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Haptics in teaching handwriting: the role of perceptual and visuo-motor skills

Abstract

Two studies were carried out in order to better understand the role of perceptual and visuo-motor skills in handwriting. Two training programs, visual-haptic (VH) and visual (V), were compared which differed in the way children explored the letters. The results revealed that improvements of VH training on letter recognition and handwriting quality were higher than improvements after V training. We suppose that VH training was more efficient because it improved both perceptual and visuo-motor skills. In the second experiment, in order to investigate the part of each component, we assessed the link between visuo-motor skills, perceptual skills and handwriting. The results showed that only the visuo-motor tasks predict handwriting copying performance. These results are discussed in relation to the respective roles of the perceptual and visuo-motor skills on letter shape learning and handwriting movement execution.

Key words: handwriting learning, children, manual, letter, training program

1. Introduction

Handwriting is a complex task that requires perceptual, motor, cognitive, and linguistic skills (Bara & Gentaz, 2006, in press; Graham & Weintraub, 1996). Letter writing entails finding the letter's shape stored in memory, accessing the motor program, setting the parameters for that program and executing it (Viviani, 1994). Handwriting acquisition consists in learning the visual representation of letters, which is used to guide their production, as well as the motor representation specific to each one. At the beginning of learning, movements are slow and guided by visual and kinaesthetic feedbacks (Chartrel & Vinter, 2006; Sovik, 1974). With practice, writing becomes automatic and the control of movement is mostly proactive (based on an internal representation of the motor act (for a review see Zesiger (1995))). Handwriting acquisition is generally slow and difficult, and several years of formal instruction are necessary before young children master this skill. Because of the influence of handwriting on other writing skills, like transcription and composing (Berninger et al., 1997; Bourdin & Fayol, 1994, 2000; Fayol & Miret, 2005; Graham, 1990; Jones & Christensen, 1999), and because handwriting problems do not disappear without specific intervention (Smits-Engelsman & van Galen, 1997), the investigation of teaching programs and their efficiency is of crucial interest. The goal of these interventions is to enable the child to acquire fast and legible handwriting, in order to free attention, which can be used for high writing processes (Kellogg, 2001; Olive, Favart, Beauvais, & Beauvais, 2008).

Graham et al. (2008) have recently surveyed handwriting instruction methods in the USA. A large majority of primary school teachers indicated that they taught handwriting for at least 70 minutes per week, while 10% did not teach it at all. Handwriting teaching consists in showing children how to reproduce letters according to a standard. In order to produce the letter trajectory, children must be able to perceive both the shape of the standard and the

deviation between their own handwriting product and the standard, and must be able to produce fine motor movement. Thus, to perform handwriting tasks, children must develop perceptual, motor, and visual-motor integration skills. Weintraub and Graham (2000) showed that the knowledge of children's gender, finger functioning, and visual-motor status resulted in the correct classification of 77% of the 5th grade participants as good or poor handwriters.

Accurately perceiving letter shapes is a critical factor for the development of handwriting legibility, because the quality of letter handwriting depends on memory references for the motor system. The role of perceptual skills in handwriting acquisition was highlighted by studies which compared the effects of different kinds of teaching interventions. Karlsdottir (1996) proposed two programs for children in grade four, one involving copying exercises and one consisting in visually and verbally explaining the letter shape. The writing quality of the group of children who participated in the letter copying program did not improve compared to an equivalent group that did not participate in the program. However, the group of children who received an instructional program consisting in the verbal/visual demonstration of the letter shape improved their handwriting quality. Hays (1982) and Sovik (1976) also showed that visual and verbal prompting of letter shapes improved handwriting accuracy. Wright and Wright (1980) reported that copying letters improved when a dynamic model, a model that depicted motion, was presented. Berninger et al. (1997) selected first grade children who were experiencing difficulties in learning to write and assigned them to five handwriting treatment groups and a phonological awareness control condition. The four ways of teaching handwriting were as follows: (a) the child wrote the letter after seeing the instructor writing it, (b) the child wrote the letter after seeing a copy of it with arrows indicating the order and direction of each stroke, (c) the child wrote the letter from memory after examining a copy of it, and (d) the child wrote the letter from memory after examining a copy of it with arrows indicating the order and direction of each stroke. The results showed

that all the handwriting treatment groups made greater handwriting gains than the control group, with the highest training performance for the group that wrote the letters from memory after seeing a copy containing numbered arrows. Jongmans, Linthorst-Bakker, Westenberg, Smits-Engelsman, and Bouwien (2003) investigated the effect of task-specific self-instruction on handwriting speed and quality in children with poor handwriting quality attending regular and special education schools. The child had to write the letter several times and to indicate which of them was best. The results showed that children who received the self-instruction method improved the overall legibility of their handwriting, but not their handwriting speed, compared with children who did not receive this kind of instruction. These results suggest that the ability of children to accurately perceive letter shape determines handwriting quality. They are consistent with information-processing models of learning (Sternberg, 1969), in which the learning process starts with the perception and storage of letter shapes in memory. It is possible that perceptual learning leads to greater difficulties than does the acquisition of motor skills for beginning writers.

The role of fine motor skills, which underlies the ability to use a pencil to produce letters, was not clearly demonstrated. Even though fine motor skills are linked with handwriting difficulties, teaching these skills does not always have a productive effect on handwriting acquisition. Cornhill and Case-Smith (1996) compared children divided into two groups on the basis of their handwriting quality. They showed that the two groups differed significantly on tasks that measured motor development, visual-manual coordination, or unimanual manipulation of objects. Rigal (1976) showed that the finger-function tasks (e.g., touching the thumb with each finger in sequential order without viewing; raising the finger touched by the experimenter) were quite reliable and valid for assessing handwriting. Maarse, van de Veerdonk, van der Linden, and Pranger-Moll (1991) attempted to show that practicing movements such as arcades, clockwise circles, counterclockwise circles, and factory rooftops,

improved handwriting quality. However, because the training group was compared with a group who did not receive instruction, the effective role of fine motor skills was not demonstrated in a convincing way. Moreover, Karlsdottir (1996) observed that a program that involves copying exercises was not efficient.

If perceptual and motor skills seem necessary for handwriting acquisition, the combination of these two skills, as in visual-motor integration tasks, is as well a strong predictor of children's writing skills. The Developmental Test of Visual Motor Integration (DTVMI; Beery, 1997) is used to assess visual-motor skills and consists in copying geometric shapes. It has been reported that the DTVMI significantly predicts handwriting from grades 1 to 9 and is therefore considered an indicator of handwriting readiness (Cornhill & Case-Smith, 1996; Maeland, 1992; Tseng & Chow, 2000; Tseng & Murray, 1994; Weintraub & Graham, 2000; Williams, Zolten, Rickert, Spence, & Ashcraft, 1993; Yochman & Parush, 1998). Volman, van Schendel, and Jongmans (2006) found significant correlations between visual-motor integration and the quality of handwriting in children with developmental coordination disorder. However, the usefulness of this test in predicting handwriting quality was challenged by Marr and Cermak (2002), who showed that this test was only predictive for girls. Consequently they suggested that for kindergartners and first graders, who are not yet writing sentences, an evaluation of letter copying (using the SCRIPT for example) is more helpful in targeting children who might need early assistance in handwriting. Moreover, the correlations between the DTVMI and handwriting quality decrease with age (Karlsdottir & Stefansson, 2003).

Beery (2004) defined visual-motor integration as the coordination between visual perception and finger movement. He differentiated visual-motor integration from motor coordination (which is assessed by tracing tasks, like drawing a line between two lines). However, this differentiation is not a consensus even though visual-motor integration requires

more visual perception accuracy than hand-eye coordination (which relies more on visual control). For example, Hammill, Pearson, and Voress (1993) included both tracing and copying tasks in a visual-motor score. Kaiser, Albaret, and Doudin (2009) assessed the role of visual-motor integration and of hand-eye coordination (tracing items) on handwriting quality. They showed that, in second grade children, the association of these two skills was predictive of handwriting quality. The role of perceptual and motor skills in handwriting was assessed in a recent study by Vinter and Chartrel (in press). They compared the effect of three training programs on letter handwriting performance in five year old children: visual (observing motion models), motor (copying models), and visual-motor (observing and copying motion models). The results showed that the visual-motor training was the most effective. The improvement in handwriting was shown by a decrease in movement duration, a decrease in the number of velocity peaks, and an increase in velocity, which occurred earlier than in the other training methods. Even though perceptual, motor, and visual-motor skills are involved in handwriting, some other linguistic abilities, like letter knowledge, play a role in handwriting acquisition. Karlsdottir and Stefansson (2002) did not find any distinction between good and poor writers concerning their perceptual-motor skills, but they showed that good writers had better abilities in naming and writing letters before the formal writing instruction began. The same results were found by Molfese, Beswick, Molnar, and Jacobi-Vessels (2006) who showed that preschool children with high letter-naming scores also had high scores in letter handwriting.

Visual and kinaesthetic feedback information is required to perform handwriting; however, the role of kinaesthesia is not very clear. Kinaesthesia commonly refers to the ability to discriminate position of body parts and amplitude or direction of movement without visual or auditory cues. Studies by Laszlo and Bairstow (1984) and Laszlo and Broderick (1991) found a link between kinaesthetic sensitivity and handwriting, and they showed that

specific training aimed at improving kinaesthetic sensitivity, improved handwriting skills as well. Harris and Livesey (1992) also found that kinaesthetic practice improved the handwriting level of children, whereas handwriting practice did not. However, these results were not reproduced by Doyle, Elliott, and Connolly (1986) and Elliott, Connolly, and Doyle (1988). More recently, Sudsawad, Trombly, Henderson, and Tickle-Degnen (2002) investigated the effect of kinaesthetic training on handwriting performance in first-grade students (6 to 7 years of age) who experienced handwriting difficulties. The children were assigned to either a kinaesthetic training group, a handwriting practice group, or a no treatment group. There was no significant improvement of handwriting legibility as measured by a standardized test in any of the groups. Thus, the authors concluded that the use of kinaesthetic training is not suitable to improve handwriting legibility in first-grade students. These studies have produced conflicting results that point out the difficulties in measuring kinaesthetic function (which is often confused with proprioception).

In a recent study, we used an original haptic-kinaesthetic training program to improve handwriting in first grade children (Palluel-Germain, Hillairet de Boisferon, Hennion, Gouagout, & Gentaz, 2007). In our view, haptic-kinaesthesia refers to movement trajectory and amplitude perception (Gentaz, 2009). An original haptic feedback interface was developed and used to teach children how to reproduce a letter according to a static *and* *dynamic* standard (Hennion, Gentaz, & Bara, 2005). We supposed that a good way to improve handwriting acquisition was to provide a standard letter that is not only static (shape) but also dynamic (production rules) in order to help children to improve the proactive strategy to control handwriting movement. This interface, whose basic device is a force-feedback programmable pen (a “1.5 Phantom” display), can maximize haptic-kinaesthetic feedback (Bluteau, Coquillart, Payan, & Gentaz, 2008; Bluteau, Hillairet, & Gentaz, 2009). Different exercises were proposed in which children grasp the pen and follow the outlines of virtual

concave letters. A force generated by the interface attracted the pen on the correct trajectory and maintained the pen between two borders that formed the letter shape. This force was progressively reduced during the exercises. The results revealed that average velocity, number of velocity peaks, and number of pen lifts, in cursive letter handwriting, decrease more after the training sessions in comparison to control training.

The role of haptic exploration of letters on letter recognition, reading, and handwriting was investigated in other studies (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Bara, Gentaz, & Colé, 2007; Gentaz, Colé, & Bara, 2003; Bara, Fredembach, & Gentaz, in press). Haptic exploration of raised letters improved letter recognition and reading more than visual exploration. With concave letters, the results were quite different. No more improvement in letter recognition and reading were found in comparison to visual exploration. However, haptic exploration of concave letters leads to progress in handwriting but only for the stroke direction, not for the dynamic aspects of handwriting. This suggests that learning production rules, allowed by the haptic feedback interface may cause improvement in the dynamic aspects of letter handwriting. An investigation of haptic exploratory procedures used for concave and raised letters showed that they depend on the type of letter which was explored. With concave letters, children used a procedure that consisted in following the shape outlines with the finger, which focused on the stroke direction. With raised letters, a global procedure was first introduced (the child held the letter and explored it with his whole hand) and then a more specific exploration of the shape outlines with the finger was produced. We make the hypothesis that these differences in exploratory procedures should lead to different effects on handwriting in function of the type of letter explored. The first global procedure for raised letters should lead to a better perception of the letter, thereby enhancing its visual representation, which will guide motor production. Thus letter recognition and handwriting quality should improve more after haptic exploration than after visual exploration. Experiment

1 tested this hypothesis and assessed the effects of a training program that involves haptic exploration of raised letters on kindergarten children's letter recognition and handwriting. The aim of Experiment 2 was to evaluate more precisely the respective role of perceptual and visuo-motor skills in handwriting acquisition.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty-four kindergarten children (21 girls and 23 boys, with a mean age of five years and five months), from two French classes took part in this study. All the children belonged to families of average socioeconomic status. Children in the two training groups (Visual-Haptic and Visual) were matched on the following criteria (Student *t*-tests, all $p > .25$):

-*Scores on the WIPPSI blocks* (part of the nonverbal IQ);

-*Letter recognition*. The experimenter said the name of a letter, and the child had to show it among ten other letters, printed in black on a sheet of paper. Each correct response was scored 1, before training, all the 26 letters were presented (score out of 26);

-*Phoneme identification*. Children were asked to look for the five phonemes, which had been included in the training sessions. The phonemes were in initial or in final position in the words. The experimenter chose a picture and said the corresponding word. Among three pictures, the child had to find the one corresponding to the word "which starts with the same sound" or "which ends with the same sound". Scores were out of 5 for the two tasks (phoneme in initial position and phoneme in final position). These tasks were used to match children because of the strong link between phonemic awareness and letter knowledge

(Lonigan, Burgess, & Anthony, 2000; Wagner et al., 1997; Whitehurst & Lonigan, 1998).

Thus it was necessary to control the effect of this skill.

-Loop tracing (hand-eye coordination task). Children had to produce continuous lines of loops in counterclockwise and clockwise rotational direction, and in alternating both rotational directions. For the third item (alternating rotational direction), a model was presented. The lines of loops had to be produced between two horizontal lines of 1 cm high. Each line of loops was scored as follows: 0 no trace, 1 incorrect rotational direction, 2 discontinuous line but with a correct rotational direction, 3 continuous line and correct rotational direction but incorrect size, 4 continuous line, correct rotational direction, correct size (score out of 4 for each line of loops, global score out of 12 for each child).

The mean scores in these five pre-training session tasks are presented in Table 1. Only children who participated in all training sessions were included in the sample for the statistical analyses (six children were taken out of the sample). The 38 children remaining were all right-handed and normally developing without any learning disorders. There were 19 children in the VH training group (10 girls and 9 boys, with a mean age of 5 years 4 months), and 19 children in the V training group (7 girls and 12 boys, with a mean age of 5 years 4 months).

(Insert Table 1)

2.1.2. *Materials and procedure*

The five cursive letters used for the training sessions (a, d, n, b, and p) were chosen in function of their frequency in French and in order to propose different types of letters (vowel, stop consonant, nasal consonant, voiceless and voiced consonants). For the VH training, the letters were made with foam (5 mm thick). Two sizes of letters were proposed in order to make the haptic exploration easier. The small letters -a- and -n- were 2.5 cm high while the letters -d-, -p- and -b- were 4.8 cm high. The large letters -a- and -n- were 5 cm high and the

letters -d-, -p- and -b- were 10 cm high. For the V training, the letters (same size and shape as those of the VH training) were printed on a white sheet of paper.

a) Pre-and post-tests

The children's performances were assessed two weeks before and two weeks after the training sessions by means of three tasks:

-Letter recognition. The experimenter said the name of a letter and the child had to recognize it among five other letters, printed in black on a white sheet of paper (score out of 5);

-Handwriting letters from dictation. The child had to write the five letters from memory on a white sheet of paper. The number of letters remembered was rated (score out of 5);

-Letter copying. The child had to copy each of the five letters on a digitalized tablet. A model of the letter, printed on a sheet of paper, was placed in front of the tablet. The stroke order was rated, one point for each letter written in the conventional stroke direction (score out of 5). A global evaluation of letter quality was performed by three elementary school teachers. The three judges were blind to the aim of the study and to the training groups. The teachers had to judge the overall quality of each letter and to give a score between 0 and 5 (scores from 0, unrecognizable letter to 5, letter considered as perfectly handwritten for a child of that age). For each child the global score of handwriting quality corresponded to the mean of the five scores (one for each letter). Computerized analyses were conducted to assess dynamic aspects of handwriting (number of velocity peaks, number of pen lifts and pen "in air" time).

b) Training sessions

A specific training program was taken by each group of children: Visual-Haptic (VH) or Visual (V). Each program consisted in five training sessions (one a week) with one session for each letter. The two training programs involved perceptual tasks (visual and/or haptic exploration of letters) and motor tasks (copying exercises). A copying exercise was added in

order to bring a sufficient amount of practice in handwriting in the two training groups. Furthermore, through this exercise the letter exploratory order was presented to the children in both training groups. Only the way of exploring letters differed in the two training groups. In the VH training sessions, the letters were explored visually and haptically, whereas in the V training sessions the letters were only explored visually. Each training session took place in an acoustically insulated room in order to optimize children's attention. Children sat in groups of five or six around a table in order to encourage their interaction. The experimenter involved each of them during the different exercises.

VH training sessions

- *Letter identification.* The experimenter gave a small raised foam letter to each child who had to guess its name. For this exercise, haptic exploration was free;
- *Visual-haptic and haptic exploration.* The large letters (fixed to a 20 cm × 25 cm board) were handed out. Children were first told to explore the letter with their fingers however they wanted. Then, the experimenter showed them how to explore the letter in a fixed exploratory order corresponding to its writing. The children had to run their index finger along the shape outlines in the same way as the experimenter. Haptic exploration of the letter was carried out without visual control;
- *Haptic discrimination.* Two small letters (which share perceptual similarity) were put under a cover. The child had to handle the two letters and to identify the target letter. We associated -a- with -e-, -n- with -r-, -d- with -t-, -b- with -l- and -p- with -q-;
- *Letter copying.* The child had to copy the letter four times, on a white sheet of paper, with the conventional stroke direction.

V training sessions

- *Letter identification.* A letter printed on a sheet of paper was given to each child who had to guess its name.

- *Visual exploration.* The experimenter asked children to follow the drawing of the letter with their eyes and to focus on the shape, and on the lines and curves it contained.
- *Visual discrimination.* Children were asked to cross out the target letter presented together with distractor letters. Then cards were spread on the table and each child had to take one and to judge whether the letter they had taken corresponded to the target letter or to a distractor. The letter -a- was associated with -e-, -c- and -x-; -n- with -r-, -s- and -m-; -d- with -t-, -b- and -k-; -l- with -t-, -b- and -h-; -p- with -q-, -j- and -g-.
- *Letter copying.* The child had to copy the letter four times, on a white sheet of paper, with the conventional stroke order.

2.2. Results

An ANCOVA 2 (Training Program) \times 2 (Period) was performed for each measure. Scores before training in WIPPSI blocks, letter recognition, phoneme identification, and loop tracing, were taken as co-variants.

2.2.1. Letter recognition

The mean number of letters that were recognized in the pre- and post-test, and in V and VH training, are presented in Fig. 1. The main effect of period was significant, $F(1, 36) = 146.66$, $p < .01$: The number of letters correctly recognized was better after training ($M = 4.07$) than before ($M = 2.15$). The main effect of the training program was not significant ($F(1, 31) = 1.3$, $p = .26$). The interaction was significant, $F(1, 36) = 10.06$, $p < .01$. The post-hoc Newmans-Keuls comparisons showed that the difference between the two training programs was not significant in pre-test. In post-test more letters were recognized after VH training ($M = 4.21$) than after V training ($M = 3.21$).

(Insert Figure 1)

2.2.2. Letter handwriting (dictation task)

The main effect of period was significant, $F(1, 36) = 6.14, p < .05$: The mean number of letters handwritten under dictation was better after training ($M = 1.79$) than before ($M = 1.05$). The mean effect of training type ($F(1, 31) = 0.46, p = .68$) and the interaction ($F(1, 36) = 0.13, p = .75$) were not significant.

2.2.3. Letter copying

a) Stroke order

The main effect of period was significant, $F(1, 36) = 12.24, p < .01$: The mean number of letters copied with the conventional stroke direction was greater after training ($M = 1.79$) than before ($M = 1.05$). The mean effect of training type ($F(1, 31) = 0.32, p = .57$) and the interaction ($F(1, 36) = 1.36, p = .25$) were not significant.

b) Global quality

The mean scores and standard deviation in global quality in pre- and post-test in V and HV training are presented in Table 2. All inter-judge correlations (Bravais Pearson test) for the evaluations done by the three teachers were significant ($r^2 = .38, r^2 = .39$, and $r^2 = .43$; all $p < .05$). Consequently, we decided to work on the average of the three evaluations.

The main effect of period was significant, $F(1, 36) = 21.35, p < .01$: The mean scores in post-test ($M = 2.75$) were better than the scores in pre-test ($M = 2.2$). The main training type effect was not significant ($F(1, 33) = 0.65, p = .42$). The interaction was significant ($F(1, 36) = 5.26, p < .05$). The post-hoc Newmans-Keuls comparisons showed that the difference between the two training programs was not significant in pre-test. In post-test, the global quality score was higher for children in the HV group ($M = 2.93$) than for those in the V group ($M = 2.57$).

(Insert Table 2)

c) Dynamic measures

In summary, these analyses only revealed a main effect of period which depends on the type of letter. We observed a decrease between pre-test and post-test in pen “in air time” (letters l, d, and p), in the number of pen lifts (letter d), and in the number of velocity peaks (letters n and d).

2.3. Discussion

The aim of this experiment was to evaluate the effects of haptic training on letter recognition and handwriting in kindergarten children. Thus two training programs were compared, one that involved visual-haptic and haptic exploration of raised letters (VH training) and another that only involved visual exploration (V training). The results showed that haptic exploration of raised letters allowed better recognition of letters than visual exploration, and improved the global quality of handwriting more. Haptic exploration permitted children to better perceive, identify and memorize letters, which were thus better recognized than after visual exploration. The representation of letter in memory is essential because it drives movement production. If we consider that the quality of handwriting depends on the quality of the trace in memory, we can understand why the global quality of handwriting improved more after HV training. Haptic exploration, associated with visual exploration would allow a more complete perception of the letter. Accurately perceiving letter shape seems to determine handwriting quality. Haptic exploration involves both perceptual and motor learning and is thus more efficient for teaching handwriting than visual exploration.

The fact that we did not obtain more improvement on stroke direction after HV training than after V training, which was the case with concave letters, can be explained by the exploratory procedures used for perceiving these two types of letters (Bara, Fredembach, &

Gentaz, in press). Indeed, concave letters lead to the systematic use of a procedure that consists in following the shape outlines with the finger, which allows a better memorization of the stroke direction. For raised letters, this exploratory procedure is less used by children, thus they are less focused on the tracing direction. However, the experimenter required children to investigate the letter according to an order corresponding to its writing, after the first phase of free exploration. This stage does not seem to have been important enough to provoke a considerable change in the stroke order. We should also remember that in both types of training (VH and V), children carried out letter copying exercises which allowed them to acquire handwriting rotational direction. Concerning the absence of training effect on dynamic measures, it is possible that the copying exercise (included in each training group) has masked some differences between the two training groups. This raises a question about the role of that motor task on the dynamic aspects of handwriting.

3. Experiment 2

This study was performed in order to better understand the results of the first study on letter handwriting. As letter recognition and handwriting quality improved more after VH training than after V training, we suppose that haptic exploration improves the visual representation of letters, which guides motor production. Thus, because handwriting depends on both perceptual and motor skills, the VH training was more efficient in improving these two abilities. Handwriting can be seen as a perceptual-motor task in which the perceptual component corresponds to the letter shape and the motor component to the movement producing the letter trajectory. Perceptual skills may contribute to learning the shape of the letters (global quality of letter handwriting), whereas motor skills may contribute to handwriting movement execution (dynamic aspects of handwriting). In order to investigate the part of each component, we assessed the link between visuo-motor tasks (producing loops and shape outlines), perceptual tasks (letter recognition, accuracy, and velocity) and

handwriting (dictation and copy) in children. We suppose that global quality of handwriting should be more linked to perceptual skills, whereas dynamic measures of handwriting (number of velocity peaks, number of pen lifts, and pen “in air” time) should be more linked to visuo-motor skills.

3.1. Method

3.1.1. Participants

Twenty-one first grade children (13 girls and 8 boys), with a mean age of six years two months, took part in this study. They belonged to families of average socioeconomic status. All children were right-handed, and normally developed without any learning disorders.

3.1.2. Materials and procedures

Children were individually evaluated on letter knowledge, perceptual tasks, visuo-motor tasks, and letter handwriting (dictation and copying tasks). Five cursive letters were used, the same as in Experiment 1 (a, b, d, n, p).

Letter knowledge was assessed by means of two tasks: letter name knowledge (the experimenter showed a letter printed on a sheet of paper and the child had to name it) and letter recognition (the experimenter said the name of a letter and the child had to find it among ten different letters printed on a sheet of paper).

Perceptual task (letter recognition velocity). A model of each of the five letters was shown and the child had to find this letter among ten letters (two models of three perceptually similar letters and three models of the letter perceptually modified, in which parts were erased). The time it took to recognize each letter was reported.

Visuo-motor tasks: Loop tracing (which can be classified as a motor coordination tracing task or a hand-eye coordination task). Children had to produce two lines of loops in a continuous way, one in counterclockwise rotational direction and one other in clockwise rotational direction. The lines of loops had to be produced between two horizontal lines 1 cm high. Each line of loops was scored as follows: 0 no trace, 1 incorrect rotational direction, 2 discontinuous line but with a correct rotational direction, 3 continuous line and correct rotational direction but incorrect size, 4 continuous line, correct rotational direction, correct size (score out of 4 for each line of loops, global score out of 8 for each child).

Shape outlines (which can be considered as a visual-motor integration task): Children had to draw the outlines of five shapes (square, circle, rectangle, star, and flower) four times. Each shape was scored as follows: 0 no trace, 1 random drawing, 2 discontinuous outlines and incorrect shape, 3 discontinuous outlines but correct shape, 4 continuous outlines and correct shape (score out of 4 for each shape, global score out of 20 for each child).

Handwriting tasks: In the two tasks (handwriting letters from dictation and letter copying), letters were handwritten on a digital tablet. The number of velocity peaks, the number of pen lifts and the pen “in air” time were collected. A global evaluation of letter shape quality was done by two elementary school teachers (scores from 0, unrecognizable letter to 5, letter considered as perfectly handwritten for a child of that age).

-Handwriting letters from dictation: The experimenter said the name of the letter and the children had to write it. In addition to the quality score, the number of letters remembered was rated (score out of 5);

-Letter copying: The children had to copy each of the five letters with a model printed on a sheet of paper and placed in front of the tablet.

3.3. Results

Inter-judge correlations (Bravais Pearson), for the scores in global handwriting quality done by the two teachers, were significant ($r^2 = .74$, $p < .01$, for the handwriting letters from dictation task, and $r^2 = .78$, $p < .01$, for the letter copying task).

Correlations between the performances of children in each task were performed (Table 3). Significant correlations were found between the two tasks of letter knowledge (letter name and letter recognition), between the two visuo-motor tasks (loop tracing and shape outlines), and between the two handwriting tasks (handwriting letters from dictation and letter copying). Significant correlations were found between the two tasks of letter knowledge and the number of letters handwritten from memory (dictated letters). Performances in the two visuo-motor tasks were significantly correlated with performances in handwriting quality, but only for the letter copying task. There were significant correlations between the loop tracing task and the number of pen lifts (dictated letters) and the pen “in air” time (copied letters).

(insert Table 3)

Hierarchical regression analyses were performed in order to evaluate the role of visuo-motor skills in handwriting quality (Table 4). Age, letter name, letter recognition, and recognition velocity were entered first because these variables were not significantly correlated with handwriting quality. The scores in the shape outline task and in the loop tracing task were entered alternately at the last step. The shape outline score was a significant predictor of handwriting quality performance, $t(15) = 2.88$, $p < .05$. The shape outline task explains a significant part of variance in handwriting quality performances (for copied letters). However, this part of variance (25%) was only significant when this task was entered at step 5 before the loop tracing task. This result suggests that it is the combination of these two tasks which can predict handwriting copying performance.

(insert Table 4)

Hierarchical regression analyses were also performed to assess the role of visuo-motor skills in dynamic aspects of handwriting (Tables 5 and 6). Age, letter name, letter recognition, and recognition velocity were entered first because these variables were not significantly correlated with handwriting quality. The scores in the shape outline task and in the loop tracing task were entered alternately at the last step. The loop tracing score was a significant predictor of some dynamic aspects of handwriting (pen “in air” time: $t(14) = -3,33, p < .01$; pen lifts: $t(14) = -2,64, p < .05$). Entered at the last step of the regression analyses, the loop tracing task explains a significant part of variance in some dynamic aspects of handwriting. It explained 35% of variance in pen “in air” time (copied letters) and 25% of variance in number of pen lifts (dictated letters).

(Insert Tables 5 and 6)

3.4. Discussion

The goal of this second study was to evaluate the role of perceptual and visuo-motor skills on handwriting. The results showed that performance in the two visuo-motor tasks was correlated with handwriting copying quality. Regression analyses revealed that the combination of the two visuo-motor tasks predicts handwriting copying performance. If we consider that these tasks measure visuo-motor skills (visual-motor integration and hand-eye coordination), it confirms the important role that this ability plays in handwriting acquisition (Daly, Kelley, & Krauss, 2003; Kaiser et al., 2009; Tseng & Murray, 1994; Volman et al., 2006). The hand-eye coordination task predicts some dynamic aspects of handwriting (pen “in air” time and number of pen lifts). This result confirmed one part of our hypotheses and showed that a tracing task, which involves the motor system, is strongly linked with the motor component of handwriting. We also attempted to show the role of visual-perceptual abilities in handwriting acquisition. As copying relies on visual stimuli, we supposed that our task of

letter recognition should predict the quality of letter shape. The results did not underscore significant correlation between our perceptual task and handwriting performance. However, only five letters were tested and only one perceptual task was proposed, which is insufficient in our point of view. As we expected, handwriting letters from dictation was linked to letter knowledge. In fact, writing a letter from memory requires a high level of letter knowledge.

4. General discussion

Two studies were carried out in order to better understand the role of perceptual and visuo-motor skills in handwriting. In the first study, we assessed the effect of haptic training on letter recognition and letter handwriting (dictated and copied letters). This training program was compared to a visual one. In these two training programs, perceptual exercises on letter shape (visual and/or haptic exploration), and motor exercises (copying letters) were performed. The way of perceiving letters differed according to training: in the visual training (V), letters were explored visually, whereas, in the visual-haptic training (VH), letters were explored visually and haptically. Results showed that after VH training children improved their performances in letter recognition and handwriting quality (for copied letters) more than after V training. Current research that has revealed a close link between perception and action highlight the role of perceptual and motor skills in learning processes, and the interaction between these two abilities (Chao & Martin, 2000; Longcamp, Anton, Roth, & Velay, 2003; Longcamp, Boucard, Gilhodes, Anton, & Nazarian, 2008; Longcamp, Zerbato-Poudou, & Velay, 2005; Viviani, 2002). These studies showed that the representation of letters in the brain is not only visual but includes a motor component. Handwriting movement activates the visual representation of letters. Because motor knowledge has an impact on movement perception, handwriting can be used as a teaching method for letter learning. This was shown by Longcamp et al., (2005), who compared the effects of handwriting and typing on letter learning. The results revealed that writing knowledge improved the recognition of letter

orientation and thus perceptual errors between mirror letters decreased. The contribution of hand movements on letter recognition and reading acquisition was outlined in a series of studies that showed the positive effects of multisensory training (Bara, Gentaz, & Colé, 2007; Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Gentaz, Colé, & Bara, 2003). If we consider that letters are represented in the brain both by their motor and visual representations, we understand why a way of exploring letters that involves both visual and haptic perception was the most efficient for letter memorization and recognition. Another important result in Experiment 1 concerns the improvement in letter handwriting quality which was greater after VH training than after V training. We suppose that the improvement in letter recognition may have constrained the improvement in letter copying quality. Indeed, letter copying relies on both perceptual and motor skills. As it was shown by some studies, perceptual learning is as important as motor learning and good letter representation is necessary for handwriting (Berninger et al., 1997; Hays, 1982; Karlsdottir, 1996). The way of presenting letters is essential for handwriting acquisition and constrains the quality of their visual representation. Visual information processing may be a factor of poor motor outcome. The respective roles of perceptual and motor information in handwriting acquisition are not clearly understood. In adults, we can consider that kinesthetic and proprioceptive feedbacks are necessary to update motor memories, whereas visual information adjusts the motor command. In children, visual and kinaesthetic information is probably used for building motor programs. However it is difficult to determine in which way they exactly constrain handwriting.

The aim of the second study was to attempt to evaluate more precisely the role of perceptual and visuo-motor skills in handwriting. Thus, by means of correlation and regression analyses, we assessed the link between performance in perceptual and visuo-motor tasks and performance in handwriting. The investigation of the link between visual perception and handwriting is important for our understanding of handwriting acquisition and for

improving efficiency of teaching methods. Perception of form consistency enables the child to discriminate between similar letters and may influence handwriting. Poor visual letter memory should impact handwriting. Difficulties in letter handwriting can be determined by both difficulties in visual perception and in motor control. Our idea was that a perceptual ability like recognizing the shape of letters should be linked with handwriting quality (mostly evaluated by the adequacy of the shape with a standard). On the other hand, motor skills should be linked with the quality of the movement that produces the letter trajectory. Thus we expected to find a link between letter recognition (accuracy and velocity) and handwriting quality, and between visuo-motor tasks and dynamic measures of handwriting (number of velocity peaks, number of pen lifts, and pen “in air” time). The results partially confirmed our hypothesis. Performance in the visuo-motor tasks (loop tracing and shape outlines) were correlated with performance in letter handwriting. These two tasks in combination permitted us to predict performance in handwriting quality, with an advantage of the shape outline task which predicts a larger part of variance in handwriting performance. This confirmed results of previous studies which showed that handwriting quality was both linked to visual-motor integration and hand-eye coordination (Kaiser et al., 2009; Volman et al., 2006). As in Tseng and Murray (1994), visual-motor integration was not a single predictor of handwriting quality, which also depends on hand-eye coordination (loop tracing task). The shape outline task is a visual-motor integration task, because the child has to coordinate vision and motricity to produce a shape very similar to the model. The child has to precisely perceive the shape and to reproduce it, thus perceptual and motor components interact in this task. This can explain why this task predicts handwriting quality. We encounter difficulties in separating the perceptual and motor components of handwriting, and our two tasks are visuo-motor tasks, and rely both on motor and perceptual abilities. In fact, we can suppose that the perceptual part of the shape outline task (accurately perceiving the shape) is linked to the perceptual part

of handwriting, evaluated by the quality of letter shape. Visual-motor integration, which is the ability to coordinate visual information with a motor response, allows the child to reproduce letters. Our results are consistent with studies that show that visuo-motor skills are necessary for handwriting acquisition (Daly et al., 2003; Kaiser et al., 2009; Marr, Windsor, & Cermak, 2001; Tseng & Murray, 1994; Volman et al., 2006; Weil & Amundson, 1994). The loop tracing task is more a motor task because no model has to be reproduced. This task requires fine motor control because digital movements of the hand were performed to produce continuous lines of loops. The thin space between the two lines constrained the motor control which has to be very accurate. This task relies on visual control whereas the shape outline task relies on visual-perceptual skills. Thus the perceptual component seems to be less important in the loop tracing task than in the shape outline task. The strong link observed between the loop tracing task and some dynamic aspects of handwriting confirmed our hypothesis concerning the link between motor skills and the quality of movement necessary for producing the letter trajectory. Number of pen lifts and pen “in air time” are two measures of the quality of movement. The real time dynamic characteristics of handwriting provide a better understanding of motor control mechanisms. It was surprising that the link between handwriting and visuo-motor tasks was shown only for copying and not for dictation. In the dictation task, the number of letters handwritten was linked with letter knowledge, but not the quality of handwriting. This result is similar to that obtained by Molfese *et al.* (2006) study, who found a link between letter naming and letter writing. Further studies are needed to better understand the link between perceptual and motor skills and the different components of handwriting. The challenge for future research is to find various tasks to better isolate the perceptual and motor components in handwriting acquisition.

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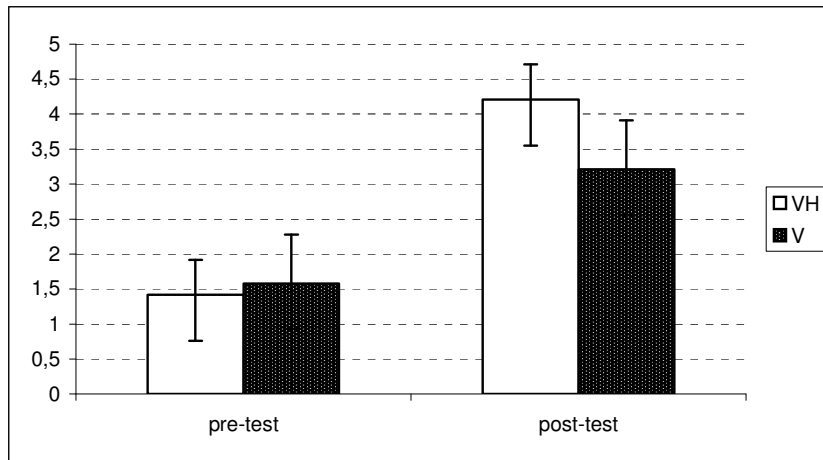


Figure 1: Mean number and standard deviation of letters recognized (score out of 5) in pre and post-test, in each training group (VH = Visuo-haptic training group and V = Visual training group)

Table 1: Mean scores (and standard deviation) in phoneme identification, non verbal performance, letter recognition and loops tracing before the training sessions in each training group

Training group	Final phoneme identification (/5)	Initial phoneme identification (/5)	WIPPSI blocks	Letter recognition (/26)	Loops tracing (/12)
VH	2.84 (1.61)	2.53 (1.07)	23.1 (6.87)	10.31 (5.28)	8.79 (1.99)
V	3.05 (1.22)	2.74 (1.45)	22.58 (7.06)	10.05 (4.88)	9.1 (2.02)

Table 2: Mean scores and (standard deviation) in global handwriting quality for the copying task before and after the training sessions in each training group

	Pretest	Post-test
Training group		
VH	2.11 (0.55)	2.93 (0.78)
V	2.25 (0.76)	2.57 (0.61)

Table 3: Correlations between performances in letter knowledge, perceptual task, visuo-motor tasks and handwriting (N=21)

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Letter name	-												
2. Letter recognition	.76*	-											
3. Recognition velocity	-.35	-.17	-										
4. Loops tracing	.20	.15	-.51*	-									
5. Shape outlines	.09	.25	-.41	.67*	-								
6. Number of letter handwritten	.73*	.47*	-.30	.21	.15	-							
7. Quality of letter handwriting	.13	-.04	-.24	.42	.28	.34	-						
8. Number of velocity peaks (handwriting)	.22	.01	-.15	.32	.23	.45*	.15	-					
9. Number of pen lift (handwriting)	-.28	-.18	.01	-.08	.00	-.55*	-.27	-.12	-				
10. In air time (handwriting)	-.31	-.32	.29	-.55*	-.14	-.41	-.21	-.14	.44*	-			
11. Quality of letter copying	-.15	-.13	-.32	.45*	.58*	.05	.55*	.20	-.10	-.12	-		
12. Number of velocity peaks (copy)	.06	-.08	-.10	.06	.14	-.16	-.28	.57*	.36	.29	.03	-	
13. Number of pen lift (copy)	-.20	-.31	.21	-.62*	-.43	-.31	-.31	-.13	.57*	.72*	-.47*	.21	-
14. In air time (copy)	.10	-.11	.09	-.35	-.17	.15	-.09	.29	.40	.64*	-.07	.37	.64*

Table 4: Hierarchical regression analysis to predict handwriting quality in the copying task

	b	SE b	β
1. Age	.06	.07	.18
2. Letter name	-.08	.11	-.17
3. Letter recognition	-.04	.20	-.07
4. Recognition velocity	-.00	.00	-.55
5. Loops tracing	.20	.11	.43
6. Shape outlines	.15	.07	.60
5. Shape outlines	.16	.05	.65*
6. Loops tracing	.03	.13	.07
$R^2 = .48$ * $p < .05$			

Table 5: Hierarchical regression analysis to predict pen “in air” time in handwriting to dictation task

	b	SE b	β
1. Age	-92.15	54.7	-.36
2. Letter name	-108.58	82.54	-.27
3. Letter recognition	-68.75	148.04	-.15
4. Recognition velocity	-.12	1.54	-.03
5. Loops tracing	-186.4	87.04	-.50*
6. Shape outlines	122.05	52.9	.61*
5. Shape outlines	16.22	54.73	.08
6. Loops tracing	-319.25	95.94	-.86**
$R^2 = .56$ * $p < .05$ ** $p < .01$			

Table 7: Hierarchical regression analysis to predict number of pen lifts in the copying task

	B	SE B	β
1. Age	-.05	.03	-.36
2. Letter name	-.04	.05	-.16
3. Letter recognition	-.09	.09	-.33
4. Recognition velocity	.00	.00	-.08
5. Loops tracing	-.14	.05	-.65*
6. Shape outlines	.01	.03	.13
5. Shape outlines	-.04	.03	-.31
6. Loops tracing	-.16	.06	-.73*

$R^2 = .52$ * $p < .05$