Paper III

Motor Coordination Difficulties in a Municipality Group and in a Clinical Sample of Poor Readers

Synnøve Iversen[1,*], Karin Berg[2], Bjørn Ellertsen[3] and Finn-Egil Tønnessen[3]

[1] *Section of Physiotherapy Science, Department of Public Health and Primary Health Care, University of Bergen, Norway*
[2] *Department of Physiotherapy, Faculty of Health and Social Science, Bergen University College, Norway*
[3] *The Reading Centre, University of Stavanger, Norway*

The purpose of the study was to investigate incidence, severity and types of motor problems in two groups of poor readers compared to good reading controls. A group of children with severe dyslexia referred to specialist evaluation, a teacher selected municipality sample comprising the 5% poorest readers, and a control group consisting of the 5% best readers were all assessed applying a norm-based, standardized measure by Henderson and Sugden 1992; (*The Movement Assessment Battery for Children*. Kent: The Psychological Corporation). The three groups were compared with regard to total motor impairment scores as well as motor function within the areas of manual dexterity, ball-skills and balance. More than 50% of the children in both groups of poor readers showed definite motor coordination difficulties at or below the 5th centile, for which motor intervention is recommended. Children in both groups showed difficulties within the sub-area of manual dexterity in particular and also performed significantly worse than controls within the sub-area of balance, but not in ball-skills. The high incidence of motor coordination problems in the two groups of poor readers indicates that all children with reading difficulties should be screened for possible motor difficulties. Copyright © 2005 John Wiley & Sons, Ltd.

Keywords: poor readers; dyslexia; motor function; Developmental Coordination Disorder; Movement Assessment Battery for Children

*Correspondence to: Synnøve Iversen, Odinsgate 14 A, N-4011 Stavanger, Norway. E-mail: syiverse@online.no; ivsy@sir.no; Contract/grant sponsor: Foundation for Education and Research in Physiotherapy (Norway)

Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/dys.297

INTRODUCTION

While growing up, many children experience difficulties in various developmental areas. In spite of normal intelligence, some children struggle to learn how to read or do math, to perform everyday motor tasks, to understand the social codex and/or display problems within the area of attention. How to conceptualize the various developmental disorders has been, and continues to be, a much-debated issue. Although one feature of these children's difficulties often stands out, pure and isolated problems tend to be the exception, not the rule. Far more often children present with various combinations of difficulties (Bax, 1999; Dewey, Kaplan, Crawford, & Wilson, 2002; Henderson & Barnett, 1998; Kadesjö & Gillberg, 1998; Kaplan, Wilson, Dewey, & Crawford, 1998; Richardson & Ross, 2000). Longitudinal studies have shown high rates of comorbidity between motor control problems, ADHD, speech-language deficits, specific learning disorders, perceptual deficits and behavioural and psychiatric disorders (Cantell, Smyth, & Ahonen, 1994, 2003; Hellgren, Gillberg, Bågenholm, & Gillberg, 1994; Gillberg, Carlstrom, Rasmussen, & Waldstrom, 1983; Gillberg, Gillberg, & Groth, 1989; Losse *et al.*, 1991; Rasmussen & Gillberg, 2000). However, as emphasized by Visser (2003), although comorbidity is a widely acknowledged phenomenon, there is still a tendency within research to neglect this issue. The possibility that children in samples of specific developmental disorders may have multiple difficulties is frequently not taken into account. In this article we particularly focus on the co-occurrence of reading difficulties and motor coordination problems.

There are many potential courses of reading difficulties, and the diagnostic methods of the most frequent term 'developmental dyslexia' are debated (Lyon, 1995; Tønnessen, 1997). A commonly applied criterion provided by the World Federation of Neurology (1968), characterizes developmental dyslexia as a learning disability in children who despite conventional instruction and socio-economic opportunity fail to attain the language skills of reading, writing and spelling commensurate with their intellectual abilities. The prevalence of developmental dyslexia is estimated to be between 5 and 15% in the population, depending on diagnostic criteria, methods of sampling, and the language in which it is studied (Caravolas, 2003; Catts, Hogan, & Fey, 2003; Frith, Wimmer, & Landerl, 1998; Snowling, 2000).

A variety of terms have been used in order to describe children with motor coordination difficulties (Barnett, Kooistra, & Henderson, 1998; Missiuna & Polatajko, 1995). At a consensus conference in 1994 researchers agreed to use the term 'Developmental Coordination Disorder' (DCD) from the DSM-IV classification system (Polatajko, Fox, & Missiuna, 1995). According to the DSM-IV criteria, the children must present with motor function significantly below chronological age, motor impairment must interfere significantly with activities of daily living and must not be related to a medical condition (American Psychiatric Association (APA), 1994). According to international estimates, the prevalence of DCD is at least 5–6% (APA, 1994; Henderson & Hall, 1982; Kadesjö & Gillberg, 1998).

Co-occurrence of reading difficulties and motor coordination problems has been reported in several studies over the years (e.g. Dewey *et al.*, 2002; Fawcett & Nicolson, 1992; Kadesjö & Gillberg, 1998; Kaplan *et al.*, 1998; Moore, Brown, Markee, Theberge, & Zvi, 1995; Mæland & Søvik, 1993; Nicolson & Fawcett, 1990, 1994, 1999; Ramus, Pidgeon, & Frith, 2003). Results from different studies are, however, often difficult to compare due to differences in diagnostic procedures with regard to dyslexia as well as developmental coordination disorder. Research methods and choice of measures also differ between studies and research traditions. While researchers primarily focused on DCD commonly apply standardized and norm-referenced measures resulting in broad motor profiles (i.e. the Movement Assessment Battery for Children (M-ABC), Henderson & Sugden, 1992) and the Bruininks–Oseretski test of Motor Proficiency (BOTMP, Bruininks, 1978)), research on motor difficulties within the field of dyslexia has been more targeted, focusing on certain aspects of motor function, with less use of broad standardized measures (Ramus, 2003). In more recent research from the field of DCD, Kaplan *et al.* (1998) assessed motor function in a large sample of children referred because of learning and attention problems. An extensive motor evaluation was conducted, using a combination of BOTMP (Bruininks, 1978), M-ABC (Henderson & Sugden, 1992) and the DCD Questionnaire (Wilson, Dewey, & Campbell, 1998). Within this sample they found high prevalence of DCD compared to normal controls, and a major overlap between reading disorder (RD), ADHD and DCD. From a different angle, but using the same measures of motor function as the Kaplan *et al.* (1998) study, Dewey and colleagues (2002) investigated problems of attention, learning and psychosocial problems evidenced by a group of children with DCD, children with suspected DCD and controls. Results revealed that both children with DCD and suspected DCD obtained significantly poorer scores on measures of attention and learning (reading, writing and spelling). O'Hare and Khalid (2002) reported a high risk of reading and writing delay for children with DCD.

In a series of research within the field of dyslexia, the research from Nicolson, Fawcett and collaborators in Sheffield point to motor problems and abnormalities in muscle tone as common symptoms in the majority of dyslexic children (Fawcett & Nicolson, 1992, 1999; Nicolson & Fawcett, 1990, 1994, 1999). They interpreted their findings as supporting the automatization deficit hypothesis of dyslexia. According to their research findings the cerebellum plays an important role in this type of deficit (Fawcett, Nicolson, & Dean, 1996; Nicolson, Fawcett, & Dean, 2001). This has recently been supported by neuroanatomical and neuroimaging findings (Nicolson *et al.*, 1999; Rae *et al.*, 1998, 2002). However, other researchers have failed to replicate these findings. While Yap and van der Leij (1994) reported a partial replication, other attempts have been unsuccessful (van Daal & van der Leij, 1999; Kronbichler, Hutzler, & Wimmer, 2002). Wimmer, Mayringer, and Raberger (1999) reported that balance problems disappeared when dyslexic children with additional ADHD symptoms were excluded from the sample. In a recent study, Raberger and Wimmer (2003) further investigated the relationship between reading disability and ADHD to balancing problems. Results indicated that poor balancing (both as single and dual-task) was not found to be associated with RD, but with ADHD. Ramus *et al.* (2003) found motor difficulties in postural stability, bead threading and the finger to thumb tasks in about half of a group of English dyslexic children. They concluded that while their study supports the presence of motor difficulties in many children with dyslexia, comorbid disabilities such as ADHD and DCD might be the main explanation for these difficulties. Thus, research regarding motor coordination difficulties and dyslexia is somewhat conflicting and further research from different angles is warranted.

In the present study we assessed motor coordination difficulties in two different groups of children with reading difficulties; a group of poor readers from one municipality and a clinical group of severe cases that had been referred for extensive multi-disciplinary assessment at a Regional Competence Centre. We wanted to investigate incidence and severity of motor problems in the two groups compared to controls, types of motor difficulties and possible differences between the two groups of children with reading difficulties.

METHOD

Participants

The study was administered in accordance with the guidelines of the Declaration of Helsinki and also had local ethical committee approval. Three groups of children were studied: a clinical sample formally diagnosed as children with dyslexia (CD), a group of teachers identified poor readers in one municipality (MUN) and a control group consisting of the best readers in the same community (CON). None of the poor reading children had been identified on the basis of motor coordination problems. The children in the CD group comprised 20 children (17 boys, 3 girls), with a mean age of 11 years 1 month, who over a period of 14 months were referred to a regional Competence Centre in Norway due to severe reading problems. They were all examined and received a diagnosis of dyslexia by an experienced team that included psychologists, speech therapists and physiotherapists. The criteria for participation in the study were: age between 10 and 12 years, dyslexia as primary clinical problem, full-scale intelligence quotient (IQ) within 1.5 *S.D.* of the normative mean ($M = 100$, $S.D. = 15$) on the Norwegian version of the WISC-R (Wechsler, 1974), Norwegian as a first language, and living in Norway since very early childhood. Children with syndromes or other comorbid diagnoses expected to interfere with motor problems were excluded. None of the children had the comorbid diagnoses ADHD or Tourette. By being referred to the Regional Competence Centre from community based school psychology services, the children represented severe and 'difficult' cases, which the local system could not assess and/or treat adequately. Based on formal reading and writing tests routinely administered at the Competence Centre, all 20 children satisfied the psychometric criteria of literacy skill at least 1.5 *S.D.* below that expected for their age and grade level.

The MUN group consisted of 17 children identified as poor readers in a Norwegian municipality with 14 000 inhabitants. There were, on an average, 200 pupils at each grade level. Teachers of children in grade 6 (corresponding to 10–11 years) were asked to select the best and poorest 5% of readers from their classes. Such sampling provided a cross-section of poor readers, because the poor readers were selected on the basis of their overall reading difficulties rather than by the presence of a particular type of reading deficit. The CON group selected represented the best possible contrast with regard to reading. This extreme group comparison was chosen in order to obtain a clear differentiation between the groups. Twenty-five pupils were randomly selected from each of these two extreme groups for further assessment of motor performance and for psychometric testing. The group of children identified as poor readers were administered a test battery assessing literacy and cognitive skills. A standardized reading test (Høien & Lundberg, 1991), a spelling test to oral dictation, and the Norwegian version of the WISC-R (Wechsler, 1974) were administered. No additional testing of the teacher selected 5% of best readers was carried out due to time and resource constraints. Results from the literacy skill assessments showed that 21 out of the 25 pupils (84%) who were selected as poor readers by their teachers satisfied the psychometric criteria for a diagnosis of specific reading difficulties. Each of these 21 readers had a full-scale intelligence quotient (IQ) within 1.5 *S.D.* of the normative mean ($M = 100$, $S.D. = 15$) and literacy skill at least 1.5 *S.D.* below that expected for their age and grade level.

Four poor readers and three good readers were absent from school during the data collection that took place at a local school two days only. There is no reason to assume that these children differed from the participants. The remaining sample comprised 39 children, 17 poor readers (11 boys, 6 girls), with a mean age of 10 years 6 months, and 22 good readers (7 boys, 15 girls), with a mean age of 10 years 5 months.

Measures

Geuze, Jongmans, Schoemaker, and Smits-Engelsman (2001) conducted a review of 176 studies on Developmental Coordination Disorder, and showed considerable variability in procedures of operationalization and reports about how the diagnostic criteria of the DSM-IV had been met. Different measures seem to some extent to identify different children. Of the available instruments to-day, Geuze *et al.* (2001) recommended the Movement Assessment Battery for Children (M-ABC) (Henderson & Sugden, 1992) as the most appropriate with regard to identification of children who fulfill criteria A of the DSM-IV. The M-ABC is a comprehensive assessment battery consisting of the M-ABC Checklist, the M-ABC test and guidelines for remediation. The M-ABC Checklist focuses primarily on the assessment of movement problems at activity level in educational settings. The M-ABC test, which was used in this study, yields an overall motor impairment sum-score indicating increasingly pronounced motor difficulties with increasing scores. There are four age-bands covering 4–6, 7–8, 9–10 and 11–12 years. The test yields sub-scores for the areas manual dexterity, ball skills and balance as well as sub-test scores within these areas. The test consists of 8 different test-items, yielding ordinal data scored from 0 to 5, with 5 indicating severe motor difficulties on the particular item and 0 indicating no problems. Item 1–3 measure manual dexterity: (1) speed and precision of each hand separately, (2) coordination of two hands performing a single task, (3) eye–hand coordination as required in the control of a pen. Item 4–5 measure ball skills: (4) accurately throwing an object, (5) catching an object. Item 6–8 measure different aspects of balance: (6) static balance, (7) fast and explosive movements, (8) slow and controlled movements. The M-ABC has been standardized in the USA, but Mæland (1992) concluded that norms were appropriate for Norwegian children. The test is extensively used as a clinical tool in Norway. According to the manual, overall reliability is good, ranging from 97% agreement in 5-year-old children to 73% in 9 years old. Because the M-ABC is a modification of the Test of Motor Impairment (TOMI; Stott, Moyes, & Henderson, 1984), Henderson and Sugden (1992) stated that the evidence supporting the sound psychometric properties of the TOMI can be generalized to the M-ABC.

Procedure

For the CD group, the M-ABC test was administered as a part of the clinical assessment battery at the Regional Competence Centre by an experienced pediatric physiotherapist with extensive method experience. All children were tested with the same test-kit, following the administering procedures described in the test-manual.

For the MUN and CON group, the M-ABC test was administered by three experienced pediatric physiotherapists. The therapists were blinded with regard to group membership. They all had extensive practice in administering the M-ABC. In order to further enhance inter-tester reliability, preparatory video-analyses of testing-procedures and scoring was undertaken. All tests were performed at a local school in the same test-room and with the same test-kit, following the administering procedures described in the test-manual.

Analyses

Data were analysed using the SPSS 10.0 statistical package. Overall group comparisons were analysed using one-way ANOVA and Boneferroni *post hoc* tests were used for direct group comparisons. In addition, Cohen's *d* effects sizes were calculated for differences between groups. Chi-square was used to analyse frequency tables. Significance level was set at $p = 0.05$ for two-tailed tests. Sensitivity and selectivity of the data with regard to correctly classifying poor readers and control children was analysed using discriminant function analyses, entering variables both separately and hierarchically.

RESULTS

There was an overall significant difference between the three groups on the total M-ABC impairment score, as shown by one-way ANOVA for independent samples ($F(2{,}58) = 6.23$, $p = 0.004$). There was also significant difference between groups in Manual Dexterity ($F(2{,}58) = 9.18$, $p < 0.001$ and in Balance ($F(2{,}58) = 3.54$, $p = 0.036$), but not in Ball Skills. The mean scores for the Total M-ABC score and the three sub-areas are presented in Figure 1.

Bonferroni *post hoc* tests of group differences yielded significant differences between each of the poor reading groups and controls with regard to total M-ABC score and the Manual Dexterity score. The Cohen's *d* effect sizes between the groups with regard to M-ABC total scores were 0.78 for MUN versus CON and 0.97 for CD versus CON. MUN versus CD yielded an effects size of 0.09. There were no significant differences in total score or sub-area scores between the two groups of poor readers. Individual total M-ABC scores in the three study

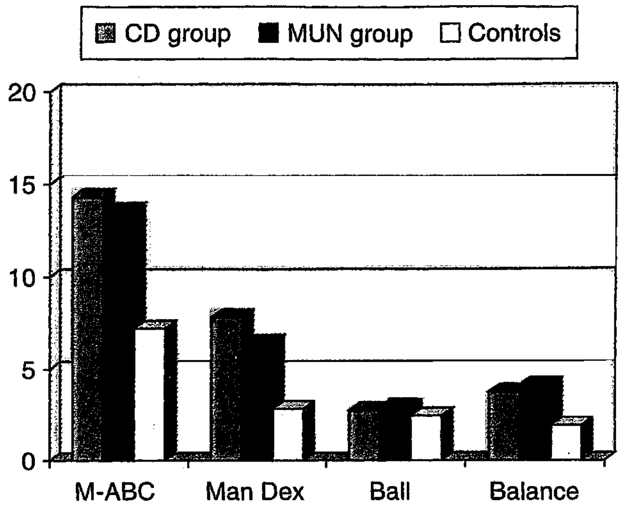

Figure 1. Total M-ABC score as well as scores for the sub-areas manual dexterity, ball skills and balance for the clinical dyslectic group (CD group), the municipality group of poor readers (MUN group) and controls (CON group) are shown.

Table 1. Shows the individual total M-ABC scores for the CD group ($n = 20$), the MUN group ($n = 17$) and the controls ($n = 22$)

	CD group	MUN group	CON group
1	25.5	29.5	23.5
2	25.0	25.0	22.5
3	21.5	22.5	16.0
4	20.0	19.0	11.0
5	19.5	19.0	10.5
6	18.5	19.0	10.0
7	16.0	18.0	9.5
8	16.0	18.0	7.0
9	16.0	16.0	7.0
10	15.5	11.5	6.5
11	14.5	9.5	5.5
12	14.0	9.0	5.0
13	12.5	7.5	5.0
14	12.0	3.0	4.0
15	9.0	3.0	3.5
16	9.0	1.0	3.5
17	7.0	0.5	3.0
18	6.0		2.5
19	5.0		1.0
20	4.0		1.0
21			1.0
22			0.5

groups are presented in Table 1 and it can be seen that the patterns were clearly different between controls and the two poor reading groups.

Severity of motor problems in the three study groups is summarized in Table 2. As shown in the table, 12 ($n = 20$) children, or 60%, in the CD group and 9 ($n = 17$) children, or 53%, in the MUN group obtained a total motor impairment

Table 2. Number and percentage of children in the CD group ($n = 20$), the MUN group ($n = 17$) and control group ($n = 22$) who obtained total M-ABC scores at a clinical level ($\leqslant$5 centile), borderline level (> 5 to $\leqslant$15 centile) or at a normal level (> 15 centile)

	CD group	MUN group	CON group
Clinical scores	12 (60%)	9 (53%)	3 (13.6%)
Borderline scores	2 (10%)	1 (5.9%)	3 (13.6%)
Normal scores	6 (30%)	7 (41.1%)	16 (72.7%)

score at or below the 5th centile, compared to 3 children, or 13.6%, in the control group. In other words, slightly more than half of the children in both groups of poor readers obtained a total motor impairment score indicating severe motor difficulties, warranting a possible DCD diagnosis. Two ($n = 20$) children from the CD group and one ($n = 17$) child from the MUN group obtained a score within a borderline area, while 6 ($n = 20$) from the CD group and 7 ($n = 17$) from the MUN group obtained scores above the 15th centile or within a normal area. The table shows that the number of children with definite and borderline motor problems (at or lower than the 15th centile on M-ABC) was slightly higher in the CD group compared to the MUN group. The frequency of definite and borderline problems was relatively higher in the control group than what would have been expected on the basis of normative data.

The mean scores on the 8 test-items of the M-ABC are presented in Figure 2. ANOVA of the sub-scales yielded significant effects for Manual 2 ($F(2,58) = 4.00$, $p = 0.024$), Manual 3 ($F(2,58) = 12.72$, $p < 0.001$), Balance 1 ($F(2,58) = 4.67$, $p = 0.013$) and Balance 2 ($F(2,58) = 7.40$, $p = 0.001$). Thus only 50% of the sub-scales of the M-ABC were found to discriminate between groups. Among the significant test-items, the sub-test Manual Dexterity 3 stood out particularly. This test-item consists of drawing a continuous line between defined borders as precisely as possible. Mean score on this test item in the two groups of poor readers was 3.5 (3.9 for the CD group, 3.1 for the MUN group and 1.1 for controls). Chi-square analysis of the frequency table of CD versus CON yielded $\chi^2(1,42) = 22.51$, $p < 0.01$ and $\chi^2(1,39) = 7.97$, $p < 0.01$ for MUN versus CON.

Bonferroni *post hoc* tests showed significant differences between the MUN and CON groups on Manual 3 whereas comparison between CD and CON yielded significant differences on Manual 2, Manual 3 and Balance 2. There were no significant differences between the two groups of poor readers. Thus, composite scores differentiated stronger between the poor readers from both samples and controls than the sub-scales, with the exception of the sub-scale of test-item 3 from the area of manual dexterity.

Average data may not represent the performance of any particular individual within a group. Therefore, to test whether the majority of the poor readers in our sample were more impaired than the controls with regard to different sub-areas of the M-ABC we applied discriminant function analyses, entering variables both separately and hierarchically. The sensitivity of a test can be ascertained by the percentage of a target group correctly identified (i.e. the 'hit rate' for identifying poor readers), whereas the selectivity can be ascertained by the ability of the test to correctly reject members of the non-target group (CON). Each of the variables

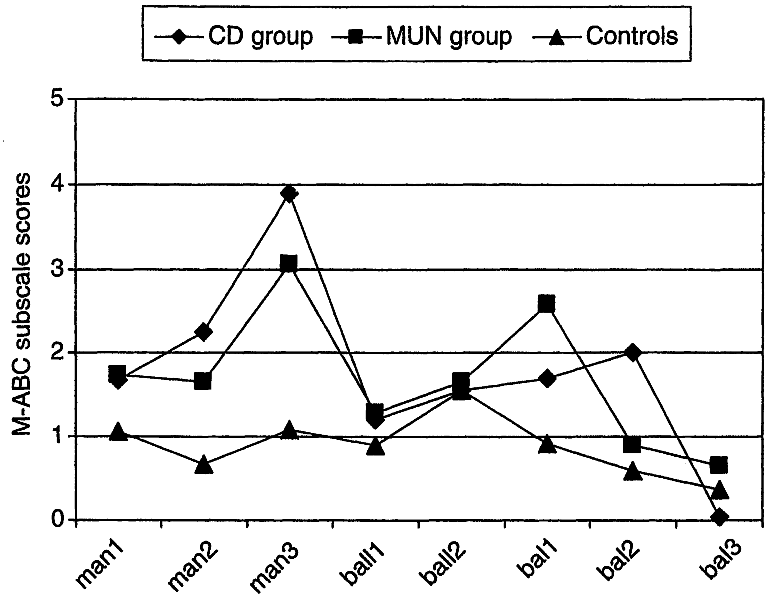

Figure 2. The subscale scores of the M-ABC for the three groups: clinical dyslexia (CD group), municipality group of poor readers (MUN group) and controls are shown.

alone were found to be an adequate yet significant, predictor of group membership, correctly classifying between 71 and 82% of the cases. Best prediction was obtained by entering total impairment score, manual dexterity score, balance score and the sub-tests Manual 3 and Balance 1.

DISCUSSION

This study demonstrates that there is a strong degree of co-occurrence between reading difficulties and motor coordination problems. The finding that this is about equally true in a selected group of severe cases, referred for specialist evaluation, and a group consisting of teacher referred 5% poorest readers in a community, is somewhat surprising. However, the incidence of 60% (CD group) and 53% (MUN group) of severe difficulties is comparable to the findings from other studies using the same type of general norm-based, standardized measurement (Dewey *et al.*, 2002; Kaplan *et al.*, 1998; Sugden & Wann, 1987). As stated by Ramus (2003), many studies of motor function within the field of dyslexia have utilized only one or two specific motor tasks for assessment, which complicates comparison of findings across studies. Fawcett and Nicolson (1992, 1999) and Nicolson and Fawcett (1990, 1994, 1999) have reported high prevalence of motor difficulties in the sub-area of balance in children with dyslexia when a secondary interfering cognitive task was introduced, including children without additional ADHD symptoms. In contrast, and applying the same tasks and type of assessment, other researchers have reported that the occurrence of motor problems seemed confined to children with dyslexia and comorbid ADHD (Raberger & Wimmer, 2003; Wimmer *et al.*, 1999). In the present study, none of the children in the CD or MUN group had an additional ADHD diagnosis. However, they were not systematically screened for attention deficits. Future studies should include assessment of ADHD related symptoms in order to make more direct comparisons possible.

We identified several children in the CD and MUN group with low total impairment scores on the M-ABC, or motor function within the normal area .We also identified 3 children in the CON group who displayed severe motor problems. Owing to resource constraints, the CON group was not further assessed with regard to literacy skills, but due to the fact that they belonged to the top 5% readers, it is likely to believe that these 3 children belonged to the group of children with DCD who show no literacy problems. As commented by Ramus (2003), the occurrence of seemingly pure cases within the developmental disorders raises important research questions: What characterizes these children with respect to other developmental qualities? How do they compare to children with concomitant disorders? In order to answer these questions properly, researchers from the various fields of developmental disorders need to study and compare pure, as well as comorbid cases carefully in target areas such as attention, motor functioning, auditory and visual information-processing, general cognitive functioning and specific learning abilities. In order to make such comparisons possible, a consensus with regard to basic measurements within the various target areas is needed. With regard to motor function, and in line with Geuze *et al.* (2001), we suggest that a norm-based standardized measure should be applied as standard, and more targeted measures added, depending on specific research questions.

The finding of 3 children in the CON group with definite motor difficulties as measured by the M-ABC warrants an additional comment. As reported, the CON group consisted of the 5% best readers at a grade level in the municipality. As such, they differed from a regular randomly selected control group, leaving open the possibility that the children in question may have developed a special interest in reading and enhanced their reading abilities in order to compensate for motor problems.

With regard to types of motor problems, both groups of poor readers had significant problems performing manual dexterity and balance tasks, but not ball-skill tasks as compared to controls. A similar pattern was reported for children with DCD and learning difficulties (LD) by Jongmans, Smits-Engelsman, and Schoemaker (2003). In our study, the sub-area of manual dexterity stood out as the most difficult area for both groups of poor readers. Manual Dexterity 3 was particularly demanding for both groups, and consists of drawing a continuous line within defined borders, thus resembling the task of writing. There was a significant difference between the two poor reading groups and controls, but also a non-significant, but slight difference between the CD and MUN group. However, due to small numbers in the study, a possible difference within this area of motor function between severe clinical cases and teacher referred poor readers must be further investigated, and a wider range of targeted motor measures included.

Smits-Engelsman, Wilson, Westenberg, and Duysens (2003) investigated 32 children with DCD and comorbid learning disabilities using kinematic movement analysis of fine-motor performance in order to test various hypotheses about the nature of the children's motor deficits. Their results did not support a general slowness hypothesis, but pointed to difficulties with regard to modes of motor control: the children with DCD/LD relied more on feedback during movement execution, and had difficulties compared to controls in switching to a feedforward or open-loop strategy of motor control. The children's problems were particularly evident during continuous, cyclic movements. Discrete movements did not differ significantly compared to controls (Smits-Englesman *et al.* 2003). When a cyclic fine motor task is performed, the next movement must be planned during the ongoing movement, thus putting greater demands on feedforward, open-loop motor control strategies. The findings that this particular type of fine motor task was the most sensitive of all the M-ABC test-items could be interpreted as yielding support to an automatization deficit in children with reading difficulties (Nicolson & Fawcett, 1999; Nicolson *et al.*, 2001). Such a framework could also explain why the ball-skills items of the M-ABC did not yield any significant differences between the two groups of poor readers and controls. During these test-items all participants naturally use feedback strategies in order to accommodate throw/catch force and precision to the demands of new ball-tasks unfamiliar to the children, and performance is consequently less dependent on feedforward modes of motor control.

Alternatively, our findings could be interpreted within the framework of the suggested magnocellular hypothesis of dyslexia (Stein, 2001, 2003). The magnocelluar system plays an important role in mediating steady direction of visual attention and eye fixations. Accordingly, weak mangocellular function leads to unfocused visual attention and unstable eye-control (Stein, 2003). A magnocellular deficit has been reported in several studies, of children with dyslexia (e.g. Sperling, Lu, Manis, & Seidenberg, 2003; Stein, 2001, 2003; Talcott, Hansen, Assoku, & Stein, 2000; Talcott *et al.*, 2003). The precise, continuous hand-movements during test-item Manual Dexterity 3 put substantial demands on visual attention as well as stability of eye movements, and impaired visual search could influence the steadiness and quality of motor performance negatively. The non-significant findings on ball-skills could also be explained within this framework, as stationary targets put less demands on visual search mechanisms.

The high incidence of severe motor coordination problems found in a community based sample of teacher referred poor readers as well as a clinical group of 'difficult' cases referred for specialist evaluation, has important clinical implications for the public health and educational system, as well as specialist health and educational service. At a specific level, the findings point to multidisciplinary assessment of children with specific reading difficulties as important and recommendable, not only for children referred to specialist centers due to severe dyslectic difficulties, but for all children with reading problems (Dewey *et al.*, 2002; O'Hare & Khalid, 2002). The very high incidence of difficulties with the test-item Manual Dexterity 3 emphasizes that many children with reading difficulties experience serious difficulties with the motor aspects needed in writing, with important implications for choice of intervention strategies.

Viewing the findings in a broader perspective, researchers have pointed to motor coordination difficulties as a possible marker for a whole range of developmental disorders (Missiuna, Rivard, & Bartlett, 2003; Rasmussen & Gillberg, 2000). In a developmental perspective, it is possible to identify motor coordination difficulties at an early age, whereas learning problems, ADHD and other comorbid difficulties become more gradually evident (Hadders-Algra, 2002; Kadesjö & Gillberg, 1998; Missiuna *et al.*, 2003). If motor problems are detected at an early age, teachers and other professionals should be prepared for the possibility of gradual occurrence of other developmental difficulties as well.

CONCLUSION

In this study, slightly more than half of a clinical group of children with severe dyslexia as well as a municipality cohort of teacher referred poor readers showed definite motor coordination difficulties, as assessed with the M-ABC, at or below the 5th centile, for which motor intervention is recommended. Children from both groups showed difficulties within the sub-area of manual dexterity in particular, and the ability to perform continuous, precise fine-motor movements was severely affected. The two groups of poor readers also performed significantly worse than controls within the sub-area of balance, but not in ball skills. Our results suggest that further and more targeted research is needed with regard to various types of fine motor function in children with reading difficulties. The diversity and complexity of developmental disorders, with comorbid as well as seemingly pure cases, point to the importance of providing multidisciplinary assessment and intervention within a broad dynamic developmental framework. In order to further investigate and compare cases across developmental fields of research, consensus with regard to basic measurers is needed. In this study, we did not systematically evaluate motor function at the ICF (World Health Organization, 2001) levels of activity and participation. In order to clarify functional consequences of motor difficulties for children with reading difficulties, this needs to be undertaken.

ACKNOWLEDGEMENTS

We would like to thank the children and their parents for taking part in the study. The study was supported by the Foundation for Education and Research in Physiotherapy, Norway.

REFERENCES

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.) (DSM-IV). Washington DC: American Psychiatric Press.

Barnett, A. L., Kooistra, L., & Henderson, S. E. (1998). 'Clumisness' as syndrome or symptom. *Human Movement Science, 17,* 435–447.

Bax, M. (1999). Specific learning disorders/neurodevelopmental disorders. *Developmental Medicine and Child Neurology, 41,* 147 (Editorial).

Bruininks, R. H. (1978). *Bruininks–Oseretsky test of motor proficiency: Examiner's manual.* Circle Pines, MN: American Guidance Service.

Cantell, M. H., Smyth, M. M., & Ahonen, T. P. (1994). Clumsiness in adolescence: educational, motor, and social outcomes of motor delay detected at 5 years. *Adapted Physical Activity Quarterly, 11,* 115–129.

Cantell, M. H., Smyth, M. M., & Ahonen, T. P. (2003). Two distinct pathways for developmental coordination disorder: Persistence and resolution. *Human Movement Science, 22,* 413–431.

Caravolas, M. (2003). Similarities and differences between English and French poor spellers. In N. Goulandris (Ed.) *Dyslexia in different languages*. London: Whurr.

Catts, H. F., Hogan, T. P., & Fey, M. (2003). Subgrouping poor readers on the basis of individual differences in reading related abilities. *Journal of Learning Disabilities, 36*, 151–164.

Dewey, D., Kaplan, B. J., Crawford, S. G., & Wilson, B. N. (2002). Developmental coördination disorder: Associated problems in attention, learning, and psychosocial adjustment. *Human Movement Science, 21*, 905–918.

Fawcett, A. J., & Nicolson, R. I. (1992). Automatisation deficits in balance for dyslexic children. *Perceptual and Motor Skills, 75*, 507–592.

Fawcett, A. J., & Nicolson, R. I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of Motor Behavior, 31*, 68–78.

Fawcett, A. J., Nicolson, R. I., & Dean, P. (1996). Impaired performance of children with dyslexia on a range of cerebellar tasks. *Annals of Dyslexia, 46*, 259–283.

Frith, U., Wimmer, H., & Landerl, K. (1998). Differences in phonological recoding in German and English speaking children. *Scientific Studies of Reading, 2*, 31–54.

Geuze, R. H., Jongmans, M. J., Schoemaker, M. M., & Smits-Engelsman, B. C. M. (2001). Clinical and research diagnostic criteria for developmental coordination disorder: A review and discussion. *Human Movement Science, 20*, 7–47.

Gillberg, C. (1998). Hyperactivity, inattention and motor control problems: Prevalence, comorbidity, and background factors. *Folia Phoniatrica et Logopaedia, 50*, 107–117.

Gillberg, C., Carlstrom, G., Rasmussen, P., & Waldstrom, E. (1983). Perceptual, motor and attentional deficits in seven year old children. Neurological screening aspects. *Acta Paediatrica Scandinavia, 72*, 119–124.

Gillberg, I. C., Gillberg, C., & Groth, J. (1989). Children with preschool minor Neurodevelopmental disorders. V. Neurodevelopmental profiles at age 13. *Developmental Medicine and Child Neurology, 31*, 14–24.

Hadders-Algra, M. (2002). Two distinct forms of minor neurological dysfunction: Perspectives emerging from a review of the Groningen perinatal project. *Developmental Medicine and Child Neurology, 44*, 561–571.

Hellgren, L., Gillberg, I. C., Bågenholm, A., & Gillberg, C. (1994). Children with deficits in attention, motor control and perception (DAMP) almost grown up: Psychiatric and personality disorders at age 16 years. *Journal of Child Psychololgy and Psychiatry, 35*, 1255–1271.

Henderson, S. E., & Hall, D. (1982). Concomintants of clumsiness in young school children. *Developmental Medicine and Child Neurology, 24*, 448–460.

Henderson, S. E., & Barnett, A. L. (1998). The classification of specific motor coordination disorders in children: Some problems to be solved. *Human Movement Science, 17*, 449–469.

Henderson, S. E., & Sugden, D. A. (1992). *Movement assessment battery for children*. Kent: The Psychological Corporation.

Høien, T., & Lundberg, I. (1991). *Kartlegging av Ord Avkodings Strategier (KOAS) test*. Stavanger, Norway: Centre for Reading Research.

Jongmans, M. J., Smits-Engelsman, B. C. M., & Schoemaker, M. M. (2003). Consequences of comorbidity of developmental coordination disorders and learning disabilities for severity and pattern of perceptual-motor dysfunction. *Journal of Learning Disabilities, 36*, 528–537.

Kadesjö, B., & Gillberg, C. (1998). Attention deficits and clumsiness in Swedish 7-year-old children. *Developmental Medicine and Child Neurology, 40*, 796–804.

Kaplan, B. J., Wilson, B. N., Dewey, D., & Crawford, S. G. (1998). DCD may not be a discrete disorder. *Human Movement Science, 17*, 471–490.

Kronbichler, M., Hutzler, F., & Wimmer, H. (2002). Dyslexia: Verbal impairments in the absence of magnocellular impairments. *Neuroreport, 13*, 617–620.

Losse, A., Henderson, S. E., Elliman, D., Hall, D., Knight, E., & Jongmans, M. (1991). Clumsiness in children—do they grow out of it? A 10-year follow-up study. *Developmental Medicine and Child Neurology, 33,* 55–68.

Lyon, G. R. (1995). Toward a definition of dyslexia. *Annals of Dyslexia, 45,* 3–27.

Missiuna, C., & Polatajko, H. (1995). Developmental dyspraxia by any other name: Are they all just clumsy children? *American Journal of Occupational Therapy, 49,* 619–627.

Missiuna, C., Rivard, L., & Bartlett, D. (2003). Early identification and risk management of children with developmental coordination disorder. *Pediatric Physical Therapy, 15,* 32–38.

Moore, L. H., Brown, W. S., Markee, T. E., Theberge, D. C., & Zvi, J. C. (1995). Binaual coordination in dyslectic adults. *Neuropsychologia, 33,* 781–793.

Mæland, A. F. (1992). Identification of children with motor coordination problems. *Adapted Physical Activity Quarterly, 9,* 330–342.

Mæland, A. F., & Søvik, N. (1993). Children with motor coordination problems and learning disabilities in reading, spelling, writing and arithmetic. *European Journal of Special Needs Education, 8,* 81–98.

Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A framework for dyslexia research? *Cognition, 35,* 159–182.

Nicolson, R. I., & Fawcett, A. J. (1994). Comparison of deficits in cognition and motor skills among children with dyslexia. *Annals of Dyslexia, 44,* 147–164.

Nicolson, R. I., & Fawcett, A. J. (1999). Developmental dyslexia: The role of the cerebellum. *Dyslexia, 5,* 155–177.

Nicolson, R. I., Fawcett, A. J., Berry, E. L., Jenkins, H. I., Dean, P., & Brooks, D. J. (1999). Association of abnormal cerebellum activation with motor learning difficulties in dyslexic adults. *The Lancet, 15,* 1662–1667.

Nicolson, R. I., Fawcett, A., & Dean, P. (2001). Dyslexia, development and the cerebellum. *Trends in Neurosciences, 24,* 508–511.

O'Hare, A., & Khalid, S. (2002). The association of abnormal cerebellar function in children with developmental coordination disorder and reading difficulties. *Dyslexia, 8,* 234–248.

Polatajko, H. J., Fox, M., & Missiuna, C. (1995). An international consensus on children with developmental coordination disorder. *Canadian Journal of Occupational Therapy, 62,* 4–6.

Raberger, T., & Wimmer, H. (2003). On the automaticity/cerebellar deficit hypothesis of dyslexia: Balancing and continuous rapid naming in dyslexic and ADHD children. *Neuropsychologia, 41,* 1493–1497.

Rae, C., Harasty, J. A., Dzendrowskyj, T. E., Talcott, J. B., Simpson, J. M., Blamire, A. M., Dixon, R. M., Lee, M. A., Thompson, C. H., Styles, P., Richardson, A. J., & Stein, J. F. (2002). Cerebellar morphology in developmental dyslexia. *Neuropsychologia, 40,* 1285–1292.

Rae, C., Lee, M. A., Dixon, R. M., Blamire, A. M., Thompson, C. H., Styles, P., Talcott, J. B., Richardson, A. J., & Stein, J. F. (1998). Metabolic abnormalities in developmental dyslexia detected by ^{1}H magnetic resonance spectroscopy. *The Lancet, 351,* 1849–1852.

Ramus, R. (2003). Developmental dyslexia: Specific phonological deficit or general sensorimotor dysfunction? *Current Opinion in Neurobiology, 13,* 212–218.

Ramus, R., Pidgeon, E., & Frith, U. (2003). The relationship between motor control and phonology in dyslexic children. *Journal of Child Psychology and Psychiatry, 44,* 712–722.

Rasmussen, P., & Gillberg, C. (2000). Natural outcome of ADHD with developmental coordination disorder at age 22 years: A controlled, longitudinal, community-based study. *Journal of the American Academy of Child and Adolescent Psychiatry, 39,* 1424–1431.

Richardson, A. J., & Ross, M. A. (2000). Fatty acid metabolism in neurodevelopmental disorder: A new perspective on associations between attention-deficit/hyperactivity disorder, dyslexia, dyspraxia and the autistic spectrum. *Prostaglandins, Leukotrienes and Essential Fatty Acids, 63,* 1–9.

Smits-Engelsman, B. C. M., Wilson, P. H., Westenberg, Y., & Duysens, J. (2003). Fine motor deficiencies in children with developmental coordination disorder and learning disabilities: An underlying open-loop control deficit. *Human Movement Science, 22,* 495–513.

Snowling, M. J. (2000). *Dyslexia.* Oxford: Blackwell.

Sperling, A. J., Lu, Z., Manis, F. R., & Seidenberg, M. S. (2003). Selective magnocellular deficits in dyslexia: A 'phantom contour' study. *Neuropsychologia, 41,* 1422–1429.

Stein, J. (2001). The magnocellular theory of dyslexia. *Dyslexia, 7,* 12–36.

Stein, J. (2003). Visual motion sensitivity and reading. *Neuropsychologia, 41,* 1785–1793.

Stott, D. H., Moyes, F. A., & Henderson, S. E. (1984). *The Henderson revision of the test of motor impairment.* Guelph, Ontario: Brook Educational Publishing.

Sugden, D. A., & Wann, C. (1987). The assessment of motor impairment in children with moderate learning difficulties. *British Journal of Educational Psychology, 57,* 225–236.

Talcott, J. B, Gram, A., van Ingelghem, M., Witton, C., Stein, J. F., & Tønnessen, F. E. (2003). Impaired sensitivity to dynamic stimuli in poor readers of a regular orthography. *Brain, Language, 87,* 259–266.

Talcott, J. B., Hansen, P. C., Assoku, E. L., & Stein, J. F. (2000). Visual motion sensitivity in dyslexia: Evidence for temporal and energy integration deficits. *Neuropsychologia, 38,* 935–943.

Tønnessen, F. E. (1997). How can we best define 'dyslexia'? *Dyslexia, 3,* 78–92.

van Daal, V., & van der Leij, A. (1999). Developmental dyslexia: Related to specific or general deficits? *Annals of Dyslexia, 49,* 71–103

Visser, J. (2003). Developmental coordination disorder: A review of research on subtypes and comorbidities. *Human Movement Science, 22,* 479–493.

Wechsler, D. (1974). *Manual for the Wechsler intelligence scale for children—revised.* New York: The Psychological Corporation.

Wilson, B. N., Dewey, D., & Campbell, A. (1998). *Developmental coordination disorder questionnaire (DCDQ).* Calgary, Canada: Alberta Children's Hospital Research Center.

Wimmer, H., Mayringer, H., & Landerl, K. (1998). Poor reading: A deficit in skill-automatization or a phonological deficit? *Scientific Studies of Reading, 4,* 321–340.

Wimmer, H., Mayringer, H., & Raberger, T. (1999). Reading and dual-task balancing: Evidence against the automatization deficit explanation of developmental dyslexia. *Journal of Learning Disabilities, 32,* 473–478.

World Health Organization. (2001). *International classification of functioning, disability and health.* Geneva: World Health Organization.

Yap, R. L., & van der Leij, A. (1994). Testing the automatization deficit hypothesis of dyslexia via a dual-task paradigm. *Journal of Learning Disabilities, 27,* 660–665.

