Chapter 6

Fine motor deficiencies in children diagnosed as DCD based on poor grapho-motor ability

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Abstract
A sample of 125 children from grades 4 and 5 of two normal Dutch primary schools were investigated regarding the incidence of handwriting problems and other fine motor disabilities. Handwriting quality was assessed with the Concise Assessment Method for children’s handwriting (BHK) and the school questionnaire for teachers (SQT). Two groups of 12 children each were formed, one group of good writers and a group of poor writers selected from the lower performance range. The latter group was investigated in depth by assessing general and fine motor ability using the Movement Assessment Battery for Children (M-ABC test) and the Motor Performance School Readiness Test (MSRT). We hypothesised that poor handwriting is part of a wider neuromotor condition characterised by faster and cruder movements, lack of inhibition of co-movements and poor co-ordination of fine motor skills. To test the theory kinematic measures of drawing movements were collected on the flower-trail-drawing item of the M-ABC test. Moreover, the experimental group of poor writers received physiotherapy during a three-month period and was tested for handwriting proficiency after therapy and again nine months later. The results revealed that 34 % of the group of 125 children displayed handwriting problems. The analysis confirmed that serious handwriting problems are accompanied by fine motor deficits. We suggest that in these children an enhanced level of neuromotor noise is compensated for by enhanced phasic stiffness of the limb system. This results in higher movement velocity and fewer velocity peaks. In the children who received physiotherapy the quality of handwriting improved.
Movement control during fine motor tasks such as writing and drawing has been studied extensively in normal children (e.g., Meulenbroek & Van Galen, 1988; Wann, Wing, & Søvik, 1991). The complexities of these tasks are nevertheless hardly understood. Research into deviant development of fine movement behaviour has not resulted in definitive insights, which is unfortunate since research on disturbed motor behaviour in children has important implications for the development of theory-based intervention programs. Studies of deviant motor behaviour are complicated by the fact that the neuromotor system works according to the principle of output optimisation. This makes it hard to distinguish whether the altered properties of a movement pattern should be attributed to some primary disorder or to the adaptation to the disorder. In the latter case the “abnormal” movement pattern that has evolved could be seen as the optimal task solution given the altered properties of the neuromotor system. In that case, it should be seen as a “normal” adaptation, considering the reduced number of available strategies or fewer degrees of freedom (Latash & Anson, 1996).

The latter view is in particular true for handwriting and drawing movements. In these tasks various end-effector segments are involved which give the system a considerable amount of flexibility under changing temporal and spatial task conditions. Handwriting requires a high level of co-ordination and high-precision force regulation, which makes it a relevant task for studying the causes and effects of motor co-ordination disorders. Children with co-ordination disorders lack the normal redundancy in movement strategies. Consequently, they will be less flexible to adapt to task constraints (Smits-Engelsman, 1995). Not surprisingly, writing problems are frequently mentioned symptoms in children with Developmental Coordination Disorder (DCD; APA, 1994).

In general, studies of dysgraphia have been conducted from a descriptive, product-oriented approach. In that tradition, the main feature of dysgraphic children is that they are not capable of producing a good quality script. Dysgraphic handwriting is said to lack consistency (Keogh & Sugden, 1985; Hamstra-Bletz, 1993) and the observed inadequacies are typically of a motor nature and not due to carelessness or ignorance, nor are poor spelling or other psycholinguistic problems the primary cause (Wann & Kardirkamanathan, 1991; Smits-Engelsman & Van Galen, 1997). Another common feature of children with dysgraphia is that they, even with the proper amount of instruction and practice in school, fail to make sufficient progress in the acquisition of the skill. In a one-year follow-up study on the persistence of deficiencies of fine motor skills and dysgraphia (Smits-Engelsman, Van Galen, & Portier, 1993, 1994) it was shown that poor writers who did not receive remedial treatment had not caught up, nor had their performance improved much in the one-year period. On the basis of these results it was concluded that poor handwriting is not caused by a developmental delay but rather by a specific neuromotor condition.
When the child’s teacher has given the child additional support for some time but no progress is made and the child is found to be hampered in school by its poor graphomotor performance, physiotherapy is often prescribed. Studies evaluating physiotherapy treatment for children with a DCD are limited in number and scope, and the results from the few studies that have been conducted are inconsistent. The findings from most efficacy studies so far are indeterminate or of little relevance to improve our insight into the possible causes of the eventual effects of a therapy programme. The reasons for this are the lack of theory-based tasks for evaluation, the heterogeneity of children diagnosed as DCD, the different (or insensitive) evaluative instruments, and the divergent treatments of children with DCD. Motor problems in children with DCD are mostly evaluated by means of product or result-oriented psychomotor tests (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). Most efficacy studies have concentrated on the evaluation of motor performance per se without paying attention to the processes underlying the production of the movements. In the present study, which was inspired by a process-oriented approach, it is argued that studying the kinematics of the children’s movements may be of help to gain insight into the causes of failure to produce an acceptable movement product. In this way we expect to enhance the insight into the possible causes of the differences between good and poor performers, as well as increase our understanding of possible changes brought about by therapy.

The test most commonly used to measure the effects of intervention on everyday, routine motor skills is the M-ABC test (Laszlo, Bairstow, Barttip, & Rolfe, 1989; Losse et al., 1991; Schoemaker, Hijnkema, & Kalverboer, 1994a; Schoemaker, Schellekens, & Kalverboer, 1994b; Wright & Sugden, 1995; Smits-Engelsman, Schoemaker, Van Galen, & Michels, 1996; Rintala, Pienimäki, Ahonen, Cantell, & Kooistra, 1998). Although norm-reference tests are necessary to discriminate between normal and deviant motor performance, such product-oriented ways of testing do not provide any insight into the strategies and dynamics of the way the child moves or has changed moving as a result of treatment. Another backlash of these tests is that they may not be sensitive or specific enough to measure the effects of intervention (Henderson, 1986; Schoemaker et al., 1994b).

The aim of the approach used in the present study is to relate changes in motor behaviour to underlying motor control processes. A major assumption of such a research strategy is that grapho-motor tasks are the joint outcome of several cognitive and neuromotor processes. Knowing more about the processes underlying motor disorders may help to make diagnoses more articulate, and thus lead to more precise evaluations and treatment programmes. Therefore, in this study the outcomes of traditional motor performance tests are related to kinematic analyses of the writing and drawing movements in order to better scrutinise intervention effects.
In earlier studies by Smits-Engelsman et al. (1996), DCD children with poor handwriting were compared with controls and it was found that both the quality of writing and the writing speed (the amount of letters written in 5 minutes) of the poor writers had significantly improved after physiotherapeutic treatment. In a few other studies (e.g. Schoemaker et al., 1994b; Smits-Engelsman & Van Galen, 1997) an XY tablet (digitizer) was utilised to record handwriting and/or drawing movements and analyse their kinematics. Although performance did indeed change, the authors were not able to detect which specific factors of the therapy altered motor execution in the different diagnostic and age groups or the different tasks. Different diagnostic groups (DCD with overall poor motor function versus children with fine motor problems only) seem to apply different, age-dependent strategies for the various tasks to adapt to their deficiency (for more details see Smits-Engelsman, Van Galen, & Schoemaker, 1997). A particular movement strategy that has been observed in impaired children is that of slowing down the end-effector speed, leading to a slower overall movement performance (Schoemaker et al., 1994b). Another strategy mentioned in the study is the absence of co-articulation possibly in order to avoid computationally costly joint rotations. The result is that movement trajectories are less well formed. Yet another strategy was brought forward by Van Galen, Portier, Smits-Engelsman, and Schomaker (1993) based on the theory that poor writers are characterised by increased levels of noise in the neuromotor system. The latter authors state that poor writers filter their noisy motor commands through the application of an enhanced limb stiffness regime, either by increasing movement speed (phasic stiffness), or by scaling up muscular co-contraction (tonic stiffness), exploiting friction with the writing surface through enhancement of pen pressure, or by a combination of these biophysical adaptations. The role of stiffness for effective movement control is discussed in more detail in Van Gemmert and Van Galen (1997).

**Goals of the present research**

There are three questions that we wanted to confirm in this study. The first was after the prevalence of writing problems among Dutch school children. This has been estimated in previous studies to range from 5% to 25% (Hamstra-Bletz, 1993; Smits-Engelsman, 1995; Mojet, 1991). The second question referred to what the underlying deficit of motor control may be. Previous findings imply that poor writers have typical kinematic profiles (low spatial accuracy, noisy velocity profiles with high energy in the tremor-related bands of the spectrum, high movement velocity), pointing in the direction of a poor muscular initiation process as the underlying deficit (Smits-Engelsman et al. 1997; Van Galen et al., 1993). The third question to be verified was the effectiveness of intervention (physiotherapy) (Schoemaker et al., 1994a,b; Smits-Engelsman et al., 1996).
Secondly, we introduced a new set of research questions that relate to: (1) the prevalence of more general motor dysfunction, fine motor dysfunction and noisy or immature motor patterns in children with poor writing performance, (2) the effectiveness of intervention on readability and writing speed, (3) the changes in the movement kinematics of children with poor grapho-motor skills after physiotherapy.

Method

Subjects and selection procedure

Parents were informed by letter of the research to be conducted in the schools of their children. All parents consented to their children participating in the first part of the study (up to the intervention). The procedure we used to determine whether a child was to be diagnosed as a good, a poor or a dysgraphic writer consisted of the administration of the concise assessment method for children's handwriting (BHK, Hamstra-Bletz, De Bie, & den Brinker, 1987), the result of which was verified by the school questionnaire for teachers (SQT, Smits-Engelsman, Van Galen, & Michels, 1995). All children attending grades 4 and 5 of two regular schools were administered the BHK (N = 125). Ninety children were in grade 4 (7-9 years) and 35 children in grade 5 (8-10 years). Ages ranged between 6.10 and 9.10, mean age was 8.4 years.

The SQT was administered when a child was diagnosed as a poor or dysgraphic writer (BHK score $\geq 20; n = 41$). The criterion for motor problems on the SQT was failing at least four out of six items. Target children (N=19) were those who failed both the BHK and the SQT. The parents of these children were informed about the intervention study and were asked to get a referral for physiotherapy from their general practitioner. The parents of 7 children did not think the problems were urgent enough to warrant professional help. In total, 12 children (8 boys and 4 girls, mean age 8.4) were referred for physiotherapy. These children received a more detailed examination with the M-ABC Test (Henderson & Sugden, 1992) and the Motor Performance School Readiness Test (MSRT, Huyberechts, 1981). The performance of these twelve children on the latter two tests was compared to the norm scores.

From the classmates who were classified as good writers (score BHK $< 19$) 12 children were randomly selected as a control group (6 boys and 6 girls, mean age 8.6). The control group was formed to compare their results with those of the poor writers group on tasks for which no norms were available, i.e. the experimental flower trail drawing task.
Measuring instruments

The concise assessment method for children’s handwriting (BHK)

The concise assessment method for children’s handwriting, or BHK, by Hamstra-Bletz et al. (1987) is a screening tool to recognise dysgraphia on the basis of a completed piece of handwriting. This writing task consists of copying a standard text in 5 minutes or at least the first five lines if the child is a very slow writer. The standard text gradually increases in difficulty as the text proceeds, while at the same time the size of the print decreases for each consecutive paragraph. The first five sentences have a degree of difficulty equal to a grade 3 level reading exercise (Hamstra-Bletz, 1993). The child copies the text, which it has not seen before, on unruled paper.

Handwriting quality is evaluated using the dysgraphia scale of the BHK. This scale is based on the assessment of thirteen dysgraphia features, i.e. deviations from the standard handwriting model. The first two items are scored on the basis of the entire written work. Both items are measured on an ordinal scale with six categories resulting in a score from 0 to 5. For the remaining 11 items, the first five sentences are scored as to whether or not a particular feature is present in that sentence. A score of 0 is given if the feature is absent. The maximum score for a feature is 5. Each child's total score on all 13 items is then used to determine if the child is dysgraphic. Classification was done as follows: (a) not dysgraphic: a score of 0-19; (b) poor writers: a score of 20-28; (c) very poor writers / dysgraphic: a score of 29 or higher.

To determine copying speed the number of letters written by the child in the allotted 5 minutes, including corrections, are counted. This score is translated to a decile score scaled to the norm for the child’s grade. Hamstra-Bletz (1993) defines as slow writers children with scores in the first or second decile, while those whose scores are in the eighth to tenth decile are said to be fast writers. Hamstra-Bletz reports satisfactory results regarding inter-rater reliability on the items (r = 0.71–0.89) and intra-rater reliability for grades 4 (r = 0.87–0.94) and 5 (r = 0.79–0.88). In this study the BHK is used both as a selection and an outcome evaluation instrument.

The school questionnaire for teachers (SQT)

This questionnaire, developed by Smits-Engelsman et al. (1995) is based on the teacher’s assessment of a child’s handwriting proficiency. The scale has 7 items that measure several different aspects of writing, such as the form of the letters, the presentation of the written work, the continuity of the hand, the exertion required for writing and the fluency of the hand. In addition, 3 items are included that ask for information on the child’s spelling, general learning performance and general motor skills. The questionnaire does not provide a definition of “normal” so that each teacher has to use his or her implicit norm for what a child of a particular age ought to be able to do.
When a child had been classified as a poor or dysgraphic writer (BHK score $\geq 20$) the teachers provided their assessments of the child's abilities on each of the SQT dimensions on a five-point scale (internal consistency $\alpha = 0.93$). When at least four of the items 1, 2, 3, 5, 6, and 10 are scored below average the child is regarded as definitively experiencing writing problems. Classification with the SQT is comparable to results yielded by the Groninger Motor Observation Scale (82% agreement) (Van Dellen & Kalverboer, 1990), or a general motor test (the KTK; 86% agreement) (Kiphard & Schilling, 1974).

**The Movement Assessment Battery for Children (M-ABC test)**

The most frequently used test of motor performance for children with motor disorders is the M-ABC test developed by Henderson and Sugden (1992) and validated for the Dutch population by Smits-Engelsman (1998). This instrument was developed to provide an indication of a child's motor functioning in everyday life. Research has shown that the M-ABC test is a useful instrument for identifying children with motor difficulties (Henderson & Hall, 1982; Laszlo & Bairstow, 1985; Sugden & Wann, 1987; Henderson, May, & Umney, 1989; Smits-Engelsman, Henderson, & Michels, 1998). The M-ABC test consists of four age-related item sets. Each set is built up of eight items that measure different aspects of motor ability; three items measure manual dexterity, two items measure ball skills and three items measure static and dynamic equilibrium. Children can score between 0 and 5 on each item, so that the total score will vary from 0 to 40. The total scores can be transformed into percentile scores that show the child's level of performance in comparison with its peers. The test has a moderate to good validity and reliability (Henderson & Hall, 1982; Lam & Henderson, 1987). Henderson and Sugden (1992) found a 62–100% agreement in classification (scores) between different raters and Smits-Engelsman (1998) 90–96% agreement of classification of motor performance between two measurements at a two-week interval. Smits-Engelsman et al. (1998) studied the relationship between the M-ABC test and the 'Körperkoordinationstest für Kinder' (Kiphard & Schilling, 1974) in 202 children. A correlation of 0.62 and a Cramer's $V$ of 0.56 was found for the classification of motor performance.

The M-ABC test was administered to collect data on general motor performance for the poor handwriting group. The children were tested by an experienced paediatric physiotherapist.

**The Motor Performance School Readiness Test (MSRT)**

The MSRT (Huyberechts, 1981) was originally designed as an early screening instrument for perceptual-motor deficits that may be indicative of later learning problems. The norms used are based on children aged 5–6.8 years and provided by the test manual. This test was used because of its proven sensitivity to detect fine motor
problems in poor writers even though the items have usually already been mastered by children 6.8 years of age (Smits-Engelsman, 1995).

The test consists of 19 neuro-developmental items (e.g., walking on heels, diadochokinesis, recognition and labeling of body parts, and left–right discrimination) scoring five factors; gross motor functions (static and dynamic balance), co-ordination of involuntary movements (e.g., diadochokinesis), fine motor functions and laterality, complex functions, and body scheme.

The total test score and the scores on the factor co-ordination of involuntary movements and the factor co-ordination of fine motor functions are hypothesised to be the most important scores for children in this study. Involuntary associated movements are seen in young children, but they also occur in older children (> 8 years), in particular during the performance of unusual or very difficult movements. If involuntary movements are present, smoothness will be affected, although the quantitative scores may well be within the normal range (Touwen, 1979).

Flower-trail drawing item of M-ABC test

One of the manual dexterity items of the M-ABC test (Henderson & Sugden, 1992) is the flower trail. In each age-related battery there is such an item measuring pencil control. The flower-trail item for 7- and 8-year-old children (Fig. 1) was used in this study for the recording of the children’s movement dynamics. The children were instructed to draw a line between the two solid lines of the flower trail as accurately as possible. They were also told not to lift the pen while drawing the trace. There was no speed instruction or time constraint. The child was allowed to draw the line in either the clock-wise or anti-clock-wise direction. Prior to the experiment each child was allowed to practice so that it could familiarize itself with the experimental setting, which also allowed the experimenter to check that the child understood the task. The flower-trail tasks were printed on normal sheets of A4 paper, three test figures per page. All children had to complete 10 flower trails. They were seated at a table on which the digitizer was placed. For every series of three test figures a fresh sheet with three flower trails was laid upon the digitizer. Subjects wrote with a wireless electronic pen of normal appearance and weight.

Pen position data over time were recorded using a Wacom UD-1218-RE digitizer with a wireless inking pen and the OASIS software (De Jong et al., 1996). The position of the pen tip, and the force exerted along the axis of the pen, was recorded with a sampling frequency of 206 Hz. All data were stored for later analysis using the same software package. OASIS was especially designed for psychological tests and experiments that employ a digitizer. Before each experiment a calibration of the pen pressure on the digitizer was performed at 0.25 N intervals. In the analysis, the start and end (vertical) parts of the flower trial were not taken into account. For each dependent variable the mean and the standard deviation of ten repeated flowers was taken for

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further analysis. The following kinematic variables were used as dependent variables: Trajectory Length in cm: distance in centimetres covered by the pen tip; Movement Time in seconds: total time in seconds taken to complete the flower; Velocity in cm/seconds: average of absolute velocity of the pen tip; Number of Velocity Peaks: number of times absolute velocity reached a peak; Pen-up Time: time during which the pen was not on the digitizer; Number of Lifts: number of times the pen was not on the digitizer; Pen Pressure in N: average axial pen pressure in Newtons.

Intervention
Two paediatric physiotherapists treated the children 18 times over a period of approximately 3 months. The child-specific therapy was based on the individual assessment results. The actual writing of letters or words was not trained. The therapy approach was build on the following three elements:
1. Prewriting exercises, aimed at learning to adapt force to different contexts and with different materials (Smits-Engelsman & Van Tuyl, 1998). Starting point for these exercises is that children experience fluent movements during trajectory formation. From there on movements with different amplitudes are trained (force generation) until
a certain level of constancy is obtained. After that, exercises to train spatial and temporal constraints are brought into the program.

2. Fine motor training if manipulative skills were found to be insufficient to perform prewriting exercises.

3. "Gross" motor function training only if one or more of the prerequisites for sitting and independent arm movements were lacking (See 2).

**Procedure**

The drawing task was administered individually in a quiet room. The total time needed for the motor performance measurements of the children with writing problems was about 2 hours and the drawing task took about 30 minutes. The poor writers were re-assessed twice after the physiotherapy intervention, approximately 3 and 12 months after the first measurement.

**Data analysis**

To test differences in general or more specific aspects of motor proficiency between the experimental group and the control children we analysed the results on the motor assessment scales, the school performance data, and the kinematic data of the flower trail. For the contrast analyses on BHK data t-tests (corrected for equality of means) were used. The kinematic variables used were mostly skewed, so comparisons were made with non-parametric tests for significance, the Mann–Whitney U test for differences between groups and the Wilcoxon test for changes over the three-month period.

Because of the small number of subjects, we could have used a less conservative significance level, but to correct for multiple comparisons, the probability level was set at 0.025 to establish significant effects. Since group data obscure individual differences between subjects, we will report how many children in the experimental group really deviated from the norm values.

**Results**

*Prevalence of writing problems in the pre-selection group (N = 125)*

On the basis of the concise assessment method for children’s handwriting (BHK, Hamstra-Bletz et al., 1987) children were classified as good, poor or dysgraphic writers. Scores ranged from 5 to 41, mean score was 17 and were normally distributed. This procedure resulted in identifying 84 good writers (67%), 34 poor writers (27%) and 7 dysgraphic writers (6%). Nineteen children (15%) failed on both the BHK and the SQT, which indicates they were not only characterised by substantially lower writing performance levels given their chronological age, but that their teachers had also reported interference with daily school activities.
Comparison between the academic performance of the poor writers and the normative data

Because handwriting proficiency was the basis for assigning children to either the group of good or (very) poor writers, it is not surprising that a significant difference was obtained on the handwriting quality score of the BHK, as well as on all handwriting items of the SQT. The spelling performance of the children with poor handwriting, however, fell within the normal range. No significant differences were found for copying speed. Table 1 presents an overview of the performance of the poor writing group and the control group on the BHK and SQT.

<table>
<thead>
<tr>
<th></th>
<th>Poor writers (n = 12)</th>
<th>Good writers (n = 12)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHK handwriting quality</td>
<td>25 (6)</td>
<td>12 (6)</td>
<td>0.0001</td>
</tr>
<tr>
<td>BHK copying speed</td>
<td>132 (35)</td>
<td>138 (23)</td>
<td>n.s.</td>
</tr>
<tr>
<td>Teachers' rating for writing</td>
<td>5.1 (0.64)</td>
<td>6.2 (0.49)</td>
<td>0.002</td>
</tr>
<tr>
<td>Total score SQT</td>
<td>38 (4.7)</td>
<td>26 (6.7)</td>
<td>0.001</td>
</tr>
<tr>
<td>Writing items SQT</td>
<td>20 (3.7)</td>
<td>12 (3.8)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Prevalence of overall motor dysfunction, fine motor dysfunction, and noisy or immature motor patterns in the group of poor writers

Of the 12 children selected for a more detailed examination of overall motor function, three scored below the 15th percentile on the M-ABC test. Seven children scored below the 15th percentile on the manual dexterity scale of this test. Compared to the norm scores of the MSRT for 6.8-year-old children, the scores of three poor writers were still deviant (below the 30th percentile) on the total MSRT. On the factor fine motor skills 10 children were found to have deviant scores and on the factor co-ordination of involuntarily movements seven children (see Table 2 for their individual scores).
Table 2. Description of the poor writers' gender, age and their individual scores on the BHK, M-ABC, M-ABC manual dexterity, the MSRT-raw total, 2nd, and 4th factor scores with decile scores (2nd factor is fine motor skills and laterality and the 4th factor is coordination of involuntary movements)a

<table>
<thead>
<tr>
<th>Gender</th>
<th>Age</th>
<th>BHK-score</th>
<th>M-ABC</th>
<th>M-ABC-manual</th>
<th>MSRT Factor 2</th>
<th>MSRT Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>7.8</td>
<td>27 *</td>
<td>5.5</td>
<td>0</td>
<td>54–9</td>
<td>10–3 *</td>
</tr>
<tr>
<td>F</td>
<td>7.9</td>
<td>22 *</td>
<td>9</td>
<td>4 *</td>
<td>55–9</td>
<td>12–6</td>
</tr>
<tr>
<td>F</td>
<td>7.7</td>
<td>28 *</td>
<td>6</td>
<td>2</td>
<td>52–8</td>
<td>9–1 *</td>
</tr>
<tr>
<td>M</td>
<td>8.2</td>
<td>20 *</td>
<td>5</td>
<td>4 *</td>
<td>59–9</td>
<td>11–4</td>
</tr>
<tr>
<td>M</td>
<td>8.6</td>
<td>23 *</td>
<td>7.5</td>
<td>4 *</td>
<td>45–6</td>
<td>9–1 *</td>
</tr>
<tr>
<td>F</td>
<td>8.0</td>
<td>31 *</td>
<td>5</td>
<td>2</td>
<td>45–4</td>
<td>8–1 *</td>
</tr>
<tr>
<td>M</td>
<td>9.0</td>
<td>27 *</td>
<td>21 *</td>
<td>10.5 *</td>
<td>38–3 *</td>
<td>8–1 *</td>
</tr>
<tr>
<td>M</td>
<td>7.8</td>
<td>23 *</td>
<td>9</td>
<td>7 *</td>
<td>39–3 *</td>
<td>8–1 *</td>
</tr>
<tr>
<td>M</td>
<td>9.3</td>
<td>20 *</td>
<td>12.5 *</td>
<td>10 *</td>
<td>48–8</td>
<td>10–2 *</td>
</tr>
<tr>
<td>M</td>
<td>8.4</td>
<td>23 *</td>
<td>5</td>
<td>3.5</td>
<td>38–3 *</td>
<td>7–1 *</td>
</tr>
<tr>
<td>M</td>
<td>8.0</td>
<td>41 *</td>
<td>0</td>
<td>0</td>
<td>53–9</td>
<td>10–3 *</td>
</tr>
<tr>
<td>F</td>
<td>9.10</td>
<td>22 *</td>
<td>10 *</td>
<td>8.5 *</td>
<td>50–7</td>
<td>9–1 *</td>
</tr>
<tr>
<td>4M:1F</td>
<td>8.4</td>
<td>25</td>
<td>8</td>
<td>4.6</td>
<td>48</td>
<td>9.3</td>
</tr>
</tbody>
</table>

*a An asterisk (*) means deviant

Differences in the errors and kinematic profiles in the flower trail of poor and proficient writers

The mean number of drawing errors (crossings of the outlines of the flower-trail figure) was 17 for the poor writers and 5.5 for the control group (Z = –2.98, p < 0.01). No significant difference in average trajectory length of the 10 flowers was found between the two groups. However, for movement time (time needed to complete a figure) and movement velocity while drawing, main effects for groups were found. The poor writers finished the tasks in less time (p < 0.025) and they also used a higher (p < 0.025) movement velocity. There was a non-significant tendency for good writers to spend, on average, more time pausing above the paper (0.56 seconds versus 0.39 seconds for the poor writers). In guiding the pen through the flowers the poor writers' movements tended to have fewer velocity peaks. No differences were found for pen pressure, nor for the number of times the pen was lifted. Table 3 presents the means, standard deviations, test-statistics and p-values for each group.
Table 3. Kinematic data on the flower-trail drawing item and comparison of the experimental group of poor writers (n=12) and the control group of good writers (n=12) using the Mann–Whitney U test

<table>
<thead>
<tr>
<th></th>
<th>Experimental group</th>
<th>Control group</th>
<th>Z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trajectory length (cm)</td>
<td>35.1 (3.2)</td>
<td>36.3 (4.8)</td>
<td>-1.44</td>
<td>.16</td>
</tr>
<tr>
<td>Movement time (seconds)</td>
<td>28.3 (6.9)</td>
<td>36.1 (7.3)</td>
<td>-2.25</td>
<td>.024</td>
</tr>
<tr>
<td>Movement velocity while drawing (cm/second)</td>
<td>1.66 (0.32)</td>
<td>1.36 (0.16)</td>
<td>-2.48</td>
<td>.012</td>
</tr>
<tr>
<td>Number of velocity peaks</td>
<td>176.1 (39)</td>
<td>214 (49)</td>
<td>-1.73</td>
<td>.083</td>
</tr>
<tr>
<td>Pen-up time (seconds)</td>
<td>0.39 (0.28)</td>
<td>0.56 (0.24)</td>
<td>-1.85</td>
<td>.065</td>
</tr>
<tr>
<td>Number of lifts</td>
<td>1.38 (1.2)</td>
<td>2.14 (2.5)</td>
<td>-1.33</td>
<td>.20</td>
</tr>
<tr>
<td>Pen pressure (N)</td>
<td>2.25 (0.94)</td>
<td>2.26 (0.76)</td>
<td>-0.81</td>
<td>.44</td>
</tr>
</tbody>
</table>

**Writing performance of the poor writers before and after treatment**

At the time the children were assessed as having writing problems according to the concise assessment method for children’s handwriting (BHK) their writing quality score was 25. After the three-month treatment period their mean score for quality had improved to 21 (t(12) = 1.93, p < 0.05). At the third measurement, 12 months after the first, they wrote qualitatively better still, resulting in an average score of 14, which is a significant improvement of the writing product (t(12) = 5.2, p < 0.001). As to writing speed, before treatment they wrote on average 132 letters in 5 minutes, whereas after the treatment period they wrote 149 letters (t(12) = 1.4, p = 0.09, n.s.). At the third measurement they wrote 212 letters in 5 minutes, i.e., 80 letters more than before therapy (t(12) = 4.27, p < 0.001). Table 4 gives insight into the individual improvement over the 12 months period corrected for normal development.

**Changes in the kinematic profiles of the poor writers after 3 months**

The mean number of drawing errors did not decrease between the two measurements. However, a significant difference in the trajectory length measure was found (Z = –2.12, p < 0.05). At the second measurement (see Table 5) the trajectory covered was almost 2 cm shorter per flower trail (35.1 vs. 33.3 cm, respectively). For movement time, movement velocity while drawing, and number of velocity peaks no significant main effects were found. During the second measurement the poor writers completed the tasks within the same time as during the first measurement and used the same movement velocity. However, when corrected for trajectory length, the poor writers tended to use fewer velocity peaks per distance at the second measurement (Z =–1.96, p = 0.05). There was also a tendency to spend on average shorter intervals above the paper.
(39 and 18 seconds per flower; $Z = -2.09, p < 0.05$) and to lift the pen less often (1.38 vs. 0.54 times per flower; $Z = -1.96, p = 0.05$). No differences were found for pen pressure.

Table 4. Classification of the individuals (in the experimental group of poor writers) before and after treatment and one year after starting treatment on handwriting quality and copying speed using the concise assessment method for children’s handwriting (BHK; Hamstra-Bletz, et al., 1987)

<table>
<thead>
<tr>
<th>Handwriting quality</th>
<th>Copying-speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dysgraphic writers</td>
<td></td>
</tr>
<tr>
<td>Before treatment</td>
<td>2</td>
</tr>
<tr>
<td>After treatment</td>
<td>2</td>
</tr>
<tr>
<td>After 1 year</td>
<td>2</td>
</tr>
<tr>
<td>Poor writers</td>
<td></td>
</tr>
<tr>
<td>Before treatment</td>
<td>10</td>
</tr>
<tr>
<td>After treatment</td>
<td>5</td>
</tr>
<tr>
<td>After 1 year</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 5. Kinematic data on the flower-trail drawing item of the experimental group of poor writers (n=12) before and after treatment with physiotherapy (Wilcoxon test)

<table>
<thead>
<tr>
<th></th>
<th>Before treatment</th>
<th>After treatment</th>
<th>Z-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trajectory length (cm)</td>
<td>35.1 (3.2)</td>
<td>33.3 (0.7)</td>
<td>-2.12</td>
<td>0.03</td>
</tr>
<tr>
<td>Movement time (seconds)</td>
<td>28.3 (6.9)</td>
<td>24.8 (4.0)</td>
<td>-1.34</td>
<td>0.18</td>
</tr>
<tr>
<td>Movement velocity while drawing (cm/s)</td>
<td>1.66 (0.32)</td>
<td>1.75 (0.25)</td>
<td>-0.78</td>
<td>0.47</td>
</tr>
<tr>
<td>Mean number of velocity peaks</td>
<td>176.1 (39.0)</td>
<td>143.0 (24.8)</td>
<td>-1.96</td>
<td>0.05</td>
</tr>
<tr>
<td>Mean pen-up time (seconds)</td>
<td>0.39 (0.28)</td>
<td>0.18 (0.15)</td>
<td>-1.96</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of lifts</td>
<td>1.38 (1.20)</td>
<td>0.54 (0.38)</td>
<td>-2.09</td>
<td>0.04</td>
</tr>
<tr>
<td>Pen pressure (N)</td>
<td>2.25 (0.94)</td>
<td>2.20 (0.68)</td>
<td>-0.31</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Discussion

One of the aims of this study was to provide prevalence data on handwriting difficulties in a normal population of grade 4 and grade 5 children. These findings confirm once again that handwriting is a difficult skill to accomplish. One-third of the children in the sample fell short of the norms for handwriting quality of the BHK. For about 15% of the
children, both the objective BHK and subjective measures (SQT filled out by the teachers) verified writing difficulties.

The M-ABC test, an instrument for overall motor performance, provides an indication of a child's motor functioning in everyday life. Although only 3 (out of 12) children showed a below-norm total score on the M-ABC test, the children in the evaluation study meet the diagnostic criteria for DCD described in DSM-IV (APA, 1994). All selected children experienced writing difficulties according to their teachers and as measured by an objective handwriting assessment tool (BHK). Moreover, their inadequate development of a specific academic motor skill (handwriting) evidently interfered with daily school activities. Parents acknowledged the problems and general practitioners were willing to refer the children to physiotherapy. To our knowledge, the symptoms of the children were not caused by a known physical disorder like neurological or sensory deficits or mental retardation.

In addition, the M-ABC test indicated that seven of the twelve children were having problems with fine motor skills. The MSRT gave a similar picture. According to the results on the MSRT only 3 children seemed to function below the level of a normal total score. One should keep in mind, however, that the norm scores of this test apply to children between the ages of 5–6.8. Beyond this age a ceiling effect is expected because the test is designed to assess if children perform at elementary school entrance level, e.g., have adequate fine motor skills (factor 2). Likewise, an improvement is expected on factor 4, involuntary movements, because dyskinetic movements are supposed to disappear in older age groups. All but one of the 12 poor writers, however, were performing below par on factor 2, measuring co-ordination of fine motor skills and half of the children was not able to suppress mouth-hand automatism's (part of factor 4). It can therefore be stated that the group of poor writers is characterised by substantially lower performance in fine motor co-ordination given their chronological age. If one wishes to identify fine-motor co-ordination problems in children with handwriting difficulties by means of a general norm-referenced motor test, we recommend that both motor performance tests used in this study be administered (manual dexterity items of the M-ABC test and at least the items representing factor 2 of the MSRT).

When comparing the performance of the poor writers (children with DCD, mainly characterised by poor fine motor performance) to published norms and the matched controls, it became clear that they are most typically characterised by spatially inconsistent motor behaviour and by fine motor deficits. A persistent feature is a high degree of involuntary movements (dyskinesia). On the basis of the kinematic analysis of the children’s drawing movements we also found that poor writers can be characterised as being less capable to adapt to spatial demands. At the same time, they exhibit faster movements, fewer velocity peaks and fewer pauses above paper. Taken together, this may imply that they prefer a more ballistic movement strategy that is less dependent
upon visual correction. From the perspective of the neuromotor noise hypothesis as discussed in the introduction of this paper this may mean that the present group of poor writers chooses to apply higher phasic stiffness to filter a higher level of neuromotor noise in their neuromotor apparatus. In Van Galen et al. (1993) and Smits-Engelsman and Van Galen (1997) direct evidence for higher tremor-related energy in the movement velocity spectra of poor writers was found. This makes them particularly deficient in making fine adaptations to the high level of accuracy required in the experimental task used in this study and less vulnerable in the free writing task on an unruled paper (BHK). These observations are in accordance with our theory published earlier that the deficit in this group of children is caused by a problem in the recruitment of muscle force or muscular initiation stage (Smits-Engelsman & Van Galen, 1997; Van Galen et al., 1993). We have to consider, however, which other underlying processes might cause the fine motor disorder in this group of DCD children. Wilson and McKenzie (1998) conducted a meta-analysis to identify information-processing factors that characterise children with DCD. According to these authors relevant main factors are Visual Processing, Other Perceptual Processing, Motor Control, General Intelligence and Motor Skill. The present study does not support the idea that general intelligence and general motor skill are highly relevant factors. Spelling and general learning performance were in the normal range and only 3 children failed on overall motor performance (the M-ABC test). Children with DCD, however, are known to display deficits in the use of visual feedback (Geuze & Kalverboer, 1987; Lord & Hulme, 1987; Van der Meulen, Denier-van de Gon, Gielen, Gooskens, & Willemse, 1991; Wilson & McKenzie, 1998). For accuracy, visual monitoring of movement is necessary to detect errors and correct movements. Because the flower-trail is performed with full vision, kinaesthetic information may be redundant (Laszlo & Baker, 1972) and kinaesthesia is not the first deficit to be considered. During the practice trials in our experiment the children had no difficulty in pointing out the mistakes they made, they were perfectly aware that they had crossed the lines. However, we cannot conclude that visual information processing is not a factor to be considered in causing the poor motor outcome because it was not manipulated as an experimental factor in the present research.

In accordance with an earlier study by Smits-Engelsman et al. (1996) it was found that the children wrote more accurately after 3 months of physiotherapeutic treatment. Also, this improvement was still present after 9 months. One year after the first measurement, the children -their increased age levels taken into account- still wrote more letters in 5 minutes and the readability of their handwriting product had further improved. As the writing of 9 of the 12 children now was of normal quality and produced at normal speed, this change could not be attributed to a changed speed-accuracy trade-off. Immediately after treatment the poor writers produced higher
quality handwriting. After some practice the children were indeed able to increase their copying speed without any negative effect on the quality of their writing performance. In the introduction we stated that a process-oriented analysis might give insight into the changes in movement strategies. During the second measurement the less proficient writers used less time to complete the task, lifted their pens less often and for shorter periods, covered more centimetres per second, and displayed fewer velocity peaks. We already mentioned the possibility that this movement strategy may be an expression of applying higher phasic stiffness to filter out tremor. The pen pressure applied did not differ from that of the controls nor changed over time. This means that poor writers do not increase the tonic stiffness of the writing hand. Although increased pen pressure is often seen in tasks with high mental or physical stressors (Van Gemmert & Van Galen, 1997) this is not the strategy used by the present group of poor writers. The reason may simply be that children in the age groups under study already use relatively high pen pressure (Mojet, 1991). Still higher pen pressure would ask for enhanced muscular forces to drive the hand-pencil system. Higher forces, however, are typically accompanied by higher neuromotor noise and thus the strategy would not help in counteracting excessive levels of neuromotor noise.

The results of our study indicate that the poor writers contrast most clearly and selectively with the better performers in that they fail to accommodate for the spatial accuracy constraints of the experimental tasks. Three months later, after physiotherapy, the differences between the movement profiles of the children with poor handwriting and those of the controls displayed during the execution of fine motor tasks seemed to have become more pronounced. Contrary to what one might expect, the movement strategy used by the poor writers deviated more from the controls than 3 months earlier. However, they did become better in using their typical movement strategy of higher phasic stiffness, apparently in order to find an optimal task solution given their noisy neuromotor system.

Acknowledgements
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