DIFFICULTIES WITH HANDWRITING IN PRIMARY SCHOOL CHILDREN

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DIFFICULTIES WITH HANDWRITING IN PRIMARY SCHOOL CHILDREN

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CHAPTER 1

GENERAL INTRODUCTION

HANDWRITING

There is perhaps no skill that children have to acquire in primary school that currently elicits so much controversy as handwriting does. The use of digital devices like laptops, iPads and smartphones is rapidly increasing[1], resulting in a strong decrease of the use of pen(cil) and paper at schools and in society at large. In 2013, about 50% of the U.S. primary school children used a digital tablet for schoolwork several times a week (Statista, 2020), while only two years later, in 2015, a survey pointed out that 78% of the primary school children regularly used a tablet (Cavanagh & Cavanagh, 2017). While in 2018 the use of tablets in the Netherlands was limited to only 20% of the primary schools (Vermooten, 2018), it increased rapidly to approximately 90% during the corona crisis (Ministerie van Onderwijs, Cultuur en Wetenschap, 2020). Recent data on the influence of the COVID-19 period on handwriting are not available yet, but a survey among primary school teachers[2] shows that they identified problems with maintaining writing stamina after the lockdown and that they were concerned with handwriting legibility and speed, given children did practice less or insufficiently during home education.

Indeed, research shows that when handwriting tuition decreases, this results in a reduction of handwriting quality and speed (Skar et al., 2021). In addition, and as for other motor skills, handwriting is for some children a difficult skill to learn, and the acquisition of legible handwriting can be a challenge. In the literature the prevalence of handwriting problems among primary school children is estimated between 6 to 33%, depending on the assessment tool and the specific group of children included in the studies (Feder & Majnemer, 2003; Hamstra-Bletz et al., 1987; Karlsdottir & Stefansson, 2002; Overvelde and Hulstijn, 2011). How these numbers evolved during the COVID-19 period is unknown.

HANDWRITING PROBLEMS

In the Netherlands, children get formal handwriting tuition in the first classes of primary school, starting at five or six years of age. When, according to the teacher or caretaker, children show

[1] *Uitwerking Digitale geletterdheid – Curriculum.nu*. (2022). www.curriculum.nu. Retrieved May 7, 2022, from https://www.curriculum.nu

[2] *What skills have been impacted by Covid-19 and lockdown? | Attainment and Assessment.* (2021, 16 augustus). The Headteacher. Retrieved May 7, 2022, from https://www.theheadteacher.com/attainment-and-assessment/teaching-practice/what-skills-have-been-impacted-by-covid-19-and-lockdown

insufficient handwriting, referral to occupational or paediatric physical therapy to enhance their handwriting is customary.

Insufficient handwriting includes illegible or slow handwriting and/or fatigue or pain while writing (Biotteau et al., 2019; Overvelde & Hulstijn, 2011). Handwriting tuition in primary school typically presumes a universal developmental trajectory for all children. However, although literature about handwriting development during primary school is scarce, and seldomly based on longitudinal studies, current observations suggest that not all children show the same developmental profile. That is, there is one longitudinal study on handwriting development across a period of four years. It reports that six- and seven-year-old children with sufficient handwriting show a steep increase in handwriting quality across Grade 1 (in which formal handwriting tuition starts), resulting in legible handwriting at the end of Grade 1. By contrast, children with insufficient handwriting in Grade 1 show a much slower, gradual increase in handwriting quality from Grades 1 to 3, reaching legible handwriting by the end of Grade 5 only (Karlsdottir & Stefansson, 2002).

In a cross-sectional study, Overvelde and Hulstijn (2011) found that the percentage of children with insufficient handwriting decreased from 36 to 17% in Grade 2 and stabilized after that at about 6% in Grade 3. Both studies suggest that the acquisition of handwriting shows a large bandwidth in rate of development, with some children reaching sufficient handwriting within one year of tuition while other children need two or more years to reach that level of handwriting quality (Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011). Therefore, labelling handwriting, assessed during the first and second year of tuition, as 'dysfunctional', 'insufficient' or even as 'dysgraphic' (see e.g., Duiser et al., 2020; Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011) might perhaps be helpful for a small group, who genuinely have (long-term) handwriting problems, but unnecessarily stigmatizing for a larger group of children who perhaps merely acquire the skill more slowly and thus only show transitory handwriting problems. However, research is scarce on these issues.

Since children learn to write in the first classes of primary school, it is pertinent to distinguish whether children in the first grades show long-term (persistent) handwriting problems that require specific attention and/or occupational or paediatric physical therapy or, whether they show transient handwriting problems, which likely disappear with more practice and education. Although research thus far (Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011) suggests a distinction between children with transient and persistent handwriting problems at the end of Grade 1 or the start of Grade 2, this distinction has not been empirically verified, nor is it clear what factors underpin this difference in handwriting problems, if any. In Chapter 3, a longitudinal study is reported that directly addresses these issues.

CONSTRAINED LED APPROACH

In primary school, all children learn to handwrite according to handwriting methods. According to these methods, all children are expected to eventually produce letters and words in a certain ideal-typical form according to that method. However, the primary aim of handwriting is to communicate on paper, so handwriting must be, above all, legible and at a sufficient pace to contribute to academic skills or other forms of communication. As Srihari et al. (2016) found, handwriting of children becomes more individualistic when children develop through primary school. This seems contrary to the ideal-typical form(s) that the handwriting methods prescribe. Instead, children developing their own legible handwriting, appears as a coherent phenomenon (when) considering the perspective of the constrained led approach (CLA).

The CLA is based on the premise that motor behaviour emerges as result of a self-organisation process. This self-organizational process is constrained by constraints from the child itself, the task and the environment and their temporarily dynamic interactions. This creates movement behaviour that reflects stable yet flexible adaptation to the constraints (Newell, 1986). With respect to handwriting development, this means that the desired motor behaviour is legible handwriting at sufficient speed, independent of the task (e.g., writing between lines, in free text or dictation), but also that its specific form emerges from the interacting constraints. When children learn to write, they adapt to the interacting individual, task, and environmental constraints to obtain a stable, legible handwriting, which is flexible enough to respond to variations, for example, the presence of support lines (Rosengren & Braswell, 2003).

Thus far, most research on handwriting (problems) provided insights about the impact of isolated constraints, and, in particular, abilities that are most strongly associated with organismic constraints. These include the individual's ability to perceive, recognize and identify shapes and letters, alphabet knowledge, motor control and planning abilities, attention, working memory and other executive functions (Berninger & Winn, 2006; Cornhill & Case-Smith, 1996; Daly et al., 2003; Goyen & Duff, 2005; Karlsdottir & Stefansson, 2002; Rosenblum et al., 2010; Rosengren & Braswell, 2003; Smits-Engelsman et al., 2001; Volman et al., 2006). The Beery Buktenica developmental test of visuomotor integration (Beery-VMI; Beery & Beery, 2010), which is often used in children with handwriting problems has been instrumental in this endeavour. It assesses the ability of children to visually recognize and copy figures and accurately draw the same figures between lines (in the test they are often referred to as visual perception, visual-motor integration, and motor coordination, respectively). The relation between these individual abilities and handwriting quality is previously established (Volman et al., 2006). Yet, the degree to which they can also make a distinction between transient or persistent handwriting problems has not been investigated.

Organismic constraints are according to CLA not uniquely, nor solely determine handwriting skill or development. While learning to write, primary school children also have to satisfy task, besides that, handwriting is related to environmental constraints. Task constraints related to handwriting are for instance chair and table heights, type of writing tool (Feder & Majnemer, 2007), size and shape of the writing implement, use of support lines, the requirement to use lower- or upper-case letters (Greer & Lockmann, 1998; Chartrel & Vinter, 2008) or friction between writing utensil (e.g., pen) and paper (Rosengren & Braswell, 2003). Environmental constraints previously mentioned mostly refer to social constraints such as mother's educational level, family size and the time children spend at home on writing (Dunsmuir & Blatchford, 2004).

Most constraints have been studied separately, while constraints always impact handwriting development in unison. For instance, Chartrel and Vinter (2008) found that writing between lines reduces the trajectory length of the handwriting of children five to seven years of age. The influence of lining was larger in five-year-old children, while six and seven-year-old children already wrote smaller than their younger peers. This suggests that task constraints (e.g., lining) interact with organismic constraints age (e.g., age), and presumably the abilities associated with organismic constraints (e.g., related fine motor control).

In conclusion, handwriting (development) arises from the dynamic interactions of organismic, task and environmental constraints. In the present thesis, aspects associated with both organismic (Chapter 2 and 3) and task constraints (Chapter 4) are addressed. In Chapter 2 and 3 we examine whether individual abilities like visual motor integration, visual perception, and motor coordination (as measured by the Beery-VMI) underpin handwriting development, while Chapter 4 describes the influence of support lines on handwriting quality and speed in children with sufficient and insufficient handwriting. These are important addition to the current literature, because so far, no research has been done on the influence of task constraint manipulations like the use of lining on handwriting quality in children with sufficient *and* insufficient handwriting.

HANDWRITING IN RELATION TO OTHER ACADEMIC SKILLS

In the Netherlands, digital skills will be included in all school curricula in 2024[3]. Yet, also in this new curriculum handwriting continues to be considered a critical (motor) skill for children to acquire and remains a mandatory skill within the curriculum of primary school children. Most primary schools (still) teach children to write with pen and paper in their first years at school and invest considerable amounts of time into handwriting skills in Grades 4 to 6, while other schools, however, have chosen to replace a vast amount of time teaching while ‘writing’ on a keyboard (Malpique et al., 2019). The worldwide increase of tablet use, in favour of handwriting, has given a new impulse to the question whether it is important to teach handwriting as an academic skill in primary school, not only for the sake of handwriting but also for a proper development of other academic skills.

The importance of practicing and refining handwriting as a fundamental (motor) skill has been subject of controversy for a while: cognitive psychology and neuroscience apparently emphasize the necessity of handwriting (Longcamp et al., 2005; James & Engelhardt, 2012), whereas socio-cultural research seemingly favours digital writing (Wollscheid et al., 2016). Advocates of handwriting tuition cite research that confirms the usefulness of handwriting in the development of fine motor skills and cognitive skills such as reading (Mangen & Balsvik,

[3] Ministerie van Onderwijs, Cultuur en Wetenschap. (2022, 10 augustus). *Curriculum voor de toekomst*. Toekomst van het onderwijs | Rijksoverheid.nl. Retrieved May 7, 2022, from https://www.rijksoverheid.nl/onderwerpen/toekomst-onderwijs/toekomstgericht-curriculum

2016). Compared to typing, handwriting is assumed to be more complex in coordination and visuomotor control (Sülzenbrück et al., 2011). In addition, some (e.g., Longcamp et al., 2005, 2006) have argued that learning to handwrite facilitates the recognition, discrimination, and memorization of letters because of the topological similarity between writing movements and letter forms while others underline the possible advantage of typing. In fact, Ouellette and Tims (2014) did not found differences in recognition and spelling of words among Grade 2 children who practiced ten novel non-words either through writing or typing. In a review Wollscheid et al. (2016) concluded that a possible advantage of increased digitalization (in education) is that children start producing more lengthy texts, even though they did not master all separate letter in early learning stages.

So far, the research on the relevance of learning to handwrite for other primary school abilities is not conclusive. Where Longcamp et al. (2006) show advantages of learning to handwrite, Kiefer et al. (2015) did not confirm these advantages of (learning to) handwrite in recognizing letters. The research was generally lab-based. However, as primary school children learn in class or in small groups, more research needs to be done on school abilities such as learning to recognize or discriminate letters in classroom to better align with how children learn in primary school.

THESIS

In this thesis, we assess both organismic and task constraints (and their interaction) that underpin handwriting performance (and problems) and its development in primary school children. The thesis also assesses to what degree handwriting, in turn, constraints the acquisition of reading.

We describe in a cross-sectional and longitudinal study, age-related differences, and changes in handwriting among primary school children. First, in Chapter 2, we assessed the influence of aspects that are strongly associated with organismic constraints such as a child's ability to draw between lines or to copy and recognize figures on the handwriting quality and speed in Grade 2 children (i.e., after one year of writing tuition). Besides that, we determined whether there are differences in these individual abilities between children who show sufficient and insufficient handwriting. Therefore, we assessed all children on both the Concise Assessment Scale for Children's Handwriting (BHK) to measure handwriting legibility and speed and the Beery Buktenica developmental test of visuomotor integration (Beery-VMI). The Beery-VMI assumes to indicate the level of visual-motor integration, visual perception, and motor coordination in developing children, and can be considered as reflecting the individual movement abilities or constraints on handwriting (Volman e al. 2006).

After being tested in Grade 2, we assessed the same children once every year for four subsequent years (Grades 2 to 5). In Chapter 3 we present this longitudinal research on handwriting (problems). By assessing all children longitudinally, we aim to get additional insights in the developmental trajectories and interindividual variability therein. Our primary aim is to examine if persistent handwriting problems in primary school Grades 4 and 5 can be predicted at an early stage of development (i.e., Grade 2). In doing so, we are especially interested in revealing how the differences between transient and persistent handwriting problems are underpinned by children's individual abilities as measured by the Beery-VMI.

Further, in Chapter 4, we address the role of task constraints. In particular, we examine how different support lines affect handwriting quality and speed, and the degree to which support lines can promote performance of children, in particularly children who show insufficient handwriting. Two groups of Grade 2 children were asked to write a small text on a sheet with only a baseline and sheets with two and four support lines with a different separation between support lines (i.e., 3 and 4 mm central lines and with 4.5 – 3 – 4.5 and 6 – 4 – 6 mm upper, central and under lines). Writing was recorded with a digitizer to determine kinematic variables on size, velocity, and smoothness. We considered the kinematic differences between the children with sufficient and insufficient handwriting, and then examined how varying the number of lines and the separation between lines affects the handwriting characteristics in both groups.

Chapter 5 reports a classroom-based study that addresses the influence of learning to handwrite and learning to typewrite on letter recognition and discrimination abilities in preschool children without any previous formal letter tuition. Children were assessed on a letter recognition and discrimination test and received either handwriting training, touch typing training or alphabet tuition. After the training period all children were assessed again on both tests to establish the degree to which handwriting and typing can support progress in letter recognition and discrimination.

Finally, in the Epilogue we provide an overview of the main findings and a reflection on the recommendations on further research and implications for clinical practice and best practice in primary school.

CHAPTER 2

RELATIONSHIP BETWEEN THE QUALITY OF CHILDREN'S HANDWRITING AND THE BEERY BUKTENICA DEVELOPMENTAL TEST OF VISUOMOTOR INTEGRATION AFTER ONE YEAR OF WRITING TUITION

Duiser, I. H. F., van der Kamp, J., Ledebt, A. & Savelsbergh, G. J. P. (2014).
Australian Occupational Therapy Journal, 61(2), 76–82

ABSTRACT

Background: We examined whether the three subtests of the Beery Buktenica developmental test of visuomotor integration predicted quality of handwriting across and within groups of children classified as proficient, at risk or non-proficient writers according to the Concise Assessment Scale for Children's Handwriting.

Method: The Beery Buktenica developmental test of visuomotor integration and the Concise Assessment Scale for Children's Handwriting tests were administered to 240 Grade 2 children.

Results: Proficient writers scored better on the visuomotor integration subtest than non-proficient writers, while proficient and at risk writers scored better than non-proficient writers on the motor coordination subtest. No differences were found on the visual perception subtest. Girls were more often classified as proficient writers than boys, and they scored better on the motor coordination subtest. Across groups, regression indicated that gender and both the visuomotor integration subtest and the motor coordination subtest were significant predictors for the quality of handwriting (i.e., accounted for 17% of the variance).

Conclusions: After one year of writing tuition, the visuomotor integration subtest (and to a lesser extent the motor coordination subtest) but not the visual perception subtest significant relates to quality of children's handwriting as measured with the Concise Assessment Scale for Children's Handwriting. However, the relatively little variance explained also points to other abilities and/or task constraints that underlie quality of handwriting.

INTRODUCTION

Handwriting is an imperative skill for children across the world to acquire in early primary school, despite the surge in the use of computers (Feder & Majnemer, 2003, 2007; Ratzon et al., 2007). Notably, 5 – 34% of primary school children have been shown to have problems producing legible handwriting, the reported percentages depending on grade, gender, and diagnostic procedures (Feder & Majnemer, 2003; Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011; Rosenblum et al., 2003; Smits-Engelsman et al., 2001).

Handwriting, like every other perceptual-motor skill, consists of various abilities. There are often pronounced inter-individual differences in the relative contribution of the abilities that constitute a skill. These differences are, for instance, related to the level of performance or acquisition phase of the skill (Fleishman & Rich, 1963). To understand the complexity of children's handwriting and to depict a comprehensive picture of the child's strengths and weaknesses, abilities that underlie adequate handwriting skill are frequently researched. Abilities indicated to be involved in handwriting are visual perception, motor coordination, visual motor integration and attention or planning abilities (Cornhill & Case-Smith, 1996; Daly et al., 2003; Goyen & Duff, 2005; Karlsdottir & Stefansson, 2002; Rosenblum et al., 2010; Volman et al., 2006). Having this said, it is pertinent to emphasise that current evidence for therapy leads to a task-oriented approach, so remediation should always include handwriting practice (Wallen et al., 2013).

The Beery Buktenica developmental test of visuomotor integration (Beery-VMI) is frequently administered to evaluate the quality of abilities that may underlie problematic handwriting. The main idea is that the acquisition and preservation of a readable handwriting requires one to be able to recognise shapes, to use vision to control the arm, hand, and finger movements and to coordinate the movements of these effectors accurately. The three subtests of the Beery-VMI are developed to assess these abilities (Cornhill & Case-Smith, 1996; Daly et al., 2003; Kulp & Sortor, 2003; Maeland, 1992; Overvelde & Hulstijn, 2011; Tseng & Chow, 2000; Tseng & Murray, 1994; Volman et al., 2006; Weil & Amundson, 1994). The visual perception subtest (VP) measures whether children can discriminate geometric figures, the visuomotor integration subtest (VMI) is meant to assess children's ability to copy similar geometric figures, and the motor coordination test (MC) requires children to draw figures in between lines (Beery

& Beery, 2010). Although developed to assess separate abilities, it must be noted that the distinction between the subtests is not always completely clear. For example, the MC-subtest also requires visual control, as does the VMI-subtest, and conversely, the need to coordinate movements of different effectors is required for the VMI-subtest as well as for the MC-subtest.

To assess handwriting skill in clinical and experimental research, the Concise Assessment Scale for Children's Handwriting (BHK) is often used (Hamstra-Bletz et al., 1987; Kaiser et al., 2009; Smits-Engelsman et al., 2001). The BHK assesses both quality and speed of handwriting. Although the BHK and the Beery-VMI are commonly used in concert to assess children that show non-proficient or problematic handwriting skill (Overvelde & Hulstijn, 2011), it is still unclear whether the scores on the Beery-VMI subtests predicts quality and speed of handwriting indicated by the BHK. Hence, the main purpose of the present study was to (further) uncover the relationship between the two tests. Ultimately, this would not only improve the identification of children with handwriting problems but may also give insight in abilities that underlie problematic writing.

Previous work that examined the relationship between handwriting quality and the Beery-VMI subtests has provided equivocal results. This ambiguity may (at least partly) stem from different populations of children and experimental procedures. Tseng and Murray (1994), for example, reported for a group of 143 children (Grade 3 – 5) that legibility strongly correlated with the scores on the VMI-subtest (as indicated by the Beery-VMI). They also found that within the group of non-proficient writers, not the VMI-score, but motor planning measured by the Finger Position Imitation Test best predicted the quality of handwriting. By contrast, for the group of proficient writers, visual perception measured by the Test of Visual Perceptual Skills (which is partly similar to the VP-subtest of the Beery-VMI and assesses various aspects of perception, like discrimination, memory, and spatial relations) was found to be the only significant predictor. Yet, as Tseng and Murray (1994) examined children who wrote Chinese, it is not clear whether these results are also applicable to roman script learned by European, Australian and North American children.

More recently, Volman et al. (2006) investigated the relation between the BHK and the Beery-VMI in a relatively small sample of Dutch Grade 2 and 3 school children (i.e., mean age 7.4- to 8.4- year-olds). Twenty-nine children, who according to the class teacher had handwriting problems, and 20 Grade and gender matched control children were included. The results showed that in the group with handwriting problems the quality of handwriting (i.e., scores on the BHK) was significantly correlated with the VMI-subtest of the Beery-VMI. In the control group, the quality of handwriting was significantly correlated with a separate test for fine motor control. However, the within-group correlations cannot uncover the abilities that distinguish differences in quality and speed of handwriting across these groups of children. Moreover, the small number of participants, the selection procedure and the large inter-individual differences in handwriting education and experience (i.e., children from two grades were included) may have jeopardised transferability of the outcomes.

For example, the inclusion procedure (problematic writers as identified by their teachers) was somewhat idiosyncratic. Although this procedure is not uncommon (Goyen & Duff, 2005), it might have resulted in a biased selection of a subgroup of children from the entire group of children with handwriting problems. Teachers' judgments are not necessarily similar to assessments based on standardised tests (Simons & Defourny, 2004). Another difficulty to interpret the results resides in the BHK, which only distinguishes between Grade 2 and 3 children on one item (letter size). As a result, the BHK tends to classify a much larger proportion of Grade 2 children than Grade 3 children as insufficient writers (i.e., classified as dysgraphic on the BHK) as Overvelde and Hulstijn (2011) did recently report. They assessed a group of 169 Dutch Grade 2 and a group of 70 Grade 3 children with the BHK and the VMI-subtest of the Beery-VMI. The number of children classified as non-proficient ranged from 37% in Grade 2 to 6% in Grade 3. A difference in VMI-subtest score was found between the children with proficient and non-proficient handwriting in Grade 2. Yet, the MC- and VP-subtests were not considered. By including a large random sample of children from Grade 2 only, and by assessing all the Beery-VMI subtests, the present study aims to enhance the transferability of the findings regarding the relationship between the BHK and Beery-VMI-tests.

Previous studies by Tseng and Murray (1994), Volman et al. (2006) and Overvelde and Hulstijn (2011) reported that more boys than girls were non-proficient writers. This is a fairly consistent finding in the literature. Most research reports that boys in Grade 2 and above have significantly lower quality of handwriting and slower handwriting speed than girls (Berninger & Fuller, 1992; Feder & Majnemer, 2007; O'Hare & Brown, 1989; Volman et al.; Weintraub et al., 2009; Ziviani & Watson-Will, 1998), although Kuski et al. (2011) did not find gender differences in handwriting speed. Whether these possible gender differences are related to differences in perceptual-motor abilities (as measured by the Beery-VMI) has not been examined in much detail. Hence, a further aim of this study was to assess whether similar abilities underlie handwriting quality in boys and girls. To summarise, the purpose of this study was to examine the relationship between the BHK and the three subtests of the Beery-VMI for children in Grade 2 of primary school (i.e., 6- to 8-year-olds after one year of writing tuition).

METHODS

Participants

Two hundred and forty Dutch Grade 2 children, who had received one full year of writing education, participated in this study. Twenty-two children were excluded from further analysis, because they did not complete the first five lines of the BHK (see also *Procedure and design* below). The remaining sample consisted of 100 boys (mean age = 7 years, 4 months, *SD* = .4 years) and 118 girls (mean age = 7 years, 4 months, *SD* = .4 years). Eighty-four boys (84.0%) and 106 girls (89.8%) wrote with their right hand. There were no significant differences in age and handedness related to gender. Parents and children both provided written informed consent. Ethical approval for the study was obtained from Ethical Committee Human Movement Sciences, VU University, Amsterdam.

Procedure and design

The tests were administered in the classroom in the presence of the teacher. The children sat on standard school furniture and used their regular pencil. The tests were administered in groups and always presented in the same order, starting with the BHK, followed by the VMI-, the VP- and the MC-subtests of the Beery-VMI. The children received a general introduction before the start of the assessment, and more specific instructions prior to each test.

The BHK is norm referenced for children on primary school Grade 1–6. It requires the children to copy a text on unlined paper in five minutes. The handwriting is inspected on quality and speed. Quality of handwriting is assessed based on 13 items (Table 1). The norms of the items are independent of grade, except for the first item (i.e., letter size) that is corrected for grade, as are the norm scores for speed. The items are evaluated with a score on an ordinal scale between 0 and 5, with high scores indicating deviance.

Table 1

The thirteen characteristics of the quality of handwriting of the concise assessment scale for children's handwriting (BHK)

1. Letter size	8. Inconsistent letter size
2. Left-hand margin	9. Incorrect relative height of the various kinds of letters
3. Alignment	10. Odd letters
4. Word spacing	11. Ambiguous letter forms
5. Acute turns in joins or letters	12. Correction of letter forms
6. Irregularities in joins	13. Unsteady writing trace
7. Collisions of letters	

Three categories of writers are defined in accordance with the BHK guidelines: children with a total score of 29 or higher are classified as non-proficient writers, those with a total score between 22 and 28 as at risk writers, and children with total scores of 21 or less are classified as proficient writers (Overvelde & Hulstijn, 2011)[4]. Following the BHK guidelines, the children had to copy at least five lines of the text to reliably assess the quality of handwriting. Writing speed was calculated as the number of letters copied during the five minutes. For the purpose of the present study, besides the children who copied less than five lines (as the BHK guidelines require), also children who did write more than five lines but skipped one of the first 5 lines (i.e., these children copied different words, making comparison less reliable) were excluded from analysis. The first author and a student-assistant, who was naive to the purpose of the experiment, made the assessments. Both the intra-rater and the inter-rater agreement (based on 22 children) for the quality of handwriting were high (respectively r = .91 and r = .85) and in line with previous reports (e.g., Jongmans et al., 2003).

[4] Unlike the original BHK labels (see Hamstra-Bletz et al., 1987), we did opt for 'insufficient writer' over 'dysgraphic', because most of the children that are labelled as 'dysgraphic' in grade 2 would be classified as 'at risk' or 'sufficient' in grade 3. Notice also that our prime interest is in the relationship between the BHK and the Beery-VMI test, rather than in identifying children with handwriting problems or dysgraphia.

The VMI-, VP- and MC-subtests of the Beery-VMI were developed to measure children between two and years. The test is norm referenced for American children from 2 to 18 years. All three tests use 24 geometric figures, starting with simple figures and ending with more complex ones. In the VMI-subtest, the children copy geometric figures. Children had one attempt and were not allowed to use an eraser. The number of correct drawings (according to the test manual) was counted. After more than three consecutive failures, the counting stopped. In the VP-subtest, children were required to identify the correct figure from two to seven embedded figures within a maximum time of three minutes. One point was awarded for each correct item up to three consecutive incorrect items or the three-minute time limit. In the MC-subtest, the children had to draw the same figures between lines, within a maximum of five minutes, which was presumed to appeal to fine motor coordination. Again, children were not allowed to use an eraser. All correctly drawn figures (i.e., between the lines) were scored. For each of the subtests, the number of correct items was converted into standard scores. The intra-rater and inter-rater agreement were high for each of the three subtests (i.e., VMI, respectively, r = .89 and .84; VP, respectively, r = 1.0 and .99; MC r = .98 and .94).

Data analysis and statistics

Means of the BHK raw scores, the VMI, the VP and the MC standard scores were calculated. Each child was then classified as a non-proficient, at risk or proficient writer according to the BHK scores. The distributions of boys and of girls across the BHK groups were compared with a Chi-square test. Subsequently, separate three (BHK-group: non-proficient, at risk, proficient) by two (gender: girls, boys) ANOVAs were used to assess differences between groups in handwriting speed, and the standard scores of the VMI-, the VP- and the MC-subtests. Post hoc comparisons were conducted following the Bonferroni procedures. To determine if gender, one or a combination of the Beery-VMI subtests and speed of handwriting significantly predicted the BHK raw scores a regression analysis was undertaken.

RESULTS

Participants had a mean raw score of 24.4 on the BHK (SD = 7.1) and 87.0 for speed. The average standard scores of the Beery-VMI subtests were 94.8 on the VMI, 105.7 on the VP and 96.3 on the MC. According to the BHK scoring system, 28.4% of the children were classified as non-proficient writers, 33.5% as proficient writers and 38.1% was classified as at risk (Table 2). Boys and girls differed significantly on the scores on the BHK ($t(216) = 3.72$, $p < .001$) and were differently distributed among the BHK groups (χ^2 (2) = 9.97, $p < .01$). There were more girls among the proficient and at risk groups, while boys were more often classified as non-proficient writers (Table 2).

Table 2

Distribution of boys and girls among proficient, at risk and non-proficient writers as indicated by Concise Assessment Scale for Children's Handwriting (BHK)

	Proficient *N (%)*	At risk *N (%)*	Non-proficient *N (%)*	Total *N*
Boys	25 (25)	37 (37)	38 (38)	100
Girls	48 (41)	46 (39)	24 (20)	118
Total	73 (34)	83 (38)	62 (28)	218

A 2-factor ANOVA with BHK-group and gender as between factors for the scores on the Beery-VMI subtests showed a main effect of BHK-group on the VMI (F (2, 212) = 7.83, $p < .005$, η^2 = 0.069) and the MC-subtests ($F(2, 212) = 5.87$, $p < .005$, $\eta^2 = .052$). Post hoc tests indicated that the children who were classified as proficient writers scored significantly better on the VMI-subtest than the children classified as non-proficient writers, and on the MC-subtest, both the proficient and the at risk writers scored better than the children with non-proficient handwriting (Table 3). There were no differences between BHK-groups for scores on VP and speed. A significant effect of gender indicated that girls performed better on the MC than boys ($F(1,212) = 4.07$, $p < .05$, $\eta^2 = .019$). No further main or interaction effects of gender were found.

Using the enter method, a significant model emerged ($F(3,214) = 15.726$, $p < .001$, adjusted R square =.169). The significant variables were gender (Beta = -.203, t = -3.215, p = .002), VMI scores (Beta = -.255, t = -3.970, $p < .001$) and MC scores (Beta = -.181, t = -2.778, p = .006) (writing VP, speed and the interaction terms gender x VMI and gender x MC were not significant predictors in this model).

Table 3

Speed, visual motor integration, visual perception, and motor coordination scores as function of gender and Concise Assessment Scale for Children's Handwriting (BHK) score

	Speed	VMI	VP	MC
	$\overline{X}$ *(SD)*	$\overline{X}$ *(SD)*	$\overline{X}$ *(SD)*	$\overline{X}$ *(SD)*
BOYS				
Proficient	78.2 (24.7)	97.9 (8.4)	101.1 (24.2)	96.0 (16.4)
At risk	89.6 (29.8)	94.9 (8.5)	104.9 (20.4)	95.6 (11.7)
Non-proficient	81.3 (23.6)	92.2 (7.6)	102.1 (22.6)	91.5 (10.3)
Total	83.6 (26.5)	94.4 (8.0)	103.6 (21.1)	94.0 (12.6)
GIRLS				
Proficient	92.5 (31.8)	97.1 (8.8)	111.7 (10.8)	101.3 (11.6)
At risk	93.0 (27.4)	95.3 (8.0)	103.4 (25.8)	99.4 (10.6)
Non-proficient	78.8 (29.7)	91.1 (7.2)	106.9 (15.2)	92.3 (10.6)
Total	90.0 (30.0)	95.1 (8.4)	107.6 (18.4)	98.3 (12.4)
TOTAL	87.3 (28.5)	94.8 (8.2)	105.7 (19.8)	96.3 (12.6)

Note. VMI: Visual Motor integration; VP: Visual perception; MC = Motor Coordination

DISCUSSION

The goal of this study was to examine the relationship between the BHK and the three subtests of the Beery-VMI in (early) Grade 2 primary school children (i.e., 6 to 8-year-olds) that had received one year of writing tuition. The quality of handwriting was examined in relation to the scores of the VMI-, VP- and MC-subtests, to determine if the abilities, which they are thought to assess, contribute to the quality of handwriting. This was investigated for the group as a whole and for boys and girls separately to also obtain more insight in the previously observed gender-related differences in the quality of handwriting.

The results showed a significant positive correlation between the scores on the BHK and the VMI- and the MC-subtests of the Beery-VMI (i.e., the better the quality of handwriting, the better the performance on the visual motor integration and the motor coordination tests) in children with one year of writing tuition. Although the quality of handwriting was not always measured using the BHK in earlier studies, the current positive correlations between quality of handwriting and the VMI and/or MC do confirm earlier reports (Cornhill & Case-Smith, 1996; Daly et al., 2003; Goyen & Duff, 2005; Kulp & Sortor, 2003; Maeland, 1992; Tseng & Chow, 2000; Tseng & Murray, 1994; Volman et al., 2006; Weil & Amundson, 1994). Consistent with the present findings, Cornhill and Case-Smith and Tseng and Murray found that VMI- and/or MC-subtests scores predicted handwriting quality, with the explained variance ranging between 5.9% (Cornhill & Case-Smith) and 30.5% (Tseng & Murray). In the present study, the scores of the VMI- and the MC-subtests accounted for 17% of the variance in quality of handwriting.

As a consequence, abilities, or constraints other than those assessed by the Beery-VMI must also underlie non-proficient handwriting in Grade 2 children. For instance, Rosenblum et al. (2010) showed that planning abilities (i.e., the ability to organise thoughts in a way that enables children to perform actions in daily life in the correct sequence, which is assessed by the Questionnaire for Assessing Students' Organizational Abilities – for Parents, ASOA-P) in 7- to 8-year-olds explained 42% of the variance of handwriting quality. In addition, a conspicuous difference between the VMI- and MC-subtests is the presence, in the latter, of lining to guide the drawing. As both subtests contributed to explaining the inter-individual variance in handwriting quality, this may suggest that not only organismic constraints but also task-related constraints (i.e., writing lines) impact the quality of handwriting.

With respect to gender differences, girls' handwriting was of better quality than the handwriting of the boys (see also Feder & Majnemer, 2007; O'Hare & Brown, 1989; Weintraub et al., 2009). In addition, girls also performed better on the MC-subtest than boys. No effects of gender for speed, VMI and VP scores were found. Intriguingly, besides the VMI-subtest, which contributed to handwriting quality in both girls and boys, the MC-subtest predicted quality of handwriting in girls, but not in boys. These differences between boys' and girls' handwriting related to the MC-subtests were not reported previously. Possibly, boys find it more difficult to draw or write between lines than girls (see Chow et al., 2001; Livesey et al., 2007). The lines may serve as an additional demand on handwriting accuracy, requiring adjustment to additional task constraints. Future research should aim to uncover why boys have more difficulties in dealing with these task constraints. The differences between girls and boys may also be related to attention, which is an important underlying ability for handwriting quality in children (Karlsdottir & Stefansson, 2002). In this respect, it is noticeable that in the current study the most pronounced difference for gender was on the last assessment (i.e., the MC-subtest). Research has shown that young girls perform better on attention tests than boys, such as for instance tests of sustained attention (Klenberg et al., 2001). Although these tests have, as far as we know, not been directly linked to handwriting quality, differences in attention might suggest that boys need different type of instructions (e.g., more implicit rather than attention demanding explicit instructions) in more constrained task environments to promote handwriting skills than girls do at this age.

Methodological issues

Results of this study leads on to question whether the BHK is a suitable tool to identify dysgraphic handwriting in children without taking their writing experience or grade into account. That is, it is improbable that the substantial number of children who were categorised as an insufficient writer (i.e., approximately 30%) would all turn out to be dysgraphic. Importantly, this confirms the important conclusion recently drawn by Overvelde and Hulstijn (2011) that the BHK cannot differentiate between transient and persistent insufficient writers in Grade 2. The authors reported that the number of children classified as an insufficient writer on basis of the BHK reduced from over 30% in Grade 2 to below 10% in Grade 3. Obviously, only persistently insufficient or dysgraphic writers should be referred to occupational or physical therapy. To be able to do so, future research must establish different age- or experience-related norm references for the BHK (and perhaps for gender as well). This requires that a large group of children would be followed longitudinally over a period of several years for enabling more accurate estimates of the amount of dysgraphic children among the insufficient writers.

The next step would then be to assess whether children with dysgraphic handwriting have an underlying deficit in visual-motor integration and/or motor control abilities. In this regard, it remains to be seen whether the Beery-VMI tests is a suitable diagnostic tool for clinical practice. The predictive value of the test for children that have had only one year of writing tuition is relatively low (in fact, even among the children categorised as a non-proficient writer, many would fall within the sufficient range on the Beery-VMI). Yet, the present results do not rule out that for more experienced children whose handwriting should be more stable or established the Beery-VMI may be appropriate. Possibly, the Beery-VMI better reflects handwriting quality in older, more experienced children (e.g., Tseng & Murray, 1994). Again, a longitudinal study may further clarify this issue.

CONCLUSION

The present results show that the abilities captured by the VMI- and MC-subtests of the Beery-VMI are involved in the acquisition of handwriting. Together with gender, these two subtests accounted for 17% of the quality of handwriting. In addition, comparison between the three levels of handwriting quality confirmed that children with sufficient handwriting quality performed better on the VMI and on the MC subtests than children with lower handwriting quality. While abilities required to perform the VMI- and MC-subtests influence the quality of handwriting, it also became apparent that the quality of handwriting cannot solely be explained by these abilities. Although more boys were classified as insufficient writers, and more girls were classified as sufficient writers, the only significant difference between girls and boys for the Beery-VMI was found in the MC-subtest. Girls were more accurate than boys in this drawing task that involves higher spatial constraints than the VMI task.

The results also show that occupational therapists should be cautious to use the BHK for identifying dysgraphic children, especially among beginner writers with only one year of writing tuition. There is a dire need to first establish age- or experience-dependent norms to be able to distinguish persistent from transient insufficient writers. Moreover, although the Beery-VMI subtests definitely relate to the quality of handwriting, at this stage of research this should and cannot be taken as an indication that dysgraphic children have underlying deficits in visuomotor control or motor coordination abilities, nor that remediation of these abilities will improve handwriting.

CHAPTER 3

PERSISTENT HANDWRITING PROBLEMS ARE HARD TO PREDICT: A LONGITUDINAL STUDY OF THE DEVELOPMENT OF HANDWRITING IN PRIMARY SCHOOL

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Research in Developmental Disabilities, 97, 103551

ABSTRACT

Background: After one year of tuition, up to a third of primary school children show insufficient handwriting. It is unclear whether this early insufficient handwriting predicts persistent handwriting problems because there is a dearth of studies that followed developmental trajectories longitudinally. The aim of this research was to describe handwriting development in primary school children longitudinally and to determine predictive positive value and sensitivity of early handwriting assessment and to analyse whether underlying abilities helps early identification of persistent handwriting problems.

Method: 173 primary school children were yearly assessed for four years using the Concise Assessment Scale for Children's Handwriting and the Beery Buktenica developmental test of visual-motor integration.

Results: Both quality and speed of handwriting increased with years of tuition, with a pronounced increase in quality between two and three years of writing tuition. Sensitivity and positive predictive value were low. The only significant predictor of handwriting quality was handwriting quality in the previous year. For handwriting speed, no significant developmental model was revealed.

Conclusions: Quality and speed of handwriting after one year of tuition is not sufficiently predictive for distinguishing between transient insufficient handwriting and persistent handwriting problems three years later. Practitioners should hold back when referring children for remedial teaching.

INTRODUCTION

Typical handwriting development in children

Despite the increased use of computers, writing by hand remains one of the most important skills that children learn in primary school (Asher, 2006; Denton et al., 2006; Feder & Majnemer 2003; 2006; Ratzon et al., 2007). In Western countries, several handwriting methods are used to teach handwriting in primary school, starting tuition at the age of 6 years up to 10 years (e.g., Handwriting without tears; teach handwriting; Teach it English). In a pseudo-longitudinal study, Overvelde and Hulstijn (2011) charted handwriting development during the first three years of writing tuition in primary schools (in the Netherlands). After one year of tuition (at approximately 7 years of age) about one-third of the children was found to show sufficient quality of writing; after two years of writing tuition (at age 8), half the children achieved a sufficient level of handwriting, while after 3 years (at age 9), over three-quarters of the children had satisfying handwriting quality; only 6% of the children had their handwriting rated as insufficient after three years. These results suggest that for most children early insufficient handwriting is likely to be transient and will improve with regular tuition and practice (Overvelde and Hulstijn, 2011). Yet, for a small minority of children handwriting problems turnout to be persistent.

The range of prevalence of insufficient handwriting reported in the literature varies from 6 to 33%. This broad range is probably related to the diversity in assessment tools and age of the children across studies (Feder et al, 2007; Hamstra-Bletz, 1993; Karlsdottir & Stefansson, 2002; Overvelde and Hulstijn, 2011). Insufficient handwriting includes illegible handwriting, slow handwriting seed and/or fatigue and pain while writing (Biotteau et al., 2019; Hamstra-Bletz et al., 1987; Kaiser et al., 2009; Overvelde et al., 2011; Smits-Engelsman et al., 2001).

Already after one or two years of writing tuition (i.e., at the age of 6 to 7 years, Bosga-Stork, 2009), children with insufficient handwriting are often referred to a therapist. Accordingly, Biotteau et al. (2019) have suggested that occupational or paediatric physical therapy is crucial for effective improvement. Referring children to therapy, however, requires distinguishing as early as possible between children that are genuinely at risk for insufficient handwriting being permanent (i.e., handwriting that does not improve with regular tuition) and children whose handwriting problems are transient. Short-term longitudinal or cross-sectional studies failed in making a reliable distinction between transient or persistent handwriting problems (Karlsdottir & Stefansson, 2002; Overvelde and Hulstijn, 2011). To verify these observations, it is important to conduct longitudinal research that chart the developmental trajectories of handwriting in primary school children to examine sensitivity, specificity and predictivity of current handwriting tests. A longitudinal research design can also help to identify the factors related to the development of handwriting and that potentially underly persistent handwriting problems.

Prediction of persistent handwriting problems

Early prediction of handwriting problems can be grounded in assessment of handwriting quality and speed and/or based on abilities that, presumably, underpin handwriting skills. The extant literature reports only one longitudinal study that followed handwriting development over a period that extended beyond two years of writing tuition. Karlsdottir and Stefansson (2002) annually assessed handwriting in over four hundred primary school children between one and five year of writing tuition (i.e., Norwegian Grade 1 to 5). They used custom-made assessments for handwriting quality and speed. The handwriting quality of three-quarter of the children was rated as sufficient (i.e., functional) after one year of writing tuition. During the second year of tuition (Grade 2), handwriting quality of these children improved less to plateau after three years (i.e., Grade 4). For children, whose handwriting was rated as insufficient after one of year of tuition, handwriting quality also continued to improve but at slower rate than their typically developing peers. Consequently, these children ended with lower handwriting quality after four years of tuition. Importantly, however, among the children who showed insufficient handwriting after four years of writing tuition in Norwegian Grade 5 (i.e., approx. 15%), half had been assessed as having insufficient handwriting in earlier grades; these were the children with persistent handwriting problems. Yet, the other children with insufficient handwriting in Grade 5 were only rated as such in Grade 5. Conversely, for approximately four out of five children who had shown insufficient handwriting during the first three years of tuition, the problems turned out to be transient and had disappeared after four years of tuition in Grade 5.

These observations indicate that the sensitivity of the longitudinal assessment for identifying persistent handwriting problems was only 50%. Additionally, the positive predictive value (i.e., the likelihood that a child with insufficient handwriting after one year of tuition still has insufficient handwriting after four years of tuition in Grade 5) was a mere 28%. In other words, prospective developmental pathways could not be reliably predicted based on handwriting quality after one year of handwriting tuition. While these results imply that referral for handwriting problems early in the acquisition process involves substantial risk of unnecessary treatments, it is important to verify whether the low sensitivity and predictive value were not due to the particular handwriting assessment used by Karlsdottir and Stefansson (2002). The test-retest reliability of the custom-made test assessment was reported to be good. The norms, however, for distinguishing sufficient (i.e., functional) and insufficient (dysfunctional) handwriting quality were not validated, but, based "on subjective evaluations of legibility and functional speed" (Karlsdottir & Stefansson, 2002, p. 17).

Research has shown that handwriting problems can be related to problems with motor coordination and/or visuo-motor abilities (Smits-Engelsman et al., 2001; Volman et al., 2006; Weintraub & Graham, 2000). That is, these studies suggest that handwriting quality may be constrained by the ability to perceptually identify forms, to produce well-controlled movements, and to visually control the movements. These abilities have been assessed by the Beery Buktenica developmental test of visual-motor integration (Beery-VMI, Duiser et al., 2014; Kaiser et al., 2009; Volman et al., 2006), which requires children to recognize geometrical forms, the ability to draw between lines, and/or the ability to copy or redraw a form, respectively.

A cross-sectional study has shown that the outcomes of the Beery-VMI copy and drawing subtests correlate with handwriting quality in a group of children aged 9 to 12 years. However, sensitivity of the Beery-VMI for identifying handwriting problems was low (Goyen & Duff, 2005). Evidence that the visual recognition test correlates with handwriting quality is equivocal (Duiser et al., 2014). Further to this point, Karlsdottir and Stefansson (2002), showed that children's ability to copy a form after one year of tuition was positively related to handwriting quality after one year of tuition but did not relate to handwriting quality in subsequent grades. Other abilities (e.g., recognition of geometrical forms) were not assessed.

In sum, although it has been shown that visuo-motor abilities relate to handwriting performance (i.e., at one instant in time), their role in long-term handwriting development has largely been neglected.

The primary aim of the current study was to examine sensitivity and predictive values of early assessment of handwriting quality in relation to persistent and transient handwriting problems years later. To this end, we longitudinally charted handwriting development between the first and the fourth year of handwriting tuition in terms of both quality and speed, using the Concise Assessment Scale for Children's Handwriting (BHK), which is widely used within Europe (Hamstra-Bletz et al., 1987; Kaiser et al., 2009; Smits-Engelsman et al., 2001). To determine the sensitivity and positive predictive value of the BHK we used the norm-based cut-off scores, and also explored how systematic adjustments in the cut-off scores differentiating sufficient from insufficient handwriting affect its prognostic value in identifying persistent handwriting problems.

The second aim was to establish whether some of the presumed underlying perceptual-motor abilities of handwriting as assessed with the Beery-VMI test could help to distinguish between children with persistent and children with transient handwriting problems. Previous studies did show cross-sectional relationships between at least some of the Beery-VMI subtests and handwriting performance (Duiser et al., 2014; Goyen & Duff, 2005; Karlsdottir & Stefansson, 2002). Yet, it is still unclear whether these subtests also predict the development of handwriting quality and speed in subsequent years.

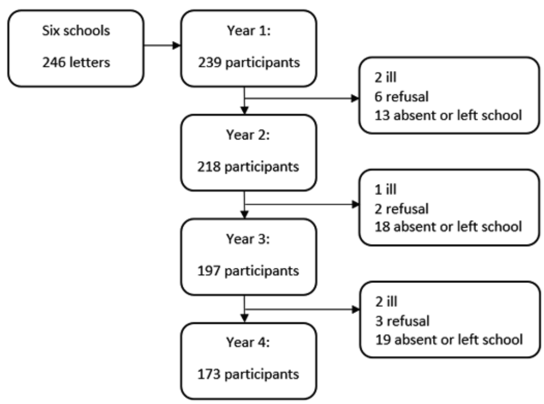
METHODS

Participants

Children from six primary schools in two medium sized towns in the west of the Netherlands participated in this study. The children attending these schools were predominantly from middleclass families. A total of 239 children participated over the four years, 173 of which completed all assessments. The other children missed one or more tests, because they were ill, moved to another school , were absent for other reasons or refused to participate (Figure 1). Handwriting quality and speed scores of the group of children who did not participate in each of the four tests did not significantly differ from other children (i.e., on the assessments they did complete). Only children that completed all test were included in the analyses. The final sample consisted of 83 boys (71 right handed) and 90 girls (81 right handed) with an average age of 7 years and 5 months during the first assessment after one year of tuition (i.e., at the beginning of Grade 4).

Figure 1

Participants participation over the four years



During handwriting tuition Dutch children learn to write the letter shapes, while the letter is pronounced by their teacher. Typically, the teacher demonstrates how to write the letter group wise, then children individually practice the letter shape in course books, following a set curriculum. In the Netherlands, children should be able to write in cursive handwriting after one year of handwriting tuition, which enables the use of handwriting assessment tools like the BHK. The faculty's ethical committee approved the study, and parents of the children provided written informed consent.

Material

The Concise Assessment Scale for Children's Handwriting (BHK) was used to assess children's handwriting. The BHK requires children to copy a text within five minutes on unlined paper and assesses handwriting in terms of its quality and speed. Handwriting quality is assessed with respect to letter size and margin of the entire text (0 to 5 points each), and with respect to alignment, word spacing, acute turns in joints or letters, irregularities in joins, collisions of letters, inconsistent letter size, incorrect relative letter height, strange, indistinctive or corrected letterforms and unsteady writing trace in the first five lines. Children get 0 (no irregularity) or 1 point (1 or more irregularities) per line. The following cut-off norms are proposed by the test manual: 0-21 points indicates non-dysgraphic handwriting, 22-28 ambiguous and 29 points or more indicates dysgraphic handwriting[5]. Intra- and interobserver reliability for quality (respectively *r* = .91 and *r* = .85; e.g., Duiser et al., 2014) is good. Test-retest reliability is low but adequate for quality and sufficient for speed (respectively *r* = .51 and *r* = .78; Hamstra-Bletz, 1993)

In addition, the Beery-VMI test was used to assess abilities that are presumed to underlie handwriting. The Beery-VMI is a norm-referenced test that evaluates children's ability to identify geometrical forms (i.e., visual perception or VP-test), to draw between lines (i.e., motor coordination or MC-test) and to copy forms (i.e., visual-motor integration or VMI-test). A detailed description of these assessments can be found elsewhere (e.g., Volman et al., 2006). The Beery-VMI is a norm-referenced test for people from 2 to 100 years. Test-retest coefficients were: VMI .88; VP .84 and MC .85 (Beery & Beery, 2010). The intra-rater and inter-observer agreements for each of the three subtests is high (i.e., VP, *r* = 1.0 and .99, respectively; MC *r* = .98 and.94; VMI, *r* = .89 and .84; Duiser et al., 2014).

Procedure and design

The BHK and Beery-VMI were annually administered over a period of four years between 2010 and 2013, after one to four years of tuition (in Dutch Grade 4 to 7, corresponding to 7 through 11 years old children) and always at the start of the school year. In the Dutch school system, the first year of handwriting tuition is in Dutch Grade 3. The final assessment was in Grade 7. In Dutch Grade 8 children are encouraged to develop their own handwriting style, frequently including both cursive and manuscript letters. This cannot be assessed by the BHK, and hence,

[5] In this paper, we will refer to insufficient handwriting rather than to dysgraphia (Hamstra-Bletz & Blöte, 1993). We have two reasons for this. First, the appellations 'dysgraphic', 'ambiguous' and 'not-dysgraphic', refer to the category labels used in the BHK. Dysgraphia has a strong association with more permanent handwriting problems. In this respect, insufficient is a more neutral term, and is meant to indicate current handwriting quality relative to an age-specific norm. We will show that insufficient handwriting at younger age did not necessarily results in handwriting problems at older age. Second, in DSM-IV dysgraphic handwriting is no longer presented (Biotteau et al., 2019)

we report across four years of tuition. Each year, all children in the relevant grade were asked to participate, irrespective of participation in earlier years.

The tests were administered group wise in the classroom with the children sitting on standard school furniture and using their regular writing device (i.e., pencil or pen). Prior to the assessment, the children received test material (i.e., the target text, a blank sheet of paper without lines, and the three Beery-VMI test forms). The BHK was always administered first, followed by the VMI-, the VP- and the MC-subtests of the Beery-VMI (in this order, as prescribed by the Beery-VMI manual). Children received a general introduction prior to the test session, and specific instructions prior to each (sub)test. After completion of each test, the test material was removed from the children's desks. The total duration of the tests was between 20 to 30 minutes.

Data analysis and statistics

Handwriting quality was measured with thirteen items according to the BHK manual, resulting in total scores between zero (i.e., sufficient handwriting) and 64 (i.e., very insufficient handwriting). Handwriting speed was measured by counting the number of letters children wrote in 5 minutes. To assess developmental changes in handwriting, the scores for handwriting quality and speed were submitted to two separate repeated measures ANOVAs with years of tuition (1, 2, 3 and 4 years) as within-factor. In case the sphericity assumption was violated, the Greenhouse-Geisser correction was used. As a measure for effect size, partial eta squared (η_p^2) was used, where .01-.06 was interpreted as a small effect, .06-.14 as a medium effect and > .14 as a large effect (Cohen, 2013). Post hoc analyses were performed using *t* test with Bonferroni adjustments.

Further, to explore what factors predicted handwriting quality and speed after four years of tuition (i.e., Grade 7) two separate path analyses were performed. With path analysis direct dependencies between a set of longitudinal variables can be uncovered (see Byrne, 2010; Ste-Marie et al., 2015). Two models were created addressing the relationships between, on the one hand, VMI-, VP- and MC-scores for each tuition year, and on the other hand, BHK handwriting quality or speed also for each tuition year. The data were analysed using AMOS 23.0. In the first model, the VMI-, VP-, MC-scores were related to the BHK for each tuition year separately. Besides that, all BHK-, VMI-, VP-, MC-scores were linearly related to the BHK scores for all subsequent tuition years (i.e., BHK tuition year 2 with year 3, 4 and 5 and so on). A similar approach was taken with respect to speed. Based on the evaluation of fit indices for the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and the chi squared (χ^2) likelihood ratio statistic (Byrne, 2010) different models were created. Fit indices were deemed to indicate good model fit if: CFI values ≥ .90, RMSEA values ≤ .06, χ^2 not significant, and $\chi^2/df < 3.00$ (Byrne, 2010). Only the model(s) with appropriate fit indices will be presented.

Finally, the raw BHK quality scores were converted into the three categories according to norm-based cut-off values in the manual: i.e., insufficient handwriting for 29 points or more, ambiguous handwriting for 22 to 28 points, and sufficient handwriting for 21 points and less. The sensitivity, specificity and positive predictive value of the test-scores were established using the percentage of children classified with insufficient handwriting quality or with sufficient handwriting quality after one and four years of handwriting tuition.

RESULTS

Developmental changes

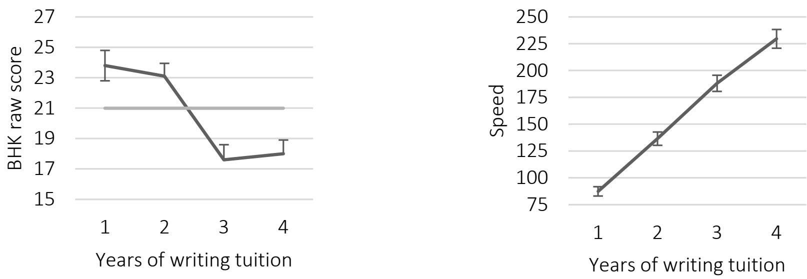
In general, handwriting quality increased with years of tuition (Figure 2a). In Grade 5 most children wrote sufficient (n = 131; 75.7%) A repeated measures ANOVA showed a significant effect for years of tuition on BHK quality scores, $F(2.554, 439.221) = 74.2$, $p < .001$, $\eta_p^2 = .30$). Post hoc comparisons indicated that the only significant increases occurred between two and three years of tuition (Figure 2a). A repeated measures ANOVA also revealed significant differences for years of tuition with respect to speed, $F(2.737, 470.688) = 524.9$, $p < .001$, η^2 .75). Post hoc comparisons indicated that with each additional year of tuition children wrote significantly faster (Figure 2b).

Predicting persistent and transient handwriting problems

First, each child in each year was classified according to raw BHK quality scores as insufficient, ambiguous, and sufficient (Figure 3a). The distribution of children over those three categories changed over the years: after one and two years of tuition the children were approximately equally distributed across the three categories while thereafter, most children were classified as sufficient.

Figure 2

Mean BHK scores (95% CI standard error) for quality (a) and speed (b) as a function of years of tuition. Horizontal line in (a) indicates the cut-off score between sufficient and ambiguous handwriting as indicated in the BHK

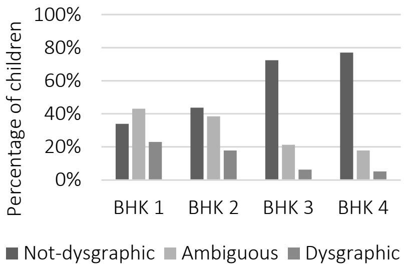


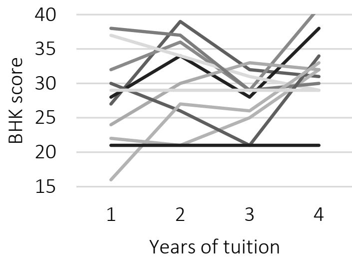
After four years of tuition, only nine children showed insufficient handwriting (8 boys, 1 girl; Figure 3b). Among these children, three boys had shown insufficient handwriting quality in all three foregoing years; two boys had shown ambiguous handwriting after one year of handwriting tuition, insufficient handwriting in subsequent years. The remaining three boys showed variable handwriting performances across the four years of tuition, with quality scores fluctuating between sufficient and insufficient (Figure 3b, green, light, and deep brown lines). Finally, the one girl within this group showed a decrease in handwriting quality over the years (i.e., after one year of tuition her handwriting was rated as sufficient, while it was rated ambiguous in the two years thereafter, and insufficient after four years).

Handwriting quality appeared relatively instable across the four years. That is, only in 19.1% of the children (n = 34; 13 boys) the handwriting quality was rated in the same BHK-category in each of four assessments. In 19.7% of the children the handwriting ratings stayed the same in the final three years (n = 35; 15 boys), whereas 32.6% of the children (n = 58; 28 boys), had the same handwriting quality rating after three and four years of tuition. Handwriting pathways appeared to be fluctuating between BHK-categories in 28.6% of the children (*n* = 46; 20 boys; Figure 4).

Figure 3

Handwriting quality after four years of tuition, (a) percentage of children per category per grade and (b) handwriting quality scores across the four years of tuition of the children who showed insufficient handwriting. Horizontal lines indicate the cut-off scores between sufficient and ambiguous handwriting (i.e., at score 21) and between ambiguous and insufficient (i.e., at score 29)





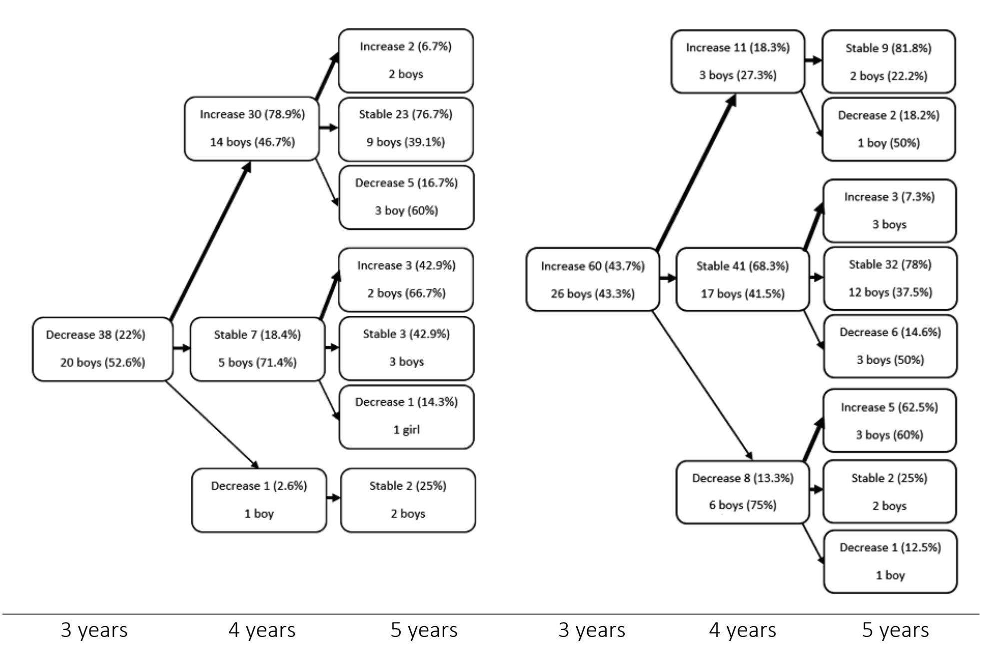
Longitudinal development

Separate path analyses were performed for BHK quality scores and speed. The first path analysis, which addressed dependencies between the BHK quality scores and the scores for the Beery-VMI subtests, showed that none of the created models with the Beery-VMI subtest had had appropriate fit indices. This means that the VP, MC and VMI, despite showing significant individual correlations with handwriting quality scores within the same grade (VMI between $r = -.171$ and $-.336$, VP between zero and $r = -.198$, and MC between $r = -.251$ and $-.473$), did not contribute to a developmental model of handwriting quality in subsequent years.

A longitudinal model based on handwriting quality showed a good fit ($\chi^2(1) = 1.553$, $p = .213$, CFI = .99, RMSEA = .052, and $\chi^2/df = 1.553$; Figure 5). The quality of handwriting after four years of tuition was positively related to the quality after three years of tuition ($\beta = .51$, $p < .001$). In turn, the quality of handwriting after three years of tuition was positively related to quality after two years of tuition ($\beta = .42$, $p < .001$), which was related to quality after one year of tuition (β = .35, p < .001). This model explained 38% of the quality of handwriting after four years of tuition (Figure 5). All other paths in the model failed to reach significance (p's > .05).

Figure 4

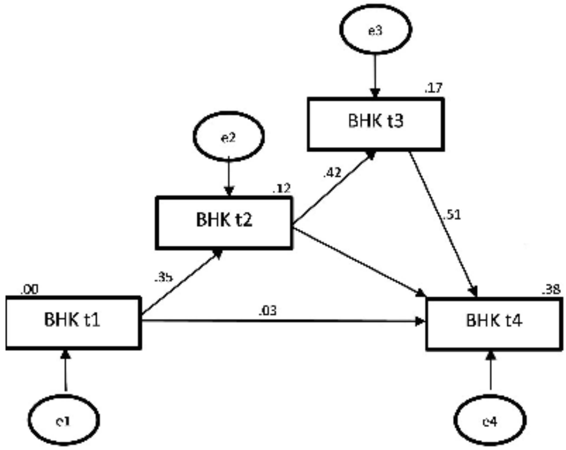
Changes in handwriting quality over the years, number of children; decrease in handwriting quality from year 2 to 3 (a); increase in handwriting quality from year 2 to 3 (b)



The second path analysis addressed the dependencies between the handwriting speed scores and the scores for the Beery-VMI subtests. None of the created models with the Beery-VMI subtests had appropriate fit indices. This means that the VP, MC and VMI did not contribute to a developmental model of handwriting speed. Also, a longitudinal model based on handwriting speed did not show a good fit ($\chi^2(1) = 6.122$, *p* = .013, CFI = .967, RMSEA = .172, and χ^2/df = 6.122). There were, however, significant but weak correlations for speed between the different years of tuition, ranging *from r* = .237 between 1 and 4 years of writing tuition and *r* = .580 between 3 and 4 years of tuition (all p's < .001).

Figure 5

Model for the longitudinal development of handwriting quality. The numbers above accompanying the BHK raw scores represent the explained variance by the model. The numbers accompanying the arrows are the standard regression coefficients

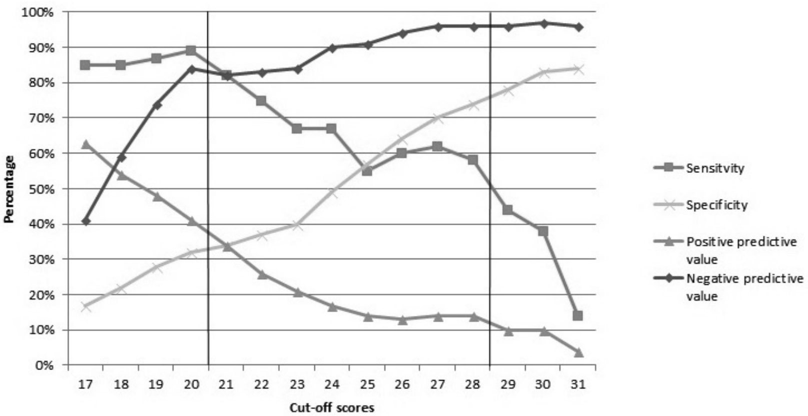


Sensitivity, specificity, and predictive values

Sensitivity, specificity, and predictive values were calculated by using the cut-off between ambiguous and insufficient handwriting as indicated in the BHK manual (corresponding to the score of 29). The positive predictive value (i.e., the likelihood that a child with insufficient handwriting after one year of tuition also had insufficient handwriting after four years) was 10%. The sensitivity (i.e., the likelihood that a child with insufficient handwriting after four years of tuition had insufficient handwriting after the first year of tuition) was 44%. The specificity (i.e., the probability that a child rated as having sufficient handwriting after four years of tuition was also rated as sufficient after one year of tuition) was 78%. And finally, the negative predictive value (i.e., the likelihood that a child with sufficient handwriting after one year of tuition was also rated as sufficient after four years) was 96% (Figure 6).

Figure 6

Sensitivity, positive and negative predictive values, and specificity as a function of cut-off point. The two vertical lines indicate the cut-off scores between dysgraphic and ambiguous (between 28 and 29) and not-dysgraphic) between 21 and 22) according to the BHK manual



DISCUSSION

We aimed to chart handwriting development in primary school during the first four years of writing tuition to examine whether insufficient writing after one year of tuition does predict persistent handwriting problems later during development. Previous research suggested that early handwriting quality assessment had poor sensitivity and positive predictive value for handwriting quality four years later (Karlsdottir & Stefansson, 2002). The present study tried to further bolster these observations using widely used and standardized tools for the assessment of handwriting and the underpinning perceptual-motor abilities.

The results revealed an average increase in handwriting quality and speed across the first four years of writing tuition, with a particularly significant gain in handwriting quality after two years of writing tuition, resembling the developmental differences that were previously reported by Overvelde and Hulstijn (2011). For handwriting speed, the improvement increased more gradually across the four years. Accordingly, the number of children categorized with insufficient handwriting strongly decreased from the second to third year of tuition and then stabilized, resulting in approximately 5% of children (n = 9) with insufficient handwriting after four years of tuition. Importantly, the present data show that the vast majority of children (87%) who had shown insufficient handwriting after one year of tuition improved had caught up after four years of tuition and handwriting experience. Their early insufficiencies turned out to be transient.

The children that showed insufficient handwriting after four years of writing tuition potentially are children with persistent insufficient handwriting, that is, handwriting problems. Yet, a closer inspection of the individual developmental trajectories of these nine children showed a large variability in handwriting quality across the four years (Figure 3b). Specifically, only three out of these nine children consistently showed insufficient handwriting across the four years. Individual developmental profiles of the handwriting quality scores across the four years revealed that handwriting development is often not improving gradually, and sometimes even showed regressions (Figure 4). This variability in developmental profiles resulted in low positive predictive value and sensitivity, and complicating the early identification of children that are at risk of developing persistent insufficient handwriting. The outcomes of the path analysis, showing that handwriting quality (and to a lesser extent also speed) at a given year is best predicted by the quality of the preceding year, underline the poor prognostic value of early handwriting assessment for identifying later handwriting problems. The low positive predictive value and poor sensitivity are in line with the data reported by Karlsdottir and Stefansson (2002). Based on the present data we suggest that previous and actual results reveal that the low predictability is an inherent characteristic of the variable development trajectory of handwriting and not merely the result of unreliable assessment tools.

The prediction of handwriting quality after four years was not strengthened by adding perceptual-motor abilities into the prediction model. The path analysis showed that the abilities to copy, trace and recognize forms as assessed with the Beery-VMI did only correlate to current handwriting quality, and did not contribute to the prediction of handwriting quality later in development. The significant correlations between the Beery-VMI subtests and handwriting quality within a year replicate previous cross-sectional studies reporting significant associations (Duiser et al., 2014; Kaiser et al., 2009; Volman et al., 2006). In the only study that did look at predictions across years, Goyen and Duff (2005) reported that the sensitivity of the Beery-VMI in relation to handwriting quality was low (34%). This is in line with the low positive value and sensitivity in the current study. Taken together, these results indicate that although the perceptual-motor abilities measured in the Beery-VMI provide an indication of current handwriting performance, they do not predict the development of handwriting over a period of 3 to 4 years.

Typically, the amount of teacher-directed tuition for handwriting will have decreased across the four years in which we followed the children. This means that self-regulation becomes increasingly important for improvement (and perhaps maintenance) of handwriting quality. Especially, self-efficacy and motivation have been shown to be important determinants of learning and development, also for motor skills (e.g., Kisantas et al., 2000; Ste-Marie et al. 2015). Future research monitors should therefore monitor these self-regulatory processes, also because current abilities to copy, trace and recognize forms may directly affect self-efficacy and motivation.

Limitations and implications

After four years of writing tuition nine of the 173 children had insufficient handwriting (5%). The low prevalence of insufficient handwriting may have adversely influenced the positive predictive value. When we lower the threshold for insufficient handwriting quality, both sensitivity and positive predictive value increase (Figure 6). But, with a less conservative cut-off for insufficient handwriting, the test's specificity would decrease. Hence, if these lowered thresholds were used, then therapists would risk overtreatment of children without handwriting problems, which obviously does not offer a genuine solution. However, therapists should be aware that with the present norm values, the BHK does not allow to identify children who develop handwriting problems after one or two years of writing tuition.

While the relative low test-retest reliability of the BHK for handwriting quality (Hamstra-Bletz, 1993) has to be considered when interpreting the results, test-retest reliability for handwriting speed is sufficient (Hamstra-Bletz, 1993) and intra- and inter-observer reliability scores for quality are good (Duiser et al., 2014; Jongmans et al., 2003). Accordingly, rather than the BHK assessment falling short, we are inclined to argue that low test-retest reliability reflects the inherent instability of children's handwriting performance (see also Hamstra-Bletz, 1993).

Clearly, this suggestion needs to be substantiated in further research. This been said, therapists should be cautious to use the BHK for the early identification of children with persistent handwriting problems. It seems warranted to hold back and limit the use of the BHK to verify current handwriting quality and speed, if regular schoolwork or teacher suggests insufficient writing. Besides that, it is advisable to compare the handwriting product produced during the BHK with actual schoolwork, to rule out the instability of children's handwriting.

Despite the obvious practical problems in terms of feasibility, for further research, it is advisable to increase sample size, such that the prevalence of children with handwriting problems after four years of handwriting tuition is increased.

CONCLUSION

Handwriting quality after one year of tuition did not predict handwriting quality after four years of tuition. Most of the children with insufficient handwriting after one year of tuition did show sufficient handwriting three years later. Only 10% of children with insufficient handwriting after one year of tuition showed insufficient handwriting three years later. Most children with sufficient handwriting at an early stage of the acquisition process showed good handwriting after three years. Furthermore, perceptual and motor abilities in the first year did not predict the quality of handwriting three years later.

CHAPTER 4

THE EFFECTS OF NUMBER AND SEPARATION OF SUPPORT LINES ON THE SIZE, VELOCITY, AND SMOOTHNESS OF HANDWRITING

Duiser, I. H., Ledebt, A., van der Kamp, J. & Savelsbergh, G. J. (2022).
Motor Control, 26(3), 317–333

ABSTRACT

Background: We examined the effects of number of and separation between support lines on handwriting characteristics of primary school students with sufficient and insufficient handwriting.

Method: Students (mean age 7.9 years) copied a text on paper with a baseline and with two or four support lines with a separation of 3 or 4 mm between the central lines. Handwriting size, velocity and smoothness were determined for the four conditions relative to baseline.

Results: Children with insufficient handwriting wrote larger and had more lifts during baseline condition. Writing between support lines, especially with small separation, immediately reduced the size of handwriting, but also adversely affected velocity and smoothness.

Conclusions: In general, manipulations of support lines did not improve handwriting. Future research is needed to assess long-term effects.

INTRODUCTION

Despite ubiquitous digitalization, handwriting is still one of the crucial motor skills that children acquire in primary school. It is therefore a matter of concern that a considerable number of children show insufficient or dysgraphic handwriting. For example, about one out of three Dutch children are found to show low quality and/or velocity of writing after one and two years of handwriting tuition (Duiser et al., 2014; Duiser et al., 2020; Overvelde & Hulstijn, 2011). In fact, some students are referred to paediatric physical or occupational therapists because their handwriting is considered problematic (Bosga-Stork et al., 2009; Jongmans et al., 2003). Improvement of handwriting skills is not only important for legibility, but also because poor handwriting has been associated with lower academic achievement (Feder & Majnemer, 2007) and lower self-efficacy when participating in leisure activities (Engel-Yeger et al., 2009). It is important, therefore, to find appropriate interventions for improving handwriting in children with handwriting problems.

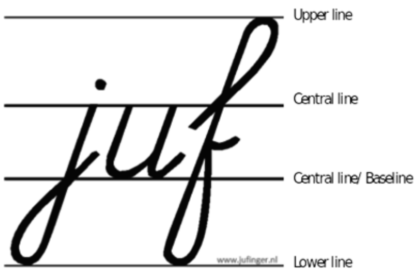
Handwriting problems typically refer to a reduced handwriting quality and/or velocity or both (Hamstra-Bletz et al., 1987). Similar to other motor skills, handwriting skills arise from reciprocal dependencies between perception, action, and cognition (e.g., Mangen & Velay, 2010). According to the constraint-led approach, performance and learning of motor skills reflect the interaction between individual, task, and environmental constraints, and cannot be uniquely attributed to processes internal to the individual (Newell, 1986). Constraints do not prescribe motor patterns but serve to shape or channel the search for adaptive movement dynamics. In handwriting, individual constraints relate to alphabet knowledge, visual perception, hand and finger size and flexibility, among others (Cornhill & Case-Smith, 1996; Rosengren et al., 2003; Volman et al., 2006). Task and environmental constraints include factors like chair and table heights, the type of writing tool (Feder & Majnemer, 2007), the size and shape of the writing implement, the presence of support lines, the requirement to use lower- or upper-case letters (Chartrel & Vinter, 2008; Greer & Lockmann, 1998) or the friction between writing utensil (e.g., pen) and paper (Rosengren & Braswell, 2003).

Although the use of support lines in handwriting tuition can thus be considered as a manipulation of task constraints meant to promote handwriting, there is actually a paucity of studies addressing the effect of support lines on children's handwriting characteristics. To the best of our knowledge, there is no research investigating the effects of manipulating the separation between support lines on handwriting characteristics among typically developing children.

By using support lines children are invited to write smaller and/or show less variability in letter height. However, handwriting methods used at schools do not use uniform lined paper. In the Netherlands, for example, the use of horizontal lines to constrain the size of the letters at the start of writing tuition (i.e., Dutch Grade 3, equivalent to US Grade 1) varies: in some methods no lines are used (blank paper) while in others four horizontal lines with different separations are used. In higher grades the separation between the lines is reduced, and first two and then only one line (i.e., a baseline) is provided. Common methods used in the Netherlands advise to use either 3 mm or 4 mm separations between the central lines with an upper line and a lower line (resulting in three distances, e.g., 6 – 4 – 6 mm) (Figure 1; Chartrel and Vinter, 2008; *Handschrift | lesmethode schrijven groep 1–8 | Malmberg*, z.d.; *Uitgeverij Boreaal | Novoskript*, z.d.; *Pennenstreken*, z.d.). The handwriting methods have in common that with increasing skill they require children to write with smaller letters. Hence, both the separation and the number of lines decrease when tuition proceeds.

Figure 1

Letters between supporting lines (central lines and upper and lower line). In the case of four lines, three separations are distinguished: one central separation (between the two central lines) and two distal separations (lower line to baseline and central line to upper line)



However, to date, the effects of manipulating the number of and separation between supporting lines on handwriting characteristics have not been examined in much detail. Particularly, it is unclear whether the number of and/or separation between lines does indeed benefit handwriting quality, especially among children with insufficient writing levels. Children with insufficient handwriting show poor legibility, but they also have been found to write with a greater variability in letter height, a larger number of segments and a larger number and duration of stops, more 'in-air' time and increased variability in paper time, and more inversions in the direction of velocity (Dvorkin et al., 2006; Gargot et al., 2020; Rosenblum et al., 2003, 2014; Rosenblum, Goldstand et al., 2014).

To the best of our knowledge, there is no research investigating the effects of manipulating the separation between lines on handwriting characteristics. By contrast, there are a few studies examining the influence of manipulating the number of lines. For example, one study examined legibility of handwriting in kindergarten children before they had received formal writing tuition. In these children, legibility was not affected by the presence (or absence) of a baseline (Daly et al., 2003). In addition, Di Brina et al. (2008) compared writing without base or support lines to writing with two support lines. 7- to 9-year old boys with poor handwriting wrote larger letters without lines than their peers with good handwriting. However, with support lines, the size of the letters written by the boys with poor handwriting turned out to be comparable to that of their peers with good handwriting, suggesting beneficial effects of adding support lines. The authors also reported that velocity of handwriting decreased with the support lines in both groups. This decrease in velocity may point to an accuracy-velocity trade-off: both the children with poor and good handwriting decreased velocity in order to write accurately between the lines. Writing size was also influenced when four support lines were added. Five-year-olds (i.e., without formal writing tuition) wrote smaller letters with four support lines (i.e., separation between the lines was 5 – 3 – 5 mm) compared to a baseline only. However, the four support lines did not affect the writing in six-, and seven -year-old children (Chartrel & Vinter, 2008). In addition, the use of four support lines also resulted in fewer velocity peaks and lower pen pressure, suggesting more fluent handwriting movements. By seven years of age (i.e., after two years of tuition), the support lines only reduced the number of velocity peaks (Chartrel & Vinter, 2008).

In sum, although not unequivocal, these findings do suggest that adding support lines has positive effects on handwriting characteristics like size, velocity and smoothness. However, it has remained unclear to what extent such effects can be attributed to the added lines alone or whether the separation between these lines also affects these characteristics. The current study therefore investigated the effects on children's handwriting characteristics when providing two and four support lines with 3 and 4 mm separation between the central lines, compared to writing with a baseline only. We were especially interested in the degree to which variations in separation and number of support lines that are currently used in education benefit the handwriting of children with insufficient handwriting quality. Previous work has reported that children with insufficient handwriting show reduced writing velocity and more 'in air' time (Rosenblum et al., 2003; Rosenblum, Dvorkin et al., 2006), an increase in the number of segments and an increased writing size compared to children with sufficient handwriting (e.g., Rosenblum et al., 2003; Rosenblum, Dvorkin et al., 2006).

Because children at Dutch primary schools are initially taught connected writing, we assessed handwriting characteristics across words and sentences, including the connections between the letters. Consequently, and unlike several previous studies, we did not use outcome measures based on single strokes or letters (Wicki et al., 2014). A digital handwriting tablet was used to measure kinematic variables related to writing size, velocity, and smoothness (Hogan & Sternad, 2009; Rohrer et al., 2002). We expected that the provision of support lines would decrease writing size and increase writing velocity and smoothness, especially among children with insufficient handwriting quality. We also anticipated that reduced separation would elicit smaller, slower, and more smooth handwriting in both groups.

METHODS

Participants

Children with one and half year of writing tuition (all attending Dutch Grade 4, which is equivalent to US Grade 2) were included in the study. Eighteen primary schools in the Netherlands were invited to participate. After the schoolteachers and board of seven schools agreed, an information letter and informed consent was sent to the parents (n = 181). A total of 80 children (43 boys, age 6.5 to 9.2 years) with positive informed parental consent participated. Their handwriting quality was assessed with the Concise Assessment Scale for Children's Handwriting (BHK) and categorized according to the scores as either sufficient, ambiguous, or insufficient handwriting (see also *Procedure and design* below). With an $\alpha = .05$, $1 - \beta = .95$ and effect size $f = .25$, the minimum sample size required based on an ANOVA with between and within interaction is 36. Further exclusion criteria were motor (e.g., spasticity of the upper limbs) or visual disabilities that potentially affect fine motor coordination (assessment based on schoolteachers' report). None of the volunteering children met these exclusion criteria. The ethical committee of the Faculty of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam, approved the study. Parents and children provided informed consent prior to the study.

Procedure and design

Pretest

Children were assessed class-wise with the Concise Assessment Scale for Children's Handwriting (BHK). The BHK is a norm-referenced assessment for handwriting quality in primary school children. Children copied a text for five minutes on unlined paper (i.e., without baseline). The handwriting product was inspected on quality and velocity (Hamstra-Bletz et al., 1987) by a trained senior physical paediatric therapist (i.e., first author). The assessment includes thirteen items: letter size, left-hand margin, alignment, word spacing, acute turns in joins or letters, irregularities in joins, collisions of letters, inconsistent letter size, incorrect relative height of the various kinds of letters, odd or ambiguous letter forms, correction of letter forms, unsteady writing trace. This resulted in a total score between zero and 64. Handwriting velocity was measured by counting the number of letters written in five minutes, irrespective of the quality of the handwriting (i.e., slow 0-98 letters, intermediate 99-123 letters, fast more than 123 letters). A score of 21 points or fewer and with intermediate or fast handwriting was qualified as sufficient. The handwriting of children with a score of 22 to 28 points was qualified as ambiguous. With a quality score of 29 points or more or with slow handwriting (fewer than 58 letters), handwriting was qualified as insufficient. Intra-rater and inter-rater agreement for the quality of handwriting were previously reported as high (respectively $r = .91$ and $r = .85$; Duiser et al., 2014).

The BHK was administered in the classroom in the presence of the teacher. The children sat on standard school furniture and used their own regular pencil or pen. Children received a general introduction before the start of the assessment. Three weeks after the BHK assessment, the children with sufficient and insufficient handwriting were further assessed for the study. Children with ambiguous handwriting did not further participate.

Experiment

To measure the kinematic characteristics of handwriting, a Wacom digitizer tablet was used. Children copied five sentences on the digitizer, which took 5 to 10 minutes. To rule out an additional cognitive task load, the children copied a paragraph from a Grade 1 textbook (Figure 2).

Figure 2

The text children had to copy (and the English translation)

Kasper is een slang.	Kasper is a snake.
Hij is mijn beste vriend.	He's my best friend.
Het is geen echte slang hoor.	It's not a real snake though.
Nee, Kasper is van stof.	No, Kasper is made of cloth.
Hij slaapt bij mij in bed.	He sleeps in bed with me.

Children wrote the text on different sheets fixed on a Wacom tablet. One sheet had only a baseline, with a separation of 15 mm between subsequent lines. The independent variables were (Figure 3):

1. Number of lines: two (N2, only central lines) and four (N4, two central lines, one upper and one lower line)
2. Separation between the central lines: 3 mm (S3) and 4 mm (S4). The separation between the central lines and the upper and lower lines were adjusted proportionally: the three separations were for S3 4.5 – 3 – 4.5 mm and for S4 6 – 4 – 6 mm (see Figure 3).

The combination of these two variables resulted in four experimental conditions: S3xN2, S3xN4, S4xN2, S4xN4. The order in which the conditions were presented was counterbalanced. The children were assessed individually, in a quiet room.

Equipment

Children wrote with an Intuos inking pen on a Wacom Intuos tablet. The tablet was linked to a laptop for data acquisition and analysis. The position of the pen on the digitizer in vertical and horizontal coordinates was sampled with a frequency of 100 Hz. The raw data were filtered at a frequency of 5 Hz by means of a Butterworth low-pass filter.

Figure 3

Lining on the worksheets for central line/baseline (first panel), 3 mm central lines (second panel), 4 mm central lines (third panel), 4,5-3-4,5 lines (fourth panel) and 4-6-4 lines (fifth panel)

Baseline: Central line	S3N2: 3 mm central lines	S4N2: 4 mm central lines	S3N4: 4,5 – 3 – 4,5	S4N4: 6 – 4 – 6

Data analysis and statistics

Outcome measures for the experiment were indicative for writing size, velocity, and smoothness across sentences. As a proxy for writing size, we measured total writing distance (w, in cm, see equation 1).

$$w = \sum_{i=1}^{N} \sqrt{x_i^2 + y_i^2} \quad (1)$$

Subsequently, writing velocity was calculated as the total writing distance divided by total time. Total time was the time (s) to complete the entire paragraph, whereas writing time was the time spend with the pen on paper, and percentage writing was the time spend on paper with respect to total time. The literature reports different measures for smoothness, for example, number of segments (Rosenblum, Dvorkin et al., 2006), root-mean-square-value (Hester et al., 2006), signal to noise velocity fluctuations (Danna et al., 2013), and mean arrest period ratio and jerk (Rohrer et al., 2002).

As the present study considered the kinematics across sentences, we measured smoothness with the number of lifts and mean arrest period ratio (MAPR) (see for similar methods, Rohrer et al., 2002, Hester et al., 2006, Hogan & Sternad, 2009). A lift of the pen was measured when the pen was lifted from the paper identified as a clear drop of the tablet signal. The mean arrest period ratio (MAPR) corresponded to the ratio between the time spent with a velocity close to zero and the total writing time (Rohrer et al., 2002). Previously, Rohrer et al. (2002) set the threshold under for velocity to be close to zero at 10% of the maximum velocity. However, in children, handwriting peak velocities are relatively high, and hence, we used 20% of the mean velocity as a threshold to establish the MAPR. Fewer lifts of the pen and lower MAPR indicated smoother handwriting.

To assess the difference in handwriting characteristics between the two groups in the baseline condition, the dependent variables size (writing distance), velocity (total time, writing time, percentage writing time and velocity) and smoothness (number of lifts, MAPR) were submitted to a MANOVA with group as between factors. In case of a significant difference, independent *t* tests were planned to identify the dependent variables that significantly varied as a function of group.

Next, difference scores were calculated between the four experimental conditions and the baseline (i.e., baseline score – experimental condition score; the larger the difference score either + or -, the larger the experimental effect relative to the baseline). To establish the changes in handwriting characteristics induced by separation and/or number of lines among the children with sufficient and insufficient handwriting quality the difference scores were submitted to separate 2 (group: insufficient and sufficient handwriting) x 2 (separation: S3, S4) x 2 (number: N2, N4) ANOVA with repeated measures on the two last factors. Post hoc tests were performed using Bonferroni adjusted *t* tests, and additional one-sample *t* tests were used to verify if difference scores exceeded zero. Partial η^2 were used to report effect sizes, where partial $\eta^2 < .06$ were considered small, partial $\eta^2 < .14$ as moderate, and partial $\eta^2 > .14$ as large.

RESULTS

Participants

Eighty children were assessed on the BHK in their classroom, 25 of whom demonstrated sufficient handwriting (BHK score 16.4 ± 3.2; 13 boys, 52%), 23 had insufficient handwriting (BHK score 33.0 ± 4.2; 15 boys, 62.5%) and 1 child (girl) did not finish the first five lines (slow handwriting). The remaining 31 children showed ambiguous handwriting (BHK score 24.1 ± 2.1; 48.4% boys) and did not further participate in the experiment. The 49 children with sufficient and insufficient handwriting were mainly righthanded (90%). There was no significant difference in age nor gender between the two groups, age: $t(47) = 1.96$, $p = .06$; gender: $\chi^2(1,49) = 1.090$, $p = .296$ (Table 1)[6].

Table 1

Group Characteristics

		Age *M* (*SD*)	Girls *N* (%)	Righthanded *N* (%)
Sufficient writing	*N* = 25	8.2 (0.4)	12 (48.0)	23 (92)
Insufficient writing	*N* = 24	7.9 (0.5)	9 (37.5)	21 (87.5)

Handwriting characteristics

Table 2 shows the baseline measures in the two groups. The MANOVA confirmed a statistically significant difference in handwriting characteristics between the sufficient and insufficient handwriting group, $F(7, 39) = 2.56$, $p = .03$; Wilk's $\Lambda = .67$, partial $\eta^2 = .33$. Subsequent *t* tests indicated a significant difference between groups for writing distance, $t(45) = -2.29$, $p = .03$, and number of lifts, $t(45) = -2.71$, $p = .01$.

Children with sufficient handwriting quality had smaller writing distance and fewer lifts than children with insufficient handwriting (i.e., indicating smaller and more smooth handwriting).

[6] Because the age effect approached significance, we examined the groups in more detail. This showed that one child in the insufficient group was relatively young (i.e., 6.5 years). However, removing her from the statistical analyses did not affect the outcomes. Hence, it was decided not to exclude her from analyses.

Table 2

Baseline characteristics

	Sufficient handwriting	Insufficient handwriting	*t*	*p* values
SIZE				
Writing distance (cm)	170.0 (33.8)	193.0 (37.8)	-2.23	0.03
VELOCITY				
Total time (sec)	174.0 (52.1)	197.7 (74.6)	-1.28	0.21
Writing time (sec)	107.4 (34.1)	114.7 (45.4)	-0.63	0.53
Percentage writing time (%)	62.0 (6.5)	58.7 (8.5)	1.53	0.13
Writing velocity (cm/sec)	1.70 (0.55)	1.86 (0.64)	-0.95	0.35
SMOOTHNESS				
Number of lifts	56 (6)	65 (15)	-2.58	0.01
MAPR	23.1 (6.8)	25.7 (8.2)	-1.22	0.23

The effects of manipulating the separation and number of lines on handwriting characteristics

The next analyses focused upon the effects of varying the separation and number of lines on handwriting characteristics relative to the baseline. To this end, differences scores with the baseline were compared between groups and conditions. Note that a difference score of zero indicated no change with respect to baseline.

Size

The ANOVA revealed a main effect of separation for writing distance, $F(1,39) = 158.52$, $p < .001$), $\eta^2_p = .22$, but no further effects of group, number of lines or interactions. The main effect showed that difference scores in the S3- and S4-conditions were of unequal magnitude. In particular, the negative differences for S3-conditions indicated that the handwriting distance of children in both groups became smaller compared to the baseline, while for S4-conditions no significant decrease (or increase) was found.

One-sample *t* tests with Bonferroni correction confirmed this (see Table 3). The two S3-conditions (i.e., S3N2 and S3N4) differed significantly from the baseline condition in both groups, while no significant differences were present for the S4 conditions.

Table 3

Writing distance (cm): mean and SE of the difference scores in sufficient and insufficient handwriting

	Sufficient handwriting		Insufficient handwriting	
	Mean (*SE*)	One sample *t* test	Mean (*SE*)	One sample *t* test
S3N2	-18.1 (6.13)	t(22) = -2.95, p = .007*	-31.7 (4.9)	t(22) = -6.45, p < .001*
S3N4	-19.3 (5.9)	t(23) = -3.27, p = .003*	-34.1 (6.18)	t(20) = -5.51, p < .001*
S4N2	7.1 (6.59)	t(22) = 1.08, p = .29	-6.03 (5.86)	t(23) = -1.03, p = .31
S4N4	15.7 (7.08)	t(23) = 2.21, p = .04	-1.39 (5.11)	t(22) = -0.27, p = .79

* significant difference ($p < .0125$; Bonferroni corrected) between difference scores and zero

Velocity

The ANOVA revealed no effects of lining on total time or writing time, but did reveal a significant interaction between group, separation, and number of lines for the percentage of writing time, $F(1,45) = 5.75$, $p = .02$, $\eta^2_p = .11$. Post hoc tests indicated a larger difference score for the S4N4 condition compared to the S4N2 condition in the group with insufficient handwriting. The other comparisons did not reach significance.

Table 4

Percentage writing time: mean and SE of the difference scores in sufficient and insufficient handwriting

	Sufficient handwriting		Insufficient handwriting	
	Mean (*SE*)	One sample *t* test	Mean (*SE*)	One sample *t* test
S3N2	2.5 (.8)	t(24) = 3.10, p = .005*	2.2 (.9)	t(23) = 2.54, p = .018
S3N4	1.4 (.7)	t(24) = 2.07, p = .049	0.09 (1.1)	t(22) = 0.08, p = .939
S4N2	1.7 (.8)	t(24) = 2.25, p = .034	0.05 (.9)	t(23) = 0.05, p = .960
S4N4	1.9 (.7)	t(24) = 2.69, p = .016	3.6 (1.3)	t(23) = 2.84, p = .009*

* significant difference ($p < .0125$; Bonferroni corrected) between difference scores and zero

One-sample *t* tests showed that this difference could be attributed to a significant increase in the percentage writing time in the S4N4 condition relative to the baseline condition for the group with insufficient handwriting (Table 4). Additionally, the group with sufficient handwriting demonstrated a significant increase in the percentage writing time in the S3N2 condition compared to the baseline condition.

Finally, a main effect of separation was found for writing velocity, $F(1,45) = 24.27$, $p < .001$, $\eta^2_p = .35$, indicating that writing velocity showed larger differences with the baseline condition in the S3 conditions compared to S4 conditions. Accordingly, one-sample *t* tests showed that writing velocity for the two S3-conditions decreased significantly relative to baseline, while such differences were absent for the two S4-conditions (Table 5).

Table 5

Writing velocity (cm/s): mean and SE of the difference scores in sufficient and insufficient handwriting

	Sufficient handwriting		Insufficient handwriting	
	Mean (*SE*)	One sample *t* test	Mean (*SE*)	One sample *t* test
S3N2	-0.19 (0.06)	t(24) = -2.98, p = .006*	-0.37 (0.08)	t(23) = -4.78, p < .001*
S3N4	-0.23 (0.05)	t(24) = -4.75, p < .001*	-0.41 (0.1)	t(21) = -4.18, p < .001*
S4N2	0.04 (0.08)	t(24) = 0.53, p = .603	-0.13 (0.09)	t(23) = -1.53, p = .139
S4N4	0.06 (0.09)	t(24) = 0.61, p = .548	-0.19 (0.11)	t(23) = -1.70, p = .102

* significant difference ($p < .0125$; Bonferroni corrected) between difference scores and zero

Smoothness

The ANOVA revealed no main or interaction effects on the difference score for the number of lifts, $F(1, 39) = .50$, $p = .49$, $\eta^2_p = .01$. One-sample *t* tests showed no significant differences in difference scores between the experimental conditions and the baseline (Table 6).

Table 6

Number of lifts: mean and SE of the difference scores in sufficient and insufficient handwriting

	Sufficient handwriting		Insufficient handwriting	
	Mean (*SE*)	One sample *t* test	Mean (*SE*)	One sample *t* test
S3N2	-0.22 (0.58)	t(22) = -0.38, p = .711	-2.65 (1.9)	t(22) = -1.39, p = .178
S3N4	0.46 (0.79)	t(23) = 0.58, p = .569	-1.00 (1.34)	t(20) = -0.74, p = .465
S4N2	0.83 (1.15)	t(22) = 0.72, p = .481	-1.08 (1.5)	t(23) = -0.72, p = .478
S4N4	0.33 (1.06)	t(23) = 0.31, p = .757	-1.65 (0.85)	t(22) = -1.94, p = .065

For MAPR, only a main effect of separation was found, $F(1,41) = 11.04$, $p = .002$, $\eta^2_p = .212$, indicating that difference scores with the baseline were larger for the S3 compared to the S4 conditions. Moreover, one-sample *t* tests showed that MAPR in the S3- conditions in both groups had significantly increased relative to the baseline, while such differences were absent for the two S4-conditions (Table 7).

Table 7

Mean Arrest Period Ratio: mean and SE of the difference scores in sufficient and insufficient handwriting

	Sufficient handwriting		Insufficient handwriting	
	Mean (*SE*)	One sample *t* test	Mean (*SE*)	One sample *t* test
S3N2	2.93 (0.84)	t(23) = 3.47, p = .002*	3.11 (0.92)	t(23) = 3.38, p = .003*
S3N4	2.44 (0.75)	t(23) = 3.23, p = .004*	3.16 (1.01)	t(20) = 3.15, p = .005*
S4N2	1.51 (1.08)	t(22) = 1.39, p = .177	0.81 (1.07)	t(23) = 0.76, p = .456
S4N4	0.31 (0.84)	t(23) = 0.37, p = .711	0.49 (0.89)	t(22) = 0.55, p = .588

* significant difference ($p < .0125$; Bonferroni corrected) between difference scores and zero

DISCUSSION

We examined the effects of the manipulation of support lines on the handwriting quality in children with sufficient and insufficient handwriting as assessed after one year of handwriting tuition. Previous research had indicated that the use of multiple lines positively influences the kinematic characteristics of handwriting relative to a single baseline or blank paper. However, previous research did not indicate whether it was the separation between the lines and/or the number of lines that affected handwriting in children with sufficient and insufficient handwriting. We expected that both the number of lines and the separation between these lines would be associated with a decrease in handwriting size, an increase in writing velocity and smoother handwriting (i.e., less interruption and more time spend on the paper), especially in children with insufficient handwriting. The present study did not entirely confirm the anticipated effects of lining.

First, we found that with a single baseline, children with insufficient handwriting quality showed significantly longer writing distance and more lifts than children with sufficient handwriting, that is, they wrote larger and less smooth than children with sufficient handwriting. This is largely in accordance with previous findings (Rosenblum et al., 2003; Rosenblum, Dvorkin et al., 2006; Rosenblum, Goldstand et al., 2006). We did not find differences between groups in writing velocity. This contradicts the findings of Rosenblum et al. (2003) and Rosenblum, Dvorkin et al. (2006), who reported that proficient writers wrote faster than non-proficient writers. In Rosenblum et al. (2003) the participants wrote Hebrew, which only contains separate characters, while participants in our study were instructed to use cursive connected handwriting. In Rosenblum, Dvorkin et al. (2006) letters and parts of letters were analysed. The number of reversal segments in children with non-proficient handwriting was larger, which may have been associated with reduced writing velocity. Since in connected handwriting there are less reversals of segments, this may have minimized differences in writing velocity among children with insufficient and sufficient handwriting in the present study. In fact, this would underline that kinematic characteristics of handwriting are not a uniquely, individual trait, but are always shaped from the interaction with task and environmental constraints (Rosengren & Braswell, 2003).

Despite these differences in writing distance and smoothness in the baseline condition, the children with sufficient and insufficient handwriting responded almost similarly to the introduction of additional support lines with different separations, while we had hypothesised that children with sufficient handwriting would benefit more from additional constraints. Both children with sufficient and insufficient handwriting wrote smaller, slower, and less smooth when support lines with the smaller distance (3 mm) were added compared to the single baseline line. These changes occurred irrespective of the number of lines. This finding confirms previous research by Di Brina et al. (2008) and Chartrel and Vinter (2008), which showed that the introduction of lining also led to smaller handwriting compared to no lining. However, the effect was significant only for the smallest separation.

In addition to the observation that the handwriting becomes smaller when writing between (smaller) lines, the use of these 3 mm lines also introduced effects on speed and smoothness (as assessed by the mean arrest period ratio) in both groups (sufficient and insufficient handwriting). The reduction of the separation between the central lines thus also immediately affected the way the handwriting was controlled (e.g., more slowly and less smooth). The effects we found on velocity and smoothness may reflect the efforts to adapt to new spatial constraints: smaller (than usual) separation may increase the need for online control in order to comply with the increased accuracy requirements (i.e., speed-accuracy trade-off). Whether these immediate changes may later progress into more automatic control of handwriting (i.e., faster, and more fluent) and thus ultimately would benefit learning, requires further research. This would especially be relevant for children with insufficient handwriting as a longer training with this type of lining may help them to write with smaller letters in a more efficient way.

The use of lining, as an additional constraint relative to a single baseline, evoked changes of the handwriting in children that were irrespective of the number of lines added to the baseline. This suggest that the separation between the lines is more compelling than the number of lines. Presumably, this can be explained by the 3 mm separation forcing children to write smaller compared to the baseline condition. For the 4 mm separation no differences emerged in handwriting, neither with two nor with four supporting lines. Hence, provided that the 4 mm supporting lines did not require an adjustment in size, this shows that the number of support lines was not of significance. Further research is needed to confirm whether indeed the number of support lines is not a critical constraint, or alternatively, whether the current kinematic variables for writing size, velocity and smoothness were sufficiently sensitive to uncover any effects on handwriting quality especially when considering sentences rather than isolated letters.

The manipulation of separation and number of lines had largely similar effects on handwriting among children with sufficient and insufficient handwriting. Accordingly, the introduction of additional support lines did not specifically promote handwriting in children with insufficient handwriting. Yet, the percentage writing time was found to increase in both groups relative to the baseline, but for the children with sufficient handwriting this was with two supporting lines with the smallest separation, while for children with insufficient handwriting this was with four supporting lines and the larger separation (4 mm). An increase in the percentage writing time (time spend in contact with paper), corresponding to a decrease of the percentage of time ‘in air’ (or time without contact with paper), has previously been associated with better handwriting (Rosenblum et al., 2003). Gargot et al. (2020) obtained similar results with children who wrote using cursive handwriting. Hence, the observation that the S4N4-condition evoked a larger percentage writing time in children with insufficient handwriting might be promising for developing more specific teaching interventions based on the manipulation of lining. Yet, before pursuing such intervention further insights are needed. For example, it is possible that implementing the two spatial constraints in combination (i.e., the separation between the central lines and the separation between the outer lines) is not effective for weak writers, but that introducing them stepwise might be more beneficial.

In general, the present results did not entirely confirm the expected effects of support lines on children's handwriting characteristics. Thus, while the presence of at least two lines reduced, as expected, the size of the letters and writing velocity, it unexpectedly reduced, the smoothness in both groups. It has been suggested that due to ongoing development of handwriting in children of this age, the produced handwriting is relatively instable (Duiser et al., 2020). This not only results in large inter- and intra-individual differences in children's handwriting, but may also obscure systematic effects of manipulating support lines on handwriting characteristics, if any . Accordingly, at later ages, when handwriting has stabilized, the effects of manipulation support lines may become more apparent.

Strengths and limitations of the study

Typically, sufficient, and insufficient handwriting are compared based upon outcome variables related to single letters (i.e., quality and speed of handwriting only). A strength of this study is that we also scrutinized process measures (i.e., velocity, MAPR and number of lifts) and derived these across sentences. Yet, this comes with a limitation, as it was not clear beforehand which of the measures can or are most relevant in distinguishing sufficient and insufficient handwriting in children who are still developing their handwriting skills. For example, MAPR, which was used as an indicator of writing smoothness, was included based on its sensitivity in examining handwriting in adult patients with Parkinson's and stroke (Hester et al., 2006; Hogan & Sternad, 2009; Rohrer et al., 2002).

However, we found no literature examining children that could serve as a direct comparison. Yet, in the present study smoothness did not distinguish children with sufficient handwriting from those with insufficient handwriting. This been said, many of the kinematic measures, even if they did not distinguish between the groups, were influenced by lining, especially with respect to separation. In addition, because we used cursive connected writing, we chose to use kinematic measures that reflect the handwriting across whole text, while we classified the children as showing sufficient and insufficient writing on basis of the BHK. While four of the BHK-criteria concern the whole text (i.e., ‘left-hand margin’, alignment, word spacing and unsteady writing trace), the main focus of the assessment is toward the topology of the letters and the connections between successive letters (i.e., acute turns in joins or letters, irregularities in joins, collisions of letters, inconsistent letter size, incorrect relative height of the various kinds of letters, odd or ambiguous letter forms, correction of letter forms). This suggests that analysing kinematics at the letter-level may potentially widen the differences between the two groups and increase sensitivity for the effects of lining.

Finally, it must also be pointed that we distinguished sufficient and insufficient handwriting in young children that are still at a learning stage but do not necessarily have sufficient and insufficient developmental outcomes (Duiser et al., 2020). This may reduce generalisability of the findings. Similarly, it is necessary to further assess whether the observed effects on writing size, speed and smoothness are transient or encompass more enduring learning changes in handwriting, especially among children with insufficient handwriting who are still developing the skill. If these immediate negative effects on velocity and smoothness turn out to be enduring, then they may have important ramifications for current tuition methods.

CONCLUSION

The current study showed that with only one baseline children with insufficient handwriting wrote larger and with more lifts than children with sufficient handwriting. All children wrote smaller when additional lining with relatively small separations was used. Yet, this happened at the expense of handwriting speed and smoothness. In the group with insufficient handwriting, four supporting lines with the largest separation evoked longer writing time on paper. In conclusion, for both children with sufficient and insufficient handwriting, the presence of support lines affected the handwriting, but these effects were not entirely beneficial regarding handwriting characteristics.

CHAPTER 5

DOES LEARNING TO WRITE AND TYPE MAKE A DIFFERENCE IN LETTER RECOGNITION AND DISCRIMINATION IN PRIMARY SCHOOL CHILDREN?

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ABSTRACT

Background: A corollary of the increased use of computers at primary school is a decrease in handwriting time, which may adversely affect the ability to recognize and discriminate letters. Our purpose was to examine if in-classroom handwriting and touch typewriting tuition makes a difference for the recognition and discrimination of letters in novel readers.

Method: 81 Dutch primary school children (4.0 till 6.1 years), were assigned to either a handwriting, a touch typewriting, or an alphabet tuition control group. During three weeks they weekly received two 20-minutes classroom-based tuition sessions a week. All children were assessed on a recognition and discrimination letter test before and after the tuition sessions.

Results: Children recognized and discriminated more letters after tuition, irrespective of the type of training they had received.

Conclusions: The novice readers among primary school children did not learn to recognize and discriminate letters better after classroom-based handwriting than after touch typewriting, or alphabet tuition.

INTRODUCTION

In recent years, the use of computers, digital tablets, and thus keyboards in primary school classrooms has dramatically increased at the expense of the time that children spend on handwriting (Mangen & Balsvik, 2016). This adversely affects handwriting skill and legibility. However, the reduction in handwriting tuition or penmanship practice is not restricted to handwriting; it has been found to affect children's basic fine motor skills as well (Sülzenbrück et al., 2011; see also Seo, 2018). In fact, there is much controversy among researchers whether the acquisition of handwriting skills may even influence children's further or broader development (Wollscheid et al., 2016). Ding et al. (2020), for example, found a reciprocal relationship between handwriting fluency and spelling accuracy in Chinese children. Further to this point, many researchers have argued that the reduced time spend on practicing handwriting in the classroom affects children's reading skills, including their ability to recognize, discriminate and memorize letters (Preminger et al., 2004; Longcamp et al., 2005, 2006; Arndt, 2016; Mangen & Balsvik, 2016).

Also, practitioners are increasingly worried about children's reading skills, based on a general assumption that learning to write promotes reading. The assumption underpins various teaching programs at primary schools internationally (e.g., *The Spalding method* in the US and Australia; *Reading to learn* and *The THRASS Institute – Teaching Handwriting, Reading and Spelling Skills* in Australia; *A Programme That Grows with Your Children - Jolly Phonics* in the UK and *Pennenstreken* in the Netherlands).

The supposed relation between learning to write and reading skills is consistent with the premises of embodied cognition theories. These increasingly influential theories posit that the development of cognitive skills such as numeracy, mathematics and reading are grounded in action, rather than that they solely originate from cognitive (or brain) processes. They hold that perception and cognition cannot be separated from bodily action, and that perceptual and cognitive skills grow out of or are constituted by action (Barsalou, 2008; Chemero, 2013; Mangen & Balsvik, 2016). In reading, for example, learning to copy or produce the shape or topology of a letter in handwriting is thought to promote the recognition and identification of that letter (Mangen & Velay, 2010; James & Engelhardt, 2012; Kiefer & Trumpp, 2012).

Evidence that reading skills are indeed grounded in writing skills via letter topology was first presented in research by Longcamp et al. (2005). The authors did this by comparing children's ability to recognize letters following a weekly 30-minute tuition in handwriting or typewriting across three weeks. The three- to five-year-olds were asked to either write or type twice a series of twelve letters, which were verbally and visually presented. Only the older children in this group (and not the younger children) who received handwriting tuition learnt to recognize more letters than the children who received typewriting tuition. Longcamp et al. (2005) concluded that the embodied linkage between reading and bodily action is restricted to handwriting. It would not encompass typewriting, presumably because unlike handwriting, typewriting movements do not share the topological characteristics with the (visual) letter shapes (see also James & Engelhardt, 2012; Kersey & James, 2013).

Later observations by Kiefer et al. (2015) did not confirm the advantage of handwriting over typewriting tuition in recognizing letters. Four-to-six-year-old children received handwriting or typewriting tuition through letter games. Eight letters were taught over a four-week period, with children practicing four times a week for 25 minutes. Tuition increased children's handwriting and typing skills, and more so than in the study by Longcamp et al. (2005). Importantly, after tuition, both groups had improved letter recognition, but this improvement did not differ between the handwriting and typewriting group. This contrasts with the hypothesis that benefits of handwriting for letter recognition is through topological similarity, because since such similarity is absent for typewriting movements, letter recognition should not be facilitated by typewriting.

One possibility may be that the benefits of handwriting, if any, are only short-lived, and thus may have been concealed by the longer duration of the tuition in Kiefer et al.'s study (i.e., 400 minutes in Kiefer et al. [2015] versus 90 minutes in Longcamp et al. [2005]). Alternatively, the letter games in Kiefer et al. (2015) involved story telling during which the target letter shapes were also presented visually and combine with an explication of the corresponding sound and lip-movements. In addition, the children were encouraged to find other words starting with the target letter. Because no control group was present that only received visual-verbal tuition, Kiefer et al.'s (2015) study does not rule out that the increased letter recognition followed from this visual-verbal practice rather than from handwriting and/or typewriting.

Recently, Zemlock et al. (2018) did include a group to control for the effect of practicing visual recognition of letters independent of handwriting. They compared the effects of handwriting tuition of letters and digits on letter recognition, discrimination, and identification in three- to seven-year-old children. The children received 12 tuition sessions in small groups across six weeks. They either practiced copying letters or digits, each letter or digit four times or they drew mazes with the exit showing a letter or a digit (i.e., visual practice of letters or digits only). The letters and digits were never pronounced. Zemlock et al. (2018) found that both the letter and digit writing tuition groups showed enhanced letter recognition compared to the visual practice group. This implies that a topological similarity between handwriting movements and letter forms may be not a prerequisite for increased letter recognition. Zemlock et al. (2018) argued that it is the visual guidance of the fine movement forms per se (i.e., high demand of visual control while writing letters and digits) rather than topological similarity that facilitated the recognition of letter forms.

Finally, it must be noted that these studies each include aspects that make them less representative for classroom-based tuition, for example setting a fixed number of letter repetitions and/or removing verbal support are unlikely to happen in regular classes. To also make the findings representative for classroom-based tuition, it is pertinent to impose as few experimental constraints on the method of tuition as possible.

If indeed a mere increase in movement demands promotes visual recognition of letters, then this may also be a conceivable effect for typewriting. In this respect, both Longcamp et al. (2005) and Kiefer et al. (2015) had children type in a hunt-and-peck fashion, that is, typing all letters with one and the same preferred finger. Accordingly, in both studies movement control requirements were reduced since no specific linkages were present between letter shape and typing movements. By contrast, in touch typewriting, proficient typists touch a limited number of designated keys with each of eight fingers with the hands in the same initial position, i.e., touch typewriting involves a degree of specificity of the finger movements to letter shapes that is absent in hunt-and-peck typing. Consequently, for novices, touch typewriting increases the attentional control demands of individual finger movements compared to hunt-and-peck typing.

The aim of this study was to further investigate the purported superiority of handwriting tuition for learning to recognize and discriminate letters in primary school children compared to touch typewriting tuition. Because we were not only interested in testing hypotheses based on embodied cognition but also in the degree to which tuition in handwriting and typewriting can actually make a difference in schools, we conducted a classroom-based study. Two groups of children, without previous formal reading tuition, either practiced handwriting or touch typewriting in small classroom groups. In addition, a control group followed the typical Dutch tuition method for alphabet learning that present letters visually and verbally, using rhymes and words. Children look at letter shapes, listen and repeat phonemes and words of the target letter, but do not write or type. To gauge reading skills (Le Roux et al., 2017), we used the letter recognition test previously used by Longcamp et al. (2005) and Kiefer et al. (2015), in which children selected the target letter between forms with similar but divergent shapes as the target letter (e.g., its mirror image). Additionally, we conducted a letter discrimination test, in which children distinguished the target letter between other letters –as in reading (Bara et al., 2004; 2011).

Following embodied cognition, we hypothesized that children's letter recognition and discrimination ability would benefit both from handwriting and touch typewriting tuition compared to alphabet tuition only. We expected this advantage to be larger for handwriting tuition because of the higher degree of specificity (i.e., topological similarity) between handwriting movements and letter shapes.

METHODS

Participants

Dutch primary school children who had not received any formal reading and writing tuition at school were eligible for the study (Grade 1 and 2). Power analysis (G*Power 3.1) showed that a minimum number of 66 participants was needed (i.e., based on the initially planned ANOVA with repeated measures within-between interaction, effect size $f = .25$, $\alpha = .05$ and $1\text{-}\beta = .95$). To recruit children, four primary schools were contacted. In the Netherlands, there is no division in private and public schools, and the vast majority of primary schools is government funded. Consequently, a school's student composition typically reflects the social-economical characteristics of the neighborhood. The participating schools were from middle class neighborhoods in medium sized cities in the Netherlands. After schoolteachers and the board of two schools agreed to participate, a recruitment letter, which included an information letter and informed consent form, was send to the parents. The parents of 83 children gave written consent for participation of their children. Children were then screened for motor disability, using the Movement Assessment Battery for Children-2, Dutch version test (M-ABC-2-NL, see below), and/or visual disabilities that may affect fine motor movements (i.e., writing and/or typing). No child was excluded for these reasons. Finally, two children left school shortly after the pretest (both from the alphabet control group) and were excluded from analysis. There were no further dropouts. The local university's ethical committee approved the study.

The final sample consisted of a total of 81 children (mean age = 5.1 years, *SD* = 0.6). They were randomly assigned to one of the three groups (i.e., handwriting, typewriting and alphabet control group), which were matched for pretest scores on the recognition and discrimination tests. Children were first categorized as scoring above chance on neither, one or both the recognition and discrimination tests, and then proportionately distributed across the three groups (see section 2.3). There were no significant differences in age, grade, and manual dexterity scores (subscale of the M-ABC-2-NL, see section 2.2) between the three groups (respectively, F (2, 78) = .34, p = .71, $X^2(2)$ = .18, p = .91, and $X^2(2)$ = 2.05, p = .36, Table 1).

Table 1

Participants characteristics as a function of group

	Handwriting	Typewriting	Alphabet	Total
Number	30	29	22	81
Age	5.1 (0.6)	5.2 (0.6)	5.1 (0.6)	5.1 (0.6)
Grade 1 / 2	13 / 17	11 / 18	9 / 13	33 / 48
Manual dexterity standard score; subscale M-ABC-2-NL	10.3 (2.5)	9.8 (2.5)	10.5 (1.9)	10.2 (2.3)
Number of children with delay according to M-ABC-2-NL	1	2	1	4

Note. M-ABC-2-NL = Movement-Assessment Battery for Children-2, Dutch version, norm scores for Manual Dexterity are 10±3

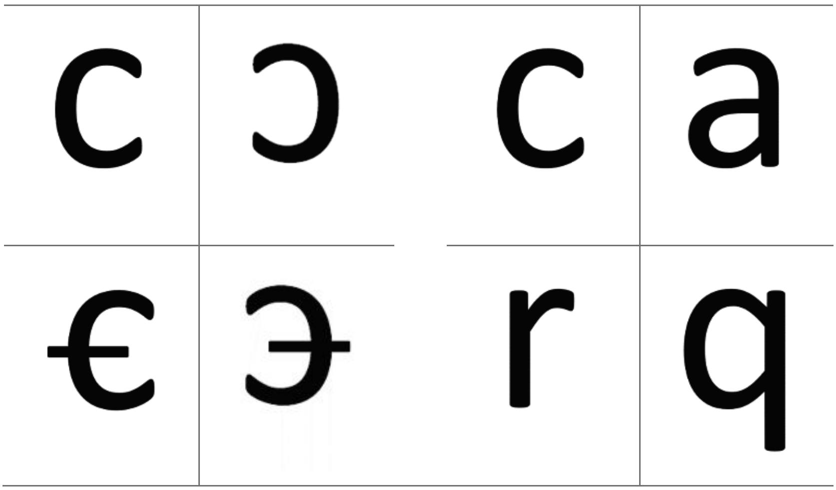
Material and equipment

Letter recognition and discrimination tests

During the pre- and posttests, the children performed the letter recognition, and the letter discrimination tests individually, and in randomized order (a computer program pointed out which test came first). The two tests included the same twelve target letters as the letters that were introduced during tuition (i.e., c, e, f, h, j, k, m, n, r, s, t, z). The same printed block lowercase letters were used for the tests and for the lessons. The choice was based on the letters having an asymmetrical shape, such that the mirror image could be used as distractor in the letter recognition test. In the letter recognition test (Longcamp et al., 2005; 2006), the twelve target letters were shown on a monitor. One target letter was presented together with three distractors (i.e., the mirror image of the target letter, the target letter with an extra stripe, and the mirror image of this modified target letter, Figure 1a). In the letter discrimination test, the twelve lowercase target letters were also shown together with three distractor letters. Distractor letters were letters from the alphabet other than the target letter and including the other eleven target letters (Figure 1b).

Figure 1

Letter 'c' in the letter recognition assessment (a) and discrimination assessment (b)



Movement Assessment Battery for Children-2, Dutch version

During the pretest the fine motor abilities were assessed by using selected items of the Movement Assessment Battery for Children-2, Dutch version (M-ABC-2-NL, Henderson et al., 2007; Smits-Engelsman, 2010). The M-ABC-2-NL is a standardized test to determine motor development. Dutch norm scores are available (Smits-Engelsman, 2010). Items include manual dexterity, ball skills and static and dynamic balance. For the present study, the children only performed the three items for the manual dexterity for first age band, that is, putting coins in a box, stringing beads, and drawing between lines. Reliability of the manual dexterity norm scores was reported fair to excellent (Van der Linde et al., 2013; Griffiths et al., 2018).

Procedure and design

A pretest, intervention, posttest design was used. The pretest was carried out at all schools, three to six weeks before the first lesson, while the posttest was conducted between one and three days after the final lesson. The period between pretest and the start of tuition was organizationally needed to test and assign children to groups. Children were not encouraged to read at home during this period and the remainder of the study. Yet, if they did so, or had done so before the start of the study, was not verified. In the two tests, children were individually assessed on letter recognition and discrimination by the main experimenter (first author) or a research assistant. Letter recognition and discrimination tests included 24 trials with four alternatives.

In both the recognition and discrimination test, the experimenter pronounced the target letter as a phoneme, and asked the child to point out the corresponding letter among the four shapes (in the recognition test) or the four letters (in the discrimination test) shown on the monitor. The shape or letter pointed out by the child was recorded. In both tests, all twelve target letters were assessed twice in a random order (i.e., total of 24 letters per test), each time with another configuration of neighboring distractors. Type of distractor, the location and order of the presentation were randomized across trials. We used the Excel function ‘ASELECT’ to randomize the order of the tests, the letters, and distractors in both the pre- and posttest.

Based on four alternatives, a binominal distribution test indicated that to perform above chance, children had to recognize or discriminate at least 11 of 24 items correctly. Based on this, children were divided into three pretest performance categories: performance in both the recognition and discrimination tests were above chance (*n* = 41; 50.6%); one of the two tests was above chance (*n* = 27; 33.3%), or both tests were performed at chance (*n* = 13; 16.0%).

Next, children from each category were randomly assigned to the handwriting, typewriting or alphabet control group using a randomizer algorithm (also using the Excel function 'ASELECT'). Subsequently, these groups were controlled for the number of children with delay according to M-ABC-2-NL assessment (see Table 1). It took a second round of randomization for the four children with delay to be equally distributed across groups. This resulted in 30 children (10 girls, 2 lefthanded) being placed in the handwriting group, 29 children (12 girls, 5 lefthanded) in the typewriting group and 22 children (11 girls, 2 lefthanded) in the alphabet control group (Table 1).

Tuition

General procedure

Children received classroom-based tuition twice a week for a period of three weeks. Each lesson took 20 minutes and was performed in groups of two to four children. Children sat on standard adjustable school furniture. The children in the handwriting and touch typewriting groups sat at tables, while children of the alphabet control group sat in a small circle without tables. The main experimenter or the research assistant led the lessons. For each group, the letters that were practiced were presented visually and verbally in the same fixed order across lessons. In the first lesson, j and f were taught, in the second s, t and h, in the third e, r and k, in the fourth z and n, and in the fifth lesson c and m. From the second lesson onwards, the new letters and all the previously introduced letters were practiced (similarly to Kiefer et al., 2015). In the sixth lesson, all twelve letters were rehearsed. In each group, the lesson started with the experimenter or assistant naming the letters, that is, pronouncing them as phonemes. At the same time the letter was shown visually, printed in A4 size.

In addition, the letter was contextualized as the first letter of a spoken word or as a letter clearly apparent within the spoken word. Children were encouraged to pronounce the letter and think of words of their own, which contained the target letter. On the child's request, a letter was shown again during practice. Practice was standardized across groups with respect to the time-on-task. That is, the practice time was fixed (20 minutes), and the number of letters and words each child wrote, typed, or pronounced was free to vary[7]. The rationale behind standardization of time-on-task was to prioritize the representativeness of the classroom-based tuition relative to regular teaching methods at schools (e.g., Hurschler Lichtsteiner et al., 2018), which is typically organized in fixed time slots rather than in number of practice repetitions.

Additionally, this allowed individual children to practice in their own pace, resulting in more repetitions among both the handwriting and typewriting group in the more skilled children. However, a minimum criterion for all children was set. They had to write or type at least 30 letters within a lesson, with the two or three newly introduced letters at least 5 times and all the previously introduced letters at least twice. For reference, this minimum per lesson was higher than the total number of repetitions in the Longcamp (2005) and Zemlock (2018) studies.

Handwriting tuition

In the handwriting tuition group, after the target letters were visually and verbally presented, the children were instructed to trace the letter once over a letter, which was printed in plain lines on a worksheet. They were then told to write the novel target letter on the worksheet. A standard worksheet taken from a regular Dutch handwriting method ('Schrijven leer je zo') was used. It had no lines, and one example of the target letter was shown. Children wrote with regular pencils and could write the letter in any size they chose. Children were told to write the shape of letter correctly; the experimenter indicated were to start and how to write the letter (i.e., by showing the prescribed sequence and direction of strokes, as indicated in the manual). When the child did not adhere to these instructions (i.e., incorrect form or sequence), the experimenter or assistant would show the child how to write the letter shape correctly. From

[7] We did not register the exact number of letters written, typed, or pronounced by individual children. Having additional assistants and/or multiple video cameras in the classroom was considered too intrusive for the normal classroom procedures.

the second lesson onwards, after practicing all the newly introduced target letters, the children were asked to rehearse the target letters learned in the previous lessons, separately or in words. If children wanted to write words, the experimenter wrote these words as an example on the worksheets, so the children could copy them.

Touch typewriting tuition

In the touch typewriting group, children used laptops with Qwerty keyboards with all letter keys blinded with colored stickers. After the target letters were visually and verbally presented, the experimenter or research assistant wrote the letter on the corresponding sticker and explained what finger to use. During practice, a row of letters was presented on the monitor. The children were asked to copy the letters beneath the example row using the correct finger. In the first and subsequent lessons, children always started with the left index finger for the f and the right index finger for the j. In the second lesson, after rehearsing the f and j, the new target letters were introduced and rehearsed. From the third session onwards, after rehearsing the f and j and the new target letters, the children were instructed to rehearse all letters that were learned in previous sessions, separately or in words. When the children typed the wrong letter, the experimenter or research assistant deleted it using the backspace key, and the child was asked to type the correct letter. When the child used the wrong finger (as identified by the experimenter, the research assistant, or the children themselves), the letter was deleted, and the child was given the opportunity to type the correct letter with the correct finger. Children were required to type for 20 minutes, regardless of their typewriting speed and the number of letters or words they typed. Yet, the experimenter and assistant made sure the children typed at least all the new and previously rehearsed letters in each lesson. In comparison, the fast-typing children would likely make more letter repetitions than the fast writers within a lesson.

Alphabet tuition

In the alphabet tuition control group, in addition to the visual and verbal presentation of the target letter, the experimenter or assistant read rhymes about the target letters from a children's book for reading ('Het alfabet van Anders', Oomen, 2002). The children pronounced the target letters (as a phoneme) and they watched pictures and talked about words that contained the target letter. Also, the experimenter or research assistant provided words that included the target letters. When talking about a letter or when a child asked for it, the letter was shown again using the A-4 page. Every child was given the opportunity to find and pronounce new words containing the target letters.

The lessons in the alphabet group lasted for 20 minutes. Each lesson started with the rhymes about the novel target letters, and from the second session onwards, thereafter the previously introduced letters were rehearsed. The rehearsed letters were pronounced by the children together. When a target letter was discussed (either new or previously rehearsed), every child was given the opportunity to pronounce the letter or a word containing the letter, so that the children pronounced the letters or words containing the letters at least twice in each session. In addition, the children listened to the other children rehearsing the letters and words.

Data analysis and statistics

The number of correct answers (out of 24) on the recognition and discrimination tests was counted. Next, difference scores with respect to the number of correct answers between pre- and posttest were calculated for both tests. Thereafter, the difference scores on the recognition and discrimination tests were compared with two separate ANCOVAs with difference scores as dependent variable and pretest score as covariate. This ANCOVA was not initially planned but performed to take the observed inter-individual differences in reading skills at the start of the study into account, because these differences potentially affect the amount of improvement that can be achieved with tuition. Effect sizes were expressed using partial eta-squared (η_p^2), with values of .01, .06, and .14 interpreted as small, medium, and large effects, respectively (Cohen, 2013). In addition, for both the recognition and discrimination tests, McNemar's tests were conducted to examine whether the number of children that performed above chance in the pretest compared to the posttest increased across the three groups.

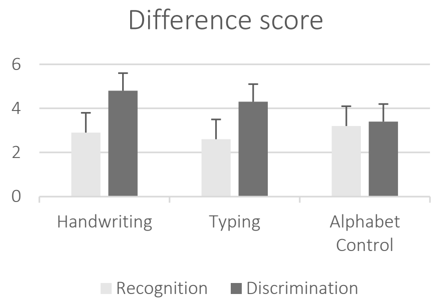
RESULTS

Eight children missed one of the six lessons (i.e., three in the handwriting group, three in the typewriting group and two in the alphabet control group). However, they were included in the analyses since the pattern of results were similar with and without inclusion of the children who missed one lesson[8].

Figure 2 shows the average number of correct answers for the recognition and discrimination tests. All three groups improved recognition and discrimination of letters from the pretest to the posttest, yet the magnitude of these improvements did not appear to differ between groups. Accordingly, one sample *t* tests confirmed that the difference scores on the recognition and discrimination tests showed exceeded zero for all three groups (*t*'s > 2.89; *p*'s < .007). Additionally, the ANCOVAs for the difference scores of the letter recognition and discrimination tests revealed significant effects for the pretest score co-variate, $F(1,77) = 24.2$, $p < .001$, $\eta^2_p = .24$ and $F(1,77) = 77.8$, $p < .001$, $\eta^2_p = .50$, respectively, but not for group (resp. $F(2,77) = 0.33$, $p < .718$, $\eta^2_p = .009$ and $F(2,77) = 0.82$, $p < .444$, $\eta^2_p = .01$; Figure 2). A lower pretest score was associated with a higher difference score after training both for recognition test, Pearson's $r = -.48$, $p < .001$, and for the discrimination test, Pearson's $r = -.71$, $p < .001$).

Figure 2

Difference between pre- and posttest scores with standard errors for the recognition and discrimination test



[8] We performed the same ANCOVAs as reported in the text, but then excluding the children who missed of one of the lessons. This showed similar statistical patterns; no main effects of groups for the difference score in recognition, $F(2, 69) = 0.44$, $p = 0.645$ and discrimination, $F(2, 69) = 0.91$, $p = 0.408$.

Because the absence of evidence is not equal to evidence of absence (Stefan et al., 2019), we performed a Bayesian repeated measured ANCOVA using JASP (see Van den Bergh et al., 2020). In our model, H_0 stands for the absence of a group effect in difference scores, H_1 for the presence of a group effect and in difference scores between the pre- and posttests.

Using the Bayesian ANCOVA, allows an estimation of the model's parameters based on prior distribution hypotheses, and to calculate the ratio between two conditional probabilities (Perret & Solier, 2022). For recognition, the model with the pretest score as a predictor is about 28770 times more likely than the model with group as a predictor (Table 2).

Table 2

Model comparison for the recognition difference scores models

Model	P(M)	P(M|data)	BF_M	BF_{01}	Error %
Pretest score	0.250	0.876	21.286	1.000	
Pretest score + Group	0.250	0.123	0.422	7.112	1.053
Null model	0.250	2.580e -4	7.743e -4	3396.512	0.005
Group	0.250	3.046e -5	9.140e -5	28769.917	0.026

Note. P(M) = prior model probability; P(M|data) = posterior model probability; BF_M = posterior model odds; BF_{01} = Bayes factors of all models compared to the best model.

Table 3 shows the model-averaged results for the recognition difference score. It shows for the two predictors (pretest score and groups) the prior and posterior inclusion probabilities and the inclusion Bayes factor. The difference score is 3465 times more likely for the model that includes the recognition pretest score than under the model that includes the training group.

Table 3

Results from averaging over the recognition models in table 2

Effects	P(incl)	P(incl|data)	$BF_{inclusion}$
Group	0.5	0.123	0.141
Pretest score	0.5	1.000	3465.027

Similarly, the discrimination test difference score is 1.920e +11 times more likely under the model with the pretest score as a predictor than under the model with group as predictor (Table 4).

Table 4

Model comparison for the discrimination difference scores models

Model	P(M)	P(M|data)	BF_M	BF_{01}	Error %
Pretest score	0.250	0.832	14.814	1.000	
Pretest score + Group	0.250	0.168	0.608	4.934	0.883
Null model	0.250	2.077e -11	6.232e -11	4.003e +10	0.002
Group	0.250	4.330e -12	1.299e -11	1.920e +11	0.030

Note. P(M) = prior model probability; P(M|data) = posterior model probability; BF_M = posterior model odds; BF_{01} = Bayes factors of all models compared to the best model.

Also, the discrimination difference score is 3.983e +10 times more likely under the model that includes the discrimination pretest scores than under a model that includes the group (Table 5).

Table 5

Results from averaging over the discrimination models in table 4

Effects	P(incl)	P(incl|data)	$BF_{inclusion}$
Group	0.5	0.168	0.203
Pretest score	0.5	1.000	3.983e +10

Finally, we examined the *number* of children within each group that performed above chance level on the recognition and discrimination tests in the pretest and posttest. It must be noted that perusal of the data showed that for the letter recognition test the three incorrect alternatives (i.e., distractor options) were not equally strong. The two alternatives with the additional stripe were chosen less frequently (i.e., approximately 10% of the answers) than the mirror shape of the target letter (or the target letter). Consequently, rather than four, the recognition test effectively had two alternatives. For two alternatives, the binominal distribution test indicated that children must recognize at least 17 of the 24 items correctly for reliable above chance performance. Following this, we found on the pretest that 11 children (13.6%) performed above change in both the recognition and discrimination tests, 50 children (61.7%) in one of the two tests, while 20 children (24.7%) scored at chance on both tests.

Table 6 (recognition) and 7 (discrimination) show the number of children in each of three group performing at and above chance (i.e., for the recognition test based on the modified criteria) in the pretest and posttest. First, a McNemar's test was performed comparing pretest and posttest for all children, irrespective of tuition group membership. This indicated a significant increase in the number of children that performed above chance in the posttest compared to the pretest for both the recognition and discrimination test, $\chi^2 = 18.2$, $p < .001$ and $\chi^2 = 17.0$, $p < .001$, respectively.

Table 6

Number of children performing at and above chance on the pre- and posttest recognition

Recognition	Handwriting		Typewriting		Alphabet	
Posttest Pretest	Not above chance	Above chance	Not above chance	Above chance	Not above chance	Above chance
Not above chance	18	6	21	6	10	9
Above chance	1	5	0	2	0	3

Because the number of participants in individual cells was too small to conduct McNemar's tests within groups, we performed Chi-squared tests instead to determine differences between groups in the distribution of children performing at chance or above chance. This was done for the two tests for the pretest and posttest separately. For the recognition test, this did not reveal significant differences between the groups on the pre-test and posttest, $\chi^2 = 2.16$, $p = .34$, and $\chi^2 = 3.90$, $p = .14$ respectively. Similarly, for the discrimination test no significant effects were found on the pretest and posttest, $\chi^2 = .11$, $p = .95$, $\chi^2 = 2.03$, $p = .36$. This indicates that the increase in the number of children that performed above chance on the posttest is not different across tuition groups.

Table 7

Number of children performing at and above chance on the pre- and posttest discrimination

Discrimination	Handwriting		Typewriting		Alphabet	
Posttest	Not above chance	Above chance	Not above chance	Above chance	Not above chance	Above chance
Pretest						
Not above chance	0	7	2	5	1	5
Above chance	0	23	0	22	0	16

DISCUSSION

In the current computerized era, primary school children spend increasingly more time typewriting at the expense of handwriting. Some practitioners and scientists have raised concerns that the reduced time handwriting adversely affects the learning and/or ability to read. For example, Longcamp et al. (2005) compared improvement in letter recognition in children who received handwriting or typewriting tuition. They reported that both handwriting and typewriting benefit letter recognition, but crucially handwriting tuition was more effective than typewriting. However, a subsequent study did not substantiate this superiority of handwriting tuition (Kiefer et al., 2015).

To provide a more powerful comparison between the effects of handwriting and typewriting tuition, the present study taught 4- and 5-year-old children to touch type. Touch typewriting entails an increased degree of specificity between finger movements and letter shapes compared to hunt-and-peck typing, and thus requires more visual control of fine movements (Zemlock et al., 2018). Also, a control group that received regular visual-verbal alphabet tuition was included to ascertain that any benefit of handwriting and/or typing tuition on letter recognition and discrimination could indeed be attributed to the engagement in arm and hand motor actions.

We found that children, dependent on their initial reading abilities, indeed improved letter recognition and discrimination with handwriting and touch typewriting practice. Importantly, similar significant improvements were also found in the alphabet control group, suggesting that the handwriting and touch typewriting movements did not result in superior reading abilities compared to traditional visual-verbal alphabet tuition. This been said, these findings do demonstrate that classroom-based tuition in handwriting and touch typewriting did result in similar levels of reading ability as traditional visual-verbal alphabet tuition plus, presumably, either more proficient handwriting or touch typewriting skills.

Our leading hypothesis was that children would show additional benefits from handwriting and typewriting in learning to recognize and discriminate letters compared to alphabet tuition only. Embodied cognition approaches have suggested that these benefits would depend on the degree of specificity of the handwriting and typing movements to the letter shapes (Longcamp et al., 2005; James & Engelhardt, 2012; Kersey & James, 2013; Zemlock et al., 2018). Clearly, this degree of specificity is higher for handwriting than touch typewriting, but even in touch typewriting it is not completely absent as in hunt-and-peck typing, nor is the requirement for attentional control. The anticipated advantage for handwriting relative to touch typewriting was not found. However, we must be careful to conclude that the high degree of specificity or topological similarity of handwriting to the letter shapes does *not* have additional benefits for reading abilities. Because time-on-task rather than number of practice trials was controlled, it cannot be ruled that any advantage of handwriting over touch typewriting was concealed by more letter repetitions during touch typewriting tuition. Yet, for practitioners these classroom-based observations are significant; with equal tuition durations, touch typewriting goes not at the expense of reading abilities relative to handwriting. This been said, additional studies are needed in which the number of letter conditions is more precisely controlled to further scrutinize the degree of specificity hypothesis from embodied cognition theories.

In this respect, it is pertinent that our findings do not provide evidence that handwriting and/or touch typewriting movements facilitate the discrimination or recognition of letters over and above the visual-verbal alphabet tuition group. This indicates that among the largely novice readers in our study (i.e., the children had not received any formal reading tuition before the experiment), learning to produce arm and hand movements that were to some degree specific to the letter shapes did not promote visual recognition and discrimination of letters above verbal plus visual tuition. This was not only true for the comparably weak specificity in touch typewriting, but also for the strong topological specificity in handwriting (cf. Longcamp et al., 2005). Apparently, also the increased control demands for novice writing and touch typing did not further increase letter recognition and discrimination compared to alphabet training (Zemlock et al., 2018). Longcamp et al. (2005) suggested that older children's (i.e., approx. 4 years of age) letter recognition benefitted more from handwriting tuition than recognition by younger children (i.e., approx. 3 years of age). Possibly, because manual skills of older children are further developed. In our study, the individual differences in the letter recognition and discrimination at the start of the experiment were considerable: indeed additional analyses revealed that in the pretest, children in Dutch Grade 2 had better letter recognition and discrimination than children in Grade 1.[9] However, analyses also showed that grade itself was not a significant co-variate, and thus did not significantly affect the observed improvements from pretest to posttest in the three tuition groups.[10] Yet, initial reading ability (i.e., pretest score) was associated with improvement on both the recognition and the discrimination test. The higher the initial reading abilities, the less the children profited from the handwriting, touch typewriting and alphabet lessons. This seems a logical finding, the lessons may simply not have been sufficiently challenging for these children to further improve reading ability.

The current results do not entirely rule out embodied cognition approaches as an explanatory framework for the present findings. In all three tuition groups, children were shown and asked to pronounce the target letters. That is, also children in the handwriting and touch typewriting groups were encouraged to repeat the letters verbally or (if they wanted) to make words with them. The children in the alphabet control group were actively pronouncing letters and thinking of words that contained the target letters (i.e., to resemble the typical school tuition, the children in the alphabet tuition did not practice handwriting or typewriting). Accordingly, each group actively practiced looking, producing, and listening, and thus were engaged in multimodal perception. Previous research has shown that multimodal visual-auditory information can enhance visual recognition of letters in beginner readers (for overview on the letter-speech sound association, see e.g., Blomert & Froyen, 2010). In this respect, it is significant that producing sound not only creates auditory information but is in itself a motor

[9] Unpaired *t* tests showed significant effects for recognition, $t(79) = 4.74$, $p < .001$, and discrimination, $t(79) = 3.93$, $p < .001$. Note that formal tuition in reading starts in Dutch grade 3.

[10] Two separate ANCOVAs with grade as co-variate showed no significant effects for recognition, $F(1,76) = 1.78$, $p = .186$ and for discrimination, $F(1,76) = 2.1$, $p = .152$.

act. Consequently, it would be premature to entirely refute the general conjecture that learning to read is grounded in action.

Thus, our findings suggest that in children without any previous formal reading tuition, visual-verbal alphabet tuition suffices for learning to recognize and discriminate letters. At the same time, also handwriting and touch typewriting tuition did achieve this learning to recognize and discriminate letters, but not more so than alphabet tuition only. Ultimately, therefore, the present findings do not support the presumption that a decrease in handwriting practice would lead to a decline in reading skills for single letters.

Strength and limitations of the study

A clear strength of the present study is that it was classroom-based. The way the letters were taught, including practice duration, feedback, and time-on-task, was very similar to the tuition and practice children typically receive at primary school, albeit that in this study attention for groups, often under guidance of volunteering parents, but also frequently practice with the entire class together). This high representativeness together with the current study's adequate statistical power allows strong confidence about the generalizability of the findings to the classroom. As mentioned above, it must be noticed that we took duration or time-on-task as the main constraint on tuition and not the number of repetitions. Based on our experiment, we have no direct measures of the number of repetitions needed to learn the letters. We made sure that the number of repetitions of the letters in all groups was greater than in Longcamp et al. (2005) and Zemlock et al. (2018), but for future research it is important to delineate the relationship between number of repetitions (and time-on-task, we would argue) on improvements in reading ability.

Besides that, an issue remains with respect to the initial reading skills of the current participants (see also Wollscheid et al., 2016). Although children had not received formal reading tuition at school, about half of the children did possess some initial reading skills. Also, it remains unclear to what extend participation in the study induced reading practice at home. It is notable that this initial ability was stronger for discriminating letter shapes. The number of children that had some rudimentary recognition was clearly lower. However, here it must be kept in mind that while we used the same recognition test as in previous research (e.g., Longcamp et al., 2005), two of the distractors (i.e., the (non-) mirror letters with a stripe extra) appeared insufficiently strong. This effectively may have changed the 4-choice into a 2-choice recognition task, and thus lowered the sensitivity of the test. In future studies (e.g., addressing recognition in complete novice readers) tests should be used that better control for distractor difficulty and number of repetitions of the letters. Furthermore, the results concern the ability to read isolated letters and did not include the ability to read words.

CONCLUSION

Four- to five-year-old children were not found to learn to recognize and discriminate isolated letters better after handwriting than after touch typewriting tuition, and also not compared to regular alphabet tuition. This suggests that the decrease in time spend with handwriting related to increased use of digital tools in primary schools is unlikely to significantly decrease the recognition of letters as long as children are taught to use touch typewriting and/or regular alphabet tuition is provided.

CHAPTER 6

EPILOGUE

HANDWRITING

Handwriting is a pertinent motor skill that children acquire during their primary school years. Despite the widespread (and increasing) use of keyboards, handwriting remains a necessary skill to fulfil school tasks. Yet, a vast number of children in primary school are considered to have problems producing (legible) handwriting (5 – 34%; Feder & Majnemer, 2007; Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011; Rosenblum et al., 2004; Smits-Engelsman et al., 2001). Many of these children are referred to rehabilitation or therapy. As far as we know, both research and therapy assessments typically focus on current inadequacies in handwriting quality and speed and/or the presumed underlying factors that cause them. Often, however, the degree to which these problems are transient or persistent is not considered. In addition, in understanding the underlying factors, both research and therapy appear strongly biased to consider individual abilities or organismic constraints only, rather than also considering task and environmental constraints.

In the past 25 years, the constraint led approach has entered research and coaching within sports, but less so in rehabilitation, paediatric physical or occupational therapy (Handford et al., 1997; Woods et al., 2020). Within rehabilitation, occupational and paediatric physical therapy, the emphasis of research and therapy on understanding and counteracting handwriting problems has been on organismic constraints (Cornhill & Case-Smith, 1996; Feder & Majnemer, 2007; Rosengren et al., 2003; Rosengren & Braswell, 2003; Volman et al., 2006) and less so on environmental or task constraints (Chartrel & Vinter, 2008; Feder & Majnemer, 2007; Greer & Lockmann, 1998; Rosengren et al., 2003; Rosengren & Braswell, 2003). In this thesis, our initial focus was also on constraints that are largely associated with the individual performer, but we also proceeded to address task constraints. First, and associated with organismic constraints, we examined to what degree inadequacies in handwriting are associated with underlying abilities related to visual perception alone (VP; recognizing forms of the Beery-VMI; Beery & Beery, 2010) and fine motor control and coordination (VMI; copying figures and MC; drawing between lines tasks of the Beery-VMI). Furthermore, we also addressed whether early inadequate or unsatisfactory handwriting or less developed underlying abilities can predict persistence of handwriting problems into later school years by longitudinally charting developmental trajectories of primary school children.

Then we shifted focus to task constraints, in particular, we addressed the use of support lines to enhance handwriting quality and speed. Although the use of support lines in the primary school d is ubiquitous, there are hardly any empirical studies examining whether and how lining constrains handwriting quality and speed, and especially, if children with unsatisfactory handwriting would benefit from using support lines. Finally, we examined whether learning to handwrite enables early learning to read, specifically the abilities to recognize and discriminate letters. In this Epilogue we first provide an overview of the main findings to then reflect on implications for further research and daily practice in primary school and paediatric physical therapy.

SUMMARY OF THE EMPIRICAL WORK

In Chapters 2 and 3 we examined (the development of) handwriting quality and speed in primary school children who had received between one and four years of handwriting tuition (i.e., Dutch grade 4 to 7), and the degree to which handwriting is underpinned by the abilities to recognizing visual forms, fine motor control and coordination. We examined whether, at specific intervals during tuition, differences in these underlying abilities were related to handwriting problems (either quality or speed). In addition, we examined whether early-detected handwriting inadequacies predicted persistent handwriting problems or whether they were largely transient. In line with earlier observations (Overvelde & Hulstijn, 2011), Chapter 2 showed that, at an early stage (i.e., after one year of writing tuition; Dutch grade 4), almost a third of the primary school children show unsatisfactory handwriting according to the Concise Assessment Scale for Children's Handwriting (BHK; Hamstra-Bletz et al., 1987). Elaborating on this point, Chapter 3 reports that both handwriting quality and speed improved across primary school years. Speed developed gradually, while the increase of handwriting quality was more irregular, with the largest increase taking place between (Dutch) grades 5 and 6. The percentage of children with unsatisfactory handwriting dropped from 33% after one year of writing tuition to 5% after four years of tuition (Dutch grade 7). These findings confirm previous longitudinal studies, underlining that handwriting quality increases through primary school, with only a small number of children showing unsatisfactory handwriting at the end of primary school (Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011). However, prediction of persistent handwriting problems based on handwriting assessments early in primary school was low as only three out of 173 children (1.7%) showed unsatisfactory handwriting across all four years.

In Chapter 2, we also showed that the organismic constraints associated with fine motor control and coordination abilities (i.e., copying figures and writing between lines) constrained handwriting quality, while those related to recognizing visual forms did not (see also Overvelde & Hulstijn, 2011; Tseng & Murray, 1994; Volman et al., 2006). However, it is important to notice that the performance at the tests for motor control and coordination accounted for only 17% of the variance in handwriting quality. We also assessed the influence of these abilities on handwriting quality and speed longitudinally to examine if they were indicative for persistent handwriting problems (Chapter 3). Although the ability for motor control and coordination accounted for a small percentage of handwriting quality when measured at the same time or in the same year (i.e., 13 to 23%), they did not predict handwriting quality or speed in subsequent years.

In Chapter 4, we assessed the influence of lining on the handwriting quality in children with satisfactory and unsatisfactory handwriting. In other words, we shifted focus to task constraints. To this end, we manipulated both the number of lines (i.e., two and four) and the distance between lines (separation of 3 and 4 mm between central lines) and compared handwriting in these four conditions also with respect to writing on a sheet of paper with only a baseline. With only a baseline, children with satisfactory handwriting after one year of tuition (i.e., Dutch grade 4) wrote smaller and more smoothly than children with unsatisfactory handwriting. Providing support lines affected handwriting in both groups. Children with satisfactory and unsatisfactory handwriting adapted almost similarly to the manipulations of number and separation of lines. Both groups of children wrote smaller, less smooth, and slower between lines with the smaller separation (i.e., 3 mm), irrespective of the number of lines. This suggests that Dutch grade 4 children can write smaller letters to adapt to task constraints. Yet, the prioritization of size went at the expense of writing smoothness and velocity. Although adaptation for both groups was largely similar, a small but significant difference suggested that, relative to baseline only, children with unsatisfactory handwriting increased the percentage writing time on paper when writing between four 4 mm central lines, while children with satisfactory handwriting showed an increase in percentage writing time on paper when writing between two 3 mm central lines. Overall, children, both with satisfactory and unsatisfactory handwriting showed similar short-term adaptation to the use of lining, and, not in all aspects in a manner that would be considered an improvement in handwriting quality. Yet, long-term adaptation remains to be investigated.

Finally, in Chapter 5, we examined whether handwriting constrains reading skills. To this end, we compared letter recognition and discrimination in preschool children (i.e., before they had received formal handwriting and reading tuition) who were provided with either handwriting, touch typing or alphabet tuition. Previous research suggested that, unlike learning to type, learning to write does facilitate learning to read. This is consistent with embodied cognition theories which emphasize that by virtue of topological similarity between writing movement and letter form learning to write a letter would also bolster learning to recognize this letter (e.g., Longcamp et al., 2005, 2006; Arndt, 2016; Mangen & Balsvik, 2016). In typing, when it is conducted in a hunt and peck fashion, no topological similarity between the production of movements and letter form exists, and no other (arbitrary) relationships between the typing movement and the letter are present. Yet, previous studies had used hunt and peck typing tuition to compare with handwriting tuition. However, this does not exclude that typing in a way that does entail a degree of specificity between movement production and letter form (as touch typing does), can contribute to the development of reading similarly as handwriting is supposed to do. Hence, in our study, we used touch typing, in which all fingers were involved and designated to a subset of keys.

In Chapter 5, we assessed whether this type of (touch) typing would promote letter recognition and discrimination, and more so than handwriting. To enhance generalization of our observations to the school environment, the study was conducted in the classroom. Children received either handwriting, touch typing or alphabet tuition twice a week for 20 minutes across three weeks. We found that children from all three groups recognized and discriminated more letters after tuition (handwriting, touch typing, alphabet tuition), regardless of the type of tuition. Children thus profited from any form of letter training to recognize and discriminate letters. So, we did not find an indication of the necessity of handwriting or typing in learning to read isolated letters.

These main findings lead to considerations according to handwriting assessments, kinematic variables used in handwriting research, the constraint led approach regarding handwriting and implications for further research and daily practice in primary school and rehabilitation.

HANDWRITING ASSESSMENT

As described in Chapter 3, after one year of tuition, in Dutch grade 4, we were unable to distinguish children who had merely transient handwriting problems from children who ended up with permanent handwriting problems four years later. One explanation for this would be that children's developmental trajectories are highly variable and/or instable (i.e., with a high time and place specificity), especially early in handwriting acquisition. However, an additional explanation that cannot be ruled out is that the BHK test (and/or Beery VMI test) is insufficiently suited to reliably identify persistent handwriting problems. It is therefore important to reflect on validity and reliability of the handwriting assessments for children as they are used in research as well as in therapeutic practices.

The instruments to assess handwriting quality and speed currently used in the Netherlands by occupational and paediatric physical therapists are the Concise Assessment Scale for Children's Handwriting (BHK; Hamstra-Bletz et al., 1987), which was also used in the present research, and the Systematic Detection of Writing problems (SOS-2-NL; Smits-Engelsman et al., 2014; Van Waelvelde et al., 2012). Both the BHK and SOS assess handwriting legibility, which is based on visual inspection of a handwriting product, and handwriting speed, which is based on counting the number of written letters children produce in five minutes. By comparing the children's score to norm scores the current handwriting is deemed satisfactory or not (i.e., either according to quality, writing speed or both). The norm scores differ according to primary school grade (i.e., the raw scores are thus highly correlated with years of tuition). Both tests distinguish children with and without satisfactory handwriting. If handwriting is unsatisfactory, then this indicates handwriting problems (Overvelde et al., 2011). In this respect, the BHK refers to dysgraphic handwriting, thereby suggesting persistent handwriting problems. However, as shown in Chapter 3, the test cannot reliably predict later handwriting problems (e.g., in Dutch grades 6 or 7) using test scores early in tuition (e.g., in Dutch grade 4).

Consequently, we proposed to use the more neutral terminology of satisfactory and unsatisfactory handwriting.

Despite the good inter- and intra-observer reliability of the BHK (respectively *r* = .85 and *r* = .91; Duiser et al., 2014), the test-retest reliability of the handwriting quality of the BHK, has been shown to be relatively low (*r* = .51 and .56; Hamstra-Bletz, 1993). The test-retest reliability was conducted for Dutch grade 4 children (i.e., with one year of tuition) with two experienced assessors. Because interobserver reliability was good (*r* = .71 to .89), The present observations are in line with Hamstra-Bletz (1993) who suggested that the relative low test-retest reliability was due to fluctuations or relative instability of children's handwriting quality. In fact, since in Dutch grade 4 children are relatively novice writers, these fluctuations may reflect the high variability and instability that typically characterizes movement behaviour in the early phases of learning or developing new motor skills (Dhawale et al., 2017). Dhawale et al. (2017) argued that variability during the first, early stages of learning reflect the exploration of different motor configurations to find an optimal solution. It therefore should be considered to develop further assessments that incorporate measurement of this exploratory behaviour, that is, assessments that distinguish the 'good' variability of exploration from the 'bad' or disruptive variability of instable motor behaviour (Latash, 2010). We should note that learning to handwrite is extra complicated, because both the motor activity and the handwriting product show variability (execution and outcome variability; Müller & Sternad, 2009), especially when considering that children learn to handwrite to produce ideal typical letter shapes.

The variability in motor behaviour as a consequence of learning may partially emerge from changes in organismic constraints. We assessed organismic constraints using the Beery-VMI. The Beery-VMI has high inter- and intra-observer reliability (i.e., *r*'s between .84 to 1.0 for the different subtests, Duiser et al., 2014) as well as high test-retest reliability, with approximately 14 days between the two testing moments (i.e., *r*'s between .84 to .88, Beery & Beery, 2010). This indicates that the tested abilities of visual perception, and motor control and coordination can reliably be assessed. Since copying figures correlates with handwriting quality and the ability of motor control and coordination are largely invariant in between two weeks, it suggests that the presumed variability or instability of children's handwriting is not a consequence of high variability in these underlying motor and coordination abilities. So, when assessing children's writing one should be careful to diagnose handwriting problems based on one single handwriting assessment (both transient and persistent). With the present state of affairs, when using handwriting assessments like the BHK and SOS, a suggestion would be to administer those assessments (which in the end only involves five minutes writing on blank paper) repetitively. This allows therapists not only to measure individual variability, but also individual invariance (i.e., similarity across assessments). Further research should determine which aspects of handwriting are invariant and which are variable and whether variability in handwriting changes throughout primary school (as children get older and more experienced).

KINEMATIC VARIABLES

In research, besides product assessments such as the BHK and the SOS, the quality of handwriting is also examined using tablets that measure writing kinematics, such as, distance, speed, and smoothness of the motion of the point of the pen. Yet, there is no consensus about the most valid kinematic variables to gauge the *development* of handwriting. For example, in Chapter 4 we used writing distance, writing time and, as indicators for smoothness, the number of lifts and mean arrest period ratio (MAPR). Children with satisfactory handwriting (as assessed by the BHK) had fewer lifts and smaller writing distance compared to children with unsatisfactory handwriting. When altering task constraints, in both groups the number of lifts remained the same, while the writing distance decreased. Also, for MAPR, both groups of children were equally influenced such that smoothness decreased. Hence, we found that kinematic variables did allow us to differentiate children with satisfactory and unsatisfactory handwriting, but use of support lines did not reduce the difference between children with satisfactory and unsatisfactory writing for these variables. We did find, however, that the use of support lines had (little) influence on the other kinematic variable of smoothness, and this effect was contrary to what we had hoped for, especially in children with unsatisfactory handwriting (i.e., rather than increasing, smoothness decreased). These apparent discrepancies between variables may point to differences between execution and outcome variability, as smoothness is a measure of execution variability and writing distance a measure of outcome variability. When using support lines children seem to give priority to adjust outcome (i.e., decrease outcome variability), this is possibly inherent to the task manipulation, which tries to evoke writing between lines with a specific distance.

Besides that, we cannot completely rule out that the number of lifts and MAPR are insufficiently sensitive for identifying critical changes in handwriting due to the manipulation of constraints in children's handwriting. In this respect, it is important to bring forward that most research of children's handwriting use kinematic variables that were validated for adults with neurological disorders (i.e., number of lifts, root-mean-square-value, number of inversions in velocity, MAPR and jerk; Danna et al., 2013; Di Brina, 2008; Hester et al., 2006; Hurschler Lichtsteiner et al., 2018; Rohrer et al., 2002). Likely, the handwriting problems these adults are confronted with differ from those of developing children, and thus further validation of the kinematic variables for developmental research is important. In doing so, it must be considered that handwriting can be highly variable or unstable during development. This will be addressed in the next section.

Additionally, the current distinction between children with satisfactory and unsatisfactory handwriting is based on an ideal typical handwriting outcome, an image of what letter shapes should optimally look like, less so on the premise that children should develop handwriting that is legible across different contexts. Starting from the premise that children need to learn to handwrite as a means of communication, we think that the aim of handwriting tuition in primary school should be learning to use legible handwriting. To determine which kinematic variables are relevant regarding legible handwriting, we first need to establish what legible handwriting is. Then, the kinematic variables that characterizes legible and illegible handwriting could be determined.

Overall, our findings suggest there is a need for alternative handwriting measurement instruments to assess legible handwriting. Such a functional approach aligns with the tenets of the constraint led approach.

ALTERNATIVE PERSPECTIVE ON HANDWRITING AND ASSESSMENT

From the constraint led approach (CLA) perspective, handwriting (quality) emerges from the dynamic interaction of organismic, environmental and task constraints. When learning to handwrite children explore various movement solutions that satisfy the constraints to write legible in different circumstances. In learning to write there is not one constraint that has logical priority (i.e., leading the learning process). Even though teachers and therapists put much emphasis on organismic constraints of the developing child, task constraints are also (unknowingly) used in the handwriting curriculum. For instance, although this is often directed towards children learning to write ideal letter forms, they do so under various constraints, copying individual letters or words or following verbal instructions, writing between lines (differing in number and separation) or without lines, using different utensils and so on. Such manipulation of task constraints or (re-)designing the practice environment has been proven effective in the development of motor skills, especially in sports (for an overview, see Woods et al., 2020). However, although task constraints are used in the primary school curriculum to support the development of handwriting, this is apparently not done systematically and/or deliberately, and also has not been extensively subjected to research. Chapter 4 shows that task manipulation can induce immediate changes in handwriting performance but whether these rapid changes have long term consequences still needs to be addressed.

Smaller separation between lines induced smaller, slower, and less smooth handwriting, and equally so in children with satisfactory and unsatisfactory handwriting. Note however, that the groups of children were formed based on the BHK (ideal handwriting outcome). Since the ultimate goal of learning to handwrite is to communicate and hence to produce legible writing, this ought to be a (primary) goal of assessment. Thus, children should be able to write readable answers on an exam, write a shopping list on a small piece of paper, make notes during a verbal presentation, write with different utensils, write while beining seated on different sized furniture and so on. In other words, the assessment to be developed should gauge children's adaptive flexibility in responding to different (handwriting) contexts. The assessment should contain the manipulation of task constraints, adjusted to the developmental stage of the child. In primary school these may include writing between (different) support lines or without support lines, writing the alphabet and number, writing sentences by heart, writing self-invented stories, self or externally paced writing, writing on different sized papers, using pen and pencil and so on. Previous research on the length of the text (Dennis & Swinth, 2001), the type of writing utensil (Feder & Majnemer, 2007; Rosengren & Braswell, 2003), length of the utensil (Yakimishyn & Magill-Evans, 2002), the size and shape of writing implement and the requirement to use lower- or upper-case letters (Chartrel & Vinter, 2008; Greer & Lockman, 1998) can serve as a starting point.

We propose that handwriting evaluation should thus not be relative to some ideal handwriting outcome, but be judged in terms of legibility, for example, a letter or word is legible if the assessor recognizes the letter instantly, and without the letter being mistaken for another letter. Perhaps a starting point is offered by the VMI copying figures assessment. It provides minimum criteria to which the figures must comply, rather than how much the figures diverge from the optimum. This approach suggests deriving minimum criteria for legible letters and words in handwriting.

Also, the possibility of a dynamic assessment (Tzuriel, 2001) and research on transient and persistent handwriting problems should be explored. In the assessment approach Tzuriel emphasizes that assessment procedures must be adapted for the developmental stage of a child. Accordingly, various characteristic Tzuriel identifies could be used in a handwriting assessment, i.e., “test materials are geared to concrete operations”. This could refer to previous mentioned different contexts like writing between (different) support lines, writing the alphabet and number or writing sentences by heart. Another characteristic Tzuriel mentions is the use and significance of scoring methods in measurement/research version. When using minimum criteria per legible letter, letters could be scored in legible, partly legible, or not legible, depending on the criteria.

Besides addressing alternative handwriting assessments, from a CLA perspective, further research should focus to delineate appropriate manipulation of constraints that consistently and systematically support children’s acquisition of legible handwriting, especially in children who have problems doing so. Possibly, our results on the support lines experiment could function as a starting point. Since support lines influences both smoothness and writing distance further research should focus on the range in number and separations of lines that increases (or degrades) legible handwriting in children at sufficient speed. From there it can be explored whether it is possible to evoke structural changes by means of manipulation of the (number or separation of) lines.

HANDWRITING AND READING

Another question raised by our research concerns the influence of handwriting (or touch typing) on other motor activities such as reading. Previously, learning to handwrite has been mentioned as a constraint that supports learning to read (Longcamp et al., 2005; 2006). However, the experiment on learning to recognize and discriminate letters after handwriting, touch typing or alphabet tuition we performed, suggests that handwriting and touch typing do not have additional contributions to letter recognition and discrimination compared to mere alphabet tuition. So, learning to handwrite is not a necessary condition for learning to read, and probably does not accelerate learning to read, at least when considering isolated letters.

The CLA typically presumes that cognition is embedded in the development of action and motor skills (Mangen & Balsvik, 2006). Our findings did not directly support this increasingly influential hypotheses of embodied cognition. In our classroom-based study, neither handwriting nor touch typewriting increased the reading ability over traditional reading tuition. This suggests that, if any, and this needs to be confirmed, the role of action may be through the movement of lips and tongue when vocalizing letters, rather than through handwriting or typing movements. Possibly, learning to read is multimodal in the sense of a hierarchical ordering of constraints, where the movements in handwriting or touch typing are less enabling than vocalizing, hearing and especially looking at letters. This undermines strong calls that advocate handwriting as a necessary skill for children to master in primary school because it supports learning to read (Longcamp et al., 2005; 2006; James & Engelhardt, 2012). Since this argument seems largely to be falling away, there may be no reason for teaching handwriting in primary school, except as a means of communication. Yet, it is also pertinent that for adults handwriting can be beneficial for memorizing. Aragón-Mendizábal et al., (2016), for example, found that when making notes in handwriting, students performed better on memory tasks, then when typing. This could be a line of inquiry and a reason to learn to handwrite. However, since making notes is only needed in secondary school and beyond, the perfect time to learn to handwrite may not be tied to primary school age.

IMPLICATIONS FOR PRACTICE

Handwriting is a motor skill that children are taught in primary school at certain grades, independently of their own (fine) motor development trajectories. Currently, children with unsatisfactory handwriting are referred to occupational or paediatric physical therapy already in early grades (Dutch grade 2 or 3) to prevent that they develop problematic delays in handwriting acquisition. This early referral, based on handwriting assessments like the BHK, is not fully supported by our observations and those of others, since most children seem to develop legible and fast handwriting later on in grade 3 and grade 4, also without therapeutic interventions (Overvelde & Hulstijn, 2011). This means that single handwriting assessments are insufficient for referral and that caution is needed to prevent overtreatment. The least that is needed are further and repetitive assessments before advising therapy. For future considerations, various aspects are important. First, product measures are based on ideal typical forms of the letters, not on legibility, so clinicians should assess children's handwriting also under varying task constraints, and foremost with respect to legibility, and discuss this legibility of handwriting with teachers. If the handwriting is not legible, therapists should get additional information about the influence of task constraints on the handwriting of that particular child with handwriting problems as an assessment tool and to use in therapy. Obviously, it is most important to develop a valid and reliable assessment for this purpose.

As a task constraint the use of lining is common in tuition and therapy. Both teachers and therapists should be aware that support lines influence handwriting of children, both with satisfactory and unsatisfactory handwriting, but do not necessarily lead to more legible handwriting. Therapists should assess which number or separation of support lines provokes the most legible handwriting in children, including lining styles that might differ from those used in school.

Finally, considering that handwriting is a motor skill that children should learn in order to communicate legibly (with a pencil on paper) and (at this moment) to perform other primary school tasks, we recognize that it is necessary to learn to handwrite. If, due to motor or other problems, it is not possible for a child after three years of writing tuition to write legibly or fast, referral to a therapist is needed or children should be able to use digital devices to communicate. Overall, there seems still to be sufficient reasons to teach handwriting at primary school. Yet, time investments need to be balanced with other activities, in this respect it may be additional important not to strive for ideal form, but implement more functional goals such as legibility. Achieving ideal, perfect shapes would then -perhaps- turn into an art form.

CONCLUSION

Overall, the current thesis points towards the importance of looking beyond organismic constraints only. Especially manipulating task constraints appears as pertinent in both promoting as well as monitoring writing skill. Admittedly, however, we have not much support for this contention, also because this was just a first exploration. Clearly, more systematic and encompassing approach and methodology is needed that scrutinizes the relevant task and environment constraint manipulations. In the end, this would put both teachers and therapists on the track of designing practice tasks and environments that allow children to develop their own legible handwriting rather than trying to embellish their writing towards a desired shape.

Which constraints exactly contribute to handwriting development and to what content is not clear yet. However, individual differences, based on anthropometrics, cognitive abilities and learning history impact the interaction between constraints. This leads to different handwriting performance and developmental-related changes therein across children. Individual children will find their own solutions and ways to develop their handwriting which results in variable developmental trajectories. The associated large variation, especially among beginner writers, likely hampers early identification of permanent handwriting problems based on correctness of letter forms. Hence, for therapists this means that they should not diagnose relative to a desired form. The task is to find out what is useful and bad variability, and what kind of variability predicts writing skills (i.e., as the ability to adapt to dynamic constraints) in future years. Presumably, therapists would then stimulate useful exploratory variability.

CHAPTER 7

NEDERLANDSE SAMENVATTING

SCHRIJVEN EN SCHRIJFPROBLEMEN

Schrijven is een motorische vaardigheid die kinderen aanleren in de eerste groepen van de basisschool. Ondanks het toegenomen gebruik van toetsenborden in de klas, blijft schrijven met pen en papier een noodzakelijke vaardigheid om schooltaken te vervullen. Een deel van de basisschoolkinderen heeft problemen met het produceren van een leesbaar handschrift (afhankelijk van de bronnen 5 – 34%; Feder & Majnemer, 2007; Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011; Rosenblum et al., 2004; Smits-Engelsman et al., 2001). Veel van deze kinderen met schrijfproblemen worden in groep 3 of 4 door leerkrachten of ouders aangemeld bij de kinderfysio- of ergotherapeut. Het wetenschappelijk onderzoek naar schrijfproblemen heeft zich tot dusver vooral gericht op de leesbaarheid en snelheid van het handschrift en/of eventuele onderliggende factoren. De mate waarin die schrijfproblemen permanent of van voorbijgaande aard zijn, is nauwelijks onderzocht. Daardoor is het niet duidelijk of voor de kinderen die in een vroeg stadium verwezen worden, therapie noodzakelijk is, of dat de schrijfproblemen door het onderwijscurriculum te volgen uiteindelijk verdwijnen.

In de afgelopen 25 jaar heeft de *constraints-led-approach* zijn intrede gedaan in het wetenschappelijke onderzoek en de praktijk van de sport. Deze theoretische benadering, gebaseerd op de aanname dat motoriek (bijvoorbeeld het schrijven) voortkomt uit de dynamische interactie tussen individuele (het kind betreffende) factoren, omgevings- en taakbegrenzingen (of -factoren), wordt in het onderzoek binnen de revalidatie, kinderfysio- en ergotherapie minder gebruikt. De nadruk van het wetenschappelijk onderzoek binnen deze gebieden ligt dan ook nog steeds grotendeels bij individuele factoren zoals bijvoorbeeld de vaardigheid om vormen en letters te herkennen en identificeren, motorische controle en alfabetkennis. Er is relatief minder aandacht voor taak- en omgevingsfactoren zoals bijvoorbeeld het gebruik van hulplijnen bij het schrijven, het gebruik van hoofd- of rompletters en de frictie tussen pen en papier. In dit proefschrift wordt het (leren) schrijven beschouwd vanuit het perspectief van zowel de individuele factoren als de taakfactoren.

Eerst is onderzocht in hoeverre schrijfproblemen samenhangen met visuele perceptie (VP; herkennen van figuren binnen de Beery-VMI; Beery & Beery, 2010), fijnmotorische controle en coördinatie (VMI; kopiëren van figuren en MC; figuren tekenen binnen lijnen binnen de Beery-VMI). Vervolgens is onderzocht of schrijfproblemen op jongere leeftijd (in de lagere groepen) schrijfproblemen op latere leeftijd (in de hogere groepen) voorspellen. Dit is gedaan door de ontwikkeling van het schrijven te volgen bij basisschoolkinderen, van groep 4 tot en met groep 7.

Daarna verschuift de aandacht van individuele factoren naar taakfactoren en wordt onderzocht of het gebruik van hulplijnen de kwaliteit en snelheid van schrijven verbetert. Hoewel hulplijnen bij het (leren) schrijven op de basisschool vrijwel altijd gebruikt worden, zijn er nauwelijks wetenschappelijke studies die onderzocht hebben of hulplijnen de kwaliteit en snelheid van het schrijven positief beïnvloeden. Ook is niet onderzocht of kinderen met schrijfproblemen baat kunnen hebben bij het gebruik van hulplijnen. Ten slotte is bij kinderen op de kleuterleeftijd onderzocht of het leren schrijven met pen en papier het leren herkennen en onderscheiden van letters faciliteert.

HANDSCHRIFTONTWIKKELING EN ONDERLIGGENDE FACTOREN

In hoofdstuk 2 en 3 is de ontwikkeling van de kwaliteit en de snelheid van het schrijven van basisschoolkinderen in de groepen 4 tot en met 7 onderzocht. Tegelijkertijd is onderzocht in hoeverre de kwaliteit en snelheid van het handschrift kunnen worden verklaard vanuit het vermogen tot herkennen en natekenen van figuren en het tekenen binnen lijnen (visuele perceptie, fijnmotorische controle en coördinatie, resp. VP, VMI en MC van de Beery-VMI). Op basis daarvan is vastgesteld of deze vermogens gerelateerd zijn aan problemen met de leesbaarheid of de snelheid van schrijven. Er is bepaald of het mogelijk was om op basis van schrijfproblemen in groep 4 of 5 vast te stellen of deze permanent of van voorbijgaande aard zijn, en in welke mate ze schrijfproblemen in groep 6 of 7 voorspellen.

Na een jaar schrijfonderwijs (groep 4), heeft bijna een derde van de kinderen moeite met leesbaar schrijven[11] volgens de Beknopte beoordelingsmethode voor kinderhandschriften (BHK; Hamstra-Bletz et al., 1987). Hoofdstuk 3 laat zien dat zowel de leesbaarheid als de snelheid van het handschrift verbeteren gedurende de basisschooltijd. De snelheid van het schrift verbetert gradueel, terwijl de leesbaarheid een onregelmatiger patroon van verandering

[11] Hamstra-Bletz et al. (1987) spreken van een dysgrafisch handschrift. Doordat niet duidelijk is of kinderen met een dysgrafisch handschrift in groep 4 of 5 permanent last hebben van schrijfproblemen, hebben wij ervoor gekozen om de kinderen die slecht scoren op de BHK te omschrijven als kinderen met een onvoldoende leesbaar handschrift. Bij een permanent aanwezig onvoldoende leesbaar handschrift is er sprake van schrijfproblemen.

laat zien. De grootste verbetering ten aanzien van de leesbaarheid vindt plaats in groep 5 en 6.

De groep kinderen met een onvoldoende leesbaar handschrift vermindert van 33% na een jaar schrijfonderwijs (groep 4) tot 5% na vier jaar schrijfonderwijs (groep 7). Dit komt overeen met de bevindingen uit eerdere onderzoeken (bijv. Karlsdottir & Stefansson, 2002). In de groep kinderen die in dit proefschrift werd onderzocht, hadden slechts drie van de 173 kinderen in groep 4 tot en met 7 een onvoldoende leesbaar handschrift (1.7%). Deze meer permanente schrijfproblemen bleken niet te voorspellen op basis van het handschrift van kinderen in groep 4 en 5.

In hoofdstuk 2 is zichtbaar dat in groep 4 individuele factoren die geassocieerd worden met de vermogens tot fijnmotorische controle en motorische coördinatie (het kopiëren van figuren en tekenen binnen lijnen) gerelateerd zijn aan de kwaliteit van het handschrift, terwijl deze relatie met het vermogen tot het herkennen van figuren afwezig was. Hierbij moet opgemerkt worden dat de testen voor fijnmotorische controle en motorische coördinatie slechts 17% van de variatie in handschriftkwaliteit verklaarden. Ditzelfde is zichtbaar in groep 5 tot en met 7, waar deze testen voor de fijnmotorische controle en motorische coördinatie ook maar een klein percentage (13 tot 23%) van de variatie verklaarden in handschriftkwaliteit in datzelfde jaar. Een belangrijke bevinding was verder dat de vermogens tot visuele perceptie, fijnmotorische controle en coördinatie geen voorspellende waarde hadden voor de handschriftkwaliteit of -snelheid in de daaropvolgende jaren.

HULPLIJNEN EN DE INVLOED OP KWALITEIT EN SNELHEID VAN HET HANDSCHRIFT

In Hoofdstuk 4 ligt de focus op taakfactoren, en is de invloed van het gebuik van hulplijnen op de kwaliteit van het handschrift bij kinderen met een voldoende en een onvoldoende leesbaar handschrift onderzocht. Hiervoor is zowel het aantal hulplijnen (twee of vier) als de afstand tussen de lijnen (3 of 4 mm tussen centrale lijnen) gemanipuleerd. Vervolgens zijn de kwaliteit en de snelheid van het handschrift in deze vier condities vergeleken met het schrijven met alleen een basislijn.

Met alleen een basislijn schreven kinderen met een voldoende leesbaar handschrift na een jaar onderwijs (groep 4) kleiner en sneller dan kinderen met een onvoldoende leesbaar handschrift. Het gebruik van hulplijnen beïnvloedde het handschrift in beide groepen op dezelfde manier. Zowel kinderen met een voldoende als kinderen met een onvoldoende leesbaar handschrift pasten zich vergelijkbaar aan manipulaties van het aantal lijnen en de afstand tussen de lijnen aan. De kinderen in beide groepen schreven kleiner, minder vloeiend en langzamer tussen hulplijnen met een kleinere centrale afstand (3 mm), ongeacht het aantal lijnen. Dit suggereert dat kinderen in groep 4 kleinere letters schrijven om zich aan te passen aan de veranderde taakomstandigheden. Dit ging wel ten koste van de snelheid en vloeiendheid van schrijven.

Hoewel de aanpassing aan de manipulaties voor beide groepen kinderen grotendeels vergelijkbaar was, was er een klein maar significant verschil zichtbaar in percentage schrijftijd. Bij de kinderen met een onvoldoende leesbaar handschrift werd het percentage schrijftijd groter als zij tussen vier lijnen met een centrale afstand van 4 mm schreven. De kinderen met een voldoende leesbaar handschrift lieten een toename van percentage schrijftijd zien bij het schrijven tussen twee hulplijnen met een centrale afstand van 3 mm. Over het algemeen laten kinderen met een voldoende en onvoldoende leesbaar handschrift, op korte termijn, een vergelijkbare aanpassing zien aan de taakmanipulaties, maar niet op een manier waarmee de kwaliteit van het handschrift verbetert. Of dat ook zo is voor het gebruik van hulplijnen op de langere termijn moet verder onderzocht worden.

LETTERHERKENNING EN -DISCRIMINATIE NA SCHRIJF-, TYPE- EN ALFABETTRAINING

In hoofdstuk 5 is onderzocht of het leren schrijven van invloed is op de leesvaardigheid. Daarvoor is het herkennen van en onderscheid maken tussen letters vergeleken bij kinderen uit groep 1 en 2 (dus voordat zij formeel schrijf- en leesonderwijs krijgen), die of schrijf-, of blindtype- of alfabettraining kregen. Eerder onderzoek suggereert dat leren schrijven, in tegenstelling tot leren typen, het leren lezen vergemakkelijkt. Dit kan begrepen worden vanuit de *embodied-cognition-theory,* die stelt dat op grond van topologische gelijkenis tussen de schrijfbeweging en de lettervorm het leren schrijven van een letter ook het leren herkennen van deze letter ondersteunt (bijv. Longcamp et al., 2005, 2006; Arndt, 2016; Mangen & Balsvik, 2016). Bij het typen, wanneer het wordt uitgevoerd met een of twee willekeurige vingers, bestaat zo'n topologische overeenkomst tussen de productie van bewegingen en de lettervorm niet, en wordt dus ook geen relatie met het leren lezen van letters verwacht.

In eerdere studies waarbij schrijven en typen zijn vergeleken is het typen met willekeurige vingers gebruikt. Dit sluit echter niet uit dat typen op een manier die wel een zekere mate van specificiteit tussen bewegingsproductie en lettervorm met zich meebrengt (zoals blind typen met tien vingers), kan bijdragen aan de ontwikkeling van het leren lezen. In hoofdstuk 5 is blind typen gebruikt, waarbij alle vingers betrokken zijn en iedere toets correspondeert met het gebruik van een specifieke vinger(positie). Onderzocht werd of deze vorm van (blind) typen letterherkenning en -discriminatie bevordert, en wel in dezelfde of meerdere mate dan bij schrijven plaatsvindt. Om generalisatie van de bevindingen naar school te bevorderen, werd het onderzoek in de klas uitgevoerd. Kinderen kregen gedurende drie weken twee keer per week 20 minuten schrijf-, blindtype- of alfabettraining. De resultaten lieten zien dat kinderen uit alle drie de groepen (schrijf-, blindtype-, alfabettraining) na de lessen meer letters herkenden en onderscheidden, ongeacht de aard van de training. Kinderen profiteerden van elke vorm van training bij het herkennen en onderscheiden van letters. Er lijkt dus geen noodzaak te zijn om te leren schrijven of blind te leren typen bij het leren lezen van losse letters.

IMPLICATIES VOOR DE PRAKTIJK

Momenteel worden kinderen met een onvoldoende leesbaar handschrift al eind groep 2 of in groep 3 doorverwezen naar kinderfysio- of ergotherapie om te voorkomen dat zij een achterstand krijgen in het leren schrijven. Deze vroege verwijzing, gebaseerd op schrijftests zoals de BHK, wordt niet volledig ondersteund door onze observaties (en die van anderen). De meeste kinderen die in groep 6 en 7 een voldoende leesbaar en voldoende snel handschrift hebben ontwikkeld, doen dat zonder therapeutische interventies (Overvelde & Hulstijn, 2011). En kinderen die dan nog onvoldoende leesbaar schrijven, zijn in eerdere groepen niet aan te wijzen. Dit betekent dat enkelvoudige schrijftesten onvoldoende zijn voor verwijzing en dat voorzichtigheid geboden is om overbehandeling te voorkomen. Het is zinvol om verder onderzoek te verrichten, en in ieder geval de schrijftest te herhalen voordat therapie wordt geadviseerd.

Voor de toekomst zijn verschillende aspecten van belang. Ten eerste meten schrijftesten vooral de mate waarin kinderen ideaaltypische kopieën van letters schrijven en niet zozeer of wat zij schrijven voldoende leesbaar is. Leesbaarheid is uiteindelijk belangrijker, therapeuten zouden deze leesbaarheid dan ook bij verschillende taken en in verschillende situaties moeten beoordelen. Verder is het zinvol de leesbaarheid van het handschrift met leerkrachten te bespreken. Als het handschrift onvoldoende leesbaar is, zouden therapeuten aanvullende informatie moeten proberen te verkrijgen over de invloed van taakfactoren die het handschrift van dat specifieke kind met schrijfproblemen beïnvloeden (hetzij positief, hetzij negatief). Uiteraard is het van het grootste belang om hiervoor een valide en betrouwbare test te ontwikkelen.

Het gebruik van hulplijnen is een taakfactor die veelvuldig gebruikt wordt in onderwijs en therapie. Leerkrachten en therapeuten moeten zich ervan bewust zijn dat hulplijnen het handschrift van kinderen beïnvloeden, zowel van kinderen met een voldoende als met een onvoldoende leesbaar handschrift. Helaas leidt het gebruik van hulplijnen niet noodzakelijkerwijs tot een beter leesbaar handschrift, zeker niet onmiddellijk. Therapeuten kunnen onderzoeken welk aantal hulplijnen of welke afstand tussen deze lijnen het meest leesbare handschrift bij kinderen uitlokt.

Ten slotte, omdat schrijven een motorische vaardigheid is die kinderen leren om leesbaar te communiceren (met potlood op papier) en (zoals nu gebruikelijk is) om andere basisschooltaken uit te voeren, lijkt het noodzakelijk dat kinderen blijven leren schrijven. Als een kind na drie jaar schrijfonderwijs (groep 5) door motorische of andere problemen onvoldoende leesbaar of onvoldoende snel kan schrijven, is verwijzing naar een therapeut nodig of moeten kinderen digitale apparaten kunnen gebruiken om te communiceren. De tijdinvestering die het schrijfonderwijs kost, moet echter worden afgewogen tegen andere activiteiten. Hierbij kan het extra belangrijk zijn om niet naar ideale lettervormen te streven, maar meer functionele doelen na te streven, zoals leesbaarheid. Het bereiken van ideale, perfecte vormen zou in dat geval dan – misschien – een kunstvorm worden.

CONCLUSIE

Over het algemeen wijst het huidige onderzoek naar problemen bij het schrijven bij kinderen in de basisschoolleeftijd op het belang van verder kijken dan alleen naar individuele factoren. Vooral het manipuleren van taakfactoren lijkt relevant voor zowel het bevorderen als het monitoren van schrijfvaardigheid. Deze eerste verkenning levert echter nog niet veel steun op voor deze bewering. Het is duidelijk dat een meer systematische en alomvattende aanpak en methodologie nodig zijn om de relevante taak- en omgevingsmanipulaties nauwkeurig te onderzoeken. Uiteindelijk kan dit zowel leerkrachten als therapeuten helpen om oefensituaties en -omgevingen te ontwerpen die kinderen in staat stellen hun eigen leesbare handschrift te ontwikkelen, in plaats van te proberen hun schrijven te verfraaien tot een gewenste vorm.

Welke factoren precies en op welke manier bijdragen aan handschriftontwikkeling is nog onvoldoende duidelijk. Individuele verschillen, gebaseerd op antropometrie, cognitieve vermogens en leergeschiedenis hebben invloed op de interactie tussen individuele factoren, taak- en omgevingsfactoren. Dit leidt tot individuele schrijfprestaties en ontwikkelingsgerelateerde veranderingen bij kinderen. De bijbehorende grote variatie tussen kinderen, vooral onder beginnende schrijvers, belemmert waarschijnlijk de vroege identificatie van permanente schrijfproblemen gebaseerd op de juistheid van lettervormen. Voor therapeuten betekent dit dus dat niet alleen de juiste lettervorm leidend is bij het vaststellen van een diagnose en behandeling.

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ABOUT THE AUTHOR / OVER DE AUTEUR

OVER DE AUTEUR

Ivonne Duiser is geboren op 24 augustus 1969 in Sleeuwijk (Werkendam), in Nederland. Na de middelbare school heeft zij de opleiding fysiotherapie afgerond in Breda. Na een week werken als fysiotherapeut met volwassenen was duidelijk dat daar niet haar toekomst lag. Vervolgens heeft zij enkele jaren Nederlandse taal- en letterkunde gestudeerd, waarbij zij in de zomerperiode waarnam als fysiotherapeut in het Willem Arntsz huis, psychiatrisch ziekenhuis. Via deze waarnemingen is Ivonne terechtgekomen bij Zon en Schild, afdeling Fornhese, in de kinder- en jeugdpsychiatrie, waar de interesse voor kinderen en motorische ontwikkeling is aangewakkerd. Ivonne bleek wel affiniteit met fysiotherapie bij kinderen te hebben, dat bleek een heel ander vak dan fysiotherapie bij volwassenen.

Om zich als kinderfysiotherapeut te ontwikkelen, is Ivonne in 1996 gestart met de post-hbo-opleiding kinderfysiotherapie bij de Transfergroep in Rotterdam. Tijdens deze post-hbo bleek dat niet alle vragen die zij had omtrent motorische ontwikkeling, bewegen en coördinatie beantwoord konden worden. Dit heeft ervoor gezorgd dat Ivonne direct na afronding in 1999 gestart is met de studie Bewegingswetenschappen aan de Vrije Universiteit in Amsterdam.

Tussendoor heeft zij, nadat zij bij Fornhese gestopt was, enkele jaren als kinderfysiotherapeut in een eerstelijns praktijk gewerkt. In 2000 is Ivonne samen met een maat haar eigen praktijk voor kinderfysiotherapie in Alphen aan den Rijn gestart, zodat het mogelijk was om de eigen (werk)tijd in te delen en daarnaast te blijven studeren. In 2002 is Ivonne bij de Transfergroep begonnen als docent bij de post-hbo-opleiding kinderfysiotherapie. Nadat de Transfergroep overgegaan is in hogeschool Rotterdam heeft Ivonne bijgedragen aan de transitie van post-hbo naar master kinderfysiotherapie.

In 2007 is Ivonne afgestudeerd aan de VU. Vervolgens heeft zij enkele jaren in de praktijk en als docent kinderfysiotherapie gewerkt. Als praktiserend kinderfysiotherapeut en bewegingswetenschapper liep zij tegen vragen aan die niet beantwoord werden door wetenschappelijk onderzoek, waarop zij uiteindelijk zelf besloot onderzoek te gaan doen. Na enkele omzwervingen heeft Ivonne zich in 2010 gemeld bij John van der Kamp, Annick Ledebt en Geert Savelsbergh met de vraag of zij onderzoek kon gaan doen naar schrijfproblemen bij kinderen, waarna het promotietraject is gestart.

Ivonne is nog steeds werkzaam in de praktijk in Alphen aan den Rijn, zij is in 2015 bij hogeschool Rotterdam gestopt, om in 2019 samen met collega's een nieuwe master kinderfysiotherapie te ontwikkelen bij Breederode hogeschool in Rotterdam, waar zij op dit moment programmamanager en docent is en met veel plezier, samen met enthousiaste collega's, aankomende kinderfysiotherapeuten opleidt.