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REVIEW

Developmental coordination disorder and dysgraphia: signs and symptoms, diagnosis, and rehabilitation

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Maëlle Biotteau[1]
Jérémy Danna[2]
Éloïse Baudou[3]
Frédéric Puyjarinet[4]
Jean-Luc Velay[2]
Jean-Michel Albaret[1,5]
Yves Chaix[1,3]

[1]ToNIC, Toulouse NeuroImaging Center, University of Toulouse, Inserm, UPS, Toulouse, France; [2]Cognitive Neurosciences Laboratory, CNRS-Aix Marseille University, Marseille, France; [3]Pediatric Neurology Unit, Children's Hospital, Purpan University Hospital, Toulouse, France; [4]EuroMov Laboratory, University of Montpellier, Montpellier, France; [5]Psychomotor Training Institute, University of Toulouse Paul Sabatier, Toulouse, France

Abstract: Developmental coordination disorder (DCD) is a common and well-recognized neurodevelopmental disorder affecting approximately 5 in every 100 individuals worldwide. It has long been included in standard national and international classifications of disorders (especially the *Diagnostic and Statistical Manual of Mental Disorders*). Children and adults with DCD may come to medical or paramedical attention because of poor motor skills, poor motor coordination, and/or impaired procedural learning affecting activities of daily living. Studies show DCD persistence of 30–70% in adulthood for individuals who were diagnosed with DCD as children, with direct consequences in the academic realm and even beyond. In particular, individuals with DCD are at increased risk of impaired handwriting skills. Medium-term and long-term prognosis depends on the timing of the diagnosis, (possible) comorbid disorders (and their diagnosis), the variability of signs and symptoms (number and intensity), and the nature and frequency of the interventions individuals receive. We therefore chose to investigate the signs and symptoms, diagnosis, and rehabilitation of both DCD and developmental dysgraphia, which continues to receive far too little attention in its own right from researchers and clinicians.

Keywords: developmental coordination disorder, developmental dysgraphia, clinical expressions, diagnosis, therapy, assessment tools

Introduction

Developmental coordination disorder (DCD) or dyspraxia? A poor writer or a child with developmental dysgraphia? The variety of names that have been put forward, sometimes with different diagnostic criteria, highlights the vagueness and imprecision surrounding these disorders across different disciplines and professionals (physicians, psychologists, clinical and experimental researchers, etc). What are the characteristics of children with these disorders? How common are the latter and which treatments can be recommended? Although some studies have attempted to delineate these two closely related motor disorders, regarding them as mirror images of each other, to our knowledge, none has simultaneously and comparatively reported their diagnosis and rehabilitation. In the present review, we therefore set out to report the signs and symptoms, diagnosis, and rehabilitation of DCD, as well as dysgraphia, which continues to receive far too little attention in its own right from researchers and clinicians.

Signs and symptoms

Presentation

In the *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition* (DSM-5), DCD comes under the heading of Neurodevelopmental Disorders,

Correspondence: Maëlle Biotteau
UMR 1214 - INSERM/UPS - ToNIC, Toulouse NeuroImaging Center, CHU PURPAN - Pavillon Baudot, Place du Dr Baylac, F-31059 Toulouse Cedex 3, France
Email maelle.biotteau@inserm.fr

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together with intellectual disabilities, communication disorders, autism spectrum disorder, attention-deficit/hyperactivity disorder (ADHD), specific learning disorder, motor disorder, and other neurodevelopmental disorders.[1] It is classified as a motor disorder, alongside stereotypic movement disorder and tic disorders. DCD is characterized by marked impairment in psychomotor development and perceptual-motor abilities in children with preserved intellectual abilities, in the absence of any physical, sensory, or neurological abnormalities. Nevertheless, these disturbances in psychomotor development lead to deficits in the learning and execution of coordinated motor skills (both gross and fine) that have negative impacts on activities of daily living (ADLs), particularly school learning.

Prevalence

The estimated prevalence of DCD varies according to the studies (depending on the definition, cut-off score, and population studied). Lingam et al found a prevalence of 1.8% in their study among 6,990 children aged 7–8 years in the UK, but this figure rose to 4.9% (n=341) when they also considered children with probable DCD (scoring between the 5th and 15th percentiles).[2] Other studies have reported similar prevalence rates of 6.9% or 4.3%.[3,4] Longitudinal studies show that DCD persists into adulthood.[5] Geuze reported a prevalence of 2.8% in a cohort of 468 students aged 19–23 years in Germany.[6] There is a male predominance ranging from 2:1 to 3:1.[2,7]

Warning signs and clinical expressions of DCD

The onset of DCD occurs early in childhood (before the child enters grade school). The range of developmental deficits varies from very specific limitations to general impairment of motor skills.

The motor signs encountered in DCD include difficulty executing coordinated motor actions, and fine and gross motor disorders, resulting in clumsiness, slowness, and inaccurate motor performances. Individuals with DCD may therefore exhibit deficits in postural control (hypotonia or hypertonia, immature distal control, poor static and dynamic balance, etc), sensorimotor coordination, and motor learning (motor planning, learning new movements, adaptation to change, etc).

Various ADLs may be affected by this disorder, depending on the individual's age. Children entering kindergarten display a strange gait, have problems getting dressed (buttons, shoelaces) and using cutlery and crockery (spoon, cup), poor drawing or painting skills, clumsy use of scissors, and difficulty riding a tricycle or bicycle. At primary school, they have difficulty writing, drawing, and using scissors, and demonstrate clumsiness in ballgames.[8,9] At secondary school, they continue to have problems with handwriting or typing.[10,11] Because of these difficulties at school, they often choose courses designed for lower-ability pupils.[12,13] They gradually lose motivation and experience repeated failures, which makes it considerably more difficult for them to access higher education and prestigious occupations.[14–16]

In addition, they are generally poor at sports and tend to avoid sporting activities and other forms of physical activity.[17] Consequently, they have a heightened risk of health problems such as being overweight, obesity, and cardiovascular disease.[18–21]

A wide range of problems may persist in adults with DCD, affecting their movement, mobility, visuomotor skills, and handwriting. They exhibit poorer motor performances (in manual dexterity, balance, dual tasking, ball skills, reaction time, etc) and are usually slower and more variable than peers,[16,22–24] making it harder for them to acquire essential social skills.[14]

Finally, both children and adults may exhibit associated behavioral problems. They may have emotional, social, and affective difficulties and run a heightened risk of mental health problems: anxious or depressive symptomatology, poor self-esteem, bullying, and loneliness.[11,25–30] The school experience of children with DCD plays a major role in the development of such mental health problems.[30–32]

Taken together, these symptoms have a major impact on children's and adults' daily lives, as they tend to have lower health-related quality of life, autonomy, physical and psychologic well-being, and so on.[33–35]

Dysgraphia in DCD

Beyond the heterogeneous motor deficits, about half of all children with DCD experience difficulty learning to write.[36] Handwriting skills are a social prerequisite for communication. When children fail to develop efficient handwriting, their academic success may be severely affected. Therefore, the diagnosis of dysgraphia is essential for two reasons: 1) handwriting difficulties cannot be resolved without intervention and 2) intervention seems to be effective for dysgraphia rehabilitation.[37]

According to the clear and concise definition proposed by Hamstra-Bletz and Blöte, dysgraphia is a disturbance in the production of written language, related to the mechanics of writing.[36] The symptomatology of dysgraphia is quite heterogeneous, depending on both biological (motor maturation with age and sex, type of motor deficits related to DCD, and potential comorbidity with dyslexia and/or ADHD) and social (writing habits) factors. Handwriting disorders can appear at the start of school and impact letter formation, subsequently preventing children from writing words quickly and without too much variability between and within letters.[38]

The handwriting variables impacted by dysgraphia can concern the product (ie, legibility of the written trace), the process (ie, movement that generates the trace), or both.[39] Many methods have been developed to assess handwriting, the main ones focusing on legibility and speed. It should be noted that the relationship between product and process is not direct: a legible trace can be written to the detriment of fast and fluid gestures, while by the same token, quick and fluid movement can produce an illegible trace. A speed–accuracy balance is thus required to master handwriting skills.

Concerning the product, several spatial variables may affect readability. First, letter identification can be impacted by a failure to respect the relative size of its component strokes, an incorrect number of strokes (missing or additional strokes) or an incorrect orientation or curvature of these strokes. Second, word readability can be affected by difficulty with interletter spacing (too far apart or superimposed) or letter height. Third, sentence production can be impacted by a problem of interword spacing and a failure to write in a straight line or adhere to the margin.

Concerning the process, poor control over the kinematic and dynamic variables may disturb handwriting movements. First, at the writer's level, hand posture, pen grip force, and pen tilt must all be taken into account. Second, at the pen level, dysgraphic writing can result from inappropriate pen pressure, incorrect mean speed (too fast/slow), abnormal fluctuations in velocity and/or stops, too many/lengthy lifts, or oversized movements corresponding to macrographia.[40–42] It should be noted that the tendency of some children with dysgraphia to write fewer words within a given space of time may be better explained by macrographia than by a lower production speed per se.[43,44] All the abovementioned difficulties impact not just the handwriting performance but also the writer, for whom this activity remains a struggle and may sometimes be a source of physical pain, owing to cramp. Not surprisingly, therefore, writing disorders have repercussions on motivation and self-esteem.

Diagnosis

Why?

Before addressing the ins and outs of diagnosing DCD, it is important to discuss the usefulness of doing so. Even without a diagnosis, parents, family members, close friends, or teachers soon realize that something is not right in the child's development and do not need to know that the motor difficulties result from DCD to make the necessary adjustments. However, the diagnosis of DCD can provide access to educational strategies. Children who have received a formal and accurate diagnosis are more likely to do well at home and in school if these environments have been adapted accordingly. The secondary consequences of DCD (anxiety, depression, social withdrawal, loss of confidence, or self-esteem) can therefore be averted. Furthermore, providing a diagnosis can reassure both the children and their parents about their absence of responsibility and give them something tangible to deal with.

By whom?

The diagnosis of DCD usually requires several professionals. In most countries, only a medical doctor (pediatrician) is allowed to make the DCD diagnosis. A child suspected of having DCD needs to be seen by a pediatrician or neuropediatrician, in order to carry out a differential diagnosis and ensure that the motor impairment is not due to any other physical, neurological, or behavioral disorders.

The child also has to be assessed by a psychomotor or occupational therapist, in order to identify and quantify the deficient skills. The diagnosis of DCD needs to be centered on the child, family, and immediate environment, so any input from teachers, parents, and the children can be extremely helpful.

Finally, given that children with DCD often display other learning disabilities (speech/language impairments, dyslexia, dyscalculia, ADHD), the neuropediatrician must also determine whether more than one disorder is present. For children with a comorbid disorder (language, attentional, or learning problems), the involvement and opinion of other health care practitioners (occupational therapist, speech therapist, neuropsychologist, and orthoptist) are important, and if more than one condition is present, more than one diagnosis should be given. Similarly, educational input (opportunities for learning, quality of stimulation) needs to be assessed in order to exclude the possibility that the child's motor deficiencies are due to environmental factors.

When and how?

The motor difficulties typically manifest themselves at an early age (before the child enters grade school), and the characteristics of children with DCD are first noticed by close adults (parents, grandparents, daycare staff, teachers). Even if children with DCD usually achieve the early motor developmental milestones (sitting upright unassisted, walking, etc) relatively easily, they may have problems thereafter learning new motor skills. Therefore, DCD is commonly diagnosed after age 5 years, when the motor problems are becoming increasingly apparent (highlighted by the structured demands of the child' environment) and can no longer be attributed to a developmental delay.

The diagnosis is mainly based on DSM-5 criteria (see Box 1), which are complemented by recommendations made in recent studies. In particular, Smits-Engelsman et al advised researchers and clinicians to make the diagnosis of DCD in children on the basis of (1) motor problems that interfere with ADLs (attested by parents and teachers), (2) absence of neurological disorders, (3) absence of an intellectual deficit, and (4) score below the mean on a standardized test of motor skills.[45]

The authors mainly recommended a more fine-grained terminology in relation to the cut-off scores (a much debated subject): severe DCD or DCD when the score on a validated motor test is <5th percentile; moderate DCD when the score is between the 5th and 15th percentiles; probable DCD when the score is <15th percentile but when one or more DSM-5 criteria could not be assessed, and at risk for DCD when a child below 5 years meets all the DSM-5 criteria (as child development before 5 years is highly variable, the diagnosis of DCD can only be made above this age, or after a second assessment 6 months later).

Box 1 DSM-5 diagnostic criteria for developmental coordination disorder[1]

Criterion A The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (eg, dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (eg, catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).

Criterion B The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate to chronological age (eg, self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure, and play.

Criterion C Onset of symptoms is in the early developmental period.

Criterion D The motor skills deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (eg, cerebral palsy, muscular dystrophy, degenerative disorder).

It is worth noting that the evaluation of Criterion D requires the involvement of a pediatrician in order to exclude other explanations for the motor difficulties.

Which assessment tools?

First, pediatricians perform a medical examination, in order to carry out a differential diagnosis and rule out acquired or secondary developmental motor disorders. Clumsiness and lack of motor coordination are key features of several different neurological clinical pictures (pathologies of cerebral, medullar or neuromuscular origin). The association of clumsiness, balance problems, and dysmetria or dysarthria corresponds to a cerebellar syndrome (eg, Friedreich's ataxia). Similarly, a suggestive perinatal history and the observation of pyramidal or extrapyramidal signs during the clinical examination are indicative of a disorder of central origin (eg, cerebral palsy). Lastly, pathologies of the peripheral neuromuscular system (eg, myopathies) should be envisaged where there are signs of muscle weakness or abnormal stretch reflexes.

Second, a psychomotor (or occupational) therapist may use several assessment tools to determine the child's capabilities more accurately, particularly regarding activity and the child's level of involvement in real-life situations. Assessments in a variety of functional areas are necessary both to establish the diagnosis and to design an appropriate intervention, and thereafter to measure the effectiveness of the proposed care package. The tools used will, of course, depend on the age of the child, and may include one or more of the measures detailed later (see the Rehabilitation section).

The diagnosis of DCD relies on the assessment of psychomotor impairments and their repercussions on ADLs. This assessment requires the use of standardized psychomotor development batteries and scales (guidelines for administration must be followed, to ensure reliability) designed to explore functions that underlie voluntary motor skills. Several standardized assessment tools, used in both clinical and research settings, are used to assess children's gross motor skill development. The test scores provide useful information about the nature of the movement difficulties, critical information about how the child performs relative to peers, and an indication of the severity of their motor difficulties. It is important to assess gross motor skills at an early age (preschool, then elementary school), in order to identify delays (or deficits) in motor development, quantify difficulties, make an appropriate diagnosis, establish a baseline for future comparisons, design an intervention program, monitor changes and progress, and assess treatment efficacy.

The tool most widely used to assess DCD criteria is the Movement Assessment Battery for Children-2nd Edition (MABC-2), a revised version of the MABC.[46,47] It is a reference for both clinicians and researchers.[8,45] It consists of 8 items tailored to three age ranges (3–6 years, 7–10 years, 11–16 years), and lasts 40–50 mins. These items are divided into three areas: manual dexterity (speed and accuracy of each hand separately, bimanual coordination, eye-hand coordination), ball skills (catching a moving object, aiming at goal), and balance skills (static balance, dynamic balance while moving fast or slowly). The MABC-2 can provide additional and essential details about the children's behavior during task performance, as well as about their muscle tone, postural control, processing speed, uni- and bilateral coordination, hand use, grasp patterns, attention, and so on.

The Test of Gross Motor Development, 2nd Edition (TGMD-2), a major revision of the Test of Gross Motor Development, is also used extensively.[48,49] The TGMD-2 is a norm-referenced measure of common gross motor skills designed to assist therapists in identifying children aged between 3 and 10–11 years who lag considerably behind their peers in terms of gross motor skill development. The TGMD-2 is made up of 2 subtests probing 12 skills (six skills for each subtest): Locomotor Control (running, galloping, hopping, leaping, horizontal jumping, and sliding), and Object Control (striking a stationary ball, stationary dribble, kick, catch, overhand throw, and underhand roll). The TGMD-2 can be reliably used to identify children with DCD, combining fun activities with a procedure lasting 15–20 mins. The test yields standard scores, percentile scores, age equivalents, and a Gross Motor Quotient, if both subtests are completed.

Both these tests may be supplemented with the Rey-Osterreith Complex Figure test[50] as well as with assessments of different forms of praxis (eg, Imitation of Gestures test), muscle tone, cognitive functions, memory, attention and executive functions (eg, NEPSY), and neurological soft signs (eg, NES).

The specialists' observations, together with information collected from interviews or questionnaires completed by parents or teachers, may describe the impact of the motor skill delays and coordination impairments, as another very important element of the diagnostic process is to describe how children's motor difficulties affect their daily performance and hinder self-care, leisure, social, and school (or professional) ADLs. Such information is critical for planning interventions, setting goals, developing strategies, and ensuring the ongoing management of individuals with DCD, in both childhood and adulthood. The Developmental Coordination Disorder Questionnaire (DCDQ) is the most appropriate and most widely used tool here. This brief parental questionnaire is used to screen for motor coordination difficulties in children aged 5–15 years. The MABC-2 contains a behavioral checklist, providing markers of the effect of children's motivation on assessment results (and thus, to some extent, overall compliance with testing). It also contains a teacher checklist that addresses the environmental context. For younger children, the Little Developmental Coordination Questionnaire (Little DCDQ) is required. This is a parental report measure that screens for coordination disorders (gross and fine motor skills) in 3- and 4-year-old children. It is designed to measure functional skills in several contextual areas (home, preschool environments, children's playground, etc).

Finally, a psychometric assessment of intelligence quotient is administered to rule out intellectual deficiency. This provides useful diagnostic markers and can also highlight attentional deficits (observed in half of all individuals with DCD).[51] As already reported, DCD frequently co-occurs with other neurodevelopmental disorders, in particular, autism spectrum disorder, dyslexia, and specific learning disorder. Other assessments intended to measure comorbidities, especially neurodevelopmental ones, can be considered (to test oral/written language, spelling, or math skills). Finally, if oculomotor signs are present, ophthalmologic and orthoptic examinations may prove necessary. Taken together, the psychomotor tests, complemented by these more optional tests, allow the whole child to be assessed.

Diagnosis of dysgraphia

According to the former version of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV-TR), dysgraphia can be diagnosed in the case of "writing skills that fall substantially below those expected given the individual's chronological age, measured intelligence, and age-appropriate education".[52]

Unlike DCD, there is no gold standard for diagnosing dysgraphia – probably because writing systems often differ substantially between countries and languages. Furthermore, there is considerable heterogeneity among the therapists who are charged with diagnosing dysgraphia, as they may be occupational, psychomotor, ergonomic, or even speech therapists in some countries. Consequently, a number of tests have been developed for the diagnosis of dysgraphia. Many of these are listed in the review by Rosenblum et al.[39] The common thread running through these tests is that they all evaluate the legibility of the written trace to establish a quality score and evaluate the efficiency of the handwriting process by counting the number of letters written within a given time. Here is a summary of the most recent – or most used – tests in the Latin alphabetic system.

In many European countries (eg, France, Portugal), dysgraphia is generally diagnosed using the Concise Evaluation Scale for Children's Handwriting (BHK).[53] This test was standardized on 837 children aged 6–11 years, corresponding to Grades 1–5. In the BHK, participants are required to copy a text for 5 mins on an unlined sheet of paper. Two scores are determined by the therapist, the first resulting from 13 criteria evaluating the legibility of the product, the second resulting from the speed of the writing process (number of letters written within the 5 mins). The threshold for diagnosis is fixed at two standard deviations from the standardized mean performance for each school grade. Sometimes, only one of the scores falls below the diagnostic threshold. In which case, the clinical evaluation carried out by the professional becomes particularly important, and is sometimes supplemented by the use of other tests.

The Minnesota Handwriting Assessment was developed by Reisman for children aged 5–7 years.[54,55] It requires them to copy a pangram (ie, a sentence in which all the letters of the alphabet are used at least once) in the correct order and in an order including word inversions in print handwriting. This test corresponds to the clinical version of the Minnesota Handwriting Tests that had previously been developed by the same author for the purposes of scientific studies. As with the BHK, the therapist determines a speed score corresponding to the number of letters written in 150 s, and a quality score based on five criteria: legibility, form, alignment, size, and spacing.

The Evaluation Tool of Children's Handwriting (ETCH) was developed by Amundson.[56] This criterion-referenced tool is designed to evaluate the print and cursive handwriting skills of children in Grades 1–6. The ETCH takes about 15 mins and includes 6 subtests: writing the letters of the alphabet and numbers 1–12 from memory, copying 5 sentences from a distant model (displayed on a blackboard or equivalent), writing two 5-letter pseudowords to dictation and 3 pseudowords to spelling, and writing a sentence containing at least 5 words. As in the BHK, the assessment of handwriting is based on three quality scores (for letters, words, and numbers) and a speed score (total number of items produced).

Finally, other tests have been developed to evaluate the quality of letters written by younger children (eg, Scale of Children's Readiness In PrinTing, SCRIPT)[57] or the writing speed of older children (eg, Detailed Assessment of Speed of Handwriting, DASH; version for adults aged 17–25 years: DASH 17+).[58–60] Less specific tools have sometimes also been used to assess the manual skills of children with dysgraphia, to determine whether this disorder results from a deficit in more general visuomotor integration or motor coordination skills.[61]

Rehabilitation

Which strategies?

In DCD, interventions supporting participation and activity are key to remediating motor impairments and associated problems.[62] Many years of research have given rise to various intervention methods. These can be divided into two main categories.[63]

The bottom-up category contains process-oriented (or deficit-oriented) approaches, such as kinesthetic training and sensory integration. The process-oriented approach assumes that a deficit in a specific body function or part (in particular a neural structure) or sensory process (vision or proprioception) is responsible for the impaired motor skills (eg, sensory integration, muscle strength) of children with DCD. Its aim is to remediate this underlying process deficit, thereby improving motor performance.

The top-down category contains task-oriented (functional skill) approaches, such as neuromotor task training and cognitive orientation to daily occupational performance (CO-OP). These approaches involve teaching children the ADLs they need to be able to perform effectively, focusing on their constant interaction between the activity, the child, and the immediate environment, in order to promote participation. Interventions may involve the teaching of specific skills, but also problem-solving exercises or the linking of groups of activities to promote generalization. Children remain the actors and are encouraged to think about the nature of the difficulties they encounter and how to find solutions to solve these difficulties. Adults help them explore the relevant processes and validate their strategies.

Effectiveness of these strategies

The first meta-analysis of studies published between 1983 and 1993 on process-oriented therapies showed that they were largely ineffectual, despite their popularity.[64] A second major meta-analysis of the efficacy of this type of intervention found a weak (0.12) effect size,[65] a finding confirmed by Preston et al.[66] Process-oriented approaches were therefore not included either in the recommendations of the European Academy of Childhood Disabilities on the definition, diagnosis, and treatment of DCD or in the 2012 policy statement of the American Academy of Pediatrics.[67] By contrast, reviews indicate that the task-oriented approach is effective in improving motor performance.[65,66,68,69]

Other systematic meta-analyses and reviews have recently been published. For example, Yu et al reviewed 66 studies, mostly conducted between 2008 and 2017, 18 of which were eligible for meta-analysis.[70] The authors sought to determine the characteristics and effectiveness of motor skill interventions in children with DCD, assess both the immediate and sustained effects of these interventions, and identify potential moderators of intervention effects. They found that motor skill interventions were effective in improving not only the motor skills but also the cognitive, emotional, and other psychological performances of children with DCD. Positive effects of motor intervention were reported in 85% of the studies (10/66 interventions (15%) were based on a process-oriented approach, 29/66 (44%) on a task-oriented approach, and 12/66 (21%) on a combination of the two). Fifteen (88%) of the 17 studies that conducted follow-up tests found sustained effects on motor performance. The authors also showed that both the task-oriented approach and a combined task- and process-oriented approach brought improvements, thus supporting the use of a multilevel approach for children with DCD. Both the duration (in minutes) and frequency (eg, 4–5 times per week) of the interventions influenced the magnitude of the immediate training effects (intervention dose explained 7% of the variance of treatment effects on motor performance, with longer treatments being associated with greater effectiveness). Interventions that lasted for at least 9 weeks tended to be more effective in improving the motor skills of children with DCD. Short-term positive effects on psychological or emotional factors were reported in 12 of the 13 studies assessing cognitive, emotional, and psychological functions-encouraging evidence that such problems can be remediated through motor skill interventions. Additionally, positive intervention effects were reported in all 10 studies looking at physical fitness (anaerobic capacity, strength, exercise tolerance, etc). By contrast, only three out of seven reported positive changes in physical activity and participation.

Smits-Engelsman et al's review of 30 studies (covering 25 datasets) published between 2012 and 2017 confirmed that interventions with relatively short durations (both activity-oriented and body function-oriented combined with activities), along with active video games (AVGs), and small group programs have an immediate and positive impact on performances.[62] The authors divided the studies (19 included in a quantitative synthesis and all 30 in a qualitative synthesis) into three categories: 1) body function/structure-oriented interventions designed to improve targeted body functions, selective muscle activation (biofeedback), or visual/oculomotor training; 2) activity-oriented interventions designed to improve performance in a particular activity via task-oriented interventions such as neuromotor task training (NTT) and CO-OP, general skill training, sport/play-related skill training, or virtual reality training; and 3) participation-oriented interventions designed to improve participation in a given activity in an everyday life situation. It is worth bearing in mind that transferring interventions to real-life situations requires the active involvement of the children, their parents and/or their teachers.

Most of the studies (5/5 body function-oriented, 11/12 activity-oriented, 5/7 AVGs) reported positive effects of treatment, not only in terms of activity but also in terms of impairment (body sway, strength, cardiorespiratory function). Body function-oriented therapies are now commonly combined with other forms of activity-based therapy (more functional tasks) that improve the level of transfer. However, the efficacy of body function-oriented approaches varied considerably from one study to another. The positive effect of activity-oriented interventions (eg, NTT) was consistent across a range of outcome variables, with improvements not only in activity but also in body function, in line with other reviews.[63,66,71,72] Motor skill interventions were found to bring about short-term improvements in children's motor skills, as well as in cognitive, emotional, and psychological domains. Furthermore, Smits-Engelsman et al's review provided consistent evidence that all forms of activity-oriented training (NTT, sport/play-related skill training, virtual reality training, exergames, ie, video games promoting physical exercise) can improve basic physical condition and functional strength.[62] AVG-based training was evaluated in seven studies. In most cases, these programs were implemented under supervision, either in a school setting or during small group interventions. Six studies showed positive effects of AVGs (but four reported small effect sizes). One study comparing NTT and AVGs found that the latter brought about a greater improvement.[73] Moreover, AVGs had beneficial effects on anaerobic fitness, as well as on quality and satisfaction ratings. Owing to differences in protocols, interpreting the results for group-based interventions is far from straightforward. However, both group-based interventions and individual-based training had large effects on motor performance. Training protocols varied considerably in frequency and duration across studies. However, the review showed that relatively short periods of training (around 9 weeks, although fine motor skills may require longer) can have a positive effect if the child is trained in tasks of everyday relevance.

Motor imagery training

Motor imagery (MI) refers to the mental representation of actions in the absence of concomitant body movements. Crucially, while real practice offers the system an opportunity to compare predicted feedback with actual sensory feedback and-where necessary-make online corrections, MI merely enables the system to anticipate the consequences of an action. Even in the absence of real movement, and thus of sensory feedback, however, evidence suggests that this training optimizes motor control, probably by shaping internal models, albeit ones run offline here.[74,75,76] MI training (video observation of actions performed by skilled peers, mental reproduction of the observed movement, and internal simulation/imitation) looks to be a promising means of enhancing predictive motor control (ie, internal model accuracy) and has positive effects.[77,78] Some studies of DCD rehabilitation support the inclusion of MI training in therapeutic programs. For example, Wilson et al found that the MABC scores of children who received MI training underwent the same significant improvement as those of children in another intervention group who were given perceptual-motor rehabilitation.[77,78] Moreover, the children who exhibited the most severe motor deficits in the initial assessment (scores <1st percentile) were those who benefited the most from MI training. In a pilot study, Adams et al compared a new MI training protocol with CO-OP.[79] Each group underwent nine sessions, with exercises to do at home. Results demonstrated the "feasibility of a theoretically principled treatment protocol for MI training in children with DCD" (p. 1271). Taken together, these compelling findings indicate that MI training is one of the most valuable techniques that are currently available for improving motor performances in DCD.[67]

Dysgraphia rehabilitation

There are several difficulties inherent to the rehabilitation of dysgraphia, related to the lack of a clearly established method, the diverse origins of dysgraphia (primary or secondary disorder, comorbidity), and the diversity of children with dysgraphia (age, sex, etc). Although there is no gold standard method, several strategies have been investigated and scientifically validated. The vast majority of rehabilitation strategies focus on the graphomotor component of handwriting. Children with dysgraphia have a strong aversion to writing. Consequently, therapists need to give them very simple exercises, focusing on the primitives of writing (loops, bridges, etc). These graphomotor exercises can gradually become more complex, depending on the child's level of performance and motivation, eventually leading to training in actual handwriting.[80]

Several avenues can be followed to improve the rehabilitation of dysgraphia. Regarding the question of whether there is an optimum way of presenting the model in a copy task, Berninger et al showed that a model with additional information about the ductus (ie, correct order and direction of the models to be copied) is more efficient than a static model of the written trace.[81] In the same vein, Vinter and Chartrel reported that showing a video of a writer who is writing is more efficient than a static model without any indications.[82] By contrast, joining dots to draw letters seems detrimental, as the close visual control of the pen's trajectory needed to stay on the dotted line prevents the writer from increasing movement velocity and fluency. It is also possible to focus the writer's attention on the movement rather than on the written trace itself. To this end, the best strategy is to modify the writer's perception of his/her handwriting. For instance, the use of a fake pen (ie, without ink) does away with the visual trace (but preserves the vision of the pen and of useful spatial cues) and thereby lets the writer focus on his/her movement. As suggested by Danna and Velay, this could be a good way of preventing the writer from paying exclusive attention to the visual trace.[83] It is also possible to increase the perception of tactile and kinesthetic information related to handwriting movements through digital exploration of letters in relief.[84] Using background music during rehabilitation also seems to be effective.[85] This strategy is supported by a previous finding reported by Ben-Pazi et al, who observed that poor penmanship in children correlates with abnormal rhythmic tapping, suggesting a broad functional temporal impairment in children with dysgraphia.[86] However, the therapist has to check that the music does not distract the child too much, especially if the child has attentional disorders. Finally, the use of new technologies, such as graphic or digitizing tablets, seems a promising avenue for the rehabilitation of dysgraphia. Beyond children's appetite for new technologies, digital writing makes it possible to modify the writer's perception of his/her writing by reducing the amount of visual information about the writing product[87] or increasing the amount of sensory information about the writing process, with supplementary auditory feedback[88] or real-time changes in the color of the ink according to a given kinematic variable.[89]

Today, both the diagnosis and rehabilitation of dysgraphia continue to be based on pen-and-paper tools. Digital devices could be used to complement pen-and-paper tests. Many software programs have been developed since the advent of graphic tablets (eg, OASIS by De Jong in 1996; MovAlyzeR by Teulings in the 1990s). A meta-analysis on handwriting disorders indicated that three variables supplied by graphic tablets would be particularly relevant for assessing the process of writing: movement velocity, movement fluency and, to a less extent, pen pressure.[40] It should be noted that the pressure exerted by the fingers on the pen is probably more informative than that exerted by the pen on the tablet, but this variable cannot be recorded with the tablets that are currently available. While the use of digital tools for promoting the diagnosis and rehabilitation of dysgraphia has been fully investigated at the scientific level, these new technologies are still rarely used by therapists.[90]

Goal, evaluation, and adjustment

Whatever the form the chosen intervention takes, goal attainment scaling seems a promising way of becoming fully efficient. This takes the form of a written follow-up guide between the clinician/therapist and patient, monitoring the patient's improvement and the effectiveness of the intervention.

During semi-structured interviews, the therapist can set goals and outcome measures. Prior to the intervention, the child and the parents identify areas of functional difficulty, whether these are in a home or school setting. Following the intervention, the therapist, child, and parents rate current performance (and satisfaction) for each task. This method assists with planning appropriate goals and measuring performance and satisfaction with chosen tasks following the intervention.

The School Function Assessment, Canadian Occupational Performance Measure (with children over 8–9 years of age), and Perceived Efficacy and Goal Setting System (for younger children) may be appropriate goal-setting tools.

Intermediate conclusion

Interventions designed to improve motor performance in individuals with DCD vary in type, intensity, duration, and frequency/repetition. They are more effective when they are started in small children (before 5 years), are administered in a group or home setting, at least 3–5 times per week, and for a duration of at least 9 weeks (it should, however, be noted that while high-intensity and high-frequency interventions appear to be the most effective, new evidence suggests that even relatively short-term interventions can have immediate benefits). It is also necessary to enlist the support of parents and teachers (and significant others: therapists, family members, etc), in order to leverage every opportunity for practicing and generalizing skills, and maximize the potential training effect.[62] Broadly speaking, interventions need to be:

- tailored to the characteristics of each individual child;
- begun and implemented following a full and appropriate examination to establish the exact nature of the deficits (cognitive profile, severity of the disorder, comorbidities, etc);
- linked to ADLs difficulties;
- adapted to the child's difficulties and designed to alleviate them;
- rolled out in concertation with (and with the participation of) the child, his or her parents, teachers, and

other therapists, in order to maximize the potential training effect.[65]

Combined with functional tasks, both activity-oriented and body function-oriented interventions may be offered.

AVG-based training appears promising, although additional data are required for DCD (few studies, heterogeneous methodologies, small samples). It is starting to be included in motor therapy, as it has many advantages (rehabilitation across a range of conditions, combating boredom, promoting engagement and motivation, etc). However, the issues of transfer to the real world have yet to be addressed.

Small group-based interventions (4–6 children) have started to be offered and are useful for reducing performance anxiety, improving the ability to deal with peers, and enhancing adherence and engagement.[73,91,92]

General conclusion

DCD is a common specific developmental motor disorder that shares several features with other neurodevelopmental disorders, including high prevalence, male predominance, onset during childhood (most often revealed before starting school), variable severity, lifelong persistence, academic repercussions, and long-term socio-emotional consequences. Prevalence varies from 1.8% to 6.9%, and 1 in 2 children with DCD exhibit dysgraphia. Confirming suspected DCD requires a multidisciplinary approach involving pediatricians and/or neuropediatricians in order to establish the differential diagnosis with central or peripheral neurological pathologies, a specialist in motor skills (psychomotor and/or occupational therapist) for the evaluation of motor development and motor functions based on validated tests, and other specialists according to suspected comorbidities. Although the etiology of DCD remains unknown, common etiopathogenic bases with other neurodevelopmental disorders could account for the frequent associations between them and contribute to the heterogeneity of the disorder. Early identification and diagnosis are important if children are to receive the appropriate care and benefit from educational interventions whose effectiveness has been demonstrated by recent meta-analyses.

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