walevelde et al. (2004) and Utley and Astill (2007) by combining different aspects from each. Similarly to Van Waelvelde et al., a ball catching activity was developed to compare the catching performance and movement patterns of children with DCD to two typically developing comparison groups: one matched on age and a second younger group matched on ball skills. The use of a younger control group (which was excluded from the Utley and Astill study) can help answer the question of whether the development of children with DCD is different or delayed. The developmental sequences proposed by Haywood and Getchell (2005) were used to evaluate movement patterns of children in the same way as Utley and Astill (2007). The developmental sequences include the coordination of the upper and lower limbs to evaluate a catch (Haywood & Getchell, 2005), whereas the TGMD criteria used in the Van Waelvelde et al (2004) study only focus on the preparation and reception phase of the catch with respect to the upper limbs.

In contrast to both Van Waelvelde et al. (2004) and Utley and Astill (2007), a human thrower was chosen in place of a ball machine to increase the ecological validity of the task since ball catching is a highly variable and versatile activity (Van Waelvelde et al., 2003). Research has indicated that children prefer a human thrower who can provide specific cues to which a catcher should be attentive (Williams, 1992). In addition, the ball catching activity in this study manipulated ball size and position to observe whether these constraints act to discourage some body movements and encourage others.

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Ball catching strategies in children

with and without developmental coordination disorder

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Abstract

The purpose was to examine the ball catching strategies of 15 children with developmental coordination disorder (DCD) compared to 15 of their peers without DCD, and 15 younger children matched on ball skills. A ball catching activity (catching 10 consecutive balls in five different positions) and the developmental sequences proposed by Haywood and Getchell (2005) were used to evaluate movement patterns. Children with DCD caught significantly fewer balls than their peers at the chest and above the head. Children with DCD demonstrated delayed arm action catching on the right and delayed body actions when balls were projected away from body compared to their peers. In addition, development of some body actions of children with DCD was different compared to younger children. Results suggested that children with DCD have not developed accurate and consistent movement patterns.

Résumé

Le but était d'examiner les compétences de balle et les stratégies de mouvements de 15 enfants avec un Developmental Coordination Disorder (DCD), comparé à 15 de leurs pairs sans DCD, et 15 enfants plus jeunes en égalité sur les compétences de balle. Une activité de balle (le but d'attraper 10 balles consécutives en cinq positions différentes) et les séquences développementales proposées par Haywood et Getchell (2005) ont été utilisé pour évaluer les mouvements des enfants. Les enfants avec DCD ont attrapé significativement moins balles que leurs pairs à la poitrine et au-dessus de la tête. Les enfants avec DCD ont démontré un retard d'action du bras à la droite et un délai de réaction du corps quand les balles ont été projetées loins du corps comparé à leurs pairs. Aussi, le développement de quelques movements du corps des enfants avec DCD était différent comparé aux plus jeunes. Les résultats ont suggéré que les enfants avec DCD n'aient pas encore développé des mouvement précis et cohérents

Ball catching strategies in children with and without developmental coordination disorder

The development of movement abilities is influenced by the dynamic interaction between the perceptual, cognitive, and motor systems within the individual (Thelen, Schoner, Scheier, & Smith, 2001) and from the interaction between the individual, environment, and tasks within a context (Haywood & Getchell, 2005; Van Waelvelde, De Weerdt, De Cock, & Smits-Engelsman, 2004). Rates of development can differ among individuals of the same age, however, it is hoped that by the time children reach school age, the necessary motor skills to succeed in both sport and academic settings have been acquired (Missiuna, Rivard, & Bartlett, 2003). However, some children show clear delays in achieving motor milestones (Polatajko, 1999) that interfere with school performance and/or activities of daily living (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). For some, this can simply be explained by a lack of practice and experience, whereas for other children the motor difficulties persist throughout adolescence and adulthood (Cantell & Smyth, 1994; Losse, Elliman, Hall, Knight, & Hongmans, 1991). Difficulties in motor performance that persist may indicate a developmental coordination disorder (DCD). DCD describes children with a marked impairment in the development of motor coordination that impacts daily living, which cannot be attributable to any known medical condition or low intelligence (American Psychiatric Association, 1994).

Developmental Coordination Disorder (DCD) affects 6-10% of school-aged children (APA, 1994) with more boys diagnosed than girls (Barnhart, Davenport, Epps, & Nordquist, 2003; Missiuna, 1994,). Execution of movement is most observable in physical education contexts and many children with DCD struggle to perform interceptive actions, which form an essential part of activities of daily living, sport and leisure activities (Missiuna et al., 2003). The skill of ball catching is one activity that has been shown to pose particularly difficult for children with DCD (Hoare, 1994; Wall, McClements, Bouffard, Findlay, & Taylor, 1985).

In ball catching activities, children are required to constantly observe their surroundings and adjust their bodies in response to changes in their environment (Missiuna et al., 2003). The ability to catch a ball embraces a wide range of possible movement behaviors dependent upon what is moving; the person, the target or both (Estil, Ingvaldsen, & Whiting, 2002). There are a number of factors that may influence performance, such as the size of the ball, the distance the ball travels before it is caught, the method of projecting the ball, the direction of the ball in relation to the catcher, the speed of the ball, the amount of vision and viewing time, as well as the knowledge and experience one possesses in catching. Regardless of the task constraint, a basic movement pattern always remains: 1) moving the hands into an effective position for receiving the ball, and 2) grasping and controlling the ball (Mazyn, Lenoir, Montagne, & Savelsbergh, 2007; Wickstrom, 1983). Variations in task characteristics influence both the product (i.e., number of balls caught) and process (i.e., movement pattern) of performance used in the task (Haywood & Getchell, 2005). Therefore, ball catching can be evaluated in quantitative and qualitative terms and is a useful tool for evaluating motor impairment in children (Van Waelvelde, De Weerdt, De Cock, & Smits Engelsman, 2003).

Recently, studies using kinematic analysis (e.g., Astill, 2007, Astill, & Utley, 2006; Utley, Steenbergen, & Astill, 2007) and the description of movement patterns (Utley & Astill, 2007, Van Waelvelde et al., 2004) have revealed strategy selection differences in ball catching performance between children with and without DCD. These findings have also shown that children with DCD exhibit smaller ranges of motion in the upper limbs.

For example, Van Waelvelde et al. (2004) have already established that children with DCD perform more poorly both quantitatively and qualitatively compared to their same-age typically developing peers, and are not only delayed in ball catching, but appear to use different movement strategies compared to younger typically developing children. The researchers used the long ball-catching test (Van Waelvelde et al., 2003) to evaluate ball-catching performance and a modification of the ball catching item of the Test of Gross Motor Development (TGMD, Ulrich, 1985) to evaluate the strategies used to catch the ball. The researchers included younger typically developing children to determine whether the altered properties of a movement pattern are due to a developmental delay or to a deficient motor system.

The long ball catching test consists of catching 10 consecutive tennis balls in eight different series by means of a ball machine. The protocol manipulates the method of catching the ball, in a pouch of various diameters (17 or 21 centimeters in diameter), and by using one or two hands. The direction of the ball is also changed by 5° to the left and right, and the distance between the child and the ball machine is changed from 4 to 7 meters (Van Waelvelde et al., 2003). The results from the Van Waelvelde et al. (2004) study indicate that children with DCD use different strategies than their peers and younger children, such as less elbow flexion and arm extension in preparation for ball contact. However, the authors do not provide the differences in strategy use to the changing task constraints. The researchers also *speculate* that typically developing children seem to learn from the experiences of previous catches and therefore are better able to switch their strategy to a more efficient one to catch a ball. However, the study does not address the stability of their performance (i.e., whether children with DCD continue to use the same movement patterns throughout performance). In addition, a modification of the ball catching item of the TGMD was used to evaluate the ball catching strategies. However, the criteria from the TGMD only provide the most mature movement pattern for the upper limbs while coordinated movement for a catch must include arms, hands and body. In addition, the TGMD does not include developmental sequences, only criteria for the most mature form of the catch (see Haywood & Getchell, 2005 for movement sequences of catching for arms, hands, and body).

Utley and Astill (2007) expanded on the work of Van Waelvelde et al. (2004) by using the developmental sequences for catching (Haywood & Getchell, 2005) to examine how children with DCD coordinate their actions and how their qualitative performance differs to that of typically developing peers. The children attempted to catch 30 tennis balls at chest level, which were projected by means of a ball machine. The researchers looked at each component action (arm, hand, and body) of a catch separately and then together as a whole, to create a "developmental profile." The developmental sequences describe the level or stages of coordination for catching when they appear in developmental time. From a dynamic systems perspective (Thelen et al., 2001), development is a self-organizing process and movement emerges from the interaction between constraints (individual, environmental, task). Therefore, movement patterns can change because of constraints placed on the body and the changes occurring within the body's systems (Utley & Astill, 2007). However, there is a narrowing of possible movement solutions to a few patterns, which become more stable and reliable with practice (Roberton, 1977). Clearly, times of instability are permitted for exploration of alternative movement solutions. According to Roberton (1977), a component stage of a skill is considered stable if at least 50% of all trials are classified at the same developmental level. Unstable movement patterns may be indicative of a child with DCD. Utley and Astill (2007) reported immature levels of ball control in the arms and body component actions of catching, and unstable developmental profiles overall in children with DCD. However, Utley and Astill (2007) did not manipulate any task constraints (e.g., participants were thrown 30 tennis balls directed to the chest), nor did they include a developmentally matched younger control group.

Both Van Waelvelde et al. (2004) and Utley and Astill (2007) utilized a ball-machine. However, for the present study, the use of a ball machine was considered inappropriate because a) children may be afraid or unfamiliar with the machine, and b) standardization by means of a ball machine is not ecologically valid since ball catching is a highly variable and versatile activity (Van Waelvelde et al., 2003). Although a ball machine can provide consistency of throws and can accurately change direction, a human thrower can provide specific cues to which a catcher should be attentive (Williams, 1992). Also, research has indicated that children prefer a human thrower rather than a ball machine (Williams, 1992).

Thus, it is suggested that both studies need modifications to more fully explore how children with and without DCD move and coordinate their actions. Inspired by dynamic systems theory (Thelen et al., 2001), a ball-catching activity was developed for the present study to compare the catching performance and movement patterns of children with DCD to two typically developing comparison groups: one matched on age and a second younger group matched on ball skills. The ball catching activity manipulated position (balls aimed at chest, left, right, knees, and above the head) and ball size to observe whether these constraints act to discourage some body actions and encourage others.

A tennis ball and 8.5in playground ball were used since they are both part of the test materials used in the Movement Assessment Battery for Children (MABC, Henderson & Sugden, 1992) and the TGMD (Ulrich, 2000) respectively. Also, most children are familiar with the balls within an elementary physical education program. In regard to the distance of projection, distances of more than four meters have been found to be difficult for an examiner to throw in a standardized and consistent manner (Van Waelvelde et al., 2003). Therefore, a throwing distance of 4 meters was selected.

The aim of the present study was to investigate if children with DCD display different levels of catching to varying task constraints, and to examine if they demonstrate different developmental profiles with different degrees of stability compared to age-matched controls (AMC) and to younger controls (YC). Following the results of VanWaelvelde et al. (2004), it was hypothesized that children with DCD will catch fewer balls in the ball catching activity overall and in each of the five positions compared to AMC and will demonstrate different catching strategies compared to YC. Following the results of Utley and Astill (2007), it was hypothesized that children with DCD will display movement patterns that are less advanced than AMC. In addition, children with DCD will demonstrate different movement patterns than YC. It was also hypothesized that the developmental profiles for the DCD and YC groups will be unstable, and that both groups will exhibit a greater number of developmental profiles compared to the AMC group.

Method

Participants

A total of 45 boys participated; 15 with DCD between 10 and 12 years of age (M = 10.8, SD = 0.58), 15 AMC children (M = 11.2, SD = 0.52), and 15 YC children between 7 and 9 years of age (M = 8.7, SD = 0.56). Children with DCD were paired with AMC children based on age (± 6 months). Children with DCD were developmentally matched to YC children based on a *similar* number of appropriately caught balls in the ball catching activity and on a minimum age difference of one year. The physical education teacher insured that the AMC and YC did not have any movement difficulties, and were in fact, typically developing.

Due to the higher incidence of DCD in boys than in girls (Barnhart et al., 2003; Missiuna, 1994), only boys were selected between 7 and 12 years of age. Participants were at least 7 years old since it takes six to eight years before children have gained enough skill to participate in simple catching games. Also, according to Fischman, Moore, and Steele (1992) the act of one handed catching reaches mastery by age 12.

Children with and without DCD were recruited from two elementary schools in a large metropolitan area after university (see Appendix A) and school board approval was obtained (see Appendix B). Informed consent as well as assent was obtained from parents and children respectively (see Appendix C). The selection of children with DCD involved a three-step procedure to satisfy the diagnostic criteria of the DSM-IV (APA, 1994). First, the primary researcher observed all children during their regular physical education classes for two weeks to identify potential participants. Secondly, physical education teachers were asked to confirm the primary researchers' observations and to nominate any child between 10 and 12 years of age who was experiencing difficulty with school-related motor skills. The physical education and classroom teachers were shown how to use the Checklist from the MABC (Henderson & Sugden, 1992) and completed the Checklist collaboratively. The Checklist was designed as a screening tool to help identify children with DCD. The children who score between the 6th and 15th percentile indicate borderline motor difficulties, while those who score at or below the 5th percentile demonstrate deviant motor performance. The Checklist contains items describing everyday motor tasks performed in the home and school environment.

Third, the children highlighted by the checklist as having movement problems (i.e., those who scored below the 15th percentile) were then administered individually the performance section of the MABC. Geuze et al. (2001) suggest that the 15% cut-off can be used for research purposes. Therefore, only boys who scored at or below the 15th percentile participated (M = 19.8, SD = 5.5). Also, to obtain a more clearly defined subgroup of children with DCD, only those who scored at or below the 15th percentile on the ball skills subtest were included (M = 4.9, SD = 2.1). In addition, due to the inability to obtain medical diagnosis, children's records, and/or IQ scores, the physical education and/or classroom teachers confirmed that the motor disturbance was not attributable to any known medical condition or low intelligence. Therefore, children with DCD must have met the following criteria for participation in this study: a) identified by their physical education teacher and classroom teacher by the MABC Checklist, b) scored in the lowest 15% of the MABC and in the lowest 15% of the ball skills portion of the

MABC (Henderson & Sugden, 1992), and c) have no known neuromuscular problems (Wall, 1982). The data relating to the DCD group membership can be found in Table 1.

Instruments

MABC checklist. The Checklist, taken from the MABC (Henderson & Sugden, 1992) was used as a screening tool to help identify children with DCD. The Checklist has met standards for reliability and most aspects of validity (Schoemaker, Smits-Engelsman, & Jongmans, 2003). In this study, the Checklist was only completed for those children between 10 and 12 years of age who seemed to be experiencing difficulty with school-related motor skills. The checklist took between 10 and 15 minutes to complete.

MABC test. The MABC is a standardized test designed to assess motor skills and motor development problems in children between the ages of 4 and 12 years (Henderson & Sugden, 1992). In the manual, 73-97% test-retest reliability is reported as well as satisfactory results for the validity of the MABC (Henderson & Sugden, 1992). The test measures skills within three domains: manual dexterity, ball skills, and static and dynamic balance for four age bands (4-6 years old, 7-8 years old, 9-10 years old, and 11-12 years old). The specific activities for ball skills and balance are similar to the activities typically occurring in a physical education program, while the manual dexterity portion is similar to other fine motor activities included in the classroom. Scores below the 5^{th} percentile, indicate a definite motor delay and scores between the 5^{th} and 15^{th} percentiles suggest borderline motor functioning. The MABC is a reliable and valid test based on results reported in the manual. In this study, children were tested with age band 3 (9 to 10 years old) or age band 4 (11 to 12 years old). Even though the items for each age band are different, the skills are still very similar. The administration of the MABC was conducted individually and required 20 minutes per child in a quiet area.

Ball catching activity. A ball catching activity consisted of catching 10 consecutive balls in five different positions at a distance of 4 meters. The activity manipulated the size of the ball (tennis ball and 8.5in playground ball) and the location of interception (chest, left, right, above the head, at the knee). There were 10 trials for each of the five different positions:

1. The child catches a tennis ball 10 times at chest level.
2. The child catches a tennis ball 10 times to the left.
3. The child catches a tennis ball 10 times at the knee.
4. The child catches a playground ball 10 times to the right.
5. The child catches a playground ball 10 times above the head.

The test took approximately 10-15 minutes to administer. Two standard digital video cameras (Panasonic PV-GS65) were positioned at lateral and frontal viewpoints. The videos were carefully analyzed from simultaneous anterior and lateral views.

Catching strategies. The catching strategies were scored using the catching scale proposed by Wickstrom (1983). A catching strategy was evaluated on a five-point scale according to the following criteria:

0 = not touching the ball with the hand(s) (i.e., complete miss).

1 = touching the ball with the hand(s) or body, but not catching the ball.

2 = catching the ball with the hand(s) after touching the ball with another part of the body.

3 = catching the ball with the hand(s) with fumbling.

4 = catching the ball cleanly with the hand(s).

The number of correctly executed catches (4-scores) was recorded. A failed catch corresponded to the ball being missed or caught by trapping against the body. The number of appropriately caught balls was used as the quantitative measure of performance. This dependent variable varied between 0 and 50.

Developmental sequences. The hypothesized developmental sequences for the arms, hand and body for two-handed catching proposed by Haywood and Getchell (2005) were used as criteria to assess the movement patterns of the children (see Table 2). The lower the level of movement pattern the more primitive it is, whereas the higher the level attained the more advanced the pattern. Every trial was analyzed and all components (arm, hand, and body) were classified by viewing the videos. In this study, no arm component level 1 was ever observed, however a no catch (NC) was given for those children who did not catch the ball.

Procedure

Performance on the MABC and the ball catching activity were carried out individually, in a quiet classroom, free of distractions within the school(s). To maximize consistency and ecological strength of the ball catching activity, all examiners were trained to throw accurately at the targets using an underarm toss, and the targets (i.e., locations of interception) were marked on the wall with colored tape according to a child's body size (i.e., an arm span to the left and right, one foot above the head and at the knee). Each condition (i.e., balls thrown to the chest, left, right, above the head and at the knee) was randomized across participants. Each child stood against a wall, 4 meters from the tester (i.e., thrower). Children were told to catch to the best of their ability and were encouraged to expend maximal effort. Prior to testing, participants were given ten familiarization trials (2 in each position). The participants then attempted to catch 10 balls in the 5 different positions. The thrower only started a new set of 10 trials when a child gave full attention. An observer judged each ball toss and recorded any verbalizations made during performance. Further trials were administered if a toss was deemed unfair (i.e., out of bounds).

Data Analysis

Fifty catching trials for each participant were available for analysis. Prior to analyses, inter-rater reliability had to be examined. A Kinesiology graduate categorized 450 randomly selected trials (including both the catching strategy scores and the developmental sequences) from the data set. The percent agreements between the author and independent rater were 98.8%, 98.6%, 91% and 91.4% for the catching strategy scores, and for the arm, hand, and the body components respectively. Due to the high level of inter-rater agreement, the author's scores were used for all subsequent analysis.

The quantitative data (catching strategies based on Wickstrom's catching scale) was treated in two ways. First, descriptive statistics of the three groups (children with DCD, YC, and AMC children) were calculated. A one-way multivariate analysis of variance (MANOVA) general linear procedure was adopted in order to compare how the groups differ in respect to their quantitative catching scores overall (i.e., based on the number of appropriately caught balls), and at each of the five different positions (a 3 groups x 5 positions MANOVA).

Then, the number of appropriate catches (4-scores) for each participant in each of the three positions that utilized a tennis ball (chest, left, knee) were summed and divided by 3 to obtain a mean score for the tennis ball catches. The number of appropriate catches (4-scores) in the two positions that utilized an 8.5in playground ball (right, above the head) were summed and divided by 2 to obtain a mean score for the playground ball catches. A paired samples t test was used to investigate the task constraint of ball size on performance.

The developmental data (developmental sequences) were treated in three ways resembling the data analysis in the Utley and Astill (2007) study. For each trial, the sequence level of each component (arm, hand, body) was recorded. The modal sequence level (most frequent) for each movement component was then computed for each of the five positions (chest, left, knee, right, and above the head). Then, the number of trials in which each sequence level of each component was observed within a position was recorded and transformed into a percentage of occurrence. For example, if sequence level 2 of the arm component was observed in 6 of the 10 trials at the chest and thus represents the modal sequence level, its percentage of occurrence would be 60%. This procedure was then carried out to determine the group's modal developmental sequence level for each movement component in each position. To analyze the difference in modal developmental levels between the DCD, AMC and YC groups, chi-square analyses of independence (Developmental Level x Group) were adopted for each position. If the chi-square tests indicated significant differences, follow-up pairwise comparisons were conducted to evaluate the differences among the groups (e.g., differences between DCD and YC, DCD and AMC, and YC and AMC). The Holm's sequential Bonferroni method was used to control for Type I error at the 0.05 level across all three comparisons.

Then, developmental profiles were recorded for each trial of each participant, created from the developmental sequence levels of each component. For instance, a developmental profile of A4-H2-B2 describes a catch in which a child displayed the most advanced movement level in the arm (A), and intermediate levels of the hand (H) and body (B) actions. For each child in each position, the frequency of each profile was recorded and the profile with the highest frequency was considered the modal developmental profile. The frequency of the profile was then transformed to a percentage of occurrence; for example, if A4-H2-B2 was observed in 8 trials, its percentage of occurrence would be 80%. A group modal profile and its percentage of occurrence were then determined. To test the difference between the modal profiles of each group, a chi-square analysis was conducted (Group Modal Profile x Group) for each position. If the chi-square tests indicated significant differences, follow-up pairwise comparisons were conducted to evaluate the differences among the groups (e.g., differences between DCD and YC, DCD and AMC, and YC and AMC). The Holm's sequential Bonferroni method was used to control for Type I error at the 0.05 level across all three comparisons.

Roberton's (1977) stability criterion was used to assess the stability of a developmental profile within a position. For example, if the profile A3-H1-B3 (intermediate movement level of the arm, most primitive level of the hand and the most advanced level of body action) was observed in the right position in 7 of the 10 trials, its percentage of occurrence would be 70% and would be considered stable. Finally, the number of developmental profiles out of a possible 36 (4 arm action levels x 3 hand levels x 3 body levels) displayed by each participant of each group within each position was calculated. To assess if the frequency of observed developmental profiles were different between the three groups, a chi-square analysis (Number of Developmental Profiles x Group) was conducted for each position. This chi-square test compared the number of children in the DCD group displaying a profile with the children in the AMC and YC groups exhibiting that same profile in each position. If the chi-square tests indicated significant differences, follow-up pairwise comparisons were conducted to evaluate the differences among the groups (e.g., differences between DCD and YC, DCD and AMC, and YC and AMC). The Holm's sequential Bonferroni method was used to control for Type I error at the 0.05 level across all three comparisons.

Results

Number of Catches

A MANOVA was conducted to determine group differences on the total number of appropriately caught balls at each of the five positions: the chest, left, right, at the knees, and above the head. Significant differences were found among the three groups on the dependent measures, Wilks's $\Lambda = 0.52$, $F(12, 74) = 2.36$, $p = .012$. The multivariate η^2 based on Wilks's Λ was quite strong, 0.28. Table 3 contains the means and standard deviations on the dependent variables for the three groups.

Analyses of variances (ANOVA) on each dependent variable were conducted as follow-up tests to the MANOVA. Using the Tukey HSD method for equal groups, each ANOVA was tested at the 0.05 level. The ANOVA on the total number of appropriately caught balls was significant $F(2, 42) = 10.07$, $p = .000$, $\eta^2 = .32$, on the chest scores was significant, $F(2, 42) = 4.17$, $p = 0.022$, $\eta^2 = 0.17$, on the left scores was significant, $F(2,42) = 7.85$, $p = 0.001$, $\eta^2 = 0.27$, on the knee scores was significant, $F(2, 42) = 4.99$, $p = 0.011$, $\eta^2 = 0.19$, and above the head scores was significant, $F(2, 42) = 8.62$, $p = 0.001$,

$\eta^2 = 0.29$, while the ANOVA on the right scores was nonsignificant, $F(2, 42) = 2.96$, $p = 0.063$, $\eta^2 = 0.12$. The three groups were less accurate in catching a playground ball when thrown to the right side.

Post hoc comparisons between all three groups showed the AMC group made significantly more appropriate catches than the DCD ($p = 0.006$) and YC ($p = 0.000$) groups, and more specifically made significantly more appropriate catches at the chest ($p = 0.052$), and above the head ($p = 0.002$) in comparison with the DCD group, and at the chest ($p = 0.035$), left ($p = 0.001$), knee ($p = 0.009$), and above the head ($p = 0.003$) in comparison with the YC group. Because children with DCD were matched to YC based on a similar number of caught balls in the ball-catching activity, they were not significantly different from each other.

Task Constraint: Ball Size

A paired samples t test was conducted to evaluate whether the groups were able to make more appropriate catches (i.e., caught cleanly with the hands) with a tennis ball versus a playground ball. The results indicated that the mean number of appropriate catches with the tennis ball ($M = 7.99$, $SD = 1.93$) was significantly greater than the mean number of appropriate catches with the playground ball ($M = 6.96$, $SD = 2.11$), $t(44) = 3.37$, $p = 0.002$. The tennis ball afforded more children to grasp with the hands, whereas the task constraint of the larger ball size resulted in a more primitive movement strategy.

Developmental Levels of the Arm, Hand and Body Component Sequences

Arm action. The modal levels of performance for arm, hand, and body components were examined and compared between the DCD, YC, and AMC groups. Tables 4-8 show each participant's modal level of each component (arm, hand, and body) at each position (chest, left, below knee, right and above the head). Inspection of Table 4 for the chest position shows that most participants in each group (13 DCD, 13 YC, and 14 AMC) exhibited the most advanced movement level 4 modally for the arms. Thus, the majority of participants extended their arms to meet the ball with the hands. Only participants 4 and 7 of the DCD group, 3 and 9 of the YC group and 14 of the same-age control group display level 3 modally (i.e., scooping). Chi-square analysis showed these differences to be non-significant. Thus, all participants in each group used similar movement patterns of the arms when a tennis ball is directed at the chest.

Similar results occurred when a tennis ball was thrown to the left. Most participants in each group (14 DCD, 14 YC, and all AMC) exhibited the most advanced movement level 4 modally for the arms (see Table 5). Only participant 7 of the DCD group and participant 9 of the YC group displayed level 3 modally. Chi-square analysis showed these differences to be non-significant. Thus, all participants in each group used similar movement patterns of the arms when a tennis ball is projected to the left.

Table 6 indicates that when a tennis ball was directed at the knees, participants 1, 5, and 7 of the DCD group exhibited the most primitive arm action, a NC (no catch) modally, and participant 4 displayed a level 3 modally. Only participant 3 in the YC group displayed a NC modally, and participants 1 and 9 displayed a level 3 modally. These children seem to have difficulty in catching low balls. The remaining DCD and YC displayed a level 4 modally. In contrast, all participants in the AMC group exhibited the most advanced movement level 4 modally for the arms. However, chi-square analyses show these differences to be non-significant. Thus, the majority of participants used similar arm actions when catching low balls.

Inspection of Table 7 shows that more participants in the DCD and YC groups displayed less advanced arm movements when a playground ball was projected to the right. Level 3 was seen modally in participants 2, 4, 5, 11, 13, and 15 of the DCD group, and participants 2, 4, 7, 9, and 14 of the YC group. Thus, they extended their arms under the ball and trapped it against the chest. Participant 5 of the YC group extended his arms sideways and trapped the ball against the chest (level 2). In contrast, all participants in the AMC group showed the most advanced movement sequence of level 4 modally. Chi-square analysis showed these differences to be significant, Pearson χ^2 (4, N = 45) = 9.82, p = 0.044, Cramér's V = 0.330. Follow-up pairwise comparisons show that AMC children used more advanced movement patterns of the arms than children with DCD, χ^2 (1, N = 30) = 7.50, p = 0.006, and YC χ^2 (2, N = 30) = 7.50, p = 0.024. However, children with DCD performed at a level similar to YC.

When a playground ball was thrown above the head, there were no significant differences between the three groups in the arm action since all participants exhibited the most advanced developmental level 4 modally. Thus, all participants exhibited similar arm actions when catching a ball above the head.

Hand action. Participants 4, 5, 7, and 8 of the DCD group, participants 2, 3, 7, 8, 9, 12, 13, and 14 of the YC group, and only participant 14 of the AMC group displayed the most primitive hand action modally, that being level 1 (the hands being placed palms up as they waited for the ball to be caught at the chest) (see Table 4). Participants 1, 6, 9, 12 and 15 of the DCD group, participants 1 and 15 of the YC group, and participants 1, 4, 6, 7, and 8 of the AMC group showed level 2 of the hand component modally. The remaining six DCD participants, five YC participants, and nine AMC participants displayed the most advanced level 3 modally. Thus, although initial inspection of Table 4 indicates that more children with DCD and those who are younger exhibited less advanced movements of the hands compared to AMC children, the differences were not quite significant, Pearson χ^2 (4, N = 45) = 8.49, p = 0.075, Cramér's V = 0.434. All groups performed similar hand actions when catching a tennis ball at the chest.

Participants 4, 5, 7, 8, and 15 of the DCD group, participants 7, 8, 9, 10, and 13 of the YC group, and only participant 8 of the AMC group displayed the most primitive hand action modally, that being level 1 when catching a ball to the left (see Table 5). Participants 1, 3, 6, and 9 of the DCD group, participants 1 and 11 of the YC group, and participants 6 and 7 of the AMC group showed level 2 of the hand component modally. The remaining DCD, YC, and AMC participants displayed the most advanced level 3 modally. Thus, although initial inspection of Table 5 indicates that more children with DCD and YC exhibited less advanced hand actions compared to AMC children, there were no significant differences among the groups. Thus, all groups performed similar hand actions when catching a tennis ball on the left.

Only participants 4 and 5 of the DCD group, participants 1, 3, and 9 of the YC group, and participant 14 of the AMC group displayed the most primitive hand action modally, when catching a ball at the knees. Table 6 indicates that children with DCD (participants 1, 6, 9, and 11) and AMC children (participants 7, 8 and 9) exhibited a less advanced level 2 modally more often than the YC children (only participant 15), while the remaining participants in each group displayed level 3 modally. Thus, although there appears to be hand action differences between the groups, the differences were not significant. All groups performed similar hand actions when catching a tennis ball at the knees.

Both the DCD and YC groups displayed the same amount of developmental levels 1, 2, and 3 for the hand component when catching a playground ball on the right side (see Table 7). Level 1 of the hand component is displayed in seven DCD and YC children respectively; level 2 can be seen in seven DCD and YC children respectively, while the most advanced level 3 is modal only in one participant of the DCD and YC groups. In contrast, level 1, 2, and 3 are each seen in five participants of the AMC group. Although initial inspection of Table 7 indicates that children with DCD and YC children exhibited less advanced movement of the hands compared to AMC children, the differences were not significant. Thus, all groups performed similar hand actions when catching a playground ball on the right.

None of the participants in either of the three groups displayed developmental level 1 of the hand component modally when a playground ball was caught above the head (see Table 8). Most children adjusted their palms to the flight and size of the ball (level 3), or placed their palms facing in (level 2) to catch the ball. Once again, there were no significant differences between the groups.

Body action. Only four DCD and four YC participants exhibited level 2 modally for the body component when catching at the chest (see Table 4), which indicates an awkward adjustment to the ball. The eleven remaining participants in both the DCD and YC groups displayed level 3 modally, which indicates that the body adapts fully to the ball's flight. In contrast, all of the AMC participants displayed the most advanced movement pattern (level 3) for the body component. When a ball was directed at the chest, little body movement was needed to make the catch. Thus, no significant differences were found between the groups.

On the contrary, movement of the body was necessary to successfully catch a ball when projected out to the side, up high or down low. Eleven of the DCD participants exhibited level 2 modally, while the remaining four participants displayed level 3 modally when moving to catch the ball on the left side (see Table 5). In contrast, only four YC and three AMC participants showed level 2 modally, while the remaining participants adjusted their movement fully to the flight of the ball (level 3). Statistical chi-square analysis indicated that there were indeed differences between the three groups, Pearson χ^2 (2, N = 45) = 10.56, p = 0.005, Cramér's V = 0.484. The movement patterns of children with DCD were less advanced than both YC, χ^2 (1, N = 30) = 6.53, p = 0.011, and AMC, χ^2 (1, N = 30) = 8.57, p = 0.003 on the left. Similar results occurred when the ball was thrown at the knees. Most children with DCD exhibited level 2 modally, whereas most YC and AMC children displayed level 3 modally. Chi-square analysis showed these differences to be significant, Pearson χ^2 (2, N = 45) = 9.47, p = 0.009, Cramér's V = 0.459. Children with DCD performed at a lower developmental level than YC, χ^2 (1, N = 30) = 4.82, p = 0.028, and AMC χ^2 (1, N = 30) = 8.57, p = 0.003 when catching at the knees.

In Table 7, ten DCD, five YC, and two AMC children displayed level 2 modally when moving to the right side. The remaining participants exhibited level 3 modally. Chi-square analysis showed these differences to be significant, Pearson, χ^2 (2, N = 45) = 9.27, p = 0.010, Cramér's V = 0.454; however, the differences in body action only existed between the DCD and AMC participants. The movement patterns of children with DCD were less advanced than their same-age peers, χ^2 (1, N = 30) = 8.89, p = 0.003 on the right.

Most children with DCD (8 participants) and YC (8 participants) displayed an awkward adjustment to the ball (level 2 modally) and struggled to remain balanced when caught above the head (see Table 12). In contrast, only participant 6 and 15 of the AMC group exhibited level 2 modally while the remaining participants displayed a proper, well-timed adjustment to catch the ball (level 3). Chi-square analysis indicated that differences between the groups existed, Pearson, χ^2 (1, N = 45] = 6.67, p = 0.036, Cramér's V = 0.385. The data shows that the AMC children used more advanced movement patterns of the body than children with DCD, χ^2 (1, N = 30) = 5.40, p = 0.020, and YC χ^2 (1, N = 30) = 5.40, p = 0.020. Children with DCD moved similarly to YC.

Modal Developmental Profiles

Five developmental profiles characterize the modal profiles of the DCD group (see Table 9) when catching a ball at the chest. The profiles exhibited include A3-H1-B2 (participant 7), A4-H1-B3 (participant 5 and 8), A4-H2-B2 (participant 1 and 12), A4-H2-B3 (participant 6, 9 and 15), and A4-H3-B3 (participant 2, 3, 10, 11, 13, and 14). The modal profile of the DCD group as a whole was A4-H3-B3; this profile was observed on 34% of trials and indicates the most advanced profile. In addition to these profiles, two more profiles were displayed in the YC; A3-H1-B3 and A4-H3-B2. However, the modal profile of the younger group was A4-H1-B3 indicating advanced movements of the arms and body and a less advanced hand action. This profile was observed on 29.3% of the 150 trials at the chest. By contrast, only three developmental profiles characterize the modal profiles of the AMC group. The most advanced developmental profile was modal for the

AMC group (A4-H3-B3) and was observed on 59.3% of trials. The developmental profile A3-H1-B3 was modal for participant 14, A4-H2-B3 for participants 1, 4, 7, and 8, with the remaining ten participants displaying A4-H3-B3. A chi-square analysis showed no significant differences between the groups in the frequency with which the participants exhibit the groups' modal profiles. When Roberton's (1977) stability criteria were applied to the developmental profiles of each participant, it revealed that only participant 4 of the DCD group and participants 1, 4, 5, 9 and 12 of the YC group had an unstable modal profile. Although the profile was modal (most frequent), it was not observed on 5 or more trials at the chest. By contrast, all modal profiles of the AMC participants were stable.

Table 10 indicates that six developmental profiles characterize the modal profiles of the DCD and younger groups, and only three characterize the AMC groups. The modal profile for the DCD group as a whole was A4-H2-B2 for catches to the left side, which indicates advanced movement patterns of the arms and intermediate hand and body movements; this profile was observed on 22% of trials. In contrast, the modal profile of the YC and AMC groups was A4-H3-B3 and was observed on 28% and 58.7% of trials respectively. The difference between the groups' modal profiles was not significant. Four participants with DCD had unstable modal profiles opposed to only one participant in the YC group.

In Table 11, eight developmental profiles characterize the modal profiles of the DCD group, four for the YC group and five for the AMC group. Participant 1 in the DCD group exhibited a modal profile of ANC-H2-B2, while participant 3 exhibited ANC-H3-B3 modally. Both of these participants only caught half of the trials (50%) at the knees.

However, the modal profile for the DCD group as a whole was A4-H3-B2 and was observed on 34% of trials. The profile indicates advanced movement of the arms and hands and an immature body movement. Both the YC and AMC groups displayed a modal profile of A4-H3-B3, which occurred in 34% and 46.7% of trials respectively. The difference in frequency with which the participants of the three groups exhibited the groups' modal profile was not significant. When Roberton's (1977) stability criteria were applied to the developmental profiles of each participant, it revealed that participant 7 of the DCD group, participants 1, 3, 4, 6, 7, and 9 of the YC group and participants 9 and 10 of the AMC group had unstable profiles.

Six developmental profiles characterize the modal profiles of the DCD group (see Table 12), and seven characterize the modal profiles of the YC and AMC groups when catching a playground ball to the right of the body. Two YC participants displayed A2-H2-B2 modally and one participant in the AMC group displayed A2-H2-B3, whereas none of the DCD participants showed a modal developmental profile with a level 2-arm component. A chi-square analysis showed that the difference in frequency with which the participants of the three groups exhibit the groups' modal profiles was significant, Pearson χ^2 (18, N = 45) = 30.12, p = 0.036, Cramer's V = 0.0579. However, the difference was only seen between the DCD and AMC groups χ^2 (8, N = 30) = 17.67, p = 0.024; more children in the DCD group exhibited A4-H2-B2, while more AMC children exhibited the profile A4-H3-B3. Inspection of Table 12 also shows that more YC (6 participants) and AMC (5 participants) displayed unstable modal profiles compared to the DCD group (3 participants).

Four developmental profiles characterize the modal profiles of the DCD and AMC groups and six characterize the YC group when catching above the head (see Table 13). Only participant 9 in the YC group exhibited a less advanced modal profile A2-H2-B2. However, the modal profile for each group as a whole was A4-H3-B3 and was observed on 30%, 29.3%, and 53.3% of the trials for the DCD, YC and AMC group respectively. No significant difference in the frequency of the displayed modal profiles was found. Three participants in the DCD and AMC groups exhibited unstable profiles, while a total of five YC participants displayed unstable profiles.

Frequency of Profiles in the DCD, YC, and AMC Groups

Initial inspections of Tables 9-13 show a general trend for the DCD and YC groups exhibit more profiles over the testing period compared to AMC. Profile A4-H3-B3 was observed in 34% of the DCD trials at the chest, however, a further 15 profiles were each observed in 20% or less of the 150 trials examined (see Table 9). The YC exhibited 18 profiles at the chest with A4-H1-B3 being the modal profile and observed in 29.3% of trials. There was also a further 17 profiles that were each observed in 25% or less of the 150 trials examined. In contrast the AMC children only exhibited five profiles at the chest, with each participant displaying between one and four profiles over the 10 trials. One of the profiles observed in the AMC group (A4-H2-B3) was exhibited in 34% of the 150 trials, however the modal profile A4-H3-B3 was observed on 59.3% of trials. The remaining three profiles observed in the AMC group were exhibited in 5% of the trials or less. Although initial inspection of Table 9 indicates that DCD and YC children exhibit more profiles, the statistical analysis by means of a chi-square was not significant. The children with DCD did not display more profiles than the YC and AMC groups.

However, of the 21 profiles observed at the chest only four profiles were common to the four groups: A3-H1-B3, A4-H1-B3, A4-H2-B3, and A4-H3-B3. In addition, the DCD and YC groups both showed 10 profiles, which the AMC did not.

On the left side, the DCD sample exhibited 12 profiles, with each participant displaying between two and five profiles over the experimental period (see Table 10). Profiles A4-H1-B2 and A4-H2-B2 were both observed in 22% of trials, with a further 10 profiles that were each observed in 18% or less of the 150 trials examined. The YC sample exhibited 18 profiles, with each participant displaying between two and six profiles over the 10 trials. Profile A4-H3-B3 was observed in 28% of trials with a subsequent 17 profiles each observed in 21% or less of the trials. In contrast, the AMC children only displayed 7 profiles, with each participant displaying between one and four profiles over the 10 trials. Six of the profiles observed in the AMC group were exhibited in 21% of trials or less, with the modal profile A4-H3-B3 being observed on 58.7% trials. The difference in frequency of profiles on the left side was significant, Pearson χ^2 (34, N = 122) = 59.51 p = 0.004, Cramer's V = 0.494. Pairwise comparisons showed that the DCD group displayed more profiles ob the left than the AMC group. Of the 18 profiles observed on the left, five were common to the three groups: ANC-H3-B3, A4-H1-B3, A4-H2-B3, A4-H3-B2, and A4-H3-B3. In addition, the DCD and YC groups both showed seven profiles, which the AMC did not.

Similar results occurred when a ball was thrown to the knees (see Table 11). The DCD sample exhibited 14 profiles and displayed a different modal profile (A4-H3-B2) on 34% of trials. The YC group exhibited 19 profiles and the AMC group displayed 13, yet both still had a modal profile of A4-H3-B3. The additional profiles within each group were each observed in 20% or less of the trials. The difference in frequency of profiles observed was not significant.

The children in the DCD group exhibited 16 profiles when catching on the right side, with the modal profile A4-H2-B2 being observed on 28.7% of trials (see Table 12). The YC group displayed 17 profiles, and displayed a less advanced modal profile A3-H1-B3 on 23.3% of trials. The AMC group displayed 15 profiles and continued to exhibit modal profile A4-H3-B3 on 25.3% of trials. The additional profiles within each group were each observed in 20% or less of the trials. The difference in frequency of profiles on the right side was not significant. Of the 19 profiles observed on the right, 13 profiles were common among the three groups.

Profile A4-H3-B3 was modal for each of the three groups when catching above the head. However, a further 19 profiles were each observed in 25% or less of the 150 trials examined in the DCD sample (see Table 13), and a further 17 profiles were each observed in 27% or less of the trials in the YC sample. In contrast the AMC group only exhibited a further five profiles above the head that were each observed in 21% of trials or less. Statistical analysis by means of a chi-square test did not confirm a difference in the frequency of profiles observed in the three groups. There was no significant difference between the number of profiles exhibited in all three groups. Of the 21 profiles observed above the head, only six were common among the three groups: ANC-H2-B2, A4-H1-B2, A4-H2-B2, A4-H2-B3, A4-H3-B2, and A4-H3-B3. In addition, the DCD and YC groups both showed 11 profiles, which the AMC did not.

Discussion

The purpose of this study was to compare the catching performance and movement patterns of children with DCD to two typically developing comparison groups: AMC and YC children during a ball catching activity. A secondary purpose was to explore whether children with DCD demonstrate different developmental profiles with different degrees of stability compared to AMC and YC children. Furthermore, this study manipulated the position and ball size to examine the effects on ball control skill.

First, it was hypothesized that children with DCD would catch fewer balls overall, and in the five different positions during the ball catching activity compared to AMC. The total number of appropriately caught balls (4-scores), based on Wickstrom's (1983) catching scale was used as the quantitative measure of ball-catching performance. Table 3 shows that the three groups caught more balls at the chest compared to the five other positions. Success was more likely because the ball was directed into outstretched or "ready" hands by the thrower. This lends support for previous work that found that children caught more balls when projected to the chest (Stroymeyer, Williams, & Schaub-George, 1991). The AMC group caught significantly more balls (cleanly) overall than children with DCD, which confirms that children with DCD have difficulties with catching compared to their same-age peers who have already mastered the skill (Astill, 2007; Astill & Utley, 2007; Van Waelvelde et al., 2004). This finding suggests that children with DCD are in fact delayed compared to their same-age peers. The AMC children also caught significantly more balls (i.e., were more accurate) at the chest and above the head in comparison with the DCD group, and at the chest, on left side, at the knees and above the head in comparison with the YC group. However, all three groups were less accurate in catching on the right side. When children with DCD were compared to YC children who caught a similar number of balls in the ball catching activity, the results showed that both groups also caught a similar number of balls in each position. Therefore, one position did not affect performance scores more than the other. In this study, it seems that changing the position was not the contributing factor to the poorer ball catching scores in the children. This result suggests that the task constraint of ball size may well have been the reason why the children made less appropriate catches in certain positions.

The three groups made similar adaptations to the two ball sizes; the tennis ball resulted in significantly more clean catches than the playground ball. This result is in accordance with Isaacs (1980), who found that typically developing children regress to a more primitive style of catching with a larger ball. In this study, the large ball resulted in poorer quantitative performance scores. In addition, video observations showed that DCD and younger children often showed an avoidance reaction (i.e., closed their eyes or turned their heads) when the playground ball was thrown above the head. The children with DCD seem to move and react as if they are still in the early learning stages (Missiuna et al., 2003), which could account for their lower scores when catching above the head compared to AMC children.

Throughout the ball catching activity, children were told to catch to the best of their ability. Interestingly, video analysis showed that when the tennis ball was thrown to the left side, contact with the ball was often with one hand for the AMC group; a strategy that is not listed in the catching scale nor in the developmental sequences. A one-hand catch is a sign of higher proficiency and suggests that AMC are at a higher developmental level. Some of the DCD and YC children also attempted one or two trials with one hand. Although successful at times, these children returned to using two hands in the following trial. It seems as though AMC children challenge themselves without having to be prompted to do so, whereas children with DCD resort to a more secure style of catching following failure. This is in contrast to Van Waelvelde et al. (2004), and Marchiori, Wall, and Bedingfield (1987) who found children with DCD tend to repeat a task the same way, despite their ineffectiveness.

The developmental sequences proposed by Haywood and Getchell (2005) were also used to assess the movement patterns of children with DCD. First, it was hypothesized that children with DCD would display movement patterns that were less advanced than their same-age peers, and that the movement patterns of different body components would be combined in qualitatively different ways than YC children. Second, it was hypothesized that the developmental profiles for the DCD and YC groups would be unstable; varying from one catch to the next, and that both groups would demonstrate a greater number of developmental profiles overall compared to the AMC group.

Both Van Waelvelde et al. (2004) and Utley and Astill (2007) documented that children with DCD had poorer qualitative ball catching performance than their same-age peers. Analyses of the data in this study supports the hypothesis that children with DCD do indeed exhibit less advanced movement patterns of the arms compared to AMC, however only when balls were projected to the right ($p = 0.000$). In addition, children with DCD displayed less advanced body actions when balls were projected to the left ($p = 0.003$), at the knees ($p = 0.003$), to the right ($p = 0.003$) and above the head ($p = 0.020$)

compared to AMC children. It would be expected that younger children would demonstrate more primitive movement patterns compared to older children. However, in this study, YC children actually demonstrated movement patterns similar to AMC children when catching to the left, at the knees, and to the right. However, when children with DCD were compared to YC, they continued to have significantly poorer qualitative body actions when catching to the left of the body ($p = 0.011$), and when catching at the knees ($p = 0.028$), which suggest that the developmental levels of some body components may follow a different trajectory of development. That is, the development of some body actions of children with DCD is different compared to YC children.

The qualitative descriptions provided by Haywood and Getchell (2005) show that regardless of physical ability and age, all children displayed similar movement patterns of the arm, hand, and body when catching a ball projected to the chest. The three groups exhibited advanced arm and body actions mixed with a variety of hand movement strategies including clamping (hand over hand), scooping, and grasping. When catching to the left of the body, all children in the three groups extended their arms to make a clean catch. However many children with DCD leaned awkwardly to the left to contact the ball and fought to remain balanced. In contrast, AMC children and YC children moved in front of the ball before extending their arms to make a clean catch. When catching a ball directed at the knees, all the children reached down and grasped the ball, however children with DCD displayed less advanced body actions compared to both AMC and YC children. Observations from the videos showed that children with DCD lean forward without a knee bend creating an awkward movement to the ball.

Children with DCD and YC used more primitive arm actions when a large ball was projected to the right compared to AMC children. Both groups extended their arms forward and under to scoop the ball and trapped it against the chest. Comparatively, the large ball did not affect the arm action of the AMC children as they extended their arms to catch the ball cleanly with the hands only. However, all three groups demonstrated less advanced hand actions with the large ball, placing their palms facing up or inward to grasp the ball. When moving to the right, children with DCD were less advanced in their body action component compared to both the AMC and YC groups. Children with DCD seem delayed in their body action, often rushing after the ball or hopping onto the right leg and leaning outward to scoop the ball.

When attempting to catch the large ball above the head, children in all three groups raised their arms and adjusted their hands to the size of the oncoming ball. A vertical jump was the most observed body action in all three groups. However, children with DCD and YC did not time their jumps appropriately and often missed their footing on landing and struggled to remain balanced. Leaning backwards was another body movement frequently seen in children with DCD, but they often did not take a step back to "give" with the catch and are unsteady.

Conclusion

The present results do not support the hypothesis of smaller ranges of motion in the upper limbs (i.e., less elbow flexion, less arm extension and less bending of the elbows to absorb the force) suggested by Van Waelvelde et al. (2004), Utley et al. (2007) and Astill and Utley (2006), since there were no differences between the groups in the arm and hand component actions. However, children with DCD did exhibit less advanced movement patterns of the arm when large balls were projected to the right. Moreover, children with DCD had significant difficulties coordinating their body actions when balls were projected away from the body compared to both comparison groups. These results suggest that the development of children with DCD is different compared to YC, however not all body components are affected. The AMC and YC adjusted the movement of their body to the flight of the ball, which describes a more proficient catcher (Haubenstricker, Branta, & Seefeldt, 1983; Stroymeyer et al., 1991).

The DCD group's modal profiles were advanced when catching at the chest (A4-H3-B3), and above the head (A4-H3-B3), but were less advanced when catching to the left (A4-H2-B2), at the knees (A4-H3-B2), and to the right (A4-H2-B2) compared to the AMC group (A4-H3-B3), and to the left and down low at the knees compared to the YC group. In addition, the DCD and YC groups' modal profiles were unstable in all positions, whereas the AMC group's modal profiles were all stable except for the catches on the right. However, not all the profiles of the DCD and YC participants were unstable. It was often found that children with DCD and younger children linked different action patterns of the arm, hand, and body together as a way to search for an optimal task solution. By contrast, AMC participants displayed stable modal profiles more often than the DCD and YC groups. These findings are consistent with Utley and Astill (2007) who found that AMC children were better able to refine their movements throughout the trials and frequently selected the most efficient movement patterns. Missiuna et al. (2003) noted that even when a skill is learned, children must continue to adapt to changes in the environment and their place in it. In this case, the large ball projected to the right may have influenced the poorer stability of the three groups' modal profiles. All the children seemed to be searching for the optimal task solution, but were indecisive as to which movement pattern afforded task success.

A total of 36 profiles could have occurred across the three components of arm (with NC used instead of level 1), hand, and body action. Twenty-eight of these combinations were observed overall in the data collected among the three groups. A greater number of profiles were observed in the DCD and YC groups compared to the AMC group. This lends some support for previous work that has shown that the movement patterns of children with DCD are very inconsistent (Marchiori et al., 1987). In addition, the frequency of the profiles observed within each group was only significantly different on the left. Children with DCD showed differences in the organization of their catching movements when compared to both comparison groups.

In summary, an ecologically valid ball catching task that varied position and ball size compared the quantitative and qualitative performance of children with DCD to two typically developing comparison groups: same age peers and younger children matched on ball skill. As would be expected, children with DCD caught significantly fewer balls (i.e., made less appropriate catches) compared to AMC with the greatest differences found at the chest and above the head. The movement patterns observed in the children with DCD showed that their arm action was delayed on the right and their body action was delayed when balls were projected away from the body compared to AMC.

In comparison to YC, children with DCD caught a similar number of balls cleanly with the hands in all five positions. In addition children with DCD performed similarly to YC in arm and hand components, yet demonstrated different body actions compared to YC when required to move to the left or catch down low at the knees.

The task constraint of position may have influenced the movement patterns of the DCD group. For example, when balls were projected away from the body, the body actions in children with DCD were significantly less advanced compared to AMC. However, the task constraint of ball size appears to have influenced the choice of catching strategy in all three groups. For example, the tennis ball afforded the use of hands only, whereas the large ball might have afforded more primitive catching strategies (i.e., scooping or hugging into chest). By contrast, the AMC children repeatedly caught cleanly with the hands regardless of ball size.

In addition, the results indicated that children with DCD have not developed accurate and consistent movement patterns (i.e., unstable modal profiles). It appears that children with DCD have difficulty identifying a successful movement solution.

The data from this study highlight the need to manipulate task constraints during intervention to help children search for appropriate movement solutions. Following the strategies used in a cognitive approach to intervention, it may be useful to ask questions before and immediately after performance to help children with DCD focus on how to plan and evaluate a motor skill (Polatajko, Mandich, Miller, & Macnab, 2001). Children with DCD may be attending to the wrong cues, but we can access these cues by using specific probes, and in turn we may begin to have a better understanding of how children move, think and act during a problem-solving task.

There are certain limitations to this research. Testing outside of the natural environment and with an outsider may not reflect a child's true performance. However, the main researcher observed and assisted the physical education teacher during several classes to become familiar with the students. In addition, a human thrower was used in the ball catching activity instead of a ball machine to make children more comfortable. There may have been a greater number of throwing errors, however the distance between the thrower and child was short enough to insure accuracy, and trials were repeated if a ball was out of the target area. Future exploration of this ball catching activity should manipulate task constraints evenly (i.e., use both balls at all positions).

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Table 1

Ages and movement competence scores for the DCD group

Participant Number	Age (yrs/months)	Checklist score	Percentile	Raw Impairment Score	Percentile	Ball skill score	Percentile
1	10.8	41	< 15	22.5	< 1	8	< 5
2	10.7	47	< 15	20.0	< 1	3	< 15
3	10.0	79	< 5	21.5	< 1	7	< 5
4	10.1	37	< 15	24.5	< 1	10	< 5
5	10.3	35	< 15	20.0	< 1	3	< 15
6	11.7	55	< 5	31.0	< 1	5	5
7	10.8	53	< 5	27.0	< 1	5	5
8	10.7	45	< 15	21.0	< 1	5	5
9	11.6	35	< 15	10.5	13	3.5	< 15
10	10.9	50	5	18.5	1	5	5
11	12.0	35	< 15	19.0	< 1	6	< 5
12	10.5	42	< 15	20.5	< 1	4	< 15
13	10.8	35	< 15	11.5	9	3	< 15
14	10.3	35	< 15	17.0	2	3	< 15
15	10.8	32	< 15	13.0	6	3	< 15

Table 2

Developmental sequences for two-handed catching proposed by Haywood and Getchell (2005)

Component and Level	Description of Movement
Arm-action	
Level 1	Little Response. Arms extend forward, but there is little movement to adapt to ball flight; ball usually trapped against chest.
Level 2	Hugging. Arms are extended sideways to encircle (hug) the ball; ball is trapped against chest.
Level 3	Scooping. Arms are extended forward again but move under (scoop) the object; ball is trapped against chest.
Level 4	Arms "give." Arms extend to meet object with the hands; arms and body "give"; ball is caught in hands.
Hand-action	
Level 1	Palms up. The palms of the hands face up.
Level 2	Palms in. The palms of the hands face each other.
Level 3	Palms adjusted. The palms of the hands are adjusted to the flight and size of the oncoming object.
Body-action	
Level 1	No adjustment. No adjustment of body occurs in response to the ball's flight path.
Level 2	Awkward adjustment. The arms and trunk begin to move in relation to the ball's flight path, but the head remains erect, creating an awkward movement to ball. Catcher seems to be fighting to remain balanced.
Level 3	Proper adjustment. The feet, trunk, and arms all move to adjust to the path of the oncoming ball.
NC	"No Catch." Given in the arm-action component for those children who did not catch the ball

Table 3

Means (M) and Standard Deviations (SD) for the number of caught balls overall and at each position for the DCD, YC, and AMC children

		DCD		YC		AMC		Total	
Variable	Range	M	SD	M	SD	M	SD	M	SD
Total	0-50	35.93	7.76	33.07	9.25	44.67	4.17	37.89	8.77
Chest	0-10	7.67	2.19	7.53	2.50	9.53	1.55	8.24	2.27
Left	0-10	8.27	1.79	6.93	2. 46	9.53	0.64	8.24	2.06
Knees	0-10	7.20	2.88	6.33	2.32	8.87	1.13	7.47	2.43
Right	0-10	5.40	3.38	5.00	3.09	7.60	2.97	6.00	3.29
Head	0-10	7.27	1.53	7.33	1.50	9.13	1.13	7.91	1.62

Table 4

Modal level of each component for each participant of the DCD, YC and AMC groups at the chest

	ARM						HAND						BODY					
	DCD		YC		AMC		DCD		YC		AMC		DCD		YC		AMC	
Participant Number	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials
1	4	70%	4	40%	4	100%	2	100%	2	60%	2	100%	2	100%	2	80%	3	100%
2	4	100%	4	90%	4	100%	3	100%	1	90%	3	100%	3	100%	3	100%	3	100%
3	4	60%	3	60%	4	100%	3	100%	1	90%	3	90%	3	60%	3	90%	3	100%
4	3	30%	4	70%	4	100%	1	80%	3	50%	2	90%	2	90%	2	50%	3	100%
5	4	80%	4	60%	4	100%	1	80%	3	60%	3	100%	3	100%	3	40%	3	100%
6	4	100%	4	100%	4	100%	2	100%	3	100%	2	100%	3	90%	3	100%	3	100%
7	3	40%	4	70%	4	100%	1	70%	1	100%	2	100%	2	70%	3	70%	3	100%
8	4	70%	4	80%	4	100%	1	100%	1	70%	2	100%	3	70%	3	100%	3	100%
9	4	80%	3	40%	4	100%	2	90%	1	100%	3	100%	3	100%	2	100%	3	100%
10	4	90%	4	80%	4	100%	3	80%	3	70%	3	100%	3	100%	3	100%	3	100%
11	4	70%	4	80%	4	100%	3	50%	3	80%	3	100%	3	100%	3	80%	3	100%
12	4	100%	4	90%	4	90%	2	70%	1	50%	3	90%	2	100%	2	90%	3	100%
13	4	100%	4	90%	4	100%	3	100%	1	80%	3	100%	3	100%	3	90%	3	100%
14	4	100%	4	100%	3	60%	3	100%	1	100%	1	70%	3	90%	3	100%	3	100%
15	4	100%	4	100%	4	100%	2	90%	2	80%	3	100%	3	100%	3	100%	3	80%

Table 5

Modal level of each component for each participant of the DCD, YC, and AMC groups on the left

	ARM						HAND						BODY					
	DCD		YC		AMC		DCD		YC		AMC		DCD		YC		AMC	
Participant Number	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials
1	4	70%	4	40%	4	100%	2	90%	2	70%	3	100%	2	100%	2	80%	3	60%
2	4	100%	4	90%	4	90%	3	60%	3	90%	3	80%	2	100%	3	90%	3	100%
3	4	100%	4	60%	4	100%	2	90%	3	60%	3	100%	2	100%	3	60%	3	80%
4	4	70%	4	80%	4	100%	1	100%	3	80%	3	100%	2	100%	2	90%	3	100%
5	4	90%	4	70%	4	100%	1	90%	3	90%	3	100%	2	100%	2	80%	2	80%
6	4	90%	4	70%	4	100%	2	100%	3	90%	2	100%	2	100%	3	90%	3	80%
7	3	50%	4	70%	4	100%	1	70%	1	100%	2	100%	2	90%	3	90%	3	100%
8	4	100%	4	90%	4	100%	1	70%	1	70%	1	100%	3	60%	3	100%	3	100%
9	4	90%	3	60%	4	80%	2	50%	1	100%	3	100%	2	60%	2	100%	3	70%
10	4	90%	4	70%	4	90%	3	60%	1	100%	3	100%	3	90%	3	80%	3	90%
11	4	80%	4	80%	4	100%	3	80%	2	100%	3	100%	2	60%	3	80%	3	100%
12	4	90%	4	80%	4	90%	3	100%	3	100%	3	90%	3	100%	3	90%	2	60%
13	4	100%	4	80%	4	90%	3	100%	1	100%	3	100%	3	60%	3	100%	3	100%
14	4	90%	4	90%	4	100%	3	60%	3	60%	3	70%	2	60%	3	90%	3	100%
15	4	90%	4	100%	4	100%	1	100%	3	90%	3	100%	2	70%	3	90%	2	70%

Table 6

Modal level of each component for each participant of the DCD, YC, and AMC groups at the knees

	ARM						HAND						BODY					
	DCD		YC		AMC		DCD		YC		AMC		DCD		YC		AMC	
Participant Number	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials
1	NC	50%	3	50%	4	80%	2	80%	1	90%	3	80%	2	100%	2	80%	3	80%
2	4	100%	4	50%	4	80%	3	100%	3	90%	3	100%	2	100%	3	70%	2	100%
3	4	90%	NC	50%	4	100%	3	80%	1	70%	3	80%	3	60%	3	80%	3	100%
4	3	50%	4	60%	4	100%	1	100%	3	70%	3	100%	2	100%	3	50%	2	100%
5	NC	60%	4	80%	4	90%	3	70%	3	90%	3	90%	3	90%	2	90%	3	100%
6	4	100%	4	70%	4	90%	2	100%	3	80%	3	60%	3	70%	3	60%	3	90%
7	NC	50%	4	50%	4	100%	3	80%	3	50%	2	100%	2	70%	2	90%	3	100%
8	4	90%	4	80%	4	100%	3	80%	3	80%	2	50%	2	80%	3	90%	3	100%
9	4	100%	3	40%	4	80%	2	100%	1	70%	2	70%	2	100%	2	100%	2	70%
10	4	90%	4	80%	4	60%	3	90%	3	70%	3	60%	2	60%	3	80%	3	50%
11	4	90%	4	90%	4	100%	2	100%	3	90%	3	100%	2	50%	2	100%	3	100%
12	4	80%	4	60%	4	100%	3	100%	3	100%	3	100%	2	70%	3	80%	3	100%
13	4	100%	4	90%	4	90%	3	100%	3	100%	3	90%	2	70%	3	100%	3	100%
14	4	100%	4	70%	4	90%	3	90%	3	90%	1	100%	2	70%	3	70%	3	70%
15	4	80%	4	100%	4	80%	1	90%	2	70%	3	60%	3	70%	3	100%	3	70%

Table 7

Modal level of each component for each participant of the DCD, YC, and AMC groups on the right

	ARM						HAND						BODY					
	DCD		YC		AMC		DCD		YC		AMC		DCD		YC		AMC	
Participant Number	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials
1	4	90%	4	60%	4	90%	2	60%	2	80%	3	50%	2	100%	2	80%	3	60%
2	3	40%	3	70%	4	90%	1	60%	1	70%	1	80%	2	100%	3	100%	3	90%
3	4	90%	4	40%	4	100%	2	100%	2	60%	3	80%	2	80%	2	60%	3	90%
4	3	60%	3	50%	4	90%	1	60%	1	70%	2	80%	2	100%	2	80%	3	60%
5	3	60%	2	70%	4	60%	1	80%	2	80%	2	70%	2	100%	2	50%	3	80%
6	4	100%	4	50%	4	70%	2	100%	1	80%	2	60%	2	100%	3	90%	3	50%
7	4	70%	3	80%	4	100%	1	90%	1	100%	2	100%	2	90%	3	90%	3	100%
8	4	60%	4	60%	4	100%	2	60%	1	90%	1	50%	2	50%	3	100%	3	100%
9	4	80%	3	100%	4	80%	2	60%	1	100%	1	90%	2	100%	2	60%	2	60%
10	4	90%	4	70%	4	100%	2	70%	2	50%	2	60%	3	100%	3	100%	3	60%
11	3	50%	4	80%	4	80%	1	70%	2	70%	3	80%	3	70%	3	50%	3	100%
12	4	100%	4	80%	4	80%	3	80%	2	60%	1	70%	3	90%	3	70%	3	60%
13	3	100%	4	100%	4	90%	1	100%	2	90%	3	100%	3	60%	3	100%	3	100%
14	4	50%	3	50%	4	60%	2	70%	1	50%	1	70%	2	70%	3	60%	3	100%
15	3	80%	4	100%	4	100%	1	90%	3	90%	3	60%	3	80%	3	60%	2	80%

Table 8

Modal level of each component for each participant of the DCD, YC, and AMC groups above the head

	ARM						HAND						BODY					
	DCD		YC		AMC		DCD		YC		AMC		DCD		YC		AMC	
Participant Number	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials	Level	Percentage of trials
1	4	90%	4	50%	4	100%	2	100%	2	90%	3	60%	3	80%	2	60%	3	100%
2	4	90%	4	90%	4	100%	3	80%	3	80%	3	100%	2	90%	2	60%	3	60%
3	4	70%	4	100%	4	100%	3	70%	3	100%	3	100%	2	80%	2	80%	3	90%
4	4	80%	4	80%	4	100%	3	90%	2	90%	3	100%	2	80%	2	100%	3	90%
5	4	70%	4	90%	4	100%	3	60%	3	60%	3	100%	2	50%	2	70%	3	50%
6	4	100%	4	100%	4	90%	2	100%	3	90%	3	70%	2	100%	3	70%	2	60%
7	4	100%	4	70%	4	100%	3	60%	3	50%	3	50%	2	100%	3	50%	3	50%
8	4	80%	4	70%	4	100%	3	80%	2	50%	3	80%	3	60%	2	60%	3	80%
9	4	80%	4	40%	4	100%	2	100%	2	70%	2	100%	2	90%	2	90%	3	90%
10	4	90%	4	80%	4	100%	3	90%	3	90%	3	100%	3	90%	3	90%	3	60%
11	4	90%	4	100%	4	100%	3	80%	3	100%	2	100%	3	70%	3	50%	3	100%
12	4	90%	4	90%	4	100%	3	90%	3	90%	3	60%	3	90%	3	80%	3	90%
13	4	100%	4	100%	4	100%	3	90%	2	90%	3	100%	3	90%	3	90%	3	100%
14	4	100%	4	70%	4	100%	3	70%	3	70%	3	90%	2	70%	3	70%	3	80%
15	4	80%	4	90%	4	100%	3	60%	3	100%	3	60%	3	50%	2	80%	2	70%

Table 9

Chest modal profiles and the percentage of trials on which this was displayed and the number of profiles overall for the DCD, YC, and AMC groups.

	DCD			YC			AMC		
Participant Number	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall
1	A4-H2-B2	70.0%	3	A4-H2-B2	20.0%	7	A4-H2-B3	100.0%	1
2	A4-H3-B3	100.0%	1	A4-H1-B3	80.0%	3	A4-H3-B3	100.0%	1
3	A4-H3-B3	60.0%	3	A3-H1-B3	50.0%	5	A4-H3-B3	90.0%	2
4	A3-H1-B2	30.0%	6	A4-H3-B2	30.0%	6	A4-H2-B3	90.0%	2
5	A4-H1-B3	70.0%	4	A4-H3-B3	40.0%	5	A4-H3-B3	100.0%	1
6	A4-H2-B3	90.0%	2	A4-H3-B3	100.0%	1	A4-H3-B3	100.0%	1
7	A3-H1-B2	60.0%	4	A4-H1-B3	70.0%	3	A4-H2-B3	100.0%	1
8	A4-H1-B3	60.0%	5	A4-H1-B3	50.0%	3	A4-H2-B3	100.0%	1
9	A4-H2-B3	80.0%	3	A3-H1-B2	40.0%	3	A4-H3-B3	100.0%	1
10	A4-H3-B3	80.0%	3	A4-H3-B3	60.0%	4	A4-H3-B3	100.0%	1
11	A4-H3-B3	50.0%	5	A4-H3-B3	70.0%	4	A4-H3-B3	100.0%	1
12	A4-H2-B2	70.0%	2	A4-H1-B3	40.0%	5	A4-H3-B3	90.0%	2
13	A4-H3-B3	100.0%	1	A4-H1-B3	60.0%	5	A4-H3-B3	100.0%	1
14	A4-H3-B3	90.0%	2	A4-H1-B3	100.0%	1	A3-H1-B3	60.0%	4
15	A4-H2-B3	90.0%	2	A4-H2-B3	80.0%	2	A4-H3-B3	80.0%	2
Group	A4-H3-B3	34.0%	16	A4-H1-B3	29.3%	18	A4-H3-B3	59.3%	5

Table 10

Left modal profiles and the percentage of trials on which this was displayed and the number of profiles overall for the DCD, YC, and AMC groups.

	DCD			YC			AMC		
Participant Number	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall
1	A4-H2-B2	60.0%	3	A4-H2-B2	30.0%	6	A4-H3-B3	60.0%	2
2	A4-H3-B2	60.0%	2	A4-H3-B3	80.0%	3	A4-H3-B3	70.0%	4
3	A4-H2-B2	90.0%	2	A4-H3-B2	30.0%	5	A4-H3-B3	80.0%	2
4	A4-H1-B2	70.0%	3	A4-H3-B2	70.0%	4	A4-H3-B3	100.0%	1
5	A4-H1-B2	80.0%	3	A4-H3-B2	70.0%	4	A4-H3-B2	80.0%	2
6	A4-H2-B2	90.0%	2	A4-H3-B3	70.0%	4	A4-H3-B3	80.0%	2
7	A3-H1-B2	50.0%	4	A4-H1-B3	70.0%	4	A4-H2-B3	100.0%	1
8	A4-H1-B3	40.0%	5	A4-H1-B3	60.0%	4	A4-H1-B3	100.0%	1
9	A4-H2-B2	40.0%	4	A3-H1-B2	60.0%	3	A4-H3-B3	60.0%	4
10	A4-H3-B3	50.0%	4	A4-H1-B3	70.0%	3	A4-H3-B3	90.0%	2
11	A4-H3-B2	40.0%	5	A4-H2-B3	80.0%	2	A4-H3-B3	100.0%	1
12	A4-H3-B3	80.0%	3	A4-H3-B3	80.0%	3	A4-H3-B2	60.0%	3
13	A4-H3-B3	60.0%	2	A4-H1-B3	80.0%	3	A4-H3-B3	90.0%	2
14	A4-H3-B2	30.0%	6	A4-H3-B3	50.0%	4	A4-H3-B3	70.0%	2
15	A4-H1-B2	60.0%	3	A4-H3-B3	80.0%	3	A4-H3-B2	70.0%	2
Group	A4-H2-B2	22.0%	12	A4-H3-B3	28.0%	18	A4-H3-B3	58.7%	7
	A4-H1-B2	22.0%							

Table 11

Knee modal profiles and the percentage of trials on which this was displayed and the number of profiles overall for the DCD, YC, and AMC groups.

	DCD			YC			AMC		
Participant Number	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall
1	ANC-H2-B2	50.0%	4	A3-H1-B2	40.0%	5	A4-H3-B3	80.0%	2
2	A4-H3-B2	50.0%	4	A4-H3-B3	50.0%	5	A4-H3-B2	80.0%	2
3	A4-H3-B3	100.0%	1	A4-H3-B3	20.0%	6	A4-H3-B3	80.0%	3
4	A3-H1-B2	50.0%	5	A4-H3-B3	40.0%	6	A4-H3-B2	100.0%	1
5	ANC-H3-B3	50.0%	3	A4-H3-B2	60.0%	4	A4-H3-B3	80.0%	3
6	A4-H2-B3	70.0%	2	A4-H3-B3	40.0%	5	A4-H3-B3	50.0%	4
7	A4-H3-B2	30.0%	6	A4-H3-B2	30.0%	4	A4-H2-B3	100.0%	1
8	A4-H3-B2	60.0%	4	A4-H3-B3	70.0%	3	A4-H2-B3	50.0%	3
9	A4-H2-B2	100.0%	1	A3-H1-B2	40.0%	4	A4-H2-B2	40.0%	5
10	A4-H3-B2	50.0%	3	A4-H3-B3	50.0%	5	A4-H3-B3	40.0%	5
11	A4-H2-B2	50.0%	3	A4-H3-B2	90.0%	2	A4-H3-B3	100.0%	1
12	A4-H3-B2	60.0%	4	A4-H3-B3	60.0%	4	A4-H3-B3	90.0%	2
13	A4-H3-B2	70.0%	2	A4-H3-B3	90.0%	2	A4-H3-B3	90.0%	2
14	A4-H3-B2	60.0%	3	A4-H3-B3	60.0%	5	A4-H1-B3	60.0%	3
15	A4-H1-B3	60.0%	5	A4-H2-B3	70.0%	3	A4-H3-B3	50.0%	5
Group	A4-H3-B2	34.0%	14	A4-H3-B3	34.0%	19	A4-H3-B3	46.7%	13

Table 12

Right modal profiles and the percentage of trials on which this was displayed and the number of profiles overall for the DCD, YC, and AMC groups.

	DCD			YC			AMC		
Participant Number	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall
1	A4-H2-B2	60.0%	3	A4-H2-B2	50.0%	4	A4-H3-B3	40.0%	5
2	A3-H1-B2	40.0%	4	A3-H1-B3	70.0%	3	A4-H1-B3	70.0%	3
3	A4-H2-B2	80.0%	3	A2-H2-B2	30.0%	6	A4-H3-B3	70.0%	4
4	A3-H1-B2	60.0%	4	A3-H1-B2	30.0%	6	A4-H2-B3	40.0%	4
5	A3-H1-B2	60.0%	3	A2-H2-B2	30.0%	5	A2-H2-B3	50.0%	6
6	A4-H2-B2	100.0%	1	A4-H1-B3	40.0%	4	A4-H2-B3	30.0%	6
7	A4-H1-B2	50.0%	5	A3-H1-B3	70.0%	3	A4-H2-B3	100.0%	1
8	A4-H2-B2	20.0%	7	A4-H1-B3	50.0%	3	A4-H1-B3	50.0%	3
9	A4-H2-B2	60.0%	3	A3-H1-B2	60.0%	2	A3-H1-B2	50.0%	4
10	A4-H2-B3	70.0%	3	A4-H2-B3	50.0%	4	A4-H3-B3	30.0%	4
11	A3-H1-B3	50.0%	5	A4-H2-B3	40.0%	5	A4-H3-B3	80.0%	2
12	A4-H3-B3	80.0%	3	A4-H2-B3	50.0%	4	A4-H1-B3	40.0%	6
13	A3-H1-B3	60.0%	2	A4-H2-B3	90.0%	2	A4-H3-B3	90.0%	2
14	A4-H2-B2	40.0%	5	A3-H1-B2	30.0%	5	A3-H1-B3	40.0%	3
15	A3-H1-B3	60.0%	4	A4-H3-B3	50.0%	3	A4-H3-B2	50.0%	5
Group	A4-H2-B2	28.7%	16	A3-H1-B3	23.3%	17	A4-H3-B3	25.3%	15

Table 13

Head modal profiles and the percentage of trials on which this was displayed and the number of profiles overall for the DCD, YC, and AMC groups.

	DCD			YC			AMC		
Participant Number	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall	Modal Profile	Percentage of trials	Number of profiles displayed overall
1	A4-H2-B3	80.0%	3	A4-H2-B1	30.0%	5	A4-H3-B3	60.0%	2
2	A4-H3-B2	70.0%	3	A4-H3-B2	50.0%	4	A4-H3-B3	60.0%	2
3	A4-H3-B2	60.0%	6	A4-H3-B2	80.0%	3	A4-H3-B3	90.0%	2
4	A4-H3-B2	70.0%	4	A4-H2-B2	80.0%	3	A4-H3-B3	90.0%	2
5	A4-H3-B3	40.0%	6	A4-H3-B2	40.0%	6	A4-H3-B3	50.0%	2
6	A4-H2-B2	100.0%	1	A4-H3-B3	60.0%	3	A4-H3-B2	40.0%	5
7	A4-H3-B2	60.0%	2	A4-H3-B3	30.0%	7	A4-H3-B3	30.0%	5
8	A4-H3-B3	60.0%	5	A4-H2-B2	40.0%	6	A4-H3-B3	70.0%	3
9	A4-H2-B2	80.0%	3	A2-H2-B2	30.0%	6	A4-H2-B3	100.0%	1
10	A4-H3-B3	80.0%	3	A4-H3-B3	70.0%	4	A4-H3-B3	60.0%	2
11	A4-H3-B3	70.0%	4	A4-H3-B3	50.0%	2	A4-H2-B3	100.0%	1
12	A4-H3-B3	80.0%	3	A4-H3-B3	60.0%	4	A4-H3-B3	60.0%	3
13	A4-H3-B3	80.0%	3	A4-H2-B3	90.0%	2	A4-H3-B3	100.0%	1
14	A4-H3-B2	40.0%	3	A4-H3-B3	60.0%	4	A4-H3-B3	70.0%	3
15	A4-H3-B3	30.0%	7	A4-H3-B2	80.0%	2	A4-H2-B2	40.0%	3
Group	A4-H3-B3	30.0%	20	A4-H3-B3	29.3%	18	A4-H3-B3	53.3%	6

Consent Form

My child and I have read the description of the research project and hereby agree to have him/her participate. We are aware that the results will be used for research purposes only and that the identity of the child will remain confidential and that she/he can withdraw at any time.

Parent name: ______________________ Signature: ______________________

Child's name: ______________________ Signature: ______________________

Age: _____ Date of Birth: ___________ Sex: _____

Grade: _____ Classroom Teacher: ____________________

Some quotes from children will be selected for research presentations. We give permission to use direct quotes but without using his/her name.

Parent name: ______________________ Signature: ______________________

Child's name: ______________________ Signature: ______________________

Please return this form to the Physical Education teacher or Classroom teacher at school

Appendix D

Tukey HSD post hoc comparisons between DCD, YC, and AMC groups for number of caught balls overall and at each position

Dependent Variable	Group x Group		Mean Difference	Standard Error	p value
TOTAL	DCD	YC	2.867	2.693	0.541
		AMC	-8.733	2.693	0.006*
	YC	DCD	-2.867	2.693	0.541
		AMC	-11.600	2.693	0.000*
	AMC	DCD	8.733	2.693	0.006*
		YC	11.600	2.693	0.000*
CHEST	DCD	YC	0.133	0.774	0.984
		AMC	-1.867	0.774	0.052
	YC	DCD	-0.133	0.774	0.984
		AMC	-2.000	0.774	0.035*
	AMC	DCD	1.867	0.774	0.052
		YC	2.000	0.774	0.035*
LEFT	DCD	YC	1.333	0.656	0.117
		AMC	-1.267	0.656	0.143
	YC	DCD	-1.333	0.656	0.117
		AMC	-2.600	0.656	0.001*
	AMC	DCD	1.267	0.656	0.143
		YC	2.6000	0.656	0.001*

Dependent Variable	Group x Group		Mean Difference	Standard Error	p value
KNEE	DCD	YC	0.867	0.815	0.542
		AMC	-1.667	0.815	0.114
	YC	DCD	-0.867	0.815	0.542
		AMC	-2.533	0.815	0.009*
	AMC	DCD	1.667	0.815	0.114
		YC	2.533	0.815	0.009*
RIGHT	DCD	YC	0.400	1.151	0.936
		AMC	-2.200	1.151	0.148
	YC	DCD	-0.400	1.151	0.936
		AMC	-2.600	1.151	0.073
	AMC	DCD	2.200	1.151	0.148
		YC	2.600	1.151	0.073
HEAD	DCD	YC	-0.067	0.510	0.991
		AMC	-1.867	0.510	0.002*
	YC	DCD	0.067	0.510	0.991
		AMC	-1.800	0.510	0.003*
	AMC	DCD	1.867	0.510	0.002*
		YC	1.800	0.510	0.003*

* $p < 0.05$

APPENDIX E

Results for the pairwise comparisons using the Holm's Bonferroni method

Variables	Comparison	Pearson chi-square	p value (Alpha)	Cramér's V
Right Arm	DCD vs. YC	1.091	0.580	0.191
	DCD vs. AMC	7.500	0.006*	0.500
	YC vs. AMC	7.500	0.024*	0.500
Left Body	DCD vs. YC	6.533	0.011*	0.467
	DCD vs. AMC	8.571	0.003*	0.535
	YC vs. AMC	0.186	0.666	0.079
Knee Body	DCD vs. YC	4.821	0.028*	0.401
	DCD vs. AMC	8.571	0.003*	0.535
	YC vs. AMC	0.682	0.409	0.151
Right Body	DCD vs. YC	3.333	0.068	0.333
	DCD vs. AMC	8.889	0.003*	0.544
	YC vs. AMC	1.677	0.195	0.236
Head Body	DCD vs. YC	0.000	1.000	0.000
	DCD vs. AMC	5.400	0.020*	0.424
	YC vs. AMC	5.400	0.020*	0.424
Right Modal Profile	DCD vs. YC	10.571	0.158	0.594
	DCD vs. AMC	17.667	0.024*	0.767
	YC vs. AMC	9.343	0.314	0.558
Left Frequency of Profiles	DCD vs. YC	22.971	0.150	0.502
	DCD vs. AMC	29.591	0.005*	0.608
	YC vs. AMC	27.064	0.057	0.609

* $p < 0.05$