The relationship between motor coordination and intelligence across the IQ range.

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Abbreviations:
CI   Confidence interval
DCD   Developmental Coordination Disorder
DSM   Diagnostic & Statistical Manual
EACD   European Academy of Childhood Disability
ICD   International Statistical Classification of Diseases
ID   Intellectual disability
IQ   Intelligence quotient
KABC   Kaufman Assessment Battery for Children
LD   Learning disability
M-ABC   Movement ABC (also M-ABC2)
MR   Mental retardation
SDDMF   Specific Developmental Disorder of Motor Functions
SON-R   Snijders-Oomen Non Verbal Intelligence Test – Revision
WISC   Wechsler Intelligence Scale for Children
WPPSI   Wechsler Preschool & Primary Scale of Intelligence

Contributor's statement page

Both authors confirm that they have made a substantive intellectual contribution to the study reported, in relation to each of the following criteria set out in the Author Instructions for *Pediatrics*:

1. Substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data. [NB. BSE oversaw all data acquisition and ran the data analyses. All other roles, including suggested data analyses, were conducted by both authors.]
2. Drafting the article and revising it critically for important intellectual content.
3. Final approval of the version to be published.

What is Known on this Subject
Clinical diagnosis of motor disorder is tied to intellectual ability in DSM-IV and ICD-10.

What This Study Adds
Overall, children with lower IQ scores had lower levels of motor skill, although motor skill at all levels of proficiency is seen across the IQ range, including in those with learning disability.

Abstract

Objective: In both clinical practice and research, motor delay is understood to be explained, at least in part, by intellectual abilities. However, no data are available in order to operationalise these criteria to guide clinical decision making. This study provides data on IQ and motor skill in children to answer three research questions concerning the relationship between IQ and motor skill: (1) Can motor coordination impairment be explained in terms of general intellectual retardation? (2) What level of motor performance is to be expected given the person's measured intelligence? (3) At what point are motor difficulties considered to be in excess of those usually associated with mental retardation?

Participants & Methods: IQ and motor skill data were analysed from a group of 460 children identified with/without motor difficulties from both clinical and educational settings.

Results: Typical and atypical motor skill was seen at all IQ levels, 19% of the variance in motor outcomes was explained by IQ scores, and for each standard deviation lower IQ, a mean loss of 10 percentile motor points should be expected.

Conclusions: Although individuals with a lower measured IQ more often showed poorer motor performance than those with a higher measured IQ, motor skill at all levels of proficiency was seen in all IQ categories. These findings have important implications for clinical judgements and decision-making as well as for future research directions to further operationalise the criteria relating to motor disorders in both DSM-IV and ICD-10.

INTRODUCTION

In clinical practice and in the scientific community, there are still many ambiguities in the definition of the diagnostic criteria for children with motor delays and motor coordination disorders[1]. According to the International Classification of Diseases[2], Specific Developmental Disorder of Motor Function (SDDMF, F82.0), is defined as "a disorder in which the main feature is a serious impairment in the development of motor coordination that is *not solely explicable in terms of general intellectual retardation* or of any specific congenital or acquired neurological disorder" (p.193). In the current Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR)[3], the more frequently used term, Developmental Coordination Disorder (DCD) is included in the "Motor skills disorders" (315.4) section of the "Learning disorders" chapter. Here, DCD is defined by four criteria, of which criteria A and D are of importance to this paper. In criterion A it is stated that "performance in daily activities that require motor coordination is substantially *below that expected* given the person's chronological age and *measured intelligence*" (p.58). In criterion D, it is added that "If mental retardation is present, *motor difficulties are in excess of those usually associated* with mental retardation" (p.58). Mental retardation (MR) is characterised "by significantly subaverage intellectual functioning (an IQ of approximately 70 or below) with onset before age 18 years

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and concurrent deficits or impairments in adaptive functioning" (p.37). In DSM-IV, children with MR are subclassified as borderline (IQ 71-84) or mild mental retardation (IQ 50-70)[4].

These criteria in the definition of SDDMF and DCD are based on the same underlying assumption; that a motor delay can be explained partly by intellectual or mental retardation. Additionally it is assumed that we should know how much motor delay we may expect given a certain intelligence, or how much motor delay can be explained by a certain level of mental retardation [a]. However, when trying to operationalise these criteria for a clinical practice guideline[1], no figures were available in the literature to guide clinical decision-making. Clinicians and researchers therefore often use a cut off IQ score of 70-80, and children with lower IQ levels are generally not given a diagnosis of DCD or SDDMF.

This state of affairs leads to the following research questions:
1. Can motor coordination impairment be explained in terms of general intellectual retardation (ICD-10)?
2. What level of motor performance is to be expected given the person's measured intelligence (DSM-IV, Criterion A)?
3. At what point are motor difficulties considered to be in excess of those usually associated with mental retardation (DSM-IV, Criterion A)?

The importance of these questions to clinicians and therapists is evermore crucial. It was possible to address these by a retrospective analysis of data obtained from children from mainstream and special education settings (n=302) between 2006 and 2010 and from clinical samples (n=106) over 2 years at 13 clinics. An additional mainstream group were also assessed (n=52).

PARTICIPANTS & METHODS
Participants
Data were collected from a total of 460 children (mean age 8.9 years, SD 1.9, range 4-13) over the IQ range 50-145. Only children with an IQ >50 were included because pilot data showed that they are able to complete the test items and understand the test instructions reliably[5]. Informed consent for the children's participation was obtained from the parent(s) and all procedures were in accordance with the ethical standards of the Faculty of Rehabilitation Sciences of the KULeuven (Belgium) and the Local Medical Ethics Committee of Nijmegen (The Netherlands).

Recruitment
In order to obtain data from children with a broad range of both motor and IQ abilities, participants were recruited from a range of sources. First, data from children in four types of schools were gathered including only children who were known not to be (or have been) receiving treatment for motor disorders

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[a] Mental retardation is typically used in the USA; Intellectual Disability or Learning Disability (LD) are more commonly used in the UK and Europe. In this paper we adopt the term LD.

('non-referred' group): 1) children attending mainstream schools with no history of motor difficulties (Mainstream n=52); 2) children attending schools for children with normal IQ but specific learning disorders (specific language impairment, developmental dyslexia or reading disability) and schools for children with general learning disabilities (IQ normal to below average) in the Netherlands (Special education NL n=173); 3) schools for children with general learning disabilities (IQ normal to below average) and schools for children with intellectual impairments (IQ 70-50) in Flanders (Special education FL n=129). Premature children (<36 weeks gestation) and children with epilepsy were excluded from these samples. In total this 'non-referred' group consisted of 354 children.

Second, data from children with known motor difficulties ('referred' group) were added to the dataset. These children had been referred for diagnosis or treatment to rehabilitation centres over a two year period having 'probable DCD'. Their data were eligible if IQ and motor assessments were available (n=106). Most of these children attended mainstream schools (n=75) and the rest schools for children with specific learning disorders (n=31). The IQ data for these samples were extracted from their education/clinic records. Intelligence was measured by school psychologists and trained assistants either as part of the regular diagnosis process (special education; clinical sample, n=408) or specifically for the purpose of the current study (mainstream sample, n=52) because no IQ records were available for children without motor problems. All children were tested by trained physical therapists on the Movement Assessment Battery for Children[6, 7]. For the purposes of analyses, data for all children were combined, and grouped according to the IQ categories described in DSM-IV. Participant details are shown in Table 1.

<< Table 1 about here>>

Assessment tools
   <u>Intelligence assessments</u>
IQ was measured using the following standardised tests: the Wechsler Intelligence Scale for Children (WISC-III/WISC-IV)[8, 9] and the Wechsler Preschool & Primary Scale of Intelligence (WPPSI[10]; for children aged 2.5-7 years) administered in 314 of the cases, the Kaufman Assessment Battery for Children (KABC[11]; for children aged 4-21), for 110 cases, the Snijders-Oomen Non Verbal Intelligence Test – Revision (SON-R[12], for children aged 2.5-17) for 31 of the cases. In the remaining five cases, the Raven[13] and RAKIT[14] were administered. These tests are all suitable for this age group and since scores are standardised they are appropriate for use within the same dataset as an index of IQ. Intelligence quotients (IQ) are reported. These refer to the total IQ score for the particular IQ test administered.

   <u>Motor assessment</u>
To assess the severity and extent of movement skill/difficulty of the children, the motor assessment adopted most commonly in research was used: the

Movement ABC Test (M-ABC[6]) and its more recent revision (M-ABC2[7]) (henceforth, M-ABC refers to the use of either version of the test). The aim of the M-ABC is to classify children according to degree of motor impairment. There are separate age-related item-sets, each consisting of 8 items measuring: manual dexterity (3 items), aiming and catching (2 items), and balance (3 items). Total score can be transformed into percentiles. The structure of the two versions of the M-ABC and the content of most of the items are similar. For the evaluation of motor performance, half of the children (47 %) were tested with the first edition of the M-ABC, and the other half (53 %) with the second edition (see Table 2). The proportion of children in each IQ group completing each edition of the test was split similarly. The M-ABC has been shown to be suitable for use with children whose measured IQs are as low as 45[7,15]. To be able to use data from both editions of the test, percentile scores were used.

<< Table 2 about here>>

Statistical analyses
To answer the first research question (Can motor coordination impairment be explained in terms of general intellectual retardation?), Spearman correlations were calculated between IQ and motor percentile scores. The squared correlation (R^2) was calculated as a measure of explained variance. Secondly quadratic curve estimation was tested however; this did not increase the explained variance. With respect to question 2 (What level of motor performance is to be expected given the person's measured intelligence?), we calculated mean group percentile scores on the motor test for the children with mild LD (IQ 50-70), borderline LD (IQ 71-84), and normal IQ (85+). An Analysis of Variance (ANOVA) was conducted to investigate the effects of IQ classification on motor percentile score. Post hoc t-tests were used to determine if the means of the three IQ groups differed from each other. Finally, to answer question 3 (At what point are motor difficulties in excess of those usually associated with mental retardation ?), a linear regression with motor percentile score as the dependent variable and IQ as the predictor was used to calculate the difference in motor percentile scores per IQ point in our population. The 95% confidence interval is given to indicate the reliability of these estimates in our population. A value outside the lower limit of this estimation could be considered "in excess"of what was expected in our population.

RESULTS

Question 1: Can motor coordination impairment be explained in terms of general intellectual retardation (ICD-10)?
Motor and IQ scores are shown for each participant, broken down by IQ group, in Figure 1. The correlation between IQ and motor scores across the entire group was r .44, p<.001. About 19 % of the variance in motor percentile scores was explained by IQ scores. Although there is a linear trend, clear exceptions can be seen in all groups at an individual level (see Figure 1).

<<Figure 1 about here>>

Question 2: What level of motor performance is to be expected given the person's measured intelligence (DSM-IV, Criterion A)?

A one way ANOVA with IQ group as between subject variable was conducted with motor percentile score as the dependent variable. Motor percentile scores were significantly different between the IQ groups (F (2, 457) 27.12, p<0.001, means: 27.7, 12.9, and 6.3, for normal (85+), borderline (IQ 71-84), and mild LD (IQ 50-70), respectively. Pairwise comparisons (t-tests) showed that all groups differed from each other (p < 0.01). As shown in Table 3 the majority of children with IQ below 85 scored in the impaired motor range. In our sample of children with mild LD, 82% had a score below the 5th percentile. Based on these group data one would generally not expect a child with mild LD to perform within the normal range on a motor test. Nevertheless, there are children with borderline LD (26%) and mild LD (12%) who show motor performance within the normal range.

<<Figure 2 and Table 3 about here>>

Question 3: At what point are motor difficulties in excess of those usually associated with mental retardation (DSM-IV, Criterion A)? Although the means of the IQ groups give an indication of what motor performance to expect for the groups with lower IQ, they do not give a straight answer to this question. Therefore a linear regression with motor percentile scores as the dependent variable and IQ as the predictor was used to calculate the difference in motor percentile scores per IQ point in our population. Results of this regression showed that for each IQ point, around two thirds of a percentile point are lost on the motor test (Mean 0.66, lower 0.54 and upper limits 0.77 percentile point per IQ point; B=0.44, t=10, p<.001) (see Figure 2). These findings indicate that for each standard deviation lower IQ, a mean loss of 10 percentile motor points would be expected.

DISCUSSION

In our large sample, individuals with lower measured IQ more often showed poorer motor performance than those with a higher measured IQ, substantiating the evidence that motor performance and cognitive development are interrelated[16-18]. At the very least, they are intertwined at both cognitive and neurological levels, for instance through the brain structures and networks associated with the cognitive processes involved in attention, executive function, visuomotor skill, timing and learning. However as expected there is no one-to-one relationship between cognitive ability (assessed through IQ assessment) and motor skill. Although not all individuals diagnosed as LD are poorly coordinated, the vast majority of the current sample was.

To answer the study's three focused questions, it appeared that only 19% of motor impairment can be explained by the level of general intellectual

retardation. This leaves other causes to explain the remaining 81% of the variance. It will be important to identify other factors in future research, with attention, poor automatisation and executive function as possible candidates[19, 20]. Our study highlighted that for each standard deviation drop in IQ, one would expect a reduction of 10 percentile points (95% CI 8-12 points) on the Movement ABC. The clinical implication of this finding is that, in general, a larger motor assessment deficit than this is indicative of a motor difficulty that exists over and above the impact of IQ. Moreover, the finding that only 26% of all children with learning disabilities (borderline LD) performed in the normal range on the Movement ABC is noteworthy. While it suggests that not all children with learning disabilities have motor impairments, therefore suggesting a reasonable degree of potential separation between the cognitive and motor system, it also suggests that clinicians should be cautious when interpreting the scores of children with learning disabilities on motor assessment batteries and the development of instruments with greater validity in this group may be warranted.

Although the current study has implications for the assessment of individuals with motor difficulties and/or learning disability generally, it is particularly important for those with DCD (SDDMF). The problem of diagnosing DCD (SDDMF) in children with severe learning difficulties (mental retardation) was discussed extensively within the European consensus group when developing the EACD recommendations for DCD as well as by previous groups[1,21]. In the European EACD guidelines, it was recognised that defining a specific IQ below which the diagnosis of DCD (SDDMF) is precluded seems artificial. The results of the current study have confirmed that arbitrating between cut-offs and determining discrepancy scores between motor and IQ is very complex. The data reported here highlight a very general trend of lower motor percentile scores in children with learning difficulties (IQ<70). Indeed, the number of children with motor problems is so high that general screening and extra resources to implement skills training should be recommended in this group. However, for children at the lower end of the IQ range we would urge extra care to be taken in the use/interpretation of existing motor percentile scores since these have not been developed to clarify performance at the bottom end of the scale: Children with poor and very poor performance will all score on the 1st centile, although their performance should be rated differently from each other. A large problem in interpreting the current literature is that children with lower IQ have been excluded systematically from the experimental and intervention literature, so scant data are available on this population.

As shown in this paper, children with LD show a high risk for motor impairments. The impact of poor manual dexterity and balance is not to be underestimated and requires greater public awareness. Motor skill disorders will interfere with school and after-school activities, independence, social acceptance by peers and social skills, among others[22-24]. Moreover, a large number of children with LD are likely to pursue vocational training, where these abilities are mandatory[25]. Therefore adequate assessment and the prescription of task

specific interventions are crucial. Furthermore, children with lower IQs need more time to learn a motor task. Hence early recognition and the positive influence of environmental factors are necessary to provide extra ways to practice skills during activities of daily living and leisure activities. Lastly, poor motor skills in those with LD may also lead to mental and physical health risks comparable to that seen in children with DCD. These include poor physical fitness, cardiovascular health and obesity[26-29], as well as depression and anxiety[30-33].

While this is a significant study in terms of sample size and outcome for clinicians and researchers, there are inevitably a number of limitations. The retrospective, rather than prospective nature of the study with the inevitable methodological issues that this produces, notably the use of the two editions of the M-ABC and the varied IQ tests used are concerns. However, the motor and IQ tests are all standardised across a population appropriate for the current study and the range of tests were spread similarly across all three IQ groups. Notwithstanding these limitations, this dataset allows consideration of the relationship between IQ and motor skill that would not otherwise have been possible and which has increasingly important implications for clinicians, therapists and researchers.

Although defining a specific IQ level to distinguish between children with DCD and children with coordination problems due to learning disabilities may not seem opportune, we recommend doing so until specifically adapted tests are available. Nonetheless, even without appropriate testing materials, the current study highlighted that most of the children with lower cognitive abilities included in these analyses experience motor problems that are expected to impact significantly on their daily activities. It will be crucial in future studies to investigate the relationships between measured IQ and motor skill further, to evaluate the impact of each on the measurement of the other, as well as in daily life, academic achievement and longer-term outcomes.

CONCLUSIONS
While cognitive and motor problems do not always co-vary, they do in the majority of children with borderline and mild mental retardation/learning disabilities. It is important to remember that dysfunction in one component of the neural system will affect the other components, particularly in a developing brain. The current study is the first to provide indications of expected levels of motor skill given a child's intellectual functioning and highlights the importance of considering the discrepancy between IQ and motor outcome scores in assessment and remediation.

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Table 1. Participant details, including gender, age, M-ABC percentile and IQ scores for each referral and IQ group.

	N	Gender M (F)	Age (yrs) Mean (SD) *range*	M-ABC centile Mean (SD) *range*	IQ Mean (SD) *range*
Non-referred children (mainstream and special education)	354	220 (134)	9.19 (1.75) *4-13*	21.67 (27.53) *1-100*	85,31 (16.79) *50-144*
Referred children (probable DCD)	106	89 (17)	8.01 (1.94) *4-13*	14.28 (18.51) *1-96*	97.89 (17.22) *70-145*
IQ CATEGORIES:					
Normal IQ (85+)	247	171 (76)	8.65 (1.78) *4-13*	27.68 (30.28) *1-100*	101.05 (12.87) *85-145*
Borderline LD (71-84)	152	95 (57)	9.33 (1.91) *4-13*	12.92 (17.62) *1-79*	77.77 (4.10) *70-84*
Mild LD (50-70)	61	43 (18)	8.99 (7.89) *6-13*	6.3 (13.64) *1-75*	62.25 (5.62) *50-69*
Overall total	460	309 (151)	8.92(1.86) *4-13*	19.97 (26.29) *1-100*	88.21 (17.69) *50-145*

Table 2. Percentage of children in each IQ group completing the M-ABC vs. M-ABC2.

	M-ABC	*M-ABC2*
Normal range (85+)	43.7	56.3
Borderline LD (84-71)	48	52
Mild LD (≤70)	59	41

Table 3. Percentage of normal (n=247), borderline LD (n=152) and mild LD (n=61) groups categorised as in the normal range, at risk and impaired categories on the M-ABC.

	Movement ABC classification (centile)		
	Normal range ($\geq 16^{th}$)	At risk ($6^{th} - 15^{th}$)	Impaired ($\leq 5^{th}$)
Normal range (85+)	50.2	13.0	36.8
Borderline LD (84-71)	26.3	21.1	52.6
Mild LD (≤70)	11.5	6.6	82.0

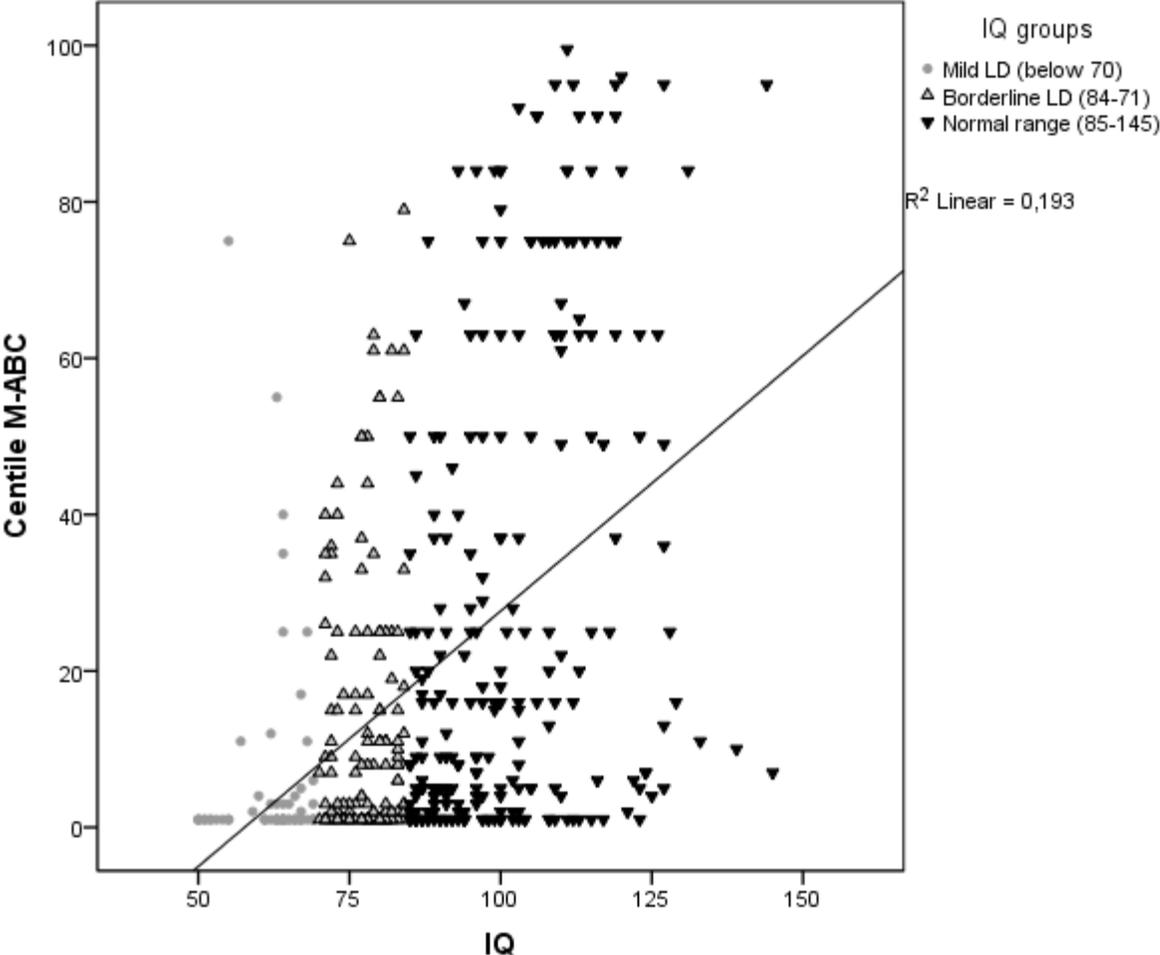Figure 1: Motor percentile and IQ scores for each participant, broken down by IQ category.