PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

The Relationship Between Motor Coordination and Intelligence Across the IQ Range

Bouwien Smits-Engelsman and Elisabeth L. Hill

Pediatrics 2012;130;e950; originally published online September 17, 2012;
DOI: 10.1542/peds.2011-3712

The Relationship Between Motor Coordination and Intelligence Across the IQ Range

WHAT'S KNOWN ON THIS SUBJECT: Clinical diagnosis of motor disorder is tied to intellectual ability in the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Revision,* and the *International Classification of Diseases, 10th Revision.*

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 to operationalize these criteria to guide clinical decision making. This study provides data on IQ and motor skills in children to answer 3 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 should 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?

METHODS: IQ and motor skill data were analyzed 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 SD 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 judgments and decision-making, as well as for future research directions to further operationalize the criteria relating to motor disorders in both the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Revision,* and the *International Classification of Diseases, 10th Revision. Pediatrics* 2012;130:e950–e956

AUTHORS: Bouwien Smits-Engelsman, PhD,[a,b] and Elisabeth L. Hill, PhD[c]

[a]Department of Biomedical Kinesiology, Katholieke Universiteit Leuven, Leuven, Belgium; [b]Avansplus University for Professionals, Breda, Netherlands; and [c]Department of Psychology, Goldsmiths University of London, New Cross, London, United Kingdom

KEY WORDS

motor development, intelligence, learning disability

ABBREVIATIONS

DCD—developmental coordination disorder
DSM-IV—*Diagnostic and Statistical Manual of Mental Disorders, Fourth Revision*
M-ABC—Movement Assessment Battery for Children
SDDMF—Specific Developmental Disorder of Motor Functions

Both authors confirm that they have made substantive intellectual contributions 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 (Dr Smits-Engelsman 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, and (3) final approval of the version to be published.

www.pediatrics.org/cgi/doi/10.1542/peds.2011-3712

doi:10.1542/peds.2011-3712

Accepted for publication May 31, 2012

Address correspondence to Bouwien Smits-Engelsman, PhD, Department of Biomedical Kinesiology, Katholieke Universiteit Leuven, Tervuursevest 101, 3001 Heverlee, Belgium. E-mail: bouwiensmits@hotmail.com

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: *The authors have indicated they have no financial relationships relevant to this article to disclose.*

FUNDING: No external funding.

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, 10th Revision* (ICD-10),[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, Fourth Edition, Text Revision*,[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 4 criteria, of which criteria A and D are of importance to this article. 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 is characterized "by significantly subaverage intellectual functioning (an IQ of approximately 70 or below) with onset before age 18 years and concurrent deficits or impairments in adaptive functioning" (p. 37). In the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV), children with mental retardation 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. (Mental retardation is typically used in the United States; intellectual disability or learning disability are more commonly used in the United Kingdom and Europe. In this article, we adopt the term learning disability.) When trying to operationalize these criteria for a clinical practice guideline,[1] however, no figures were available in the literature to guide clinical decision-making. Clinicians and researchers therefore often use a cutoff IQ score of 70 to 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 (*International Classification of Diseases, 10th Revision*)?
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 was also assessed (n = 52).

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 to 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 Rehabiltation Sciences of the Katholieke Universiteit Leuven (Belgium) and the Local Medical Ethics Committee of Nijmegen (Netherlands).

Recruitment

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 4 types of schools were gathered, including only children who were known not to be (or have been) receiving treatment for motor disorders ("nonreferred" 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 Netherlands, 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 Flanders, n = 129). Premature children (<36 weeks' gestation) and children with epilepsy were excluded from these samples. In total, this "nonreferred" 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 centers over a 2-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 attended 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 (M-ABC).[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.

Assessment Tools

Intelligence Assessments

IQ was measured by using the following standardized tests: the Wechsler Intelligence Scale for Children (versions III and IV)[8,9] and the Wechsler Preschool & Primary Scale of Intelligence[10] (for children aged 2.5–7.0 years) administered in 314 of the cases; the Kaufman Assessment Battery for Children[11] (for children aged 4–21) for 110 cases; and the Snijders-Oomen Non Verbal Intelligence Test–Revision[12] (for children aged 2.5–17.0) for 31 of the cases. In the remaining 5 cases, the Raven[13] and Revisie Amsterdamse Kinder Intelligentie Test[14] were administered. These tests are suitable for this age group and because scores are standardized, they are appropriate for use within the same dataset as an index of IQ. IQs are reported. These refer to the total IQ score for the particular IQ test administered.

Motor Assessment

To assess the severity and extent of movement skill/difficulty of the children, the motor assessment adopted most commonly in research was used: the 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 that measure manual dexterity (3 items), aiming and catching (2 items), and balance (3 items). Total score can be transformed into percentiles. The structure of the 2 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.

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. Second, 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

TABLE 1 Participant Details, Including Gender, Age, M-ABC Percentile, and IQ Scores for Each Referral and IQ Group

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

TABLE 2 Percentage of Children in Each IQ Group Completing the M-ABC Versus M-ABC2

	M-ABC	M-ABC2
Normal range (85+)	43.7	56.3
Borderline learning disability (84–71)	48	52
Mild learning disability (50–70)	59	41

person's measured intelligence?), we calculated mean group percentile scores on the motor test for the children with mild learning disability (IQ 50–70), borderline learning disability (IQ 71–84), and normal IQ (85+). Analysis of variance 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 3 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 Fig 1. The correlation between IQ and motor scores across the entire group was $r = 0.44$, $P < .001$. 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 Fig 1).

Question 2: What Level of Motor Performance Is to Be Expected Given the Person's Measured Intelligence (DSM-IV, Criterion A)?

A 1-way analysis of variance with IQ group as the 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, $P < .001$, means: 27.7, 12.9, and 6.3, for normal (85+), borderline (IQ 71–84), and mild learning disability (IQ 50–70), respectively. Pairwise comparisons (*t* tests) showed that all groups differed from each other ($P < .01$). As shown in Table 3, most children with IQ below 85 scored in the impaired motor range. In our sample of children with mild learning disability, 82% had a score below the fifth percentile. Based on these group data, one would generally not expect a child with mild learning disability to perform within the normal range on a motor test. Nevertheless, there are children with borderline learning disability (26%) and mild learning disability (12%) who show motor performance within the normal range.

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

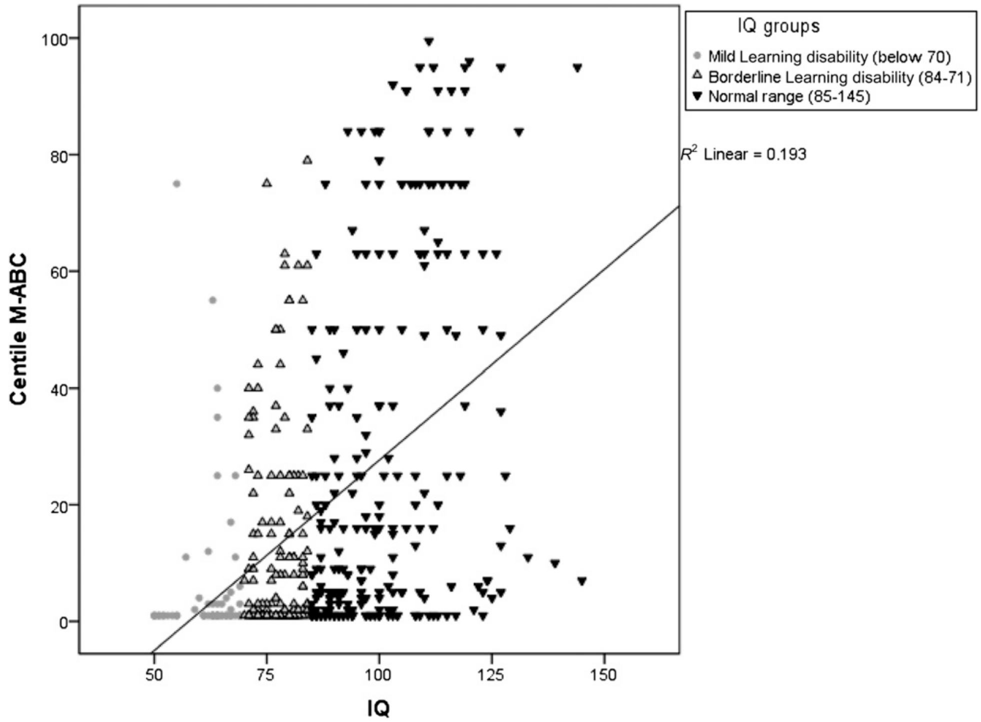

FIGURE 1
Motor percentile and IQ scores for each participant, broken down by IQ category.

TABLE 3 Percentage of Normal Range (n = 247), Borderline Learning Disability (n = 152), and Mild Learning Disability (n = 61) Groups Categorized as in the Normal Range, At Risk, and Impaired Categories on the M-ABC

	Movement ABC Classification, centile		
	Normal Range (≥16th)	At Risk (6th–15th)	Impaired (≤5th)
Normal range (85+)	50.2	13.0	36.8
Borderline learning disability (84–71)	26.3	21.1	52.6
Mild learning disability (≤70)	11.5	6.6	82.0

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, approximately 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 Fig 2). These findings indicate that for each SD 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 neurologic 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 1-to-1 relationship between cognitive ability (assessed through IQ assessment) and motor skill. Although not all individuals diagnosed as learning disabled are poorly coordinated, the vast majority of the current sample was.

To answer the study's 3 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 automatization, and executive function as possible candidates.[19,20] Our study highlighted that for each SD drop in IQ, one would expect a reduction of 10 percentile points (95% confidence interval 8–12 points) on the M-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 learning disability) performed in the normal range on the M-ABC is noteworthy. Although 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 European Academy of Childhood Disability recommendations for DCD, as well as by previous groups.[1,21] In the European Academy of Childhood Disability guidelines, it was recognized 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 cutoffs 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. For children at the lower end of the IQ range, however, we would urge extra care to be

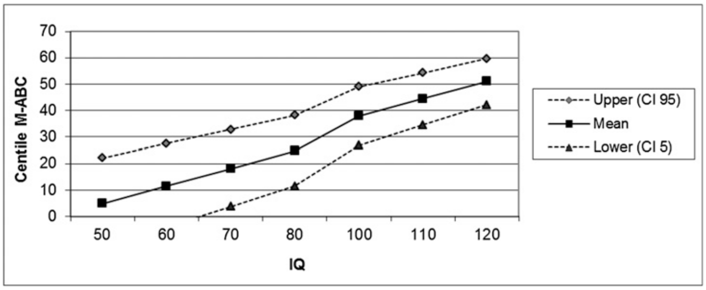

FIGURE 2
Relationship between motor percentile and IQ scores: expected motor percentile score based on 10-point IQ bands (n = 460). CI, confidence interval.

taken in the use/interpretation of existing motor percentile scores, as 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 first 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 article, children with learning disability 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 learning disability 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. Last, poor motor skills in those with learning disability may also lead to mental and physical health risks comparable to that seen in children with DCD. These include poor physical fitness and cardiovascular health, and obesity,[26–29] as well as depression and anxiety.[30–33]

Although 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 2 editions of the M-ABC and the varied IQ tests used, are concerns. However, the motor and IQ tests are all standardized across a population appropriate for the current study and the range of tests were spread similarly across all 3 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 that 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 because of 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

Although cognitive and motor problems do not always covary, they do in most 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.

ACKNOWLEDGMENTS

We are grateful to all the children, schools, and rehabilitation centers who participated in the work described here. Thanks are also due to a number of physical therapists, rehabilitation centers, Master's students at Katholieke Universiteit Leuven and Avansplus University for Professionals, Breda, Netherlands, for testing the children.

REFERENCES

1. Blank R, Smits-Engelsman B, Polatajko H, Wilson P; European Academy for Childhood Disability. European Academy for Childhood Disability (EACD): recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version). *Dev Med Child Neurol*. 2012;54(1):54–93
2. World Health Organization. *The ICD-10 Classification for Mental and Behavioural Disorders: Diagnostic Criteria for Research*. Geneva, Switzerland: World Health Organization; 1993
3. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 4th ed, text revision. Washington, DC: American Psychiatric Association; 2000
4. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders*. 4th ed. Washington, DC: American Psychiatric Association; 1994
5. Houtman M. *Children with Mild Intellectual Disabilities Can Be Reliably Tested with the*

Movement ABC-2. Breda, The Netherlands: Avansplus, University for Professionals Breda; 2011
6. Henderson SE, Sugden DA. *Movement Assessment Battery for Children*. Sidcup, UK: Psychological Corporation; 1992
7. Henderson SE, Sugden DA, Barnett AL. *Movement Assessment Battery for Children*. 2nd ed. London, UK: Pearson Assessment; 2007
8. Wechsler D. *Wechsler Intelligence Scale for Children*. 3rd ed. London, UK: Psychological Corporation; 1992
9. Wechsler D. *Wechsler Intelligence Scale for Children*. 4th ed. London, UK: Pearson Assessment; 2004
10. Wechsler D. *Wechsler Pre-school & Primary Scale of Intelligence*. 3rd ed. London, UK: Pearson Assessment; 2003
11. Kaufman AS, Kaufman NL. *Kaufman Assessment Battery for Children*. 2nd ed. Circle Pines, MN: American Guidance Service; 2004
12. Snijders JT, Tellegen PJ, Laros JA. *Snijders-Oomen Nonverbal Intelligence Test - Revised*. Göttingen, Germany: Hogrefe-Verlag; 2003
13. Raven JC, Court JH, Raven J. *Raven's Progressive Matrices and Raven's Coloured Matrices*. London, UK: H.K. Lewis; 1986
14. Bleichrodt N, Drenth PJD, Zaal JN, Resing WCM. *Revisie Amsterdamse Kinder Intelligentie Test: RAKIT*. Lisse, Netherlands: Swets & Zeitlinger; 1987
15. Spanò M, Mercuri E, Randò T, et al. Motor and perceptual-motor competence in children with Down syndrome: variation in performance with age. *Eur J Paediatr Neurol*. 1999;3(1):7–13
16. Bruggink JLM, Van Braeckel KN, Bos AF. The early motor repertoire of children born preterm is associated with intelligence at school age. *Pediatrics*. 2010;125(6). Available at: www.pediatrics.org/cgi/content/full/126/6/e1356
17. Pangelinan MM, Zhang G, VanMeter JW, Clark JE, Hatfield BD, Haufler AJ. Beyond age and gender: relationships between cortical and subcortical brain volume and cognitive-motor abilities in school-age children. *Neuroimage*. 2011;54(4):3093–3100
18. Hartman E, Houwen S, Scherder E, Visscher C. On the relationship between motor performance and executive functioning in children with intellectual disabilities. *J Intellect Disabil Res*. 2010;54(5):468–477
19. Beauchet O, Annweiler C, Montero-Odasso M, Fantino B, Herrmann FR, Allali G. Gait control: a specific subdomain of executive function? *J Neuroeng Rehabil*. 2012;9(12): 22321772
20. Kamke MR, Hall MG, Lye HF, et al. Visual attentional load influences plasticity in the human motor cortex. *J Neurosci*. 2012;32(20):7001–7008
21. Sugden D, ed. *Developmental Coordination Disorder as a Specific Learning Difficulty. Leeds Consensus Statement*. Cardiff, UK: The Dyscovery Trust; 2006
22. Smyth MM, Anderson HI. Coping with clumsiness in the school playground: social and physical play in children with coordination impairments. *Br J Dev Psychol*. 2000;18:389–413
23. Piek JP, Barrett NC, Allen LS, Jones A, Louise M. The relationship between bullying and self-worth in children with movement coordination problems. *Br J Educ Psychol*. 2005;75(pt 3):453–463
24. Sugden D, Chambers M, eds. *Children with Developmental Coordination Disorder*. London, UK: Whurr Publishers; 2005
25. Magalhães LC, Cardoso AA, Missiuna C. Activities and participation in children with developmental coordination disorder: a systematic review. *Res Dev Disabil*. 2011;32(4): 1309–1316
26. Rivilis I, Liu J, Cairney J, Hay JA, Klentrou P, Faught BE. A prospective cohort study comparing workload in children with and without developmental coordination disorder. *Res Dev Disabil*. 2012;33(2):442–448
27. Cairney J, Hay JA, Faught BE, Hawes R. Developmental coordination disorder and overweight and obesity in children aged 9-14 y. *Int J Obes (Lond)*. 2005;29(4):369–372
28. Schott N, Alof V, Hultsch D, Meermann D. Physical fitness in children with developmental coordination disorder. *Res Q Exerc Sport*. 2007;78(5):438–450
29. Green D, Lingam R, Mattocks C, Riddoch C, Ness A, Emond A. The risk of reduced physical activity in children with probable developmental coordination disorder: a prospective longitudinal study. *Res Dev Disabil*. 2011;32(4):1332–1342
30. Pearsall-Jones JG, Piek JP, Rigoli D, Martin NC, Levy F. Motor disorder and anxious and depressive symptomatology: a monozygotic co-twin control approach. *Res Dev Disabil*. 2011;32(4):1245–1252
31. Piek JP, Rigoli D, Pearsall-Jones JG, et al. Depressive symptomatology in child and adolescent twins with attention-deficit hyperactivity disorder and/or developmental coordination disorder. *Twin Res Hum Genet*. 2007;10(4):587–596
32. Pratt ML, Hill EL. Anxiety profiles in children with and without developmental coordination disorder. *Res Dev Disabil*. 2011;32(4): 1253–1259
33. Skinner RA, Piek JP. Psychosocial implications of poor motor coordination in children and adolescents. *Hum Mov Sci*. 2001; 20(1-2):73–94

The Relationship Between Motor Coordination and Intelligence Across the IQ Range

Bouwien Smits-Engelsman and Elisabeth L. Hill

Pediatrics 2012;130;e950; originally published online September 17, 2012;
DOI: 10.1542/peds.2011-3712