Developmental coordination disorder: A review and update

Jill G. Zwicker a,*, Cheryl Missiuna b, Susan R. Harris c, Lara A. Boyd c

a Department of Pediatrics, University of British Columbia, Vancouver, BC, Canada
b School of Rehabilitation Science and CanChild, McMaster University, Hamilton, Ontario, Canada
c Department of Physical Therapy, University of British Columbia, Vancouver, BC, Canada

ABSTRACT

Present in approximately 5–6% of school-aged children, developmental coordination disorder (DCD) is a neuromotor disability in which a child’s motor coordination difficulties significantly interfere with activities of daily living or academic achievement. These children typically have difficulty with fine and/or gross motor skills, with motor performance that is usually slower, less accurate, and more variable than that of their peers. In this paper, we review the history of various definitions leading up to the current definition of DCD, prevalence estimates for the disorder, etiology, common co-morbidities, the impact of DCD on the child’s life, and prognosis. As well, we briefly describe current interventions for children with the disorder and results of recent neuroimaging studies of the brains of children with DCD, including research by the authors of this paper.

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1. Description, definition and history of DCD

Matthew is a 9-year-old boy who has difficulty tying his shoes, a skill his peers learned to do three years earlier. His mother helps him cut his food and wash his hair, as he struggles to complete these tasks independently. He has not mastered how to ride his bicycle, so he is unable to ride to the park with his friends. Matthew has tried several team sports, but no one passes the ball or puck to him; because he feels excluded and inferior to his teammates, he does not want to participate in sports anymore. Matthew’s parents are worried that he is becoming socially isolated and withdrawn. At a recent parent interview, Matthew’s teacher commented that, while he is a bright and capable student, his printing is slow and often illegible. Matthew does not complete many of his school assignments and homework activities, and, as a result, his grades are suffering. Matthew’s parents are increasingly concerned, but do not know what is wrong with their son.

Matthew is like many children who have a neurological developmental disorder known as developmental coordination disorder (DCD). DCD is heterogeneous, with some children having difficulty only with fine motor skills, only gross motor skills, or both.1,2 Regardless of which skills are affected, motor performance of children with DCD is usually slower, less accurate, and more variable than in their peers.3–10 Motor learning is also impacted, with children with DCD having difficulty acquiring typical childhood skills, such as tying shoes or riding a bicycle.3,11 As Polatajko highlighted, DCD is more than just the lower end of normal variance in motor abilities12; the motor impairment significantly impacts daily life, and is not due to a neurological disorder or delayed cognitive development.

Using the International Classification of Functioning, Disability and Health (ICF) as a framework,13 the Fig. 1 depicts how Matthew’s gross motor impairments (body function) limit his ability to ride a bicycle (activity) and consequently restrict his opportunities to ride to the park with his friends (participation). These limitations in his interaction with his peers (environmental factors) further confound his frustration with his motor in coordination and contribute to his low self-esteem (personal factors). The ICF framework will be cited throughout this review, as it relates to DCD.

Per the Diagnostic and Statistical Manual, fourth edition – Text revision (DSM-IV-TR), four diagnostic criteria comprise DCD.14

A. Performance in daily activities that require motor coordination is substantially below that expected given the person’s chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling, sitting), dropping things, “clumsiness,” poor performance in sports, or poor handwriting.

B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.

C. The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet the criteria for a Pervasive Developmental Disorder.

D. If mental retardation is present, the motor difficulties are in excess of those usually associated with it.

In 2012, the European Academy of Childhood Disability (EACD) published interdisciplinary clinical practice guidelines for definition, diagnosis, assessment, and intervention for children with DCD.15 Recommendations within these guidelines resulted from extensive consultation with an international group of researchers and clinicians and were previously approved at two consensus conferences in Germany, with input from German and Swiss medical and therapeutic societies.15

We will review the history of various definitions leading up to the current definition of DCD, prevalence estimates for the disorder, possible etiology and neurobiology underlying DCD, common co-morbidities, the impact of DCD on the child’s daily life, and prognosis for the disorder. As well, we will briefly describe current interventions for children with the disorder, results of recent neuroimaging studies of the brains of children with DCD, and future research aims.

Identified by Orton in 1937, the significance of “clumsiness” was not apparent in the literature until the early 1960s.16 Since then, many terms have been used to describe children whose motor difficulties interfere with daily living17–19 e.g., clumsy child syndrome,20 sensory integrative dysfunction,21 developmental dyspraxia,22 physical awkwardness,23 and perceptual motor dysfunction.24 In Scandinavian countries, the acronym DAMP has been used to identify children with deficits in attention, motor control, and perception.25

To improve communication and knowledge among clinicians and researchers working with “clumsy” children, an international consensus meeting was held in London, Ontario in 1994 to determine which terminology should be used to describe these children. At this “London Consensus”, the term DCD was accepted.17 The term “developmental coordination disorder” and the diagnostic criteria for DCD had been added to the third edition of the DSM26 and remain in the most current edition.14 Ten years after the London Consensus meeting, over 50% of all published articles used the term DCD,27 showing that this term is gaining acceptance as the preferred terminology. The London Consensus was reconfirmed with the 2006 publication of the Leeds Consensus Statement28 highlighting the agreement of international researchers and clinicians to retain the term DCD as a distinct and unique disorder. More recently, the EACD reaffirmed the use of the term DCD in reference to children with

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*With the release of DSM-V in 2013, these criteria may undergo some revision.*
developmental motor problems,15 as well as the DSM-IV criteria14 for defining the disorder.

2. Prevalence of DCD

Depending upon the selection criteria used, prevalence estimates for DCD vary from 1.4 to 19.0% of school-aged children.29–31 Using the most commonly reported prevalence of 5–6%,14 approximately 190,000 Canadian children aged 5–11 years may meet the diagnostic criteria for DCD,32 as well as over a million children in the U.S.33 Data from other countries have ranged from a lower reported prevalence of severe DCD in the United Kingdom (1.8%),29 to an unusually high prevalence estimate in Greece (19.0%).31

A major reason for these varying prevalence rates is how cases of DCD are identified.29 Higher prevalence rates may be reported if not all diagnostic criteria for DCD are applied. Some studies include children with motor coordination challenges without quantifying intelligence or impact on activities of daily living.34 In contrast, the prevalence of DCD may be underreported due to lack of awareness of the disorder.35 For example, a survey of physicians in a large city in Canada showed that 174 of 191 (91%) had never heard of DCD.36 Variations in reported prevalence may also be due to selection of different cutoff scores used to indicate motor impairment,38 lifestyle differences in various cultures,31 or terminology used to describe these children.17

Clinical studies of children with DCD have reported higher prevalence in boys. The gender ratio for boys to girls has varied from 3:125,37 to as high as 7:1.38 However, recent population-based studies suggest a lower ratio (1.9:1.0 male to female)29 or almost equal gender distribution.39

Although reasons for the greater prevalence of DCD in boys have not been described explicitly in the literature, this difference may relate in part to the fact that DCD is more prevalent in children born at very low birth weight or very preterm (as compared to full-term, appropriately grown infants)30; several recent studies have shown that neurological outcomes are more adverse for male infants born preterm than for their female counterparts.41–43

3. Etiology and neurobiology of DCD

Although the etiology of DCD is largely unknown, it may be related to central nervous system pathology.14 DCD was first conceptualized as a form of “minimal brain dysfunction” (MBD), a term used to describe a collection of symptoms reflecting learning, attention, and motor coordination deficits.44 MBD was later replaced by complex “minimal neurological dysfunction” (MND), which reflects “a distinct form of perinatally acquired brain dysfunction, which is likely associated with a structural deficit of the brain”,45,p568 e.g., body functions and structure, as in the ICF framework (see Fig. 1).13 MND has been proposed to result from stress associated with preterm birth46; 12.5% to over 50% of children born preterm have motor impairments consistent with DCD37,46–48 and are 6–8 times more likely to develop the disorder.40 Debate continues as to whether children born preterm should be diagnosed with DCD, as they may have another neurological condition that could explain their motor deficits (Criterion C).49

Others have proposed a variant of atypical brain development as the source of DCD.50 Due to the overlapping nature of developmental disorders, Kaplan et al. suggested that diffuse, rather than specific, areas of the brain may be involved,51 i.e., children may have one or more disorders (e.g., affecting motor, attention, and/or language), depending on the extent of disruption to brain development.

Although not a cause of DCD per se, two possible mechanisms underlying the disorder have been hypothesized. One, the automatization deficit hypothesis, suggests that children with DCD, like those with dyslexia, may have difficulty
making motor skills automatic. This hypothesis leads to speculation that the cerebellum may be involved in DCD. An alternative explanation, but one also suggesting cerebellar involvement, is the internal modeling deficit hypothesis. Successful motor control is thought to result from an internal model that accurately predicts the sensory consequences of motor command. Theoretical models of motor learning posit that the cerebellum receives an efference copy of the motor command and compares the predicted movement with the actual movement; if there is a mismatch, the cerebellum sends an error signal as feedback to create a more accurate movement on subsequent occasions. Whether the mechanism underlying DCD is due to an automatization deficit or a deficit in forming an internal model, the cerebellum has been implicated in DCD.

4. Common co-morbidities associated with DCD

DCD often co-occurs with other developmental disorders, most commonly attention deficit hyperactivity disorder (ADHD). Up to 50% of children with DCD have been shown also to meet criteria for ADHD with recent evidence suggesting a genetic link between these two disorders. Learning disabilities and speech/language impairment have also been associated with DCD. A clinical study showed that more than 50% of children identified with severe dyslexia (or those in the bottom 5% of school-aged readers) showed definite motor coordination difficulties for which motor intervention would be recommended. In another small study involving 11 children with DCD, 11 with specific language impairment (SLI) and a comparison group of typically developing children, almost half of those with DCD performed similarly to the children with SLI in several measures of expressive language, leading the authors to conclude that “language impairment is a common co-occurring condition in DCD.” Children with DCD may have more than one co-morbid disorder, the high degree of overlap among these developmental disorders has led some researchers to speculate about shared etiology.

One possible common neurological substrate proposed for the co-occurrence of DCD and ADHD is the cerebellum, with up to 50% of children with ADHD showing motor difficulties that are consistent with DCD. Learning disabilities, especially dyslexia, and SLI may also be due to cerebellar involvement.

5. Impact of DCD on daily life

As outlined in Criterion B of the DSM-IV-TR diagnostic criteria, a child’s motor coordination difficulties must significantly interfere with activities of daily living or academic achievement for a DCD diagnosis, e.g., activity limitations as in the ICF framework (see Fig. 1). The types of difficulties children with DCD experience have been well documented. Self-care challenges include difficulty with dressing, managing buttons and zippers, tying shoelaces, using a knife and fork, and toileting. Difficulty with school-related tasks can negatively impact academic achievement, e.g., copying, drawing, painting, printing, handwriting, using scissors, organizing, and finishing work on time. Physical education can also be affected, as children with DCD have trouble throwing, catching, or kicking a ball, running, skipping, and playing sports. Despite average or above intelligence, children with DCD have poorer school outcomes than peers.

Difficulty with motor skills also impacts leisure participation of children with DCD. Their motor impairment not only affects sport-related skills, but other skills important in childhood, such as riding a bicycle. Perhaps as a result of their poorer athletic and social competence, children with DCD engage in fewer physical and group activities than their peers, e.g., participation restrictions per the ICF framework, which can lead to social isolation (environmental factors in the ICF framework). Beyond the motor domain, children with DCD can experience significant social and emotional problems, e.g., low self-worth and self-esteem, high rates of anxiety and depression, and emotional/behavioural disorders. DCD often co-occurs with other developmental disorders, most commonly attention deficit hyperactivity disorder (ADHD). Up to 50% of children with DCD have been shown also to meet criteria for ADHD, with recent evidence suggesting a genetic link between these two disorders. Learning disabilities and speech/language impairment have also been associated with DCD. A clinical study showed that more than 50% of children identified with severe dyslexia (or those in the bottom 5% of school-aged readers) showed definite motor coordination difficulties for which motor intervention would be recommended. In another small study involving 11 children with DCD, 11 with specific language impairment (SLI) and a comparison group of typically developing children, almost half of those with DCD performed similarly to the children with SLI in several measures of expressive language, leading the authors to conclude that “language impairment is a common co-occurring condition in DCD.” Children with DCD may have more than one co-morbid disorder, the high degree of overlap among these developmental disorders has led some researchers to speculate about shared etiology.

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6. Prognosis for children with DCD

Previously, the common belief was that children with DCD would outgrow their motor difficulties. However, longitudinal studies have shown that these motor problems can persist into adolescence and adulthood. Long-term outcomes often extend beyond the motor domain to include secondary mental health, emotional, and behavioural issues. Based upon a qualitative exploration of experiences of parents of children with DCD, Missiuna et al. proposed that there may be a developmental trajectory in DCD, extending from motor and play concerns in the early years, to self-care, academic, and peer problems in middle childhood, and to issues with self-concept and emotional health in later childhood and adolescence. Children with DCD who have co-morbid conditions (e.g., ADHD) have poorer psychosocial outcomes and higher levels of depressive symptoms than those with DCD alone.

Interestingly, children with DCD have also been shown to be at higher risk for obesity and coronary vascular disease. Compared to typical peers, they have lower cardiorespiratory and physical fitness with differences in fitness levels increasing with age.

Despite the challenges facing children with DCD, functional outcomes can be improved with intervention, with the EACD guidelines recommending that all children with DCD should receive intervention. In addition to child-focused interventions delivered by occupational therapists or physical therapists, parents and teachers can play positive roles in supporting the children's development.
roles in supporting the needs of children with DCD. As children grow, they may learn to use compensatory strategies and to adapt their occupations to ones with less demand on motor coordination, strategies leading to positive outcomes in adulthood.

7. Current intervention approaches for DCD

A variety of different treatment approaches for DCD exist, many of which have been compared with one another and systematically reviewed. Interventions can be broadly categorized into two types: process or deficit-oriented and task-specific. Deficit-oriented approaches include sensory integration therapy, sensorimotor-oriented treatment, and process-oriented treatment. The premise of these approaches is that intervention is targeted at the underlying process deficit, with remediation of the deficit resulting in improved task performance. Deficit-oriented approaches are based on outdated neuromaturational and hierarchical theories, with inconclusive evidence for their effectiveness.

Grounded in current theories of motor control and motor learning, task-oriented approaches include task-specific intervention, neuromotor task training, Cognitive Orientation to daily Occupational Performance (CO–OP), and ecological intervention. Evidence for task-specific interventions is promising, with some agreement that this approach is preferred over deficit-oriented approaches.

Despite theory and evidence favouring task-specific interventions, no single approach has been fully substantiated by research and none have been grounded in neurobiological data or informed by neuroimaging studies. Wilson argued that examining brain–behaviour interactions using a cognitive neuroscience approach might help us better understand motor learning in children with DCD. Neuroimaging studies could increase our understanding of the neurobiology of DCD and inform our thinking about interventions for children with this disorder.

Based on principles of motor learning and neuroplasticity, it is conceivable that children with DCD can demonstrate improved motor skill and relatively permanent change in association with motor learning training. At this point in time, it is not known what type and amount of training is required to induce neuroplastic change, or what training, if any, can facilitate updating of the internal model of movement in children with DCD. Functional magnetic resonance imaging (fMRI) and diffusion tensor imaging (DTI) are tools that can help elucidate answers to these questions.

8. Imaging studies of children with DCD

Recently, researchers have used fMRI to examine brain function in children with DCD. Querne et al. reported that children with DCD had significantly less activation of the left superior and inferior parietal lobules than control children during a continuous, visuomotor tracking task, thus implicating the parietal lobe in coordination dysfunction. In contrast, subsequent fMRI work by our group, involving 7 children with DCD and 7 age-matched controls performing a fine-motor trail-tracing task, demonstrated that those with DCD had greater brain activation than controls in the frontal, parietal and temporal brain regions; typically-developing children showed greater activation in the prefrontal and areas associated with motor control, motor learning, and error processing. In addition to differences in brain activation, children with DCD activated almost twice as many brain regions as control children. This finding suggests that children with DCD had to direct more effort to complete the task, consistent with clinical observations of these children when engaged in motor-based activities.

In contrast to greater brain activation in children with DCD during motor performance, we found that these children demonstrated under-activation of brain areas relative to same-age peers during a motor learning paradigm. Children with and without DCD were scanned for a second time while completing the fine motor, trail-tracing task after practicing the task for three days (four 2-min blocks per day) outside the scanner. Significant differences between groups were noted in a broad network of regions associated with motor learning, including bilateral inferior parietal lobules, right dorsolateral prefrontal cortex, and in the cerebellum (right crus I, left lobule VI, and left lobule IX). The relative under-activation of these regions in children with DCD may be associated with their poorer motor learning compared to control children, but future work with a larger sample is needed to confirm this hypothesis.

In a pilot study of children with and without DCD, Zwicker et al. used DTI to explore the integrity of motor, sensory and cerebellar pathways in the brain. The authors reported significantly lower mean diffusivity of the posterior corticospinal tract and posterior thalamic radiation in children with DCD as compared to controls. Lower axial diffusivity was significantly correlated with lower scores on a clinical test of motor abilities, suggesting that altered microstructural development of sensory and motor pathways may be implicated in DCD.

As others have suggested, we believe neuroimaging techniques, such as fMRI, can advance clinical practice by informing clinician scientists how interventions shape patterns of brain activity and lead to improved function. This is our hope in our continued line of neuroimaging inquiry involving children with DCD.

9. Conclusion

Although DCD is a relatively common disorder affecting about 5–6% of school-aged children, far less has been written about it in the child neurology literature than less prevalent developmental disabilities, such as cerebral palsy and autism spectrum disorder. This is likely due, in part, to the changing name of the disorder and its common co-morbid association
with ADHD, which has garnered far more attention and research.

This review article presents new knowledge gleaned from neuroimaging studies, i.e., fMRI and DTI, that will help paediatric neurologists and others begin to understand brain differences between children with DCD and typically developing children. As well, it draws attention to the recently published EACD clinical practice guidelines and recommendations from which future research aims can be developed. We hope that our article will assist in increasing awareness about DCD and its impact on the lives of children. Greater attention to identification and diagnosis of DCD is urgently needed to initiate support, education, and intervention for children and their families. Further research into the neurobiology of DCD will help to better understand the disorder and inform development or refinement of interventions to improve outcomes for these children. As a child interviewed in one of our qualitative studies stated: DCD is “sort of frustrating sometimes, but if you can get over the stuff that you’re bad at, then it’s, you can, it’s pretty good.” (“Tristan”, age 11; unpublished data).

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