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Is There a "Movement Thermometer" for Developmental Coordination Disorder?

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Abstract
The defining feature of Developmental Coordination Disorder (DCD) is a significant motor difficulty that has an impact on everyday life movement tasks. The notion of a 'movement thermometer' suggests that not only can the extent and severity of the motor impairment be accurately measured but also that its impact on daily activities can be gauged. Recent European guidelines on the assessment of children with DCD recommend several well established motor tests and questionnaires for application in research and clinical practice. The formal assessment of adults, however, has been largely neglected, even though the persistence of the condition has been well documented. This article considers the assessment of motor behaviour and activities of daily living in children and adults with DCD, as well as the impact of associated features and environmental factors on the performance of everyday activities. It is argued that there is a need to go beyond the formal testing of motor skills in order to adequately assess the true 'temperature' or impact of the condition.

Keywords
DCD; motor assessment; Movement ABC-2; Bruininks-Osteretsky Test of Motor Proficiency-2

Introduction
Although DCD is generally less well known and understood than other developmental disorders, interest in and research into the condition continues to grow worldwide. In recent years, recognition of the condition has been marked by two important publications directed at the international community. In 2012 the European Academy of Childhood Disability (EACD) published evidence-based recommendations for definition, diagnosis, and intervention[1] and 2013 saw publication of the 5th edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5)[2], with an updated entry for DCD. Taken together, these two publications provide a definition of the condition and use research evidence to help researchers and practitioners apply the diagnostic criteria.

The core characteristic of DCD is a difficulty in the 'acquisition and execution of coordinated motor skills'[2] p.74), which 'significantly and persistently interferes' with the performance of everyday movement tasks. Some form of motor assessment is therefore a central component of the diagnostic process. For diagnostic purposes, a cut-off point, rather than a full scale 'movement thermometer' is needed, as the main aim is to establish whether or not the motor skills are 'substantially below that expected given the individual's chronological age'. The DSM-5[2] states that the diagnosis should include an 'individual assessment using psychometrically sound and culturally appropriate standardized tests' and Blank et al[1] specifically recommend the test component of the Movement Assessment Battery for Children–Second Edition (MABC-2)[3] and the Bruininks-Oseretsky Test of Motor Proficiency–2 (BOT-2)[4]. However other general motor tests are also available, including the McCarron Assessment of Neuromuscular Dysfunction (MAND)[5] and the Zurich Neuromotor Assessment[6]. These are all 'general' motor tests in that they sample a range of behaviour across different classes or groups of motor tasks and they have been reviewed elsewhere[7-9].

The use of general motor tests in DCD
There has been some debate about what is actually measured in the motor tests mentioned above. Can the composite score be seen as representing a measure of 'general motor ability', akin to a measure of general intellectual ability from an intelligence test, or should they be seen as an indication of performance levels only on the sample of individual motor tasks presented?[10]. Early notions of a 'general motor ability' were supported by observations of the 'all round athlete' who did well at any motor activity they tried and, at the other end of the scale, those who had difficulty with almost all motor skills[11]. Formal investigations on the structure of motor abilities in *adults,* however, did not support this view but reported a number of different motor abilities. Some

presented evidence for a large number of abilities, each specific to a particular task and independent of one another[12] while others reported a smaller number as different tasks were considered to require some of the same underlying abilities for successful performance[13]. Examination of the structure of motor abilities in *children* is very limited but Rarick and colleagues'[14] early study of various aspects of motor control and coordination in 6-9 year olds identified three separate factors labelled 'gross limb-eye coordination' (in which throwing tasks had high factor loadings), 'fine visual motor coordination' (including mainly fine manipulative tasks) and 'balance'. More recently, Bruininks & Bruininks[4], Shih-Heng et al[15] and Schulz et al[15, 16] have all identified similar factors in the context of test construction, and higher intercorrelation coefficients for tasks within the sub-scales compared to between them further supports the separation of domains[4]. There is also some support for a change in the factor structure towards greater differentiation in motor abilities with age[16]. Given this lack of support for a general motor ability, Burton and Rogerson[10] recommend that composite motor test scores are viewed as representing performance of the individual tasks tested rather than "performer attributes or abilities, which implicitly represent skills not even tested" (p.357).

There is a large overlap in the type of tasks included in the general motor tests mentioned above, with each one grouping the items roughly in line with the three main factors identified by Rarick and colleagues[14]. It is unsurprising therefore, to find high correlations between the composite scores from different motor tests[17, 18] and this suggests that each of them might be considered as a 'thermometer', providing a measure of movement competence across a range of tasks that capture the main factors of motor ability in children. A thermometer gives an overall value indicating the local temperature level in units that are universally understood, although different methods (e.g. mercury and electronic) and different scales of measurement (e.g. Celsius and Kelvin) can be used. In much the same way, general motor tests give an overall or composite score reflecting the level of motor competence. Different motor tests can be used (e.g. BOT-2 or MABC-2) as well as different measurement scales (e.g. standard scores or percentiles). In contrast to thermometers, however the same score from two different tests cannot be seen as directly equivalent as the test content is not identical. Results from motor tests can be described positively in terms of proficiency or negatively in terms of the level of motor impairment, just as a thermometer reading can be described with different words (e.g. 'hot' or 'cold'). A thermometer reading can also be described with different categories (e.g. outdoor temperature might be referred to as 'moderate' or 'mild') and in the same way categories such as 'significant' or 'moderate' are used to refer to the severity of motor difficulties[3], based on the composite test score.

In the field of DCD the primary use of general motor tests is in the application of criterion A (see App A). In relation to this, Blank et al[1] recommend use of the 15th percentile on a composite score as an indication of motor impairment. However, in recognition of individual differences in the areas of motor control and coordination affected, they suggest that performance on sub-components of the general motor tests can also be considered, in line with sub-categories of gross motor or fine motor difficulties recognised by the World Health Organisation in some versions of the International Classification of Diseases (ICD-10)[191]. In this case the cut off is more stringent, with the criterion only met if performance is below the 5th percentile in one of these more specific areas. There is some support from the research literature for this distinction[20] and in the DSM-5[2], which recognises that 'individuals may be impaired predominantly in gross motor skills or in fine motor skills, including handwriting skills' (p. 75) .

The accuracy of the measure obtained by any of these tests of course depends on their various psychometric properties. In the context of DCD one of the most important features is an ability to

[1] This distinction is included in the German but not the English edition of ICD-10

discriminate between the performance of individuals with and without DCD. Both the BOT-2 and MABC-2 manuals include evidence suggesting that the tests are sensitive to the identification of DCD. For example, Bruininks and Bruininks[4] report lower BOT-2 subtest and composite scores in a group of 50 children with DCD (as identified by parents), compared with a reference group. Henderson et al.[3] report data from a much smaller but carefully diagnosed group of 15 children with DCD. They report individual data showing that all but one child in their DCD group obtained a very low total score on the MABC-2 test.

Another vital consideration is the use of appropriate norms for obtaining standard scores or percentiles on these tests. The BOT-2 norms were gathered in the USA, while the MABC-2 has UK norms. With an increasing interest in DCD and measurement issues worldwide, both of these tests have been translated into different languages and the collection of country-specific norms is growing[21, 22]. Cross-cultural studies on general motor tests can help to indicate when it is appropriate to directly apply norms and use the same items from one country to another and when adjustments are necessary[23-27]. Although few direct comparisons of national norms are available, there is some suggestion that test norms are similar across Europe for example, but that there are differences compared to data from the Far East.

One area currently lacking is the provision of motor tests with norms for adults. It is now well established that DCD is a lifespan condition and in adulthood can continue to have a major impact on everyday life at home, work and leisure[28, 29]. The persistence of motor difficulties into adulthood is recognised in both Blank et al [1] and for the first time in DSM-5[2] but no specific guidance on assessment is provided. Blank et al[1] recognise that the diagnostic criteria need to be reconsidered for adults and state that 'Although there is a problem with lack of suitable instruments, a diagnosis in adulthood should be possible' (p.65). At the moment, although the BOT-2 has North American norms up to 21 years and the MABC-2 has UK norms up to 16 years, there is a need for new tests to help diagnose and describe the condition in older adults and for norms to be gathered in different nations. In the absence of other more suitable tests both of these tools are currently recommended by those working with adult groups[30]. However, the extent to which the content of tests that have primarily been designed for children are suitable for accurately identifying and describing motor difficulties in adults is unclear.

Although different tests are available, the question sometimes arises regarding whether there is a single, 'gold standard' measure, like a universal 'movement thermometer' for DCD. Indeed, widespread use of the MABC-2 test has led some to consider whether it should be viewed and used in this way[31]. However, there are at least two problems with the notion of a 'gold standard' in this field. Firstly, the labelling of a test in this way can lead to over-reliance on test scores. It is never advised to use a single test in isolation but rather as part of a broader assessment process[1, 31]. The tests described above are not 'tests of DCD' but general motor tests that can be used to assist in the identification of significant motor difficulties. Secondly, exclusive use and focus on one test in this field of study could result in the condition becoming defined and described in terms of the test itself, which could seriously limit a full understanding of the nature of DCD.

The impact of motor difficulties on everyday life

In addition to using tests to measure the level of motor competence, for a diagnosis of DCD it is also necessary to assess the extent to which performance on everyday life movement activities are affected. This involves gauging the impact of motor difficulties on 'academic/school productivity, prevocational and vocational activities, leisure, and play' (see Criterion B, DSM-5 in Appendix A). Some everyday functional tasks are known to be commonly affected in DCD, with handwriting being a commonly cited example. In fact slow and inaccurate handwriting is included in the description of Criterion A in DSM-5 (see Appendix A). Although other writing methods, such as keyboarding are often used at home and school, handwriting is required in most classrooms on a daily basis and

remains the primary mode for written examinations. Furthermore, while for some children keyboarding is a valuable aid, for many their poor motor skill is also a barrier to the development of fast and efficient keyboarding performance[32] .Most importantly it has been demonstrated that handwriting that is slow and difficult to read is related to reduced quantity and quality of writing that is likely to receive lower grades and thus has a serious impact on progress in school[33, 34]. In recognition of the importance of this skill, handwriting assessment is recommended by Blank et al[1] and specific tools are available for this[35-38].

In order to assess broader aspects of activities of daily living (ADL) a common approach in the field of DCD is to gather information from parents and/or teachers through the use of questionnaires. A variety of different tools is available and these have been reviewed elsewhere[9, 39]. Typically, these tools contain sets of items describing functional movement skills that are part of everyday living. The assessor should be familiar with the child, having had opportunities to observe their usual performance in natural surroundings that may include the home, classroom and playground. Performance on each item is rated and total scores can be compared to norms, with cut-off points denoting impairment. Some of these tools were designed as short screening tools, so include only a small number of items relating to a limited range of everyday activities (e.g. the DCD-Q-R[40]). Others are intended to give a more comprehensive description of the impact of motor difficulties in everyday life. The latter take longer to complete but are much more detailed, giving an indication of performance across a broader range of tasks (e.g. the MABC-2 Checklist)[41]and therefore can be helpful in planning intervention. Blank et al[1] do not recommend such instruments for population-based screening, owing largely to their low sensitivity. However they do acknowledge their value in gaining 'a picture of the child's everyday activities' (p. 69).

In addition to parent and teacher views, Blank et al[1] also emphasise importance of the 'view of the child' (p. 64). This is partly because their views have been found to differ from those of their parents and other adults around them[42, 43]. However, rather few instruments have been designed specifically to obtain the views of the child in relation to ADL and Blank et al[1] acknowledge that further work is needed in this area. Harter's self-perception scales[44] have been widely used in DCD research[45, 46]. These contain some items relating to motor competence, although they concentrate on sports skills and do not include other everyday tasks that require motor skills. More recently, other interview schedules[47] and scales[48] have been specifically developed for children having difficulty with daily tasks.

It is only very recently that instruments have become available to assess ADL in adults with DCD. In this case self-ratings are even more important, as in many cases it would not be appropriate to obtain ratings from parents and teachers. As with child assessments, the available tools include short screening questionnaires as well as a longer and more detailed self-report questionnaire. The Adolescents and Adults Coordination Questionnaire (AAC-Q)[49] is a 9-item self-report questionnaire developed in Israel from a sample of 16-35 year olds. The items cover a range of aspects of motor behaviour including general 'clumsiness'/ falling, difficulties with physical activity (e.g. ball games, riding a bike, dancing) and general organisation (e.g. to pack a bag or go shopping). Each item is very general and covers a range of performance aspects. For example the question on handwriting does not distinguish between legibility and speed. Clark and colleagues[50] produced a 9-item Functional Difficulties Questionnaire (FDQ-9) from a sample of adults aged 18-63 years in the UK. Three of the items refer to performance in childhood, leaving just 6 items relating to adult performance. Four of these are very general (e.g. relating to general movement/bumping into things, organisation, general use of the hands, balance skills) and two are much more specific (e.g. related to one-handed ball catching and handwriting).

The Adult DCD Questionnaire (ADC)[51], developed and tested in the UK and Israel on 17-42 year olds, is a more comprehensive instrument. It was designed not just for screening but also as a basis for

intervention. As such it includes 10 items to rate performance in childhood and a further 30 items to rate current performance in adulthood. About half of these items consider a broad range of motor behaviours and the rest focus on behaviours beyond the motor domain. The motor items cover general movement skills (e.g. bumping into things, team games), specific aspects of self-care (e.g. shaving, eating), handwriting (speed, legibility, copying) and driving. In other domains, there are items relating to general organisation (finding your way around, preparing a meal, packing a suitcase, managing money), attention (being fidgety, losing things, poor attention) and social skills (e.g. avoiding going to clubs). Scoring does not make the distinction between the motor and non-motor items, which may help to explain the reported poor sensitivity of this tool and the low correlation of total scores with results from the MABC-2 and BOT-2 tests.[52]
Further work is needed to evaluate the AAC-Q and FDQ-9 as accurate screening instruments. While they may give an overall indication of whether or not the motor difficulties affect everyday life skills, the lack of specificity in the items make it unlikely that these would be helpful in relation to an accurate measure or 'thermometer' to gauge the impact of the condition for an individual person. In contrast the motor items from the ADC provide greater range and specificity but these need to be evaluated separately from the non-motor items in order to obtain a clearer measure of the impact on ADL. Clearly, further work is needed in this area to accurately gauge the impact of motor difficulties on ADL for adults with DCD[52].

A more direct way of assessing an individual's capacity to perform activities of daily living is to assess them directly and recent instruments have been developed to do just this for young children. For example, the Do-Eat[53], Assessment of Motor and Process Skills[54] and most recently the DCDDaily[55] involve rating the actual performance of specific everyday activities (such as buttering bread, tying shoe laces and putting on clothing). Similar tools have yet to be developed for adults with DCD to assess criterion B. Assessment of the actual performance of ADL is a useful addition to questionnaires to gauge performance levels. A further step is to gauge the level of *participation* of children and adults with DCD in various ADL. There is substantial evidence that participation is generally low across many activities[56, 57]; and new tools are being developed to specifically assess this in individuals with DCD (e.g. the Child Participation Questionnaire)[58]. DSM-5 actually requires that participation is considered at the point of diagnosis, since the level of motor skill must be below expectations in relation to the 'opportunity for skill learning and use' (see Appendix A). This was not included in DSM-IV[59] and now requires a judgment to be made regarding the child's prior exposure to a typical learning environment. However, this becomes rather circular since while reduced opportunities may impede the development of motor skill, DCD itself is associated with reduced opportunities for engagement in physical activity. This demonstrates that it is difficult to disentangle the causal factors and further work is clearly needed to examine issues relating to participation in DCD.

In sum, to fully gauge the impact of the motor difficulties associated with DCD it is necessary to assess levels of performance and participation in everyday life activities that require motor skill. Beyond this, there are other non-motor factors associated with DCD that can also impact on the performance of motor activities.

The impact of associated features
The main feature of DCD is motor difficulties and this is central in assessment issues, as outlined above. However, as with other disorders, it is well established that the core characteristics are often accompanied by difficulties in other domains. Thus there is a high co-occurrence of developmental disorders, sometimes referred to as 'co-morbidity'[60]. For example Attention Deficit Hyperactivity Disorder, Autism Spectrum Disorder, Specific Language Impairment, and Dyslexia or reading difficulties commonly co-occur with DCD[61-63]. Also associated with DCD are a range of psychological, social and emotional problems including low self-esteem[64], difficulties with peer relations[65],

anxiety[66] and depression[67]. Such problems have been well documented in the literature and can persist through adolescence[68]. Indeed more severe psychiatric problems have been reported in studies on adults with DCD[69].

It is likely that these associated features interact with the core motor difficulties in individuals with DCD and impact on performance and participation. Some existing work suggests that effects might be cumulative, for example outcomes for those with combined DCD and ADHD are worse than for those with DCD alone[70]. The exact nature of the relationships between the motor and non-motor difficulties reported in DCD has yet to be clearly establishedalthough Cairney and colleagues[71] present a useful conceptual framework to consider possible causal pathways. They outline a range of stressors shown in the research literature to be linked to DCD and consider how these interact with both the child's personal resources and their networks of social support to impact on the emergence of internalising problems such as anxiety and depression. Understandably, there has been a tendency in the literature to focus on the psychological, social, learning and behavioural *difficulties* associated with DCD. However, it would also be helpful to consider individual *strengths* and attempt to identify protective factors associated with resilience in DCD. This would inform us about what helps individuals to cope well with motor difficulties and to achieve their potential[71]. When 'taking the temperature' of DCD in children and adults, therefore, it is important that associated features (both positive and negative) are considered alongside the motor difficulties, to more fully understand the impact for the individual.

The impact of external factors

So far, this paper has considered personal or 'internal' factors, particularly the motor difficulties plus the impact of non-motor difficulties associated with DCD. However recent approaches to understand typical and atypical development take a broader approach to understanding the factors affecting development. It has been suggested that Ecological theories, such as that described by Bronfenbrenner & Ceci[72] are useful for understanding and explaining DCD as well as providing a framework to guide intervention planning[73]. Bronfenbrenner's ecological theory has the individual at the centre, nested within an environment consisting of different layers with which the individual interacts over time and this is what shapes development. The layers include the immediate environment, or 'microsystem', which consists of home, family, friends, school, colleagues and the workplace. A 'mesosystem', 'exosystem' and 'macrosystem' are also included to describe broader aspects of the environment and a 'chronosystem' describes changes over time (see Bronfenbrenner & Ceci, 1994[72] and Sugden, this volume for details).

This approach emphasises that the impact of motor difficulties for an individual and the course of development across the lifespan is determined not only by factors internal to the individual with DCD but by the interaction with a wide range of 'external' or environmental factors. These include social, cultural, physical and political factors as well as others. To give some examples, the nature of a child's friendships may influence their level of participation in motor activities. The extent to which a teacher understands DCD may influence the way that they teach and subsequently the learning experience for that child. Beyond the control of individual teachers, educational policies for supporting children with special educational needs can impact on the resources available to support children's learning in school. Beyond education, employment and disability laws and related eligibility requirements can impact on the extent of financial and other assistance received by adults with DCD, which may affect their ability to manage everyday tasks, their vocational choices and long term employment prospects.

Concluding remarks

The question set in the title of this paper "Is there a 'Movement Thermometer' for Developmental Coordination Disorder?" seems appropriate in the light of the recent surge of interest in the condition. Progress has been made in relation to the description of DCD, the guidelines for diagnostic assessment in children, and the formal recognition of the persistence of the condition into adulthood. However there is considerable work to be done to produce suitable diagnostic tools for adults and, beyond diagnosis, to develop instruments to adequately describe the motor difficulties. This needs to include assessment of their impact on the performance of and participation in the full range of ADL in both children and adults. Alongside, there needs to be consideration of the non-motor associated features of the condition and external factors which will also influence and interact with the performance of motor activities. This suggests that there is no single 'movement thermometer' but rather, a broad approach is needed for the assessment of DCD to gauge the impact or 'temperature' of the condition for an individual.

A useful accompaniment to a thermometer is a thermostat. This senses the temperature and acts as a control system whereby something happens when a particular set temperature is reached. In the field of DCD we need to ensure that there is adequate recognition of the condition, that we have a range of robust tools to sense its impact and importantly, we need the knowledge and resources to intervene in a timely and appropriate manner to support the individual to achieve their potential.

Appendices

Appendix A: DSM-5 Diagnostic Criteria (APA, 2013)

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 (e.g., dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g., catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).

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

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

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 (e.g., cerebral palsy, muscular dystrophy, degenerative disorder).

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