Handwriting Difficulties in Primary School Children: A Search for Underlying Mechanisms

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OBJECTIVE. This study investigated the contribution of perceptual-motor dysfunction and cognitive planning problems to the quality or speed of handwriting in children with handwriting problems (HWP).

METHOD. Twenty-nine children with HWP and 20 classroom peers attending regular schools (grade 2 and grade 3) were tested with regard to visual perception, visual-motor integration, fine motor coordination, and cognitive planning abilities.

RESULTS. The HWP group scored significantly lower on visual perception, visual-motor integration, fine motor coordination, and cognitive planning in comparison with classroom controls. Regression analyses showed that visual-motor integration was the only significant predictor for quality of handwriting in the HWP group, whereas fine motor coordination (i.e., unimanual dexterity) was the only significant predictor of quality of handwriting in the control group.

CONCLUSIONS. Results suggest that two different mechanisms underlie the quality of handwriting in children with and without handwriting problems. Poor quality of handwriting of children with HWP seems particularly related to a deficiency in visual-motor integration.

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Introduction

Proficient handwriting is one of the scholastic skills that children need to acquire to meet the common demands in classroom work at primary school (Weintraub & Graham, 1998). Thirty percent to 60% of the child's time is spent in fine motor activities, with writing as the predominant task (McHale & Cermak, 1992). Proficient handwriting has also been considered a prerequisite for later academic achievement (Graham, Berninger, Abott, Abott, & Whitaker, 1997; Graham & Harris, 2000). Unfortunately, handwriting difficulties are commonly observed in children at primary schools, particularly in boys. Prevalence has been estimated to range between 5% and 27% depending on grade, selection criteria, and instruments used (Hamstra-Bletz & Blöte, 1993; Karlsdottir & Stefansson, 2002; Maeland, 1992; Mojet, 1991; Smits-Engelsman & Van Galen, 1997).

Several studies have examined the development of competence in handwriting, which is usually described in terms of legibility and speed. Some studies found a gradual improvement of handwriting legibility from grade 1 (Ziviani & Elkins, 1984) or grade 3 (beginning of instruction) to grade 6 onward (Graham, Berninger, Weintraub, & Schafer, 1998; Hamstra-Bletz & Blöte, 1990); whereas other studies indicated that handwriting legibility plateaus in grade 2 or grade 3 (Karlsdottir & Stefansson, 2002; Mojet, 1991; Sovik & Arntzen, 1991). One study found that the quality of handwriting even deteriorated after grade 6, possibly due to the development of personal style (Graham et al., 1998). Handwriting speed improved more or less linearly with grades in primary school (Graham & Weintraub, 1996; Hamstra-Bletz & Blöte, 1990; Karlsdottir & Stefansson, 2002; Ziviani, 1984). Studies in which the correlation between the legibility and speed of handwriting was examined either found only weak positive correlations (Karlsdottir & Stefansson, 2002; Ziviani, 1984), or no significant relation between the variables at all (Graham et al., 1998; Rubin & Henderson, 1982; Sovik & Arntzen, 1991; Weintraub & Graham, 1998). Graham et al. (1998) found that handwriting speed did explain only 1% of the variance in handwriting legibility (when accounting for grade). Interestingly, Weintraub and Graham (1998) reported that instruction to write neatly did result in a decreased speed of handwriting.

Several studies have reported that handwriting legibility of children with handwriting problems (HWP) is clearly worse compared to children without HWP (Hamstra-Bletz & Blöte, 1993; Karlsdottir & Stefansson, 2002; Maeland, 1992; Smits-Engelsman & Van Galen, 1997; Sovik, Arntzen, & Thygesen, 1987; Tseng & Murray, 1994). On average, speed of handwriting does not seem to differ significantly between children with and without HWP (Hamstra-Bletz & Blöte, 1993; Rubin & Henderson, 1982), except for children with HWP attending special education, who were found to be slower compared to controls (Jongmans, Linthorst-Bakker, Westerberg, & Smits-Engelsman, 2003). One study reported that about 16% of children with HWP in grade 3 and grade 5 showed handwriting problems due to slow speed and poor quality, or due to slow speed only (Karlsdottir & Stefansson, 2002). According to these authors, this slow speed of handwriting could be traced back mainly to a dysfunction in the quality of handwriting. As far as we know, no other studies examined the relationship between legibility and speed specific in children with handwriting difficulties.

The underlying mechanisms responsible for handwriting difficulties are not yet understood. Handwriting is a complex activity in which lower-level *perceptual-motor* processes and higher-level *cognitive* processes continuously interact (Berninger & Swanson, 1994; Graham & Weintraub, 1996; Van Galen, 1991). It is assumed that when a child knows what to write, he or she first has to retrieve the correct letters or words from memory, put them in the right order, and convert phonemes into graphemes (higher level processes), before the corresponding motor program can be selected and executed (lower level processes). Although higher-level processes precede lower-level ones, it is further assumed that handwriting involves not only serial hierarchical processing, but also parallel processing; for example, during the evaluation and revision of what was written (Berninger & Swanson, 1994). Perceptual-motor processes in handwriting consist of perception of either visual (e.g., copying text) or auditory (e.g., dictation) information, fine motor coordination, and visual-motor integration (e.g., hand–eye coordination). Cognitive processes involved in handwriting can be divided in more generic processes, such as cognitive planning or working memory processes (McCutchen, 1995, 2000), and more specific language processes, such as phonological and orthographic coding (Berninger & Swanson, 1994).

Empirical evidence exists that problems in handwriting relate to a deficit in *perceptual-motor function*. Several studies have found that children with HWP show a deficit in fine motor control (Maeland, 1992; Smits-Engelsman & Van Galen, 1997; Smits-Engelsman, Niemeijer, & Van Galen, 2001; Van Galen, Portier, Smits-Engelsman, & Schomaker, 1993), whereas other studies reported that visual-motor integration contributes significantly to poor quality (Maeland, 1992; Tseng & Murray, 1994; Weintraub & Graham, 2000) or slow speed of handwriting (Tseng & Chow, 2000). In the study by Maeland (1992), a group of children classified as *clumsy* (half of them being *dysgraphic* and half of them *non-dysgraphic*), *non-clumsy dysgraphic*, and matched *control* were compared with regard to their quality of handwriting. It was found that quality of handwriting significantly correlated with visual-motor integration in the group classified as clumsy, but not in the group classified as non-clumsy dysgraphic and the control group. Furthermore, a significant correlation was also found between quality of handwriting and visual perception in the group classified as clumsy, but again not in the groups classified as non-clumsy dysgraphic and normal. These findings suggest that the correlation between visual perception or visual-motor integration and handwriting performance in dysgraphic children might be specifically related to coinciding developmental coordination disorder (DCD) (American Psychiatric Association, 1994). Indeed, it is known that a majority of children with DCD appear to have problems with their handwriting (Miller, Polatajko, Missiuna, Mandich, & Macnab, 2001). A study by Schoemaker et al. (2001) found that children with DCD also had problems with visual perception; in particular, with visual-motor integration. The question as to what the underlying mechanism is for the handwriting difficulties of children who do not show distinct general motor problems (e.g., the group classified as non-clumsy dysgraphic in the 1992 study by Maeland) remains therefore unsolved.

The role of a deficiency in *cognitive function* as another possible variable to explain poor quality or slow speed, or both, in children with HWP has not yet been investigated. It is known that young novice writers require full use of their attention resources on the lower-level processes of handwriting, and that this may be detrimental for fluent higher-level encoding processes during writing (Graham et al., 1997; Graham & Harris, 2000; McCutchen, 1988, 1995). An interesting question is whether a deficiency in higher-level encoding processes (e.g., phonological or orthographic coding) affects the quality or speed of handwriting, or both. Abott and Berninger (1993) found that orthographic coding contributed directly to the speed of copying text. It has also been suggested that in elementary school children, higher-level processes involved in writing are constrained by limitations in working memory capacity (McCutchen, 2000). In the present study, a pencil-and-paper test that taps cognitive planning ability and working memory capacity will be used to investigate the contribution of cognitive planning to handwriting quality and speed of children with HWP.

Purpose and research questions. The aim of the present study is to investigate the role of lower level processes (i.e., visual perception, visual-motor integration, and fine motor coordination), and higher level processes (cognitive planning) involved in a handwriting task (i.e., copying text) in children with HWP and matched controls. The following research questions were addressed: (a) what are the significant differences between children with and without HWP on the abovementioned variables; (b) how is quality of handwriting associated with speed of handwriting in children with or without HWP; and (c) which of the aforementioned variables is the best predictor of quality and speed of handwriting in children with or without HWP.

Method

Participants

A total of 49 children (29 children with HWP and 20 control children) participated in the study. A two-step procedure was applied to select children with HWP. First, class teachers of grades 2 and 3 from 23 regular schools were asked to screen children on distinct handwriting difficulties. Thirty children were pre-selected by the class teachers from a total sample of 687 children. For each child with handwriting difficulties, teachers were asked to select a control child; that is, the first child on the class list that matched for age and gender. For various reasons, not all of the teachers selected a control child, resulting in a total group of 20 control children. To confirm the classroom teachers' judgment, all children were evaluated on the Concise Assessment Scale for Children's Handwriting (Hamstra-Bletz, de Bie, & den Brinker, 1987). Twenty-nine children were diagnosed as *dysgraphic* on this assessment and were included in the study. Informed consent of parents was obtained for all 29 children with HWP and for 20 control children. In Table 1, age, gender, and the Movement Assessment Battery for Children (Movement ABC) (Henderson & Sugden, 1992) score for the HWP and control group are presented. The two groups did not significantly differ in age. The HWP group scored significantly worse on the Movement ABC total score (t = 12.60, p < .001). In the HWP group, 20 children scored below the 5th percentile, indicating that

Table 1. Age, Gender, and General Motor Coordination Ability of Participating Children

	HWP Group (N = 29)		Control Group (N = 20)	
	Grade 2 (N = 20)	Grade 3 (N = 9)	Grade 2 (N = 14)	Grade 3 (N = 6)
Age (months)	91.3	100.1	88.4	97.6
Gender (boys/girls)	16/4	6/3	11/3	4/2
Mean M-ABC score	16.8	16.5	4.1	4.1
(*SD*)	(5.0)	(4.4)	(2.3)	(1.1)

Note. HWP = Handwriting problems; M-ABC = Movement Assessment Battery for Children (Henderson & Sugden, 1992)

they had serious (general) motor problems, 6 children scored between the 5th and 15th percentile (borderline), and 3 children scored above the 15th percentile. In the control group, 1 child was identified as borderline.

Instruments

Handwriting. The Concise Assessment Scale for Children's Handwriting (BHK) (Hamstra-Bletz et al., 1987) is a standardized norm-referenced instrument to identify children with HWP. The handwriting task consists of copying a standard text presented on a printed card as neatly as possible within a time frame of 5 min (or, for slow writers, at least the first five sentences). Children were asked to write in their usual style. They wrote the text on an unlined A4 sheet of paper. Handwriting quality (legibility) was evaluated according to 13 dysgraphia handwriting features:

1. Letter size too large for the child's age
2. Left margin widening
3. Poor word alignment
4. Insufficient word spacing
5. Acute turns in connecting letters
6. Irregularities in joining letters
7. Collision of letters
8. Inconsistent letter size
9. Incorrect relative height of letters
10. Letter distortion
11. Ambiguous letter forms
12. Correction of letter forms
13. Unsteady writing trace

These features are scored on an ordinal scale from 0 to 5, a high score indicating deviance. A child is considered dysgraphic if the overall score exceeds 28 (i.e., 10th percentile). Copying speed was determined by counting the number of letters completed within 5 min, including letter corrections. To classify children as *slow*, *intermediate*, or *fast* writers, the copying speed score was also transformed to a deciles score related to the child's grade. Scores falling within the lower two deciles are considered to represent slow writers, scores in the upper two deciles represent fast writers, and scores in between are labeled *intermediate*. The interrater reliability of the BHK has been reported to vary between $r = 0.71$ and 0.89. Correlation between the BHK and the Dysgraphia Scale (De Ajuriaguerra et al., 1964) is reported to be 0.78 (Hamstra-Bletz & Blöte, 1993).

Fine motor coordination. The Movement ABC test (Henderson & Sugden, 1992) was administered to determine general motor-coordination abilities in all children. The Movement ABC test consists of eight motor tasks that are divided into three categories: (a) Manual Dexterity, (b) Ball Skills, and (c) Balance. Manual Dexterity consists of three tasks that measure different aspects of fine motor ability, namely (a) unimanual speed, (b) bimanual coordination, and (c) unimanual spatial accuracy. Because we were not interested in bimanual coordination ability, we used Unimanual Dexterity (i.e., the sum of task 1 and 3) as the first measure of fine motor coordination. The motor coordination subtest of the Developmental Test of Visual-Motor Integration (VMI) (Beery, 1997) was used as a second measure of fine motor coordination.

Visual-motor integration. The revised version of the VMI (Beery, 1997) was used to measure visual-motor integration. The VMI consists of three parts: (a) visual-motor integration, (b) visual perception, and (c) motor coordination. The revised version of the VMI is suitable to discern the different processes involved in hand–eye coordination tasks (e.g., handwriting), that is, visual perception, visual-motor integration, and motor coordination processes. In the visual-motor integration task children are asked to copy 24 geometric figures starting with simple figures and ending with more complex ones. In the visual perception task children are shown the same geometric figures, and for each figure they have to choose the correct one out of 6 alternatives. The number of correct responses is scored, either until the child fails at three successive items or the child runs out of time (3 min). In the (fine) motor coordination task, children use a pen to make a trail within border lines derived from the same geometric figures. The number of responses without mistakes is scored, either until the child fails at three successive items or the child runs out of time (5 min). Raw scores were converted to standardized scores. The VMI has been reported to be a valid and reliable test (Dickerson-Mayes & Calhoun, 1998).

Visual perception. Visual perception was measured with the VMI visual perception subtest (see previous paragraph for a description and scoring).

Cognitive planning. The Trail Making Test, Part B (TMT-B) (Reitan & Wolfson, 1985) was used as a measure of cognitive planning. The TMT-B measures the cognitive ability to shift between different kinds of tasks and, therefore, reflects not only cognitive planning, but also cognitive flexibility in particular (Arbuthnott & Frank, 2000). The TMT-B consists of tracing a line between circles containing letters and numbers. The child has to alternate between numbers and letters as the numerical and alphabetical sequences progresses. The child begins at *1*, locates and draws a line to *A*, then to *2*, then to *B*, and so on. Children were instructed to perform the task fast but not necessarily with spatial accuracy. Time taken to complete the task was measured. Slow performance is indicative for problems in cognitive flexibility. Neyens and Aldenkamp (1997) reported test–retest reliability for children between 4 and 12 years of age as .56 for the TMT-B. The TMT-B is sensitive to differences in cognitive planning between school-age children with and without academic difficulties (Naerhi, Rasanen, Metsapelto, & Ahonen, 1997; Reitan & Wolfson, 2004).

Procedure

All children were tested at their school in two sessions. The BHK was administered in the first session. The second session took place within 4 weeks from the first session. The selected children with HWP and their matched controls were administered the VMI, TMT-B, and Movement ABC test. After the VMI test, children were allowed a 15-min break. It took about 90 min to test each child. The tests were administered and scored by the second author.

Data Analysis

A 2 Group (HWP, control) × 2 Grade (grade 2, grade 3) analysis of variance (ANOVA) was applied on the BHK–quality, BHK–speed, Unimanual Dexterity, VMI–visual perception, VMI–integration, VMI–motor coordination, and TMT-B score. Because the TMT-B time scores were not normally distributed (left skewed), we transformed the TMT-B scores to logarithmic scores, which were then used for further analysis. An additional Grade × Speed of handwriting (slow, non-slow) ANOVA was applied for the HWP group, because in the control group there were no slow writers. Pearson product-moment correlation was calculated for the HWP and control group separately to determine the relationship between handwriting performance and the different tests. Stepwise linear regression analyses were applied to identify the strongest predictor of handwriting quality and handwriting speed for the HWP and control group separately with Unimanual Dexterity, VMI–visual perception, VMI–integration, VMI–motor coordination, and TMT-B as predictor variables.

Results

Differences Between the HWP and Control Group

Table 2 presents the scores on all the tests for the HWP and control group.

Table 2. Mean Scores (*SD*), *p*-Values, and Effect Sizes of Tests for the HWP Group and Control Group

	HWP Group (*N* = 29)		Control Group (*N* = 20)		*p*	η^2
BHK–quality	38.1	(5.8)	11.9	(3.7)	*	.87
BHK–speed (letters per min)	19.8	(10.2)	34.2	(7.4)	*	.39
BHK–speed (decile score)	3.1	(3.3)	7.5	(2.2)	*	.44
Unimanual Dexterity	7.1	(2.3)	0.8	(0.9)	*	.73
VMI–integration	71.1	(8.4)	112.5	(7.3)	*	.87
VMI–perception	89.0	(11.2)	114.0	(7.8)	*	.62
VMI–motor coordination	76.6	(9.9)	108.4	(5.0)	*	.79
TMT-B (sec)	150.1	(54.4)	77.0	(26.2)	*	.44

* $p < .001$. *Note.* HWP = handwriting problems; BHK = Concise Assessment Scale for Children's Handwriting (Hamstra-Bletz et al., 1987); VMI = Developmental Test of Visual-Motor Integration (Beery, 1997); TMT-B = Trail Making Test, Part B (Reitan & Wolfson, 1985).

Handwriting. Quality of handwriting in the HWP group was significantly lower compared to that of the control group ($F(1,48) = 307.63$, $p < .001$). With regard to the different handwriting features of the BHK, the HWP group performed significantly less proficiently on all features ($p < .002$) except for the features "left margin widening" and "collision of letters." Handwriting of the HWP group was also significantly slower ($F(1,48) = 26.51$, $p < .001$). According to the BHK-norms, 19 of the children with HWP (65.6%) were classified as slow writers, 5 children (17.2%) as intermediate writers, and 5 children (17.2%) as fast writers. In the control group, none of the children were classified as slow writers, 9 were classified as intermediate writers (45%), and 11 children (55%) were classified as fast writers. A significant effect for Grade ($F(1,48) = 8.16$, $p < .01$) showed that the quality of handwriting of children in grade 3 was better compared to that of children in grade 2. No significant effect for Grade was found on BHK–speed. No significant interaction effects were found.

Fine motor coordination. The HWP group scored significantly lower on Unimanual Dexterity ($F(1,48) = 110.63$, $p < .001$), and on VMI–motor coordination ($F(1,48) = 137.20$, $p < .001$) in comparison to the control group. Six children scored more than 2 standard deviations below the mean standard score on the VMI–motor coordination. No significant effects for Grade or interaction effects were found. In the HWP group, the additional Grade × Handwriting Speed ANOVA did not reveal significant main or interaction effects.

Visual motor integration. The HWP group scored significantly lower on VMI–integration ($F(1,48) = 251.26$, $p < .001$) than matched controls. Thirteen children scored more than 2 standard deviations below the mean standard score. No significant effect for Grade or significant interaction effect was found. In the HWP group, a significant Grade × Handwriting Speed interaction effect was found ($F(1,28) = 4.69$, $p < .05$), revealing that, on average, the VMI scores of children with HWP classified as intermediate writers and fast writers were better than that of slow writers in grade 3 (respectively, $M = 78.8$ versus $M = 69.4$), whereas this was not the case in grade 2 (respectively, $M = 66.0$ versus $M = 71.3$).

Visual perception. A significant main effect of Group showed that the HWP group scored lower on the VMI–visual perception ($F(1,48) = 58.12$, $p < .001$) in comparison to the control group. Two children scored more than 2 standard deviations below the mean standard score. No significant effect for Grade or significant interaction effect was found. In the HWP group, the additional Grade × Handwriting Speed ANOVA did not show significant main or interaction effects.

Cognitive planning. The HWP group was significantly slower in completing the TMT-B ($F(1,48) = 34.69$, $p < .001$) compared to the control group. Also, a significant effect for Grade was found ($F(1,48) = 7.27$, $p = .01$), indicating that children in grade 3 were faster in completing the TMT-B task than children in grade 2. No interaction effect was found. Because the trail-making task consists of a motor component and the HWP group also performed worse on unimanual dexterity, the difference in time between the two groups might be due to a motor component (e.g., movement speed) instead of a more cognitive planning component. We therefore applied a regression analyses (entered variables: Group and Movement-ABC Item 1 score; dependent variable: TMT-B score) to check whether Item 1 of the Movement ABC test (i.e., a measure of unimanual speed) would significantly contribute to the explained variance in the TMT-B time score. Group and Movement-ABC Item 1 did together explain 49% of the variance of the TMT-B, but Item 1 did not significantly contribute to the TMT-B time score differences between the two groups (beta = .29; $t = 1.71$, $p = .09$). In the HWP group, the additional Grade × Handwriting Speed ANOVA did not reveal significant main or interaction effects.

Correlations Between Handwriting and Test Variables

In Table 3, Pearson correlations between handwriting quality and speed and the other test variables are presented for the HWP group and control group. In both groups, handwriting quality was significantly correlated with Unimanual

Table 3. Pearson Correlation Coefficients for HWP Group and Control Group

	1	2	3	4	5	6	7
						HWP Group (N = 29)	
1. BHK–quality		−.18	.38*	−.48**	−.20	−.47*	.17
2. BHK–speed	.13		.12	−.05	−.11	−.11	.07
3. Unimanual Dexterity	.45*	−.10		−.48**	−.28	−.56**	.18
4. VMI–integration	−.25	−.18	.21		.25	.52**	−.19
5. VMI–perception	−.24	−.13	.08	.32		.46*	.02
6. VMI–motor coordination	.08	−.15	.16	.06	.21		.04
7. TMT-B	−.01	−.21	.43	.34	.13	.42	
	Control Group (N = 20)						

* $p < .05$, ** $p < .01$. *Note.* HWP = handwriting problems; BHK = Concise Assessment Scale for Children's Handwriting (Hamstra-Bletz et al., 1987); VMI = Developmental Test of Visual-Motor Integration (Beery, 1997); TMT-B = Trail Making Test, Part B (Reitan & Wolfson, 1985).

Dexterity. No significant correlations were found for handwriting speed and other variables for both groups, including lack of a significant correlation between quality and speed of handwriting. Only in the HWP group, quality of handwriting was significantly correlated with VMI–integration. Furthermore, in the HWP group, significant correlations were found between Unimanual Dexterity and VMI–integration; Unimanual Dexterity and VMI–motor coordination; VMI–motor coordination and VMI–integration; and VMI–motor coordination and VMI–visual perception.

Regression Analyses of Handwriting Variables on Test Variables

Stepwise regression analyses of the quality and speed of handwriting on the different test variables (Unimanual Dexterity, VMI–motor coordination, VMI–integration, VMI–perception, and TMT-B) were conducted. In the HWP group, VMI–integration was the best and only significant predictor of handwriting quality (R^2 = .22; beta = –.47; t = –2.74, p = .01). In the control group, Unimanual Dexterity was the best and only significant predictor of handwriting quality (R^2 = .21; beta = .45; t = 2.15, p < .05). None of the dependent variables significantly predicted speed of handwriting in the HWP or control group.

Individual Differences in the Group With HWP

Twenty children with HWP were identified as slow writers. However, T-tests did not reveal significant differences between this group classified as slow and the groups classified as intermediate and fast (N = 9) on any of the other dependent variables. As an illustration of the individual differences in the HWP group with regard to the performance on the different tests, the profiles of five children writing with different speeds are presented in Figure 1. Two of them were identified as slow writers, one as an intermediate, and two as fast writers. Participant #16 (BHK = 41) and participant #20 (BHK = 31) were both classified as fast writers. Participant #16 scored clearly worse compared to participant #20, but the individual profiles are rather similar with both participants performing relatively better on the TMT-B. Writing speed of participant #3 (BHK = 31) was classified as intermediate. This participant scored relatively well on the TMT-B, and poor on VMI–motor coordination. Participants #24 (BHK = 46) and #28 (BHK = 41) were both classified as slow writers. Participant #24 scores relatively worse, particularly on the VMI–perception, whereas participant #28 scores relatively well compared to the other children with HWP except for VMI–integration.

Discussion

The present study investigated the role of different processes that might underlie poor performance of handwriting in a group of children with handwriting difficulties. Fine motor coordination, visual-motor integration, visual perception, and cognitive planning ability were evaluated. Children with handwriting difficulties were less proficient on all of these tests, compared to matched control children.

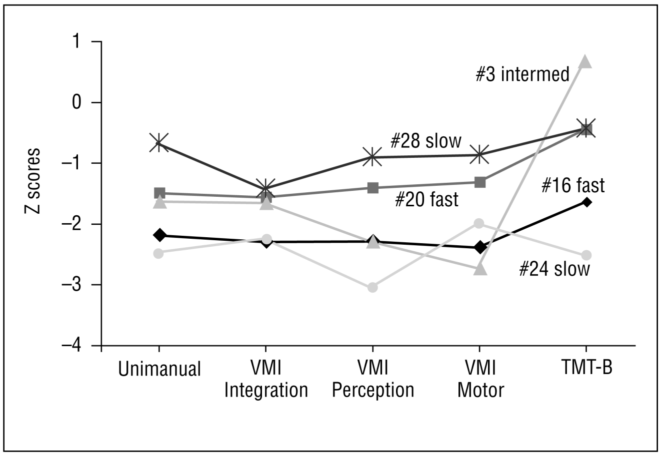

Figure 1. Examples of individual profiles of children with handwriting problems (HWP) based on Z-scores of the dependent variables (note that the zero-line is the average score of the control group).

Note. VMI = Developmental Test of Visual-Motor Integration (Beery, 1997); TMT-B = Trail Making Test, Part B (Reitan & Wolfson, 1985).

Stepwise linear regression analyses revealed that for quality of handwriting, visual-motor integration was the best and only significant predictor in the HWP group, whereas unimanual dexterity was the best and only significant predictor in the control group. No significant correlation between quality and speed of handwriting was found either in the HWP group or in the control group.

Limitations of the Study

First, it should be noted that the sample of children in the present study was rather small. Further, the finding that 20 children with HWP scored below the 5th percentile and 6 children with HWP between the 5th and 15th percentile on the Movement ABC test indicates that deficits in motor execution dominate in this group of dysgraphic children. This scoring might be an explanation for the finding that fine motor coordination and visual-motor integration, but not cognitive planning, were related to quality of handwriting in these children. Thus, the sample consisted of a rather specific group, and findings cannot be generalized easily to children with handwriting difficulties who do not have distinct general motor-coordination problems (e.g., Maeland, 1992; Schoemaker & Smits-Engelsman, 1997).

Quality of Handwriting

Both a deficit in fine motor coordination (cf. Smits-Engelsman & Van Galen, 1997; Smits-Engelsman et al., 2001) and in visual-motor integration (cf. Maeland, 1992; Tseng & Murray, 1994; Weintraub & Graham, 2000) have often been suggested as an explanation for poor quality of handwriting. At first sight, the present study confirms these findings, because both fine motor coordination as measured by unimanual dexterity and visual-motor integration were significantly correlated with quality of handwriting in children with handwriting difficulties. However, unimanual dexterity was also significantly related to handwriting quality in the control group. Moreover, visual-motor integration was the only significant predictor of handwriting quality in the HWP group, whereas unimanual dexterity was the only significant predictor in the control group. These results suggest that two different mechanisms underlie the handwriting performance in both groups, and that the underlying mechanism responsible for poor quality of handwriting in children with handwriting difficulties is related more to visual-motor integration processes than to fine-motor-control processes as such. The latter finding is in agreement with findings in the study by Maeland (1992), in which a similar correlation between quality of handwriting and visual-motor integration was found in a group of children classified as *clumsy* (nowadays labeled *DCD*), half of them showing handwriting difficulties as well. Note that in the study by Maeland, no significant correlation between visual-motor coordination and quality of writing was found in the children classified as non-clumsy with handwriting difficulties. Although some of the children in the present study were classified as non-clumsy, their number was too small to compare them with children with poor general coordination abilities (Movement ABC test < 15th percentile). Maeland also found that visual-motor integration was the best predictor of handwriting accuracy. Findings are also in agreement with those from the study by Weil and Amundson (1994), who found in kindergarten children a significant relationship between visual-motor integration and the ability to copy letters. However, in a more recent study with 5-year-old kindergartners, visual-motor integration was not found to be a good predictor of handwriting performance (Marr & Cermak, 2002).

The finding that the HWP group scored lower on visual perception compared to controls is in agreement with other studies (Maeland, 1992; Schoemaker et al., 2001). Although visual perception is a prerequisite for copying a piece of text, it did not explain inter-individual differences in the quality or speed of handwriting in children with handwriting problems (cf. Maeland, 1992; Tseng & Murray, 1994).

Speed of Handwriting

There is no consensus in the literature whether children with handwriting difficulties have a slower speed of handwriting compared to matched controls. The present study found that speed of handwriting was slower in children with handwriting difficulties, which is not in agreement with other studies (Hamstra-Bletz & Blöte, 1993; Karlsdottir & Stefansson, 2002; Rubin & Henderson, 1982). However, large inter-individual differences were found with regard to writing speed within the HWP group: the majority of the children were classified as slow writers, but 5 children were even classified as fast writers. The question is whether the underlying mechanism for both subtypes of children with handwriting problems is identical. In a recent study with children from grades 2 to 6, a group of slow and normal-speed writers were compared (Tseng & Chow, 2000). Interestingly, in this study it was found that, besides age, visual sequential memory and visual-motor integration were significant predictors of handwriting speed in the slow-speed group, whereas upper limb speed and dexterity was a significant predictor in the normal-speed group. Given the fact that in the present study children with HWP that were—on average—slow-speed writers were compared with children with HWP who were normal-speed writers, our findings are in agreement with the study by Tseng and Chow (2000) with respect to the strongest predictors of handwriting performance. However, it was not reported in that study whether the slow-speed or normal-speed writers also suffered from poor quality of handwriting. Tseng and Chow (2000) concluded that the underlying mechanisms for the handwriting performance of slow-speed and normal-speed writers is different. They suggested that slow writers rely strongly on visually directed processing, including visual-motor integration, leading to slow speed of handwriting (cf. Wann, 1987). The present study, however, showed that visual-motor integration is more related to the quality of handwriting (e.g., letter formation) rather than to handwriting speed. Comparison of the slow and non-slow writers in the group with HWP did not reveal any significant differences. In other words, children with HWP who were also classified as intermediate or fast writers clearly showed a deficit in visual-motor integration. It should be mentioned, however, that the observed interaction effect of grade with speed of handwriting revealed that children with HWP who were non-slow writers performed better on the visual-motor integration task than slow writers in grade 3, but not in grade 2 (non-slow writers in grade 2 showed even lower scores).

Although we have to be cautious in drawing conclusions, because of the small sample size, this finding raises the question of whether slow writers remain impaired on visual-motor integration and whether non-slow writers do improve on visual-motor integration from grade 2 to grade 3. Further (longitudinal) research is needed to investigate whether slow writers and non-slow writers represent two different subtypes of handwriting difficulties with different underlying mechanisms and developmental courses. Furthermore, in order to answer the question as to why children write slowly, research not only should investigate the handwriting product, but also should also focus on the process of handwriting (cf. Rosenblum, Weiss, & Parush, 2003). Slowness during the writing down of words, for example, might be indicative of visual-motor integration problems (e.g., strong reliance on visual feedback), whereas long pauses in between writing down words or sentences might be indicative of more cognitive-related problems (e.g., lack of working memory capacity). It has been suggested earlier that the quotient of the writing-down time and non-writing-down time might be a relevant predictor of handwriting difficulties (Wann & Jones, 1986).

Relation Between Quality and Speed of Handwriting

The finding of the present study that there is a low and nonsignificant relation between the quality and speed of handwriting both in children with and without handwriting difficulties is largely in line with other studies (Hamstra-Bletz & Blöte, 1993; Karlsdottir & Stefansson, 2002; Rubin & Henderson, 1982). The HWP group and the control groups differed only with regard to the sign of the correlation; that is, negative (association between fast handwriting and poor quality) in the HWP group, and positive (association between fast handwriting and low handwriting quality scores) in the control group.

In the present study, speed of handwriting was not related to quality of handwriting either in the HWP or in the control group. Even the children with HWP who were identified as slow writers did not differ from the children with HWP who were classified as non-slow writers on any of the variables. One might have expected that these slow writers would perform also more slowly on the trail-making test. However, 5 out of 20 of the children with HWP who were identified as slow writers were grade 3 children. Because we found an effect of grade on the TMT-B, this might explain why these subgroups of children with HWP did not differ on the trail-making test. Further, the finding that 4 out of 9 of the children with HWP who were classified as fast writers were all children from grade 2 raises the question of whether the handwriting quality of these children was not negatively influenced by their fast speed of writing.

Cognitive Function

On average, children with handwriting problems performed twice as long on the trail-making test than control children. Because accuracy in trail making was not demanded and unimanual movement speed did not significantly contribute to this difference, it seems that this result indeed reflects that cognitive planning (i.e., flexibility) in children with handwriting problems is less proficient compared to control children. How this deficiency interferes with handwriting remains unclear. Scores on the trail-making test did not significantly correlate with quality or speed of handwriting, either in the HWP group or in the control group. Of course, handwriting does not involve shifting between numerical and alphabetic sequences, but copying text as in the BHK does involve visual scanning and shifting between reading what to write and writing it onto paper. As we explained earlier, this shifting probably also taps working memory capacity (i.e., serial letter and number recall). Further research has to elucidate the role of cognitive function in children with handwriting difficulties. It is necessary to use more specific instruments to measure generic cognitive and specific language processes that might interfere with the handwriting quality and speed of children with handwriting difficulties.

Suggestions for Further Research

Because our sample consisted of a rather specific group of children with handwriting difficulties and distinct general motor-coordination problems, replication studies that include different subtypes of dysgraphic children (e.g., children with handwriting difficulties who are classified as non-clumsy, cf. Maeland, 1992) are needed to investigate whether the contribution of underlying mechanisms responsible for handwriting problems differ for such subtypes. Such insight may generate new guidelines for handwriting intervention programs.

As mentioned earlier, another aspect that needs to be addressed in identifying underlying mechanisms of handwriting difficulties is the online analysis of the spatio-temporal processes of handwriting (i.e., handwriting dynamics) using a graphic digitizer. The relation between process and product features (cf. Rosenblum et al., 2003) in the handwriting of children with handwriting difficulties is one of the aspects that especially needs to be addressed.

Conclusion

Findings of the present study show that children with handwriting difficulties appear to perform less proficiently on measures of visual perception, fine motor coordination, visual-motor integration, and cognitive planning in comparison with children without handwriting problems. Although the majority of the children with poor quality of handwriting were also very slow writers, no significant correlation between quality and speed of handwriting was found. Interestingly, findings from the regression analysis suggest that two different mechanisms underlie the quality of handwriting in children with and without handwriting problems. The best predictor of the quality of handwriting in children without handwriting problems appeared to be fine motor coordination, whereas visual-motor integration was the best predictor in children with handwriting problems. Findings of this study suggest that intervention for children with handwriting difficulties should focus not only on improvement of fine motor coordination, but also and foremost on improvement of visual-motor integration processes. ▲

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