Using the ICF Framework to Explore the Multiple Interacting Factors Associated with Developmental Coordination Disorder

G. D. Ferguson · J. Jelsma · P. Versfeld ·
B. C. M. Smits-Engelsman

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Abstract Developmental Coordination Disorder (DCD) is classified as a heterogeneous disorder of motor learning and functioning. The purpose of this paper is to critically analyse the current knowledge of DCD using the International Classification of Functioning and Disability Framework (ICF) model of disability. Since DCD is diagnosed on the basis of functional problems, we discuss the relationships between known activity limitations and participation restrictions, impairments of body structure and function, and contextual factors associated with these functional limitations. We conclude that the manifestation of both the primary and secondary problems seen in DCD are dependent on the integrity, capacity and adaptability of cognitive and neuromotor structures. We assert that personal and environmental factors either facilitate or restrict skill acquisition and learning. Understanding the interaction between individual and contextual factors is, thus, fundamental to designing interventions that address primary functional problems and ameliorate the development of health and psychosocial impairments in DCD.

Keywords Developmental Coordination Disorder · International Classification of Functioning · Impairments · Activity Limitations · Participation Restrictions · Personal Factors · Environment Factors · Ecological · Intervention

Introduction

It is expected that as children mature and are given opportunities to learn motor skills they would be able to perform age-appropriate daily activities with ease, and that they would become more proficient in these skills. When this is not the case, a diagnosis of developmental coordination disorder (DCD) may be made. DCD is a complex developmental motor disorder affecting at least 1.8 % of children aged 7–8 years in the general population [1] and up to 6 % of children aged 5–11 years depending on case definition [2•]. DCD is defined by delays and deficits in the acquisition and execution of motor skills and is often associated with other developmental and psychiatric disorders such as specific learning disorder, specific language impairments and problems of inattention adding to the complexity of the disorder [3]. The diagnosis of DCD is made primarily on the basis of functional motor impairment with onset in the early developmental period. Although DCD is well described in the *Diagnostic and Statistical Manual 5th edition (DSM-5)* [2•] and the *International Classification of Diseases manual (ICD-10)* [4], making operational each facet of the diagnostic criteria is challenging [5•].

Children with DCD are reported to have more difficulty than their peers in planning and executing activities of daily living, academic tasks and leisure activities. The impact of impaired motor functioning also has profound consequences for their social, psychological and cognitive development and these secondary problems are known to persist into adolescence and adulthood [6]. When examining specific problems, it appears that impaired motor functioning manifests in

G. D. Ferguson (✉) · J. Jelsma · P. Versfeld
Department of Health and Rehabilitation Sciences, University of
Cape Town, F45 Old Main Building Groote Schuur Hospital, Main
Road, Observatory 7925, Cape Town 8000, South Africa
e-mail: Gillian.Ferguson@uct.ac.za

J. Jelsma
e-mail: jennifer.jelsma@uct.ac.za

P. Versfeld
e-mail: pamversfeld@gmail.com

G. D. Ferguson · B. C. M. Smits-Engelsman
Faculty of Kinesiology and Rehabilitation Sciences, Department of
Kinesiology, Movement Control and Neuroplasticity Research
Group, Katholieke Universiteit Leuven, Tervuursevest 101, Postbox
1501, B-3001 Heverlee, Belgium

B. C. M. Smits-Engelsman
e-mail: bouwienmits@hotmail.com

various ways in different environmental contexts. This is particularly evident when examining the numerous adaptations made to questionnaires such as the *Developmental Coordination Disorder Questionnaire (DCDQ-07)* [7] in different countries [8, 9] as well as the differences in performance on tests of motor function in cross cultural studies [10, 11].

DCD is recognised as a heterogeneous condition with different functional manifestations, and because of this, various authors have attempted to classify DCD into distinct subtypes based on common functional problems. Reports suggest that some groups of children with DCD present with greater difficulties in manual dexterity and others have more difficulties with balance and visuo-perceptual abilities. However, the nature and number of subtypes of DCD vary across studies as the construction of these subgroups are largely dependent on the number and type of variables investigated [12].

The bioecological model of child development [13] posits that development is best understood as a two-way interaction between individual and contextual factors. Individual factors include aspects related to the integrity, maturation and capacity of body structures and genetic factors, which allow cognitive, emotional and physical functions to unfold. Contextual factors include the child's physical and social environments, which incorporates aspects such as societal attitudes, laws and policies. Thus, the manifestation of neurodevelopmental disorders such as DCD depends on the interaction between individual and contextual factors.

The International Classification of Disability and Functioning and Disability (ICF) [4], published by the World Health Organisation, is a classification system based on a multifactorial, interactional model of disability. The ICF framework consists of two main sections; the first section classifies functioning and disability and is divided into four components: 1) body structures, 2) body functions, 3) activities, and 4) participation. The second section refers to contextual factors, which include two components: 1) environmental and 2) personal factors. The interactive framework is dynamic and interactive, rather than linear, as all components, including the health condition, are related and influence one another.

The value of the ICF model for this paper, lies in its ability to expand our interrogation of DCD beyond the physical and cognitive impairments to a view that places equal value on the activity limitations and contextual factors [14] and examines the interrelationship between all elements. Earlier approaches to the study of DCD were based on the classical biomedical model of understanding disorders where identifying the underlying impairments in body structure and function was considered of paramount importance. Process or deficit orientated approaches to intervention arose from this model which formed the basis of interventions such as perceptual-motor

training and sensory integration therapy [15•]. While this line of enquiry yielded important insights into the understanding of DCD, conclusive evidence of damage and dysfunction (impairments) in specific cognitive or physical domains continues to elude researchers.

More recent studies, based on the cognitive neurosciences paradigm [16•] have enhanced our understanding regarding the motor control deficits seen in DCD. Although the cognitive-neurosciences approach has contributed to our understanding of DCD, this approach gives little attention to the impact of broader contextual factors. Utilising the ICF model to explore DCD, thus, transcends other approaches by examining the child's impairments and activity limitations within a meaningful context. The framework of the ICF reflects an ecological approach, as it considers the relationship between functional performance and contextual factors and is, thus, a suitable model for understanding DCD.

In the revised edition of the DSM-5, it is acknowledged that the acquisition and execution of coordinated motor skills is dependent on the availability of opportunities to learn and practice these skills (Criterion A) [2•]. This is an important consideration as environmental contexts in which DCD manifests are variable. It is apparent that the revised inclusion criteria are now better aligned with the different components of the ICF than in previous versions of the *DSM* as contextual factors are given greater recognition. Thus, criterion A may be considered as impairments of body structure and function and criterion B, is concerned with activities and participation.

The reciprocal relationship between motor function and participation challenges our way of understanding DCD. It is evident that children learn and refine motor skills by exploring their environments. The environment in turn, affords opportunities for motor learning. Children with poor motor function are known to participate less in physical activity, thus, restricting their opportunity for skill development. Consequently, a vicious cycle of poor participation leading to poor motor function and further withdrawal from activity ensues. While cause and effect cannot be conclusively determined in the case of DCD, it is, nevertheless, worthwhile to explore the impact and effect of both individual and contextual factors as this is more relevant to daily life. We acknowledge that the relationship between impairments, activity and participation are complex. However, the successful integration of multiple sources of information contained within an ICF approach may highlight the direction and strength of the link between the different components and help in formulating intervention strategies.

The purpose of this paper is to deconstruct the manifestations of DCD into the different components and explore the interaction between these components of the ICF. Our goal is not to provide a systematic review of one aspect but rather to present an overview of DCD, describing the known impairments in body structure and function, the most commonly

reported activity limitations and participation restrictions and the contextual factors that influence these deficits.

The framework of our analysis was constructed as follows: First, we created an outline of the five ICF **Components**: 1) body structures 2) body functions, 3) activities and participation 4) environmental factors and 5) personal factors. The electronic ICF browser (apps.who.int/classification/s/icfbrowser/) was then used to identify and examine the **Chapters** within each component. We selected the relevant chapters pertaining to our exploration of DCD. Regarding body structures and functions, we excluded all chapters concerning: i) the digestive, metabolic and endocrine systems, ii) the genitourinary and reproductive systems and iii) skin and related structures and functions. Within each chapter, several **Domains** of the ICF are arranged in a hierarchy. Specific domains, relative to our line of enquiry regarding DCD were then selected. Within each domain, we further selected the most relevant **Categories** (i.e., smallest units of classification) to form our framework of analysis.

In the second step, we accessed the Medline, PubMed, CINAHL and PsychINFO databases for the most recent and relevant information from published studies and inserted the findings into our framework.

Health Condition

The ICF makes provision for discussing the impact of the health condition (disorder) on functioning. In this section the current literature relating to the aetiological risk factors associated with DCD are discussed.

Considerable research has been undertaken to investigate the neurobiological and ecological basis of DCD. Population studies have identified risk factors related to prematurity, socioeconomic status and genetic factors [17–19]; however, limited evidence is available to support these hypotheses. Different underlying mechanisms have also been studied alongside investigations into finding the neural substrate of DCD.

The premature brain is vulnerable to biological and environmental stressors which may manifest as visible damage on ultrasound or magnetic resonance imaging [19]. Prematurity in general, has been linked to poor developmental outcomes at school age across a number of measures of cognition, attention and self-regulation [19, 20]. Studies suggest that the risk of developing DCD increases with decreasing gestational age and birth weight [21]. However, overt anatomical changes are rarely seen in DCD.

Neurological and behavioural outcomes seen in children born prematurely and who have no overt signs of brain damage seem to overlap with outcomes of children with DCD [22•]. This finding suggests that the aetiology of DCD may not necessarily be related to differential brain damage but

rather global dysfunction or atypical brain development. According to the atypical brain development (ABD) hypothesis [23], the differential behavioural outcomes seen in DCD emerges as a consequence of variations in brain structure and function. Importantly, the ABD hypothesis asserts that genetics and environmental affordances contribute to these differential outcomes.

The co-occurrence of DCD and other generalised developmental disabilities such as ADHD, reported in studies conducted among twins, appears to support the view that DCD may have a genetic cause [2•, 3, 18].

Reports suggest an increased risk of poor motor skills (DCD), ADHD and cognitive delays in children from less-advantaged socio-economic backgrounds [24]. This finding may be due to the increased risk of prematurity, higher prevalence of maternal stress and increased toxin exposure (e.g., cigarette, alcohol, drugs, lead, etc.) reported among these groups. Prenatal exposure to neurotoxins such as cigarette smoke and alcohol are known to be harmful to the developing nervous system and exposure is associated with decreased brain volume in children [25]. In addition, maternal stress and depression in pregnancy has also been linked to adverse motor and behavioral outcomes, particularly in boys. It is believed that high stress levels may lead to elevated cortisol and norepinephrine. These hormones can have an adverse effect on intrauterine blood flow leading to poorer oxygenation for the developing brain [26] and elevated levels of glucocorticoids which affects neurogenesis and causes delays in neuronal maturation [27]. The implication of the findings above suggests that, for DCD, overt evidence of structural brain damage may not be evident in the absence of sophisticated brain scanning technology.

Activities Participation

The ICF handbook suggests that the activity and participation components are different items on a single continuum of functioning [4]. The two components are, thus, listed together, and are organised in eight chapters. These chapters provide a framework in which a range of functional limitations in DCD can be described.

Learning and Applying Knowledge

This area concerns using the body's basic senses intentionally to experience stimuli, basic learning and applying knowledge.

Purposeful Sensory Experiences

This domain includes the experience of watching, listening, touching/feeling, tasting and smelling. The ability to predict

and calibrate movements based on accurate information from the environment may be impaired in children with DCD. Studies conducted among children with DCD have explored differences in how children with DCD use the different senses to control posture and movement [28, 29]. Accordingly, it is reported that children with DCD have poor strategies for using visual information in dynamic tasks such as ball catching for example [29] and are reliant on using vision in combination with touch information to control standing balance [28].

Basic Learning and Applying Knowledge

By definition, children with DCD struggle to acquire the motor skills needed for everyday functional activities [2••]. In motor control terms, this is considered a fundamental problem of motor learning. The ICF on the other hand, considers the acquisition of basic and complex movement skills not as a function of the nervous system (brain) but rather as an activity. Acquiring skills is defined in the ICF as developing competencies in integrated sets of actions or tasks to initiate and follow through with a skill. Learning to write or eat with cutlery is considered a basic (motor) activity and sequencing and coordinating one's movements, such as learning to play football is considered complex. One hypothesis related to the motor learning ability (skills acquisition in the ICF) proposes that children with DCD have a limited repertoire of movement which is characterised by high levels of variability compared to TD children [30].

Acquiring simple and complex motor skills is problematic in DCD. Parental reports suggest that the acquisition of even basic motor skills used in everyday life such as manipulating eating utensils, tying buttons and zippers is delayed in children with DCD leading to frustration for both parents and children [31, 32••].

Difficulty in applying knowledge is apparent in academic settings where children with DCD display difficulty in reading [3], writing [33] and calculating [34]. Inability to focus attention and filter out distractions often compounds the problem in executing these skills as DCD often co-occurs with deficits in attention [3].

General Tasks and Demands

Task complexity is a key element known to impact on motor performance. This chapter of the ICF arranges general tasks in hierarchical levels of complexity by including domains such as performing single tasks and performing complex, multiple tasks in sequence.

From a motor control perspective, one can infer that this chapter of the ICF describes the underlying features of a task that can constrain performance in DCD. The chapter includes categories related to initiating a task, organizing time, space

and materials for a task, pacing task performance, and carrying out, completing, and sustaining a task. Difficulties in one or more of these categories often present at school where children with DCD are reported to have difficulty organising themselves in class to perform written tasks, for example [35].

Evidence from behavioural and experimental studies suggests that for children with DCD, problems emerge when task complexity increases [36]. Children with DCD are reported to have more problems than their TD peers when completing single tasks with more than one component that must be carried out in sequence (e.g., putting on separate items of clothing in the correct sequence) [37]. They also struggle with performing simultaneous/dual motor tasks (e.g., carrying a tray of marbles while walking across a room), or performing multiple tasks in sequence (e.g., managing and completing daily routines at school or at home) [38, 39].

Communication

Communication comprises verbal and non-verbal, expressive and receptive language. Various studies examining these attributes report that children with DCD have difficulties in communication ability [40]. According to Bishop, co-occurring motor and language difficulties may have an underlying genetic basis as specific language impairment often co-occurs with motor coordination problems [41]. Regarding non-verbal communication skills, it is reported that children with DCD are significantly poorer compared to their TD peers [3].

Mobility

The ICF framework subdivides the chapter on mobility into six domains, including 1) maintaining and changing body position, 2) carrying, moving and handling objects, 3) walking and moving, 4) moving around using transport, 5) other specified and 6) unspecified. It appears that children with DCD experience challenges in all these major areas of mobility, [42] and the first three are discussed below.

Changing and Maintaining Body Position

Among the many recognised deficits in DCD, postural control is one of the most common [43–45]. The inability to maintain and change posture in an effortless and controlled manner impacts on functional tasks and activities such as the child's ability to sit for prolonged periods at a desk or during meals, or when required to stand upright while waiting in a queue. Recent studies suggest that children with DCD have difficulty with postural control while performing functional activities such as kicking a ball, getting onto a step and standing on one foot [45].

Carrying, Moving and Handling Objects

The skilful control of objects is a major challenge for children with DCD and they have been found to have problems with lifting and manipulating objects [46]. Functional deficits emerge during school-type tasks such as cutting and pasting, or construct type activities. Ball handling skills are important in many contexts for social interaction on the playground and for participating in sports. Ball skills performance has been studied by various authors and is considered a robust means of differentiating between skill levels, with children with DCD performing poorly [47, 48].

Walking and Moving Around Using Transport

In the systematic review of activity limitation and participation by Magalhaes (2011) approximately half of the studies examined reported that children with DCD experience challenges in mobility tasks such as running, jumping, skiing, and swimming [32•]. These activity limitations in turn influence participation in sport or activities in which these fundamental movements are required. The inability to ride a bicycle is also a cause for concern among parents of children with DCD [49].

Self-Care

Several studies describe that children with DCD have limited ability to perform self-care tasks with specific references to problems with washing, dressing, and using cutlery in a coordinated manner [37, 50].

Major Life Areas- Education

Education is considered a major life area in children of school going age. Studies show children with DCD perform poorly at school as they struggle to master the basic motor skills such as writing legibly, using scissors and completing other manual tasks [31]. In addition, performance in physical education classes or gym may also be difficult and maintaining good sitting posture at a desk in class may be challenge [51]. Children with DCD are also reported to have problems with subjects such as mathematics [52], reading and spelling [3] which may compromise their academic progression. However, many children with DCD are capable of performing well at school if their specific needs are accommodated [53].

Domestic Life

Domestic life challenges for children with DCD have mainly been reported in the context of self-care activities. The ICF takes a broader view of domestic life activities and considers items that may not be applicable to younger children such as

acquiring necessities (e.g., acquiring a place to live) or specific care of household objects (e.g., maintaining domestic appliances). The assessment of domestic activities of children is often contained with questionnaires used to examine functional impact of DCD (*Criterion B of the DSM-5*). These questionnaires may contain information about the performance of children in specific age appropriate domestic tasks outlined in the ICF, e.g., preparing meals or cleaning a living area. For example, the DCD-Daily questionnaire [54] has been proven to discriminate between children with and without DCD in terms of meal preparation tasks (e.g., buttering and cutting gingerbread, spooning up a drink and pouring a drink).

Interpersonal Interactions and Relationships

For a child of school-going age, interactions with others in an appropriate manner may include playing a team sport or game with friends, collaborating with classmates to create an art project or even assisting siblings with meal preparation. The successful participation in these activities may involve motor actions that children with DCD find difficult. Consequently, the impact of poor motor coordination skills is felt when attempting to engage in social activities at school, or at home. It is, therefore, not surprising that children with DCD may find that their ability to form relationships with others is impeded by inability to perform well in sport or other physical activity [6, 55–57] and as such, tend to prefer more isolated activities which further compromise their social development [58].

Community, Social and Civic Life

This chapter concerns participation as it pertains to the ability to function within a broader context. It is widely reported that children and adolescents with DCD engage less in physically active recreational and leisure pursuits, both organised and free-play, compared to their typically developing peers [6, 42, 50, 55, 59]. Children with DCD are reported to spend more time in solitary playground activities [55, 60]. The common view regarding participation is DCD is that it is influenced by the personal views of children with DCD that they are less competent than their peers [57].

Body Structures

Impairments in body structure refer to a significant deviation from the generally acceptable population norm in any anatomical structures. This section is organised into eight chapters, five of which have particular relevance for the study of DCD. These include: 1) structures of the nervous system, 2) the eye, ear and related structures, 3) structures involved in voice and speech, 4) structures of the cardiovascular and respiratory systems and 5) structures related to movement.

Ongoing debates regarding the primary structural impairment in DCD suggest abnormalities in structures of the nervous system, specifically the brain. Two hypotheses are considered, the first concerns the possibility of micro-structural damage to various brain areas and corticospinal tracts [61] and the second relates to intrinsic maturational problems of the developing brain and insufficient stimulation of the delayed brain [62].

Many studies, investigating the neurological basis of DCD have suggested that the poor motor behaviour seen in DCD may be related to dysfunction in the cerebellum, parietal cortex or basal ganglia based on findings from behavioural studies [63–65]. Recently, researchers have been able to investigate the possible neural substrate of DCD using sophisticated imaging technology, such as functional Magnetic Resonance Imaging (fMRI) or Diffusion Tensor Imaging (DTI) [61, 66] to examine the brain areas of children with DCD. Although minimal evidence of overt structural differences have been reported, studies using fMRI scans have linked the functional problems seen in children with DCD with differences in patterns of brain activation compared to TD children [66, 67].

As far as delayed maturation is concerned, it is known that maturation of the cerebellum is particularly affected by prematurity [68]. The cerebellum plays a key role in coordinating movement and immaturity may manifest as poor functional motor performance as the child reaches school-going age even in the absence of structural differences [69, 70].

Evidence of anatomical abnormalities or deviations in other body structures areas is also limited. There is no evidence to suggest that children with DCD present with any anatomical differences in structures of the eye, ear or structures involved in speech production or movement (i.e., joints, muscles, bones, etc.). Regarding cardiovascular differences, Chirico et al. (2011) found no detectable differences in the structure of the left ventricle of the heart between DCD and non-DCD children in their exploratory study although functional differences were reported [71].

Body Functions

Since DCD is primarily diagnosed based on functional deficits, impaired physiological and psychological functioning of structures are of particular relevance. The ICF handbook organises body functions into eight key areas, of which five are particularly relevant to the exploration of DCD. These include i) mental functions, ii) sensory function, iii) voice and speech related functions, iv) functions of the cardiovascular and respiratory system and v) neuromusculoskeletal and movement related functions.

Mental Functions

Children with DCD have impairments in both global and specific mental functions, which may influence the ability to acquire and perform motor skills and to benefit from intervention.

Global Mental Functions

According to the ICF, areas of global mental functioning include categories related to consciousness, orientation, intellectual functions, temperament, global psychosocial functions and energy and drive. Functions considered pertinent to the exploration of DCD include functions of intelligence, temperament and energy and drive.

Criterion D of the *DSM-5* specifies that motor coordination problems present, should be in excess of those expected for the mental age of the individual [2•]. Nevertheless, many studies conducted thus far excluded children with IQ scores less than 70 making it difficult to establish a relationship between lower intelligence and DCD [72].

Temperament describes the disposition of the individual to react in a particular way to situations. For children with DCD, problems in this domain include difficulty with behavioural inhibition, which describes a fearful style of reacting when confronted with a novel task. Behavioural inhibition is also linked to increased social reticence and a heightened risk for developing anxiety problems [73]. The difficulty that these children have with learning to perform a new task may be related to a problems in effortful control, defined as the ability to suppress dominant responses (i.e., fear and anxiety). Although evidence is available for deficits in some of these aspects in DCD [74], problems with effortful control require further investigation as they may be relevant to understanding motor control problems in DCD.

Energy levels and motivation are key factors in performance and participation. Children with DCD are at increased risk of leading inactive lifestyles compared to typically developing peers. This is largely influenced by factors such as low self-esteem, lower perceived competence and decreased preference for physical activity [56]. Low motivation renders children less likely to participate in activities that may enhance their motor skill development and, thus, enter a spiral of poor performance.

Specific Mental Functions

Specific mental functions include eleven different domains of the ICF. These include: 1) attention, 2) memory, 3) psychomotor functions, 4) emotional functions, 5) perceptual functions, 6) thought functions, 7) higher-level cognitive functions, 8) mental functions of languages, 9) calculation functions, 10) sequencing and coordinating

complex movement and 11) experience of self and time functions. All of these factors affect children's ability to execute activities of daily living and to benefit from intervention, however, only a few are discussed in this review.

Piek et al., suggests that problems in attention, memory and other higher-level cognitive functions (executive functions)-are common in DCD [75]. This assertion is confirmed in the meta-analysis by Wilson et al. (2013) in which pervasive difficulties across a range of specific mental functions (i.e., working memory inhibitory control, executive attention, dual task performance, and meta-cognition in skill learning) are reported [16••].

Various emotional problems have been reported in DCD, including higher levels of anxiety, depression and low self-esteem [50, 76]. Emotional problems often persist into adulthood [77] and are, therefore, considered to be among the most important secondary consequences of DCD and are considered a strong mediator of participation and functioning [78].

Perceptual problems are also reported to be associated with performance deficits in DCD [79, 80]. Specifically, problems with visuospatial and visual perception may be related to deficits in the magnocellular and parvocellular pathways and the reciprocal connections to predictive and online control networks. Large effect sizes for deficits tactile perception are also reported [16••].

Children with DCD are also reported to have difficulties in organization and planning movements. In particular, problems with motor planning for end-state-comfort have been reported to occur more often in DCD [81, 82]. Problems with sequencing and coordinating complex movement, referred to as ideomotor apraxia have also been found [80].

Studies investigating motor imagery ability using mental rotation tasks for example have provided evidence for poor problem solving ability, and impaired judgement in DCD [83]. Moreover, other motor imagery tasks using chronometry paradigms also provide insight into the impaired perception of timing and poor motor performance in DCD [36, 84].

Sensory Functions

Seeing and Related Functions

Sensory functions related to the presence of light and sensing form, size, shape are included along with visual acuity, visual field functions and quality of vision. Visual perception (i.e., discriminating shape, colour, and size) and visuo-spatial perception (i.e., distinguishing relative position of objects) are regarded as specific mental functions. Functions of structures adjoining the eye that facilitate seeing functions include visual pursuit tracking and fixation of the eye as well as aspects related to accommodation, blinking and functions of the tear glands and ducts.

Information about seeing as a related function is important to understanding the motor control deficits seen in children with DCD. Children with severe DCD have been shown to have abnormalities in binocular vision, refractive error, ocular alignment [85] and visual pursuit [86]. The poor performance on visual pursuit tasks may be related to deficits in underlying control of eye movements, but it may also be due to issues related to the development of internal models for predictive control which has been shown to be poor in children with DCD [16••]. Evidence for disturbances in the ability to control gaze behaviour is beginning to emerge in the field of DCD [8]. Children with high motor coordination skills were reported to demonstrate superior visuo-motor control during throwing and catching compared to children with moderate and low coordination ability. Large effect sizes for deficits in basic visual form detection, motion detection and visuospatial processing have also been reported [16••].

Hearing and Vestibular Functions

Postural stability and movement requires detection, processing, and integration of sensory inputs from a variety of sources including the vestibular system. Reports suggest that children with DCD have difficulty using vestibular input to regulate postural control and balance in standing [44].

Voice and Speech Functions

This chapter of the ICF is concerned with function of producing sounds and speech, including voice, articulation and fluency functions, which have received some attention in DCD studies. Slower articulation rates [87], phonological deficits [88] and speech problems [89] frequently co-occur in children with DCD.

Functions of the Cardiovascular and Respiratory Systems

The functional capacity of the cardiorespiratory system appears to be compromised in DCD. Pulmonary function tests using spirometry suggest that FVC and FEV1 in children with DCD were significantly lower than in TD children [90]. Decreased cardiorespiratory fitness (aerobic capacity) in DCD has also been reported in several studies where aerobic capacity was measured using field -based or laboratory tests [91]. The poor performance in cardiorespiratory (aerobic) fitness tests in DCD [91] is likely to result from the low levels of physical activity commonly seen in DCD [92].

Neuromusculoskeletal and Movement Related Functions

The evaluation of neuromusculoskeletal structure and function in DCD has typically been examined in the context of fitness and functional tests, although numerous simple

experimental tasks have also been conducted to understand the deficits in motor control.

Functions of Joints and Bones

Compared to TD children, children with DCD have been reported to have a higher prevalence of generalised joint hypermobility, which in adults is associated with poor performance on tests of joint position sense [93]. Apart from the association between joint hypermobility and functional limitations, Kirby and Davies report that significantly more children with DCD present with joint pain compared to TD peers highlighting an important concern [94].

Muscle Functions

Three elements of muscle functioning are commonly evaluated in DCD: muscle strength, power and endurance. Findings from studies using dynamometry report that muscle strength is generally decreased in DCD [91]. However, several other studies suggest that children with DCD do not seem to have as much difficulty generating strength, (i.e., they are able to produce maximum muscle forces as high as typically developing children [44] but that they rather struggle to regulate force and as a result force production is more variable [95].

Studies assessing explosive muscle power and muscular endurance on the other hand also report that children with DCD are poorer than their TD peers [91]. However, the validity of assessments commonly used to assess these aspects of muscle function may be confounded by the impact of deficits in motor control and coordination.

Movement Functions

Deficits in motor control are described in the context of movement related functions in the ICF, which includes 1) motor reflex functions, 2) involuntary movement reaction functions, 3) control of voluntary movement functions, 4) involuntary movement functions, 5) gait pattern functions, and 6) sensations related to muscles and movement functions.

The basis on which the diagnosis of DCD is made concerns the inability to control or coordinate voluntary movements (Criterion A of the *DSM-5*). A recent meta-analysis provides an important insight into the motor control deficits seen in children with DCD [16•]. Wilson and colleagues report that children with DCD display pronounced difficulty in three major areas of motor control including internal (forward) modelling, rhythmic coordination and executive function. Problems related to deficits in predictive control suggest that children with DCD appear to have a reduced ability to develop and update internal models of action referred to as an internal modelling deficit [16•]. It is hypothesised that increased neuromotor noise [96] may explain deficits in predictive

control in DCD. Rhythmic coordination problems and problems with timing are also reported in other studies on DCD which may be suggestive of cerebellar deficits [70, 97].

The role of the cerebellum as a primary site of dysfunction is also confirmed in fMRI studies where children with DCD demonstrated less activation in various cerebellar regions compared to TD children during a fine-motor task [67]. The cerebellar deficit hypothesis is supported by various studies. Comparisons between children with DCD and dyslexia suggest that both groups have difficulty in automatising movements [43]. Poor automatization in dyslexia has been associated with cerebellar involvement [98].

The parietal cortex is involved in processing sensorimotor transformations and motor learning. Earlier experimental studies conducted by Wilson and colleagues have suggested that impaired motor performance in DCD may be related to involvement of parietal cortex [99]. This hypothesis was confirmed in a later fMRI study in which children with DCD were required to use visual information to control motor behaviour (e.g., joystick tracking) in an experiment [100]. Findings showed altered patterns of activation in the parietal cortex of children with DCD compared to TD children, leading the authors to conclude that children with DCD have suboptimal parietal function.

Studies showing poor motor learning [101] and impaired force control in DCD [95] suggests abnormal basal ganglia functioning in children with DCD, however, these findings have not been replicated in fMRI studies.

Environmental Factors

External environmental factors includes products and technology, natural environments, social relationships, attitudes and services, systems and policies. The scope of this review is limited to the major areas relevant to DCD.

Support and Relationships

Development is shaped by the relationships children form with those closest to them. Parenting style is most often reported to impact on a child's anxiety levels, their capacity for effortful control and their capacity to pay attention [102]. These aspects are crucial to developing motor skills and, thus, stressful social or family environments may exacerbate problems seen in children with DCD.

The relationship between parents and children with DCD can be described as anxious; as parents worry that their children's impairments would restrict participation in society [103].

Another aspect of the social environment, which interacts with the manifestation of DCD, concerns differences in expectations and perceptions of performance between teachers

and parents. It is possible that a child identified as having DCD based on poor coordination problems affecting classroom function could be labelled differently in the home environment where expectations of performance are different. Alternatively, depending on the support and attitudes of parents and immediate family members, the manifestation of functional problems may not be evident in the home situation if children are not challenged enough to do things for themselves. In a study by Wang (2009) no significant correlation was found between functional performance at home and at school in children with motor coordination problems [104].

Regarding peer relationships, it is reported that children with DCD are more likely to exhibit loneliness and have greater difficulties in group activities than typically developing peers [105]. Despite this, it appears that participation in group based physical activity does mediate this effect, suggesting a possible intervention strategy.

Attitudes

This chapter of the ICF is about the observable attitudes of others that are consequences of values, norms and beliefs of individuals and societies and how these attitudes influence functioning.

In the case of DCD, the attitudes of significant people in the child's life, e.g., parents, teachers and peers, may be positive when they serve to validate and motivate the child to succeed. However, negative attitudes such as stigmatizing, stereotyping and discrimination may impact on motivation to participate in social activities with others. Studies reporting on the relationships between parents and children with DCD suggest that family members often experience frustration and anxiety over the child's inability to manage simple tasks [49, 103]. As a result, children with DCD are likely to believe that they are disappointing their parents, which may worsen their feelings of low self-worth [6]. It is further reported that some children with DCD feel supported and accepted by peer groups whereas others, usually boys, experience stigmatization for their choice of leisure pursuits.

Children with DCD are reported to avoid participation in sports and other physical activity, which may be perceived as laziness by teachers or sports coaches. Greater understanding is, thus, required to educate teachers and family members on how they can shape and influence the self-esteem of children with DCD and encourage them to participate in physical activity.

Services, Systems and Policies

Children with DCD have reduced ability to acquire and execute skills needed to function successfully in their environments. This compromises not only their physical development but has consequences for their social, emotional and academic development. Accordingly, children should be supported at

various levels and appropriate services should be made available to them. In numerous settings, resource constraints limit the possibility of timely intervention for children with DCD. Policies and systems are needed to address the health and educational challenges. These policies are likely to be specific depending on the context, but universally, the impact of DCD on functioning and participation should be acknowledged.

Interventions for DCD, thus, require not only an individual response but should also consider a broader systems based approach. This is particularly relevant in contexts where environmental and attitudinal barriers are prevalent. Camden and colleagues have identified key principles regarding the organisation and implementation of efficient and comprehensive services for children with DCD [106]. These include 1) campaigning to raise awareness of DCD, 2) establishing clear, streamlined referral pathways for diagnoses and management, and 3) scaling of service levels from population-based assessment and management to individualised interventions and self-management. These key principles embrace prevention of secondary problems, health promotion and functional evidence-based intervention where all stakeholders work collaboratively and place the needs of the child and family at the centre.

Personal Factors

Personal factors include internal factors related to the individual such as gender, age and coping style, social background and education. These factors converge to mediate the impact of disability.

Gender

Most studies report a higher prevalence of DCD among males compared to females although the ratios vary across contexts [1, 18]. This differential presentation may be due to the fact that male infants are more likely to suffer adverse neurological outcomes following premature birth compared to females [107]. This phenomenon would result in an overrepresentation of males with neuromotor problems. However, an additional explanation based on contextual factors is also plausible. Rivard et al., suggested that the overrepresentation of males may also be a consequence of a gender bias that sometimes occurs during referral and assessment processes as teachers are more likely to refer boys with poor motor skills than girls. This phenomenon is likely to be embedded within the values and societal expectations regarding the motor competence of girls and boys [108].

The impact of gender, on functioning in DCD is highlighted by Batey and colleagues who found that DCD was associated with lower physical activity among boys, but not girls

[109•]. Various possible mediators of participation, namely, age and social pressure, explain this outcome.

Age

It is interesting how age mediates the manifestation of DCD. Different authors report that, very young children, between the ages of 5–6 years, do not experience or perceive any significant difference in their competence across domains compared with peers [39, 110]. While children of school going age appear to be more anxious and see themselves as less competent than their peers [57], young adults with DCD show an ability to compensate for their poor motor performance by learn how to either avoid or cope with their motor challenges [111].

Coping Style and Self Efficacy

It is reported that children with DCD have a negative coping style which manifests as anxiety and depression [57, 76, 112•, 113]. Cairney and colleagues suggested that these problems may be due to poor coordination problems leading to secondary psychosocial stressors and the development of negative coping style [112•, 114].

Children's preference to participate in activities may be limited by motor difficulties, but further hindered by low self-efficacy. Self-efficacy toward physical activity is reported to be lower in children with DCD [115]. Interestingly, newer findings suggest that perceived task and barrier efficacy may not be as influential as previously considered. Batey and colleagues suggest that generalised, rather than specific (i.e., task and barrier) self-efficacy, perceived competence and attitude may be more important factors. These findings support the suggestion that boys with DCD have lower motivation to participate in physical activity and generally find physical activity less enjoyable compared to TD peers [116].

Socioeconomic Factors

Enriched environments that provide safe and supportive learning opportunities facilitate the holistic development of children. However, the availability of and access to resources is dependent on socioeconomic status. Since DCD is characterised by deficits in skill acquisition, it is recognised that the manifestation of functional problems in DCD would be dependent on the affordances provided by the home and school environment. Studies evaluating the impact of SES have shown a negative effect of low SES on engagement in physical activity [117] and on movement skills [24].

It is accepted that low socioeconomic status (SES) influences child development through various mechanisms including prenatal factors, parenting style and stimulation [27]. Studies on the impact of socioeconomic disadvantage on brain development offer useful insights into how motor

coordination problems may emerge. Hanson and colleagues examined MRI scans of infants from diverse backgrounds and found that infants from low-income families had lower volumes of gray matter in frontal and parietal lobes. These areas are known to be important for processing of information and execution of actions. In addition, the researchers also found slower trajectories of brain growth during infancy and early childhood in children from lower SES groups [118].

Movement skills are refined through environmental affordances and opportunities for skill development. Children whose parent's lack insight into the relationship between skills development and nurturing may, therefore, be negatively affected.

Discussion

DCD presents as a multifaceted diagnostic entity. Various aspects of impaired functioning (activities and participation) can be linked to impairments of body function. However, we are also reminded that DCD manifests in heterogeneous ways and the impact of having poor motor skills is strongly influenced by contextual factors. The relationships between various components are complex; however, we have attempted to highlight the key interactions arising from our review of the literature.

Impairments in Body Structure/ Function → Activity Limitations and Participation Restrictions

Unlike the definition of cerebral palsy, activity limitations and participation restrictions rather than impairments of body structures and function, are central to the definition of DCD. Our review clearly shows that impaired brain functioning has a cascading effect on the acquisition and refinement of an array of everyday motor skills. Cognitive (i.e., *mental functions in ICF*) and motor (*movement functions in ICF*) impairments affect all domains of activity and participation listed in the ICF.

Impaired movement and sensory functions specifically, are strongly linked to the ability to perform all physical tasks in the domains of mobility, self-care, education, domestic tasks and recreation and leisure activities. This is self-evident as the core impairments associated with of DCD is related to the inability to control voluntary movement and to predict and calibrate movements based on accurate sensory information.

The manifestation of functional problems seen in DCD is also due, in part, to impairments in global mental functions described in the ICF. These factors are especially important for learning new motor skills, carrying out single or multiple tasks, organizing routines and handling stress. Importantly, global mental functions such as motivation, energy levels and temperament and emotional status are important factors that influence participation in sport and physical play among children with DCD.

For children with DCD, the ability to cope with the functional demands within the educational context may be compromised by impairments in specific mental functions such as calculation, organising, time management and executive functioning along with impairments of movement function.

The implication of the relationship presented above might suggest that activity limitations and participation restrictions could simply be addressed by treating the underlying impairments. However, a meta-analysis of effective interventions in DCD reported that impairment-focused intervention approaches are not as effective as task-orientated approaches [15••] confirming that impairments cannot be considered in isolation. Evidently, consideration of the reciprocal link between activity and impairment is equally important.

Activity Limitations and Participation Restrictions $\longleftrightarrow$ Impairments in Body Structure/ Function

In DCD, it is evident that the primary impairments of movement, sensorimotor and cognitive functions are part of a cycle that could potentially lead to the development of further secondary impairments in body structures and functions.

Currently, the reported impairments in cardiorespiratory and muscle functions seen in DCD are considered to be secondary to poor motor control, reduced participation in physical activity and decreased levels of self-confidence [52, 92]. This combination of factors may set off a chain of events involving avoidance of physical activity, leading to further reductions in cardiorespiratory fitness and muscle weaknesses and increases in weight.

Taking another perspective, increasing activity levels may lead to positive changes in body structure/functions. Research reports suggest that active engagement and practice in an array of motor activities stimulates development and may lead to structural and functional changes in brain areas through the mechanism of neuroplasticity [119]. The developing brain has a great capacity for learning and cortical networks are constantly being pruned and strengthened through experiences. Since activity and experiences are known to affect connectivity, this has important implications for rehabilitation of children with DCD [120].

Contextual Factors $\longleftrightarrow$ Activity Limitations and Participation Restrictions $\longleftrightarrow$ (Impairments in Body Structure/ Function

Motor learning (*acquiring skills in the ICF*) necessitates active participation in a variety of motor activities. However, for some children with DCD, participation is affected by contextual barriers such as the attitudes and support of others, access to resources and self-efficacy beliefs. In the absence of opportunity to acquire skills, children may not be able to refine the neural networks associated with the production of coordinated movement patterns. These findings suggest that impairments in body functions may

be remediated by increasing activity and participation, which may be achieved by reducing the contextual barriers.

Contextual Factors $\rightarrow$ Impairments in Body Structure/ Function

The relationship between impairments in body structures and functions and contextual factors are explored by considering the aetiological risk factors for DCD and the influence of environmental and personal factors on the developing brain.

From our review, we hypothesise that poor socioeconomic status may play an important role in the aetiology of DCD through indirect mechanisms that affect the developing brain.

Antecedent factors of DCD are multi-factorial and are strongly related to gestational age. While delayed brain maturation or micro-structural damage may have a biological basis, outcomes are confounded by contextual factors such as maternal education and poverty, which consequently affect maternal behaviours (e.g., maternal stress, smoking, substance abuse, etc.) and, consequently, foetal development. This is particularly obvious when exploring DCD in poor socioeconomic contexts where prevalence is noted to be higher [1].

Our review suggests that the prevalence is likely to be highest in boys who are born preterm in low socioeconomic settings. It is, therefore, essential that screening programmes should target this group as one means of detecting children with DCD at an early age. However, the age at which screening should be conducted is unclear. The *DSM 5* suggests that onset of DCD occurs in the early developmental period (Criterion C). However, there is little evidence that neurodevelopmental tools used to assess motor performance in the first two years of life will pick up the more subtle movement disorders and have predictive validity to identify those who may develop DCD as they get older [121].

Importantly, the influence of contextual factors may play a large role in mediating motor and cognitive functions and should be taken into consideration early on [27]. We suggest that the link between contextual factors, related to lack of opportunities for skill development and access to services and support may compound the existing impairments and lead to the development of secondary problems.

Contextual Factors $\rightarrow$ Activity Limitations and Participation (Restrictions)

It is proposed that impairments in body structure and function lead to activity limitations and restricts participation. However, the relationship should not be considered as strictly linear or causal [59]. Impairments may affect the individual's ability to perform daily activities and hinder

participation, but not always, as contextual factors are equally important.

Environmental factors affect functioning and disability directly and indirectly relative to the proximity of the relationship between the person and the factor. For example, the attitudes of people close to the child, family members are valued differently compared to the attitudes of strangers or subordinates.

Environmental factors that afford opportunities for engaging in challenging motor tasks play a role in skill development. For example, the ability to ride a bicycle is important in being accepted by others in contexts where riding with peers as a form of recreational activity is considered the norm [49]. However, acquiring the skill to control a bicycle or any other mobility devices (e.g., skateboard, scooter) is linked to the availability of this resource, and the presence of a supportive adult or peer. In this way, proficiency in a motor skill is closely linked to economic and social factors. It is evident, when looking at the situation through the lens of the ICF, that the manifestation of DCD in this instance cannot solely be attributed to motor learning deficit.

A supportive social environment allows children with DCD to overcome barriers to learning associated with avoidant behaviour, attention difficulties, motivation and neuromuscular impairments. Successful engagement with motor tasks builds confidence and willingness to participate in new tasks leading to increasing levels of skill.

Participation in motor tasks is mediated by a host of factors including age, gender, social support and attitudes, and personal factors (perceived self-efficacy, motivation). Improved understanding of the factors that limit participation and activity in children with DCD is, therefore, essential in making evidence-based decisions regarding intervention [32••]. Studies investigating the relationship between participation and contextual factors point out that many factors mediate engagement in physical activity. In general, these factors include the child's attitude, perceived attitudinal barriers from peers, teachers and parents, self perceptions of competence, and external environmental factors related to transport limitations [109•, 116].

Global mental functions related to temperament and motivation may also exert a strong influence on the rate of skill acquisition. Understanding the complex interaction between various factors and participation would enable therapists to develop effective interventions strategies to increase participation and prevent secondary complications.

Addressing participation restrictions is a challenging aspect of planning treatment and improvements in physical participation may not necessarily lead to improvements in social participation.

In the ICF model, the physical, social and cultural environment into which the child with DCD is born is an important contributing factor to performance outcomes. The

environment influences not only activity and participation but may also fundamentally affect the development of body structures and functions through activity dependent changes.

Intervention aimed at reducing the impact of DCD on functioning in the long-term may start with addressing socioeconomic risk factors, related to raising awareness of DCD in antenatal care settings, working collaboratively with educators and parents to identify and diagnose DCD as early as possible and streamlining access to intervention for those at risk [106•].

Limitations

It is acknowledged that no model is perfect and the ICF framework has been criticised for providing an oversimplified view. However, the framework is helpful for understanding conditions like DCD and is an internationally recognised way of exploring functioning in a meaningful way. Impairments may affect functioning and hinder participation, but not always. Nevertheless, it is important to recognise that DCD is a heterogeneous disorder and the extent to which the impairments and contextual factors identified in this review play a direct role in the functional manifestation of DCD is open to debate.

Magalhaes et al. (2011) explained that using the ICF model to code data on activity and participation is difficult because performance difficulties are not always adequately described in the literature on DCD [32••]. We recognise that while assessments should ideally attend to all components of the ICF, the reality is that this is time consuming.

The review of the literature on DCD has identified some areas that require further investigation. While evidence exists for many of the chapters and domains of functioning in the ICF, very little research has been conducted on how children with DCD perform specific self-care, school and domestic tasks. Moreover, when considering the contextual relevance of socioeconomic situation on manifestation of DCD, there is a paucity of research in this field from developing countries.

Conclusions

The ICF provides a framework for understanding the interaction between the various manifestations of DCD and emphasises the importance of context and the dynamic interplay between all factors. Studies of children with DCD should, therefore, pay sufficient attention to all dimensions of the ICF. In this way, preventative and intervention strategies can be targeted at the components of the ICF, which appear to have the greatest influence on functioning and the impact of therapy can be maximised.

Children with DCD exhibit a range of impairments in body functioning that may negatively impact their ability to perform daily tasks. Understanding the underlying impairments remains important to plan appropriate intervention. The recognition that task-orientated intervention programmes provide the best solution for improving functional outcomes for children with DCD [15••] suggests that adequate attention should be given to the impact of DCD on functioning and participation [32••]. The identification of the precise tasks and activities related to participation, which is of greatest concern to the child, and his family may lead to appropriately targeted treatment. However, it is equally necessary to identify and address impairments that may constrain functional performance and that may lead to the development of secondary impairments.

The impaired cognitive-motor function seen in children with DCD may limit their ability to benefit from the interactions with the environment and compromises their psychosocial development. Thus, supportive, enabling environments should create opportunities for motor skill development. We acknowledge that motor skill learning is dependent on the integrity and functional capacity of the neuromotor system to benefit from these affordances.

Contextual factors constrain or facilitate the experiences of children and influence their learning outcome. Enabling the child to learn from their experiences requires task adaptation and modification. Achieving goals means that the child experiences success, and this may influence personal factors, change the attitude towards physical activity and restore the internal locus of control and positive attributes which stimulates the child to undertake new challenges.

Compliance with Ethics Guidelines

Conflict of Interest Gillian D. Ferguson, Jennifer Jelsma, Pamela Versfeld, and Bouwien C.M. Smits-Engelsman declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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