Consequences of Comorbidity of Developmental Coordination Disorders and Learning Disabilities for Severity and Pattern of Perceptual–Motor Dysfunction

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Abstract

Children with developmental coordination disorder (DCD) have difficulty learning and performing age-appropriate perceptual–motor skills in the absence of diagnosable neurological disorders. Descriptive studies have shown that comorbidity of DCD exists with attention-deficit/hyperactivity disorder (ADHD) and learning disabilities (LD). This study examined the consequences of the comorbidity of DCD and LD for the severity and pattern of perceptual–motor dysfunction. Compared to children with DCD without LD, children with comorbid DCD and LD performed lower on a standardized assessment of perceptual–motor ability. Furthermore, it appeared that children with combined DCD and LD have particular difficulty performing manual dexterity and balance tasks but not ball-skill tasks. Implications for understanding the relationship between LD and perceptual–motor problems are discussed. We conclude that the comorbidity of DCD and LD not only affects the severity of perceptual–motor dysfunction but also is associated with a distinctive pattern of perceptual–motor dysfunction.

The task force responsible for publishing the third, revised edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-III-R*; American Psychiatric Association, 1987) included for the first time a separate entry for children with developmental perceptual–motor problems. The term chosen to classify these children was *developmental coordination disorder* (DCD; see Note 1). In the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (*DSM-IV*; American Psychiatric Association, 1994), children with DCD are described as experiencing perceptual–motor problems that hinder them to such an extent that the quality of their academic performance or activities of daily living are affected in the absence of any medical explanation. The prevalence of DCD has been estimated to be as high as 6% for children in the age range of 5 to 11 years (American Psychiatric Association, 1994), although a large variation in these figures has been reported, from 2.7% in the Netherlands (Van Dellen, Vaessen, & Schoemaker, 1990) to 15.6% in Singapore (Wright, Sugden, Ng, & Tan, 1994). The types of motor learning problems encountered by these children vary from difficulties with mastering functional skills, such as tying shoelaces or riding a bicycle, to difficulties with basic perceptual–motor tasks such as making fast, goal-directed movements (e.g., touching a button as fast as possible in a reaction time task; Geuze & van Dellen, 1990; Wilson & McKenzie, 1998). The literature on children with DCD acknowledges that they are a heterogeneous group with respect to the profile of perceptual–motor problems. This has prompted a search for subtypes to gain a better understanding of possible underlying mechanisms of dysfunction and to provide clues for effective therapeutic intervention (e.g., Dewey & Kaplan, 1994; MacNab, Miller, & Polatajko, 2001; Schoemaker, Smits-Engelsman, & Kalverboer, 1997; Smits-Engelsman, Van Galen, & Schoemaker,1997).

The clinical picture that children with DCD present is even more complicated because of the frequent comorbidity of other developmental disorders (Dewey & Wilson, 2001; Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001; Henderson & Barnett, 1998). The two most commonly mentioned comorbid disorders are attention-deficit/hyperactivity disorder (ADHD) and learning disabilities (LD). For example, the rate of comorbidity between DCD and ADHD has been reported to be approximately 50% (Kadesjö & Gillberg, 1999; Landgren, Petterson, Kjellman, & Gillberg, 1996), and estimates for the rate of comorbidity between DCD and LD are of a similar magnitude (Kaplan, Wilson, Dewey, & Crawford, 1998; Lyytinen & Ahonen, 1989; Silva, McGee, & Williams, 1982). In the past, the term *deficits in attention, motor control, and perception* (DAMP) has been applied to describe children with a combination of DCD and ADHD (Landgren, Kjellman, & Gillberg, 1998). Moreover, the three conditions (DCD, ADHD, and LD) frequently show comorbidity (Dewey, Wilson, Crawford, & Kaplan, 2000). It is interesting to observe that whereas in the past much effort has been spent on defining discrete diagnostic categories of children with developmental disorders, the current wave of observed comorbidity has inspired some researchers to call for reconsidering the validity of discrete developmental disorders. For example, Kaplan et al. (1998) posed the thesis that "there are no reliably identifiable, discrete developmental disorders because they are all reflections of heterogeneous, atypical brain development (ABD)" (pp. 484–485). However, before the pendulum swings back the other way, toward an all-inclusive label, it is important to establish that children with—at the moment—accepted separate developmental disorders indeed do *not* differ from each other on a number of key characteristics. If they did, this would suggest that, at least for descriptive purposes, it is better to keep the separate diagnostic categories for the moment.

Whether children with just DCD, ADHD, or LD and children with a combination of any of these developmental disorders differ from each other in terms of the severity and pattern of their perceptual–motor dysfunction has until recently received little attention. Yet, as we have just argued, it is clear that the outcome of such comparisons is of relevance in establishing the validity of separate diagnostic entries for these three common developmental disorders. We know of only one study that has asked the question of whether perceptual–motor problems in children with DCD and children with both ADHD and DCD (DAMP) share a common underlying deficit (Pereira, Landgren, Gillberg, & Forssberg, 2001). Children with either isolated DCD or DAMP were assessed on a task measuring the coordination of grip force and load force required while lifting a small weight. It was shown that both groups failed to reach the age norm for the coordination pattern of grip force and load force specific for a grip–lift synergy. However, children with isolated DCD did not differ from children with a combination of DCD and ADHD in the control of grip force, suggesting similar perceptual–motor control problems on this task in both groups.

Experimental or descriptive studies separating the performance of children with DCD with and without LD in order to study perceptual–motor profiles in the same way as the aforementioned studies on DCD and ADHD have not, to our knowledge, been undertaken. The aims of the present study were to investigate whether there is a difference in the severity of perceptual–motor problems encountered by children with DCD with and without concomitant LD and to determine whether there is a difference in the pattern of perceptual–motor dysfunction between children with DCD with and without concomitant LD.

Method

Participants

Data collected on 749 children ranging in age from 4 to 13 years were used for this study. The children were recruited across the whole of the Netherlands (n = 594) and a part of Germany near the Dutch–German border (n = 155; see Note 2). The data set consisted of two groups of children: a randomly selected group of 535 children who took part in a study to establish Dutch norms for a test of perceptual–motor function, the *Movement Assessment Battery for Children* (MABC; Smits-Engelsman, 1998), and a group of 214 children who had been referred by their physician to a pediatric physical therapist for further examination and treatment of suspected perceptual–motor problems. The large majority of the children (n = 602; 80%) attended schools for general education. The remainder of the sample (n = 147; 20%) attended Dutch schools for children with special educational needs. Until 2001, admission to special education in the Netherlands was decided by a committee consisting of at least the school principal, a medical doctor, a welfare worker, and a psychologist or an educator. The admission process included administering psychological and academic achievement tests to the child. If the child's needs lay in the motor domain (e.g., cerebral palsy, muscular dystrophy) he or she was offered a place at a so-called Mytyl school (i.e., a school for children with a physical disability). Children without a physical disability with an average IQ of 60 to 80 were placed in a so-called MLK school (i.e., a school for children with educable mental retardation). Children with learning and pedagogic problems and an IQ of 80 or higher were placed in a so-called LOM school (i.e., a school for children with a learning disability). A learning disability was diagnosed when academic achievement was significantly (2 years) behind that expected in relation to IQ in the absence of explanatory factors, such as physical or sensory (auditory or visual) impairments or social context factors (i.e., poor education or lack of opportunity). All children participating in the current study attended a LOM school. No data were available on the ethnic origin or socioeconomic background of the children.

For the current study, children were classified as having DCD if they met the criteria described in the *DSM-IV*:

1. Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling, sitting); dropping things; clumsiness; poor performance in sports; or poor handwriting.
2. The disturbance in Criterion 1 significantly interferes with academic achievement or activities of daily living.
3. The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, muscular dystrophy) and does not meet the criteria for Pervasive Developmental Disorder.

In other words, children with a total score on the MABC below the 15th percentile (Criterion 1) who were referred to a pediatric physical therapist for their perceptual–motor problems (Criterion 2) without an observable, known neurological disorder (Criterion 3) were assigned to the DCD group. The inclusion criteria for the DCD group stipulated that the participants did not have any indication of a neurological or physical impairment.

Children attending special education were classified as children with LD. Not enough data were available on the children attending special education schools to classify them according to the *DSM-IV* criteria for reading, spelling, writing, or arithmetic disorders. However, children attending Dutch schools for LD in general experience difficulty with basic reading and language skills (80%) notwithstanding average IQ (above 80). Problems with mathematics also occur but are less common. Children with mental retardation, autism, deafness, blindness, and severe behavioral disorders attend different types of schools for special education in the Netherlands. No data were available on the presence or absence of behavioral or conduct disorders (e.g., ADHD).

The procedure just described led to the formation of four groups of children: children without DCD and without LD (Group 1; $n = 545$); children without DCD but with LD (Group 2; $n = 94$); children with DCD but without LD (Group 3; $n = 57$); and finally, children with both DCD and LD (Group 4; $n = 53$). Table 1 presents the age and gender distributions in each group. A univariate general linear model showed a main effect of age, $F(3, 745) = 2.68$, $p = .046$, adjusted R^2 for corrected model = .007, but post hoc multiple comparisons showed no significant differences between any of the groups. Chi-square analyses revealed an overall difference in the proportion of boys between the groups, $\chi^2(3, N = 437) = 33.82$, $p < .001$. Partitioned chi-square analyses showed a linear increase in the proportion of boys from the no DCD/no LD group to the DCD + LD group.

TABLE 1
Age and Gender Distribution Across Participant Groups

Characteristic	No DCD/no LD[a]	LD only[b]	DCD only[c]	DCD + LD[d]
Age (mos.)				
M	95.63	100.66	93.25	103.83
SD	26.65	27.65	22.07	21.04
Gender				
Boys/girls (*n*)	284/261	66/28	44/13	43/10
Boys (%)	52	70	77	81

Note. DCD = developmental coordination disorder; LD = learning disabilities.
[a]$n = 545$. [b]$n = 94$. [c]$n = 57$. [d]$n = 53$.

Measures

All children were assessed on the MABC (Henderson & Sugden, 1992). This test provides an indication of a child's motor functioning across fine and gross motor tasks. Performance is related to norms using age-dependent standardized scores for children ages 4 to 12 years. There are four age bands. Age Band 1 covers the ages of 4 to 6 years, Age Band 2 is for children ages 7 and 8 years, Age Band 3 for children ages 9 and 10 years, and Age Band 4 for children ages 11 and 12 years. For each age band, the test consists of eight items measuring different aspects of perceptual–motor ability; three items measure manual dexterity, two items measure ball skills, and there are three items for evaluating balance. The first manual dexterity item (MD1) seeks to measure the speed and sureness of movement by each hand separately. The second manual dexterity item (MD2) was designed to measure the coordination of two hands for performing a single operation, whereas the third manual dexterity item (MD3) assesses hand–eye coordination as required in the control of a pen or pencil. The first ball-skill item (BS1) looks at a child's ability to accurately propel an object into space, and the second ball-skill item (BS2) challenges the child to catch a moving object. The three balance items are divided into one static balance item (assessing static control; SBAL) and two dynamic balance items assessing fast and explosive movements (DBAL1) and slow and controlled movements (DBAL2), respectively. The eight tasks of the MABC were administered in the aforementioned order.

Children can score between 0 and 5 on each item. The higher the score, the poorer the performance. Three subscale scores are calculated by adding the three manual dexterity items (range = 0–15), the two ball-skill items (range = 0–10), and the three balance items (range = 0–15). Total scores can vary from 0 to 40 and can be transformed to percentile scores showing the child's level of performance in comparison to that of peers. In the present study, the 15th percentile was used as a cutoff criterion for total scores between typical and borderline/deviant motor performance. According to the data from the Dutch standardization of the MABC, the U.S. norms are valid for the Dutch population (Smits-Engelsman, 1998). Therefore, these norms will be used in the present study. According to the MABC manual, the test has acceptable validity and reliability (see also Lam & Henderson, 1987). Interrater reliability for this test ranges from .70 to .89, and test–retest reliability is .75 (Henderson & Sugden, 1992).

Statistical Analysis

To investigate the effect of various factors, univariate or multivariate general linear models (GLM) were used where appropriate. Post hoc tests consisted of multiple comparisons using the Bonferroni method. Furthermore, logistic regression analysis was performed to determine which MABC test items best predicted whether a child belonged to the group of children with only DCD or the group of children with comorbid DCD and LD. An alpha level of .05 was used throughout the study.

Results

Severity of Perceptual–Motor Problems

A univariate GLM with MABC mean total score as the dependent variable and presence/absence of LD, presence/absence of DCD, gender, and age band (see Note 3) as factors was performed (adjusted $R^2 = .543$ for corrected model). This showed a main effect of presence/absence of LD, $F(1, 732) = 89.80$, $p < .001$, partial $\eta^2 = .109$; children with LD obtained significantly higher MABC total scores compared to children without LD ($M = 14.30$, $SD = 9.68$, vs. $M = 5.81$, $SD = 5.38$, respectively). Also, a main effect of presence/absence of DCD was found, $F(1, 732) = 340.37$, $p < .001$, partial $\eta^2 = .317$; children with DCD obtained a higher mean MABC total score compared to children without DCD ($M = 19.08$, $SD = 7.42$, vs. $M = 5.48$, $SD = 5.05$, respectively). Furthermore, a main effect of age band was noted, $F(2, 732) = 14.56$, $p < .001$, partial $\eta^2 = .038$; children in the oldest age band (the combined Age Bands 3 and 4) obtained a significantly higher mean score ($M = 8.92$, $SD = 8.08$) compared to children in either Age Band 1 ($M = 6.73$, $SD = 6.85$) or Age Band 2 ($M = 6.71$, $SD = 6.52$). The main effect of gender was not significant, $F(1, 732) = .102$, *ns*.

Three interactions were noted. First, the interaction between presence/absence of LD and age band was statistically significant, $F(2, 732) = 7.29$, $p = .001$, partial $\eta^2 = .020$ (see Figure 1). This interaction was further examined by means of one-way ANOVAs. This revealed that whereas the difference in mean MABC total scores did not reach statistical significance among children of various ages without LD, $F(2, 599) = 1.81$, $p = .164$, it did among children with LD, $F(2, 144) = 3.85$, $p = .024$. Subsequent post hoc analyses revealed that the oldest children with LD obtained significantly higher mean scores compared to younger age band groups with LD ($p < .001$).

The second interaction concerned the relationship between presence/absence of LD and gender, $F(1, 732) = 7.32$, $p = .007$, partial $\eta^2 = .010$ (see Figure 2). Subsequent t tests showed that whereas there was a statistically significant difference in performance between boys and girls without LD (boys $M = 6.73$, $SD = 5.87$, vs. girls $M = 4.71$, $SD = 4.51$; $t[596] = 4.76$, $p < .001$), this difference no longer reached statistical significance among children with LD (boys $M = 14.59$, $SD = 9.60$, vs. girls $M = 13.46$, $SD = 9.98$; $t[145] = 0.62$, *ns*).

The third interaction concerned the relationship between presence/absence of LD and presence/absence of DCD with regard to MABC total scores, $F(1, 732) = 3.84$, $p = .050$, partial $\eta^2 = .005$ (see Figure 3). Further examination of this interaction by means of t tests revealed that among the children without DCD, the mean total scores of children with and without LD differed significantly, $t(104) = -6.67$, $p < .001$. Similarly, children with and without

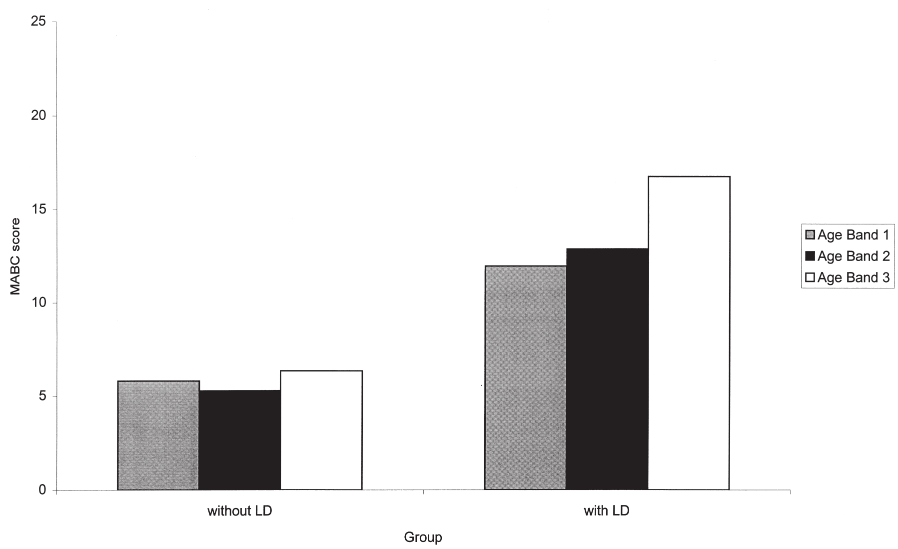

FIGURE 1. Mean MABC total scores for children of different age bands with and without LD. MABC = *Movement Assessment Battery for Children* (Smits-Engelsman, 1998); LD = learning disabilities.

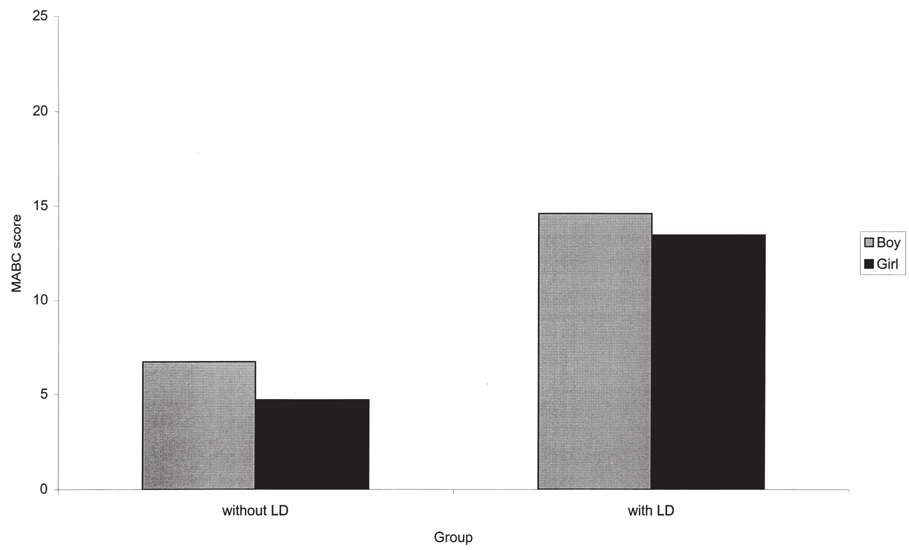

FIGURE 2. Mean MABC total scores for boys and girls with and without LD. MABC = *Movement Assessment Battery for Children* (Smits-Engelsman, 1998); LD = learning disabilities.

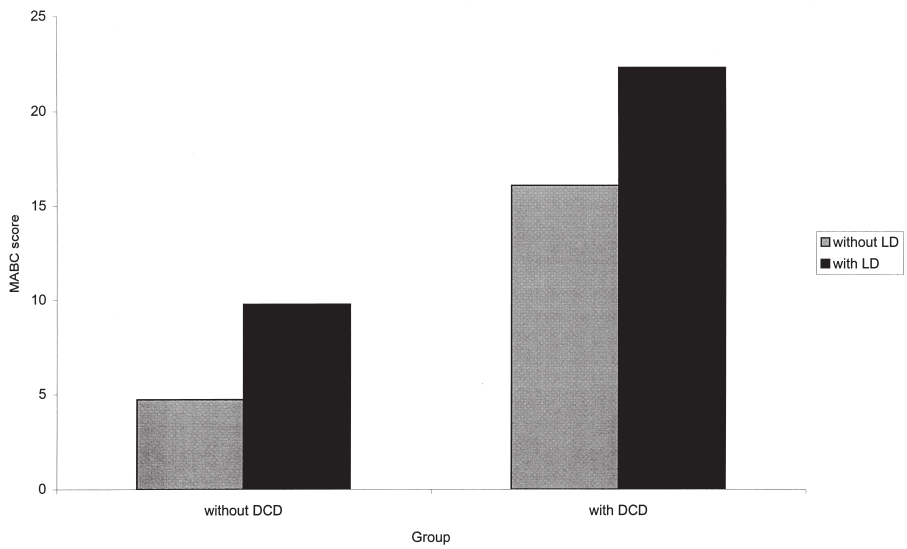

FIGURE 3. Mean MABC total scores for children with and without LD among children with and without DCD. MABC = *Movement Assessment Battery for Children* (Smits-Engelsman, 1998); LD = learning disabilities; DCD = developmental coordination disorder.

LD among the children with DCD differed significantly from each other in mean total score, $t(82) = -4.74$, $p < .001$.

Tables 2 and 3 show the mean scores on the MABC for the four groups of children. From Table 2, it appears that there is a rise in mean total MABC score across the four groups; children in the no DCD/no LD group obtained the lowest (i.e., least atypical) mean total score, followed by children in the LD-only group, DCD-only group, and DCD + LD group. This linear increase in mean total MABC score was confirmed by means of a univariate GLM, treating group as a between-participants factor, $F(3, 745) = 265.43$, $p < .001$, partial $\eta^2 = .517$, followed by post hoc analyses (all ps < .001).

Pattern of Perceptual–Motor Problems

A logistic regression analysis showed that a model containing MABC Dynamic Balance Item 2 (DBAL2; exp[β] = 1.54, $df = 1$, $p < .001$) and Manual Dexterity Item 1 (MD1; exp[β] = 1.53, $df = 1$, $p = .002$) significantly predicted whether a child belonged to the DCD-only or to the DCD + LD group, $\chi^2(2, N = 110) = 29.24$, $p < .001$. The higher the scores of a child on these two items, the more likely the child belonged to the DCD + LD group. Using these two items, 74% of the children with DCD and 70% of the children with comorbid DCD and LD were correctly classified (overall correctly classified 72%).

Discussion

It has previously been shown that children with DCD are heterogeneous not only with respect to their perceptual–motor profile of dysfunction but also with respect to the presence or absence of concomitant developmental disorders such as ADHD or LD (e.g., Missiuna, 2001; Sugden & Wright, 1998). The present study shows that if concomitant LD is present in children with DCD, the severity of perceptual–motor dysfunction increases. Furthermore, a clear difference in the children's pattern of perceptual–motor dysfunction emerged; children with a combination of DCD and LD scored particularly low on tasks measuring dynamic balance and unimanual dexterity compared to their peers with only DCD.

However, in the present study, the division between the presence or absence of a learning disability was purely based on whether the child was a student in a school for special education. It could be argued that children who showed a similar type and level of

LD but who did not attend special education might show less comorbid perceptual–motor problems than we report here. Although it is not possible to rule out such a selection bias, at the time this study was conducted, we felt it was not very likely that children who showed a type and level of LD comparable to that of children attending schools for special education would *not* attend such a school in the Netherlands. Nevertheless, the referral criteria to special education schools might have possibly led us to observe an increased level of perceptual–motor dysfunction and a rather specific pattern of such dysfunction. Therefore, our results need to be confirmed in a study in which inclusion in the group of children with LD is solely based on the outcome of individual assessment.

TABLE 2
MABC Total Scores and Subscores and Percentage of Children Scoring Below 15th Percentile by Group

Score	No DCD/no LD[a]	LD only[b]	DCD only[c]	DCD + LD[d]
Total				
M	4.73	9.79	16.08	22.30
SD	4.17	7.14	4.83	8.36
%	9	32	100	100
Manual dexterity				
M	1.85	4.44	7.11	9.63
SD	2.25	4.09	3.27	3.68
%	8	34	70	85
Ball skills				
M	1.44	1.81	3.76	5.47
SD	1.82	2.09	2.61	2.80
%	21	24	67	83
Balance				
M	1.45	3.66	5.18	7.36
SD	2.26	3.47	3.16	4.64
%	6	27	46	62

Note. MABC = Movement Assessment Battery for Children (Smits-Engelsman (1998); DCD = developmental coordination disorder; LD = learning disabilities.
[a]*n* = 545. [b]*n* = 94. [c]*n* = 57. [d]*n* = 53.

The increasing interest in and recognition of DCD not only in North America but also in European countries has given a new impetus to the longstanding discussion regarding the relationship between perceptual–motor problems and LD (Maeland & Sovik, 1993; Martini, Heath, & Missiuna, 1999). The rate of comorbidity between DCD and LD observed in the present study, in which 48% of children with DCD also attended schools for special education, is similar to the rate reported earlier (Kaplan et al., 1998). From a reverse perspective, 36% of children attending schools for children with special educational needs were identified as having DCD. This is also in close agreement with earlier observations (e.g., Sugden & Wann, 1987). It has been reported for some time that children with LD perform significantly lower than their peers without LD also in their motor skills (e.g., Dobbins, Garron, & Rarick, 1981; Rarick, Dobbins, & Broadhead, 1976; Sugden & Wann, 1987). We were able to confirm these findings by showing that even if children with DCD were excluded from the LD group, the remaining children in the LD-only group still performed significantly lower than children in the no DCD/no LD group. Apparently, the difficulty these children have with acquiring academic skills extends to the area of motor learning, even though it is not severe enough to be labeled as problematic.

Compared to children with only DCD or children with only LD, the performance in the motor domain of children with concomitant perceptual–motor and learning problems was more severely affected. We were unable to investigate whether these children also showed more severe learning disabilities as compared to the children in the LD-only group, but we hypothesize that this could be the case. Furthermore, we acknowledge that if we also had known which of the children met the full *DSM-IV* criteria for ADHD, probably even more interesting relationships would have emerged.

It was interesting to observe that children in the DCD + LD group were not simply performing lower on all eight items of the MABC compared to children in the DCD-only group. Instead, two test items stood out as being particularly difficult to perform for children in the comorbid group. The task that differentiated these two groups best was designed to measure the ability of controlling the whole body during a nonstatic balance position (DBAL2). Depending on the age of the children, the tasks included in the MABC to evaluate this ability involve walking on tiptoe over a line (Age Band 1), walking in a heel–toe gait over a line forward (Age Band 2), walking in a heel–toe gait backward (Age Band 3), and balancing a tennis ball on a board while walking (Age Band 4). None of these tasks impose a time constraint on the children. Three times as many children in the DCD + LD group failed to reach an age-appropriate performance level as children in the DCD-only group, who performed similar to children in the LD-only group. The second-best task to distinguish between the groups was the task measuring unimanual dexterity (MD1). This was a Peg-Board task requiring fast, goal-directed movements with the preferred and nonpreferred hand. From a motor control and information processing viewpoint, this is a rather complex task, requiring ballistic movements to visually located targets (holes)

TABLE 3
Means, Standard Deviations, and Percentage of Children Scoring Below 15th Percentile for Individual MABC Test Items

Item	No DCD/no LD[a]	LD only[b]	DCD only[c]	DCD + LD[d]
MD1				
M	0.70	1.60	2.33	3.52
SD	1.13	1.72	1.70	1.54
%	15	39	58	87
MD2				
M	0.60	1.41	2.25	2.85
SD	1.20	1.72	1.90	1.88
%	15	35	58	68
MD3				
M	0.55	1.32	2.56	3.23
SD	1.10	1.87	1.94	1.85
%	13	27	63	75
BS1				
M	0.67	1.09	1.90	3.08
SD	1.18	1.46	1.72	1.71
%	16	31	49	74
BS2				
M	0.78	0.72	1.84	2.40
SD	1.23	1.22	1.82	1.94
%	23	17	46	55
SBAL				
M	0.70	1.45	2.48	3.00
SD	1.20	1.58	1.69	1.66
%	17	38	65	75
DBAL1				
M	0.56	1.15	1.75	1.81
SD	1.35	1.65	2.19	2.21
%	16	33	39	43
DBAL2				
M	0.19	1.04	0.94	2.54
SD	0.76	1.72	1.68	2.01
%	5	28	21	62

Note. MABC = Movement Assessment Battery for Children (Smits-Engelsman, 1998); DCD = developmental coordination disorder; LD = learning disabilities; MD1 = Manual Dexterity subscale Item 1, etc.; BS1 = Ball Skills subscale Item 1, etc.: SBAL = Static Balance item; DBAL1 = Dynamic Balance Item 1, etc.
[a]*n* = 545. [b]*n* = 94. [c]*n* = 57. [d]*n* = 53.

and between-finger manipulation (pin) with high endpoint accuracy.

Several plausible neuropsychological explanations have been put forward for the co-occurrence of DCD and LD. Support for a significant relation between motor skill performance and language has been provided by a number of studies (Bradford & Dodd, 1996; Cermak, Ward, & Ward, 1986; Hill, 1998, 2001; Notherdaeme, Amorosa, Ploog, & Scheimann, 1988; Owen & McKinlay, 1997; Sommers, 1988; Tallal & Stark, 1982). The nature of this relation, however, has seldom been pursued in depth. Is this relation causal (i.e., does poor motor development influence the development of language, or vice versa), or is the putative relation an artifact of critical neurological variables underlying both motor and language impairment? Two hypotheses have been pursued in the literature concerning the search for such an underlying commonality: the cerebellar and the inter–intrahemispheric deficit hypothesis.

Although there is undoubtedly considerable heterogeneity in the skills of children with dyslexia, the general type of performance difficulty these children have involves difficulties when required to undertake fast, fluent, overlearned skills or novel skills that involve the blending of two actions. These problems in motor learning and automatization point to the cerebellum, which has been traditionally considered a motor area (Eccles, Ito, & Szentagothai, 1967; Holmes, 1917, 1939). However, there is now overwhelming evidence of the importance of the cerebellum in language (Ackermann & Hertrich, 2000; Allen, Buxton, Wong, & Courchesne, 1997; Fabbro, Moretti, & Bava, 2000; Leiner, Leiner, & Dow, 1989; Silveri & Misciagna, 2000; Thach, 1996), including a recent demonstration of specific cerebellar involvement in reading (Fulbright et al., 1999). Moreover, Fawcett and colleagues showed a range of classic cerebellar signs in children with dyslexia (Fawcett & Nicolson, 1999; Fawcett, Nicolson, & Dean, 1996).

The inter- and intrahemispheric deficit hypotheses were also suggested as plausible neuropsychological explanations for the co-occurrence of language and motor impairments. Sigmundsson and colleagues (Sigmundsson, Ingvaldsen, & Whiting, 1997a, 1997b; Sigmundsson, Whiting, & Ingvaldsen, 1999) stated that the co-occurrence of hand–eye coordination problems and dyslexia could be the behavioral manifestation of putative neurological disorders related to an intrahemispheric or interhemispheric disconnection. Post hoc analysis of the performance with the preferred and nonpreferred hand in the present study did not point in the direction of an interhemispheric disconnection phenomenon, as the performance of the nondominant hand was not especially lower for the LD, DCD, or DCD + LD groups. Intrahemispheric dysfunction could not be tested with our data, but studies of participants with dyslexia have suggested that they may be unable to process fast incoming sensory information adequately in any domain, both visual and kinesthetic, within the same modality (intramodal) and between modalities (intermodal). The parietal lobe in particular is thought to be necessary to monitor efference copy received from downstream motor output areas (Sirigu et al., 1995, 1996). Anatomical, electrophysiological, psychophysical, and brain-imaging studies have all contributed to elucidating that in children with reading disabilities, visual confusions relate to abnormalities of the magnocellular component of the visual system. This system, which plays an important role in guiding visual attention, is specialized for processing fast temporal information and culminates in the posterior parietal cortex (Stein, 2001).

The pattern of perceptual–motor dysfunction found in our study corroborates motor symptoms most mentioned in children with LD. These children did not score high on hand–eye coordination when required to move fast and accurately, which may be due to problems with processing fast incoming sensory information, which also supports an intrahemispheric deficit hypothesis. However, problems with making fast, fluent, reciprocal movements and balance could also point to cerebellar involvement. More experimental work is required to disentangle these underlying processes.

We conclude that among children with DCD, the presence of concomitant LD not only increases the likelihood of low performance on perceptual–motor tasks that are part of many daily motor activities but also involves a distinct pattern of perceptual–motor dysfunction characterized by problems with fast, goal-directed movements and keeping balance while moving around. These findings argue in favor of keeping DCD and LD as separate diagnostic categories for the time being, because children fulfilling the criteria for these developmental disorders are clearly distinguishable in terms of their perceptual–motor abilities. Finally, the impact of poor manual dexterity and balance is not to be underestimated, as a large number of children with LD are likely to pursue vocational training, where these abilities are mandatory.

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NOTES

1. *Not long thereafter, the World Health Organization also recognized the importance of establishing an entry for children with* specific developmental disorder of motor function *(ICD-9; World Health Organization, 1992). However, a consensus meeting held in 1994 in London, Ontario, Canada, concluded that DCD should be the preferred term (Polatajko, Fox, & Missiuna, 1995).*
2. *No statistically significant differences were noted between these two geographic samples on MABC scores, and they were, therefore, combined.*
3. *The data of the children in Age Band 3 and 4 were collapsed because of very low* Ns *in the DCD-only and DCD + LD groups tested on Age Band 4 (*N = 2 *and* N = 5*, respectively).*

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