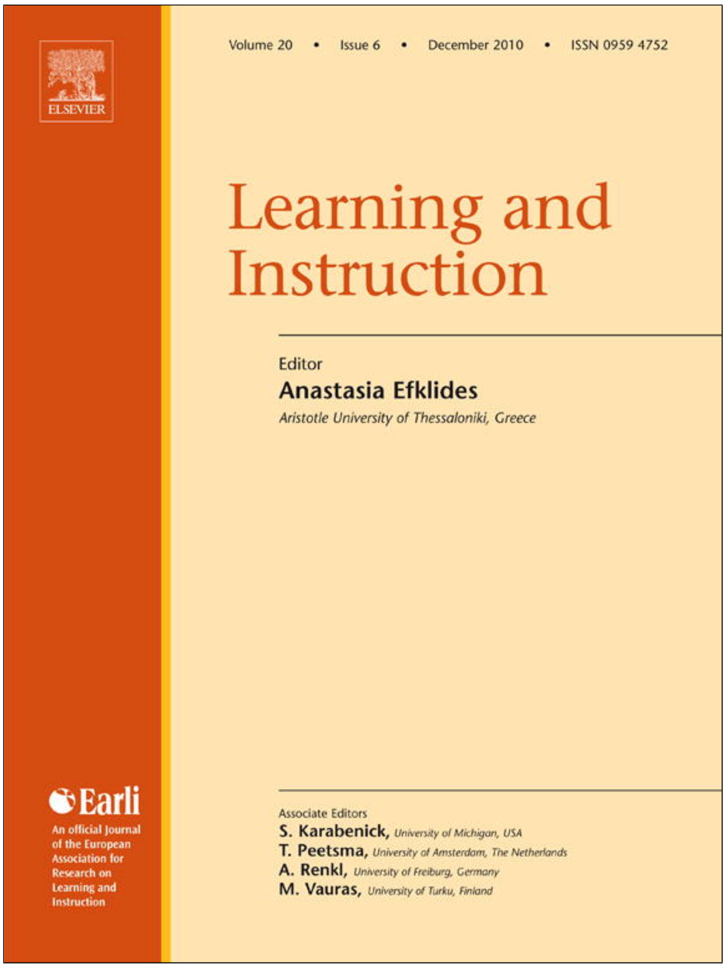
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Effects of different types of learning on handwriting movements in young children

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Abstract

This experiment aimed at studying the benefits of different types of training (visual, motor, or visual-motor), in comparison to a control group, on 5-year-olds' performance in a task of writing cursive letters. The visual-motor training was shown to be the most effective training. The efficacy of visual training was clear at the letter quality level, and the impact of the motor training was shown at the movement fluency level. We assume that the visual training better contributes to learning the shape of the letter trajectory, while the motor training better contributes to improve handwriting movement execution.

Keywords: Cursive handwriting; Children; Visual learning; Motor learning1

1. Introduction

Handwriting development has been investigated by several researchers who have demonstrated its close relationships with many different aspects of the child's development and environment (Chartrel & Vinter 2004; Graham, 2006; Karlsdottir, 1996; Rosenblum, Weiss, & Parush, 2004; Thomassen & Teulings, 1985; Van Galen, 1991). Handwriting can be conceptualized as a perceptual-motor skill in which the perceptual component pertains to the letter shape and the motor component to the movement producing the letter trajectory. As the goal is to enable children to acquire fast and legible handwriting, a failure in this learning process is often associated, if not inevitably, to poor school performance. Fayol and Miret (2005) have shown, for example, that children with poorer graphic skills performed worse in a dictation test. Thus, failure in learning to write letters involves negative consequences at the highest level of cognitive processes involved in text production (Olive, Favart, Beauvais, & Beauvais, 2009). Yet, all the studies estimate that approximately 10–20% of primary school children encounter difficulties learning to write (Alston, 1985; Maeland, 1992; Rubin & Henderson, 1982).

The reasons for problems in learning to write can be found in the child, in the teaching methods or in the interaction between the two. Some authors have questioned the content of handwriting teaching methods or the time (duration) allocated to this teaching (Asher, 2006; Graham, 1992; Sheffield, 1996). Recently, Graham et al.,(2008) have reported a well documented survey of handwriting instruction in USA. A large majority of primary grade teachers indicated that they taught handwriting, though a small percentage did not teach it at all. This could not be possible in a country like France, for instance, where teaching handwriting is obligatory and starts during the second half of the last kindergarten level (when children are aged between 5 and 6 years). Before this stage, when they are 4 years old, French children are taught to write in capitals and are trained to produce the basic components of cursive handwriting such as the loops or the waves. According to the instructions issued by the French Ministry of Education in 2002, at the end of the last kindergarten grade, when they reach 6 years of age, children are expected to be able to copy in cursive a complete sentence comprising a few words. The

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handwriting exercises comprise tracing and copying letters, as well as producing letters under dictation. Verbal descriptions of the letter shape are also recommended in the instructions of the French Ministry of Education. In USA, the teachers do not have similar governmental instructions but they make a large use of commercial materials for handwriting instruction. The survey made by Graham et al. (2008) established that if teachers modeled how to produce a letter, they less regularly described verbally how a letter is built. This disparity between countries and within teachers shows that it appears useful to test the effects of different types of learning methods used for letter writing instruction and to seek to understand how to boost this learning.

Karlsdottir and Stefansson (2002) carried out a longitudinal study over five years, aimed at identifying what differentiates the good from the poor writers and at explaining the reasons for the difficulties experienced by some children. This study indicated that there was no distinction between children with and without problems with regard to their perceptual-motor skills. On the other hand, they were differentiated by their abilities to name or write the letters before they started to learn to write. The children who later became poor writers had less knowledge about the letters at the beginning. Moreover, Karlsdottir (1996) has shown that re-introducing the teaching of letters in the 4th elementary grade, through verbal and visual instruction on the shape of the letter and its associated trajectory, enabled the quality of the productions to be improved, unlike simple copying exercises. According to Karlsdottir and Stefansson (2002), learning difficulties that appear early, between 7 and 8 years of age, may develop from letter to letter, as the result of the child's inability to understand the teacher's instructions. The child would therefore construct motor programs insufficiently differentiated from each other.

Several authors have also questioned the impact of the instructions given when copying exercises are performed. Thus, Sovik (1976) asked 8-year-olds to copy shapes after giving them no instruction, a visual demonstration of the shapes' production, or a visual demonstration combined with a verbal description of their shape. He observed that the quality of the productions improved as more information was given. Hayes (1982) has also shown that the quality of the production of 6- and 9-year-olds was getting better when they received both a visual and a verbal demonstration of how they had to copy the model of letter-like forms. Moreover, the performance was even better when the author asked the children to verbalise the instructions given. Wright and Wright (1980) reported that copying letters improved when the models to be copied were models that depicted motion.

With regard to current data revealing very close links between perception and action, the issue of learning handwriting can be approached from a new viewpoint. Many studies demonstrate that motor knowledge has an impact on movement perception. For instance, studies carried out in the field of perceptual anticipation highlight the fact that the perceptual system can use spatio-temporal information to predict the movement to come (Kandel, Orliaguet, & Viviani, 2000; Louis-Dam, Kandel, & Orliaguet, 2000; Orliaguet, Kandel, & Boë, 1997). Furthermore, research in neuroscience shows that similar neural structures (the mirror neurons) are activated in both the perception and production of the same movement (Fadiga, Fogassi, Pavessi, & Rizzolatti, 1995).

In the area of handwriting, Bartolomeo, Bachoud-Lévi, Chokron, and Degos (2002) have shown that the action of tracing the shape of a letter with a finger can help alexic patients identify the letter presented visually. Recent studies using neuroimaging techniques validate this link between the visual and motor shapes of letters (Longcamp, Anton, Roth, & Velay, 2003; Longcamp, Tanskanen, & Hari, 2006). Longcamp et al. (2003) have observed, among right-handed individuals, the activation of a particular area located in the left premotor cortex, both during a letter writing task and during a simple observation task for the same letters. On the other hand, this area was not activated when characters that the participants had never written (pseudo-letters) were presented. Thus, the cerebral representation of letters is not solely visual; it also includes a sensory-motor component. In order to highlight this component's role in the perception of letters, Longcamp et al. (2008) assessed the ability of adults to discriminate new characters from their mirror images after being taught how to produce these characters either by writing or by typing. They reported stronger and longer-lasting facilitation in the recognition of the orientation of characters that had been written by hand compared to those typed. Thus, the specific movements memorized when learning how to write participate in the visual recognition of graphic shapes and letters. A study carried out with 3–5 year-old children showed similar results from 4 years of age (Longcamp, Zerbato-Poudou, & Velay, 2005).

While it has been shown that our perception of written characters is based on motor knowledge, the literature also indicates that observation enables specific motor behaviours to be induced. Proponents of social learning argue that learning without motor action is possible (Bandura, 1977; Carroll & Bandura, 1990). This theory claims that under certain conditions, learning occurs by observing an individual doing something, without the observer necessarily having to perform the action immediately. Some studies using the serial reaction time (SRT) paradigm have shown that participants improve their performance just as much after motor training as after learning by visual observation (Heyes & Foster, 2002; Howard, Mutter, & Howard, 1992). However, the use of the SRT paradigm entails a highly global assessment of motor learning, measuring a variable that indicates the person's degree of motor preparation (reaction time) and not measuring variables that reflect motor execution more directly.

In the context of motor skills (more precisely, volleyball serves), Weeks and Anderson (2000) showed that repeated observation of models before and at the start of practice made it possible to improve participants' performance. This study, together with the study by Shea, Wright, Wulf, and Whitacre (2000), revealed the existence of an interaction between motor practice and learning by observation in adults. Bard et al. (1995) have assessed the ability of 6 and 10 year-old children to transfer the benefits of a motor, visual or visual and motor training during a perceptual-motor task. The results indicated that the participants who had received motor or visual-motor training improved their performance in the perceptual-motor task during the retention phase (one week after training). They were more accurate both spatially and temporally. Nevertheless, only the children from the "visual-motor" group developed flexible behaviour, able to adapt to the environmental constraints (variations in the speed of the stimulus). The children who had received visual training also improved their performance during the training but the benefits of this were not transferred during the retention phase when the children had to solve a perceptual-motor task. In addition, some studies focussing on learning by observation as a procedure for teaching sporting skills in children have shown that a commented or silent demonstration enabled performance to be improved in comparison to a control group (Giroud & Debû, 2004; Lafont, 1994). Regarding graphic activities, Vinter and Perruchet (2002) have shown that motor training was not necessary for learning implicitly a new graphic behaviour; implicit learning also occurred through visual observation (see also Vinter & Detable, 2003; Vinter & Perruchet, 1999, 2000). To our knowledge, no study has yet assessed the impact of visual training in the area of cursive writing in pre-writers.

1.1. The present study

The aim of the present study was to assess the respective advantages of visual, motor and visual-motor training on the performance of 5-year-olds in writing isolated cursive letters. The present study was carried out with children from the last kindergarten grade, before they had begun to learn cursive writing. These children were divided into three test groups, which were offered different types of training[1] – motor instruction (copying still models), visual instruction (observing motion models) and visual-motor instruction (observing and copying motion models) – during the second and third session of a total of four sessions. In addition to these groups, there was a control group that did not take extra training, as the other three groups did (i.e., they had only the first and fourth session), and received no visual and motor information. The control group allowed comparison so that the results shown in the experimental groups could be linked to specific handwriting training rather than to other variables, such as indirect effects of graphic activity that children received at school during the same period.

For the assessment of children's performance, kinematical characteristics of the hand movement and the quality of handwriting were measured. It was expected that there would be no variation, or little, in the performance of the control group between the first and last session, in contrast to the three experimental groups, which should present changes over the course of the four training sessions (Hypothesis 1). It was also expected that visual-motor training should give rise to the best performance, while the visual and the motor training should lead to comparable effects, with visual training possibly ahead (Hypothesis 2). This prediction was based on the fact that during the motor training the children had no motor information regarding the letter's overall trajectory; yet this visual information could facilitate the fluency of the production.

2. Method

2.1. Participants

Participants were 48 native French speaking children from the last kindergarten grade (24 girls and 24 boys). Their mean age was 5 years 7 months (from 5 years 1 month to 6 years 1 month, $SD = 0.48$). These children were all right-handed. Eight items drawn from the Bryden (1977) test were used to assess handedness (drawing, throwing a ball, holding scissors and brushing teeth, closing a bottle, hitting a nail with a hammer, lighting a match, and drying a plate with a napkin). Only children who scored at 6 or more were retained. Furthermore, these children did not show any scholastic delay or advance and their sight was normal or corrected to normal. They came from middle class families. Written informed consent was provided by parents for each child, and the experiment was conducted following the principles outlined in the Revised Helsinki Declaration of 2000.

As the children had to be divided into 4 groups according to the type of training proposed ($n = 12$ per group, half girls and half boys in each group), a preliminary analysis of their writing productions was carried out. Several days before the experiment started, the children were asked to copy the letters *f*, *l*, *m*, and *r* in cursive writing, using a still model. The productions collected were then analysed according to four criteria extracted from the French adaptation (Charles, Soppelsa, & Albaret, 2004) of the Beknopte Beoordelingsmethode voor Kinderhandschriften[2] test (BHK). The four criteria were (a) chaotic handwriting,(b) unsteadiness,(c) large writing, and (d) strange or ambiguous letters. A score of 0 was given when the criterion was not present in the letter and a score of 1 when it was present. The total scores obtained, ranging from 0 to 16, made it possible to constitute four groups equivalent with respect to the initial handwriting abilities of the children. Each group was assigned randomly to a type of instruction, namely there was the visual-motor, visual, motor, and control group. Comparison of group means using the Student *t*-test indicated that the scores on the BHK test groups with the highest difference, namely the visual-motor ($M = 7.2$, $SD = 1$) and the motor ($M = 8.1$, $SD = 1.24$) groups, were not significantly different, $t(22) = -1.45$, $p = .16$.

The experiment took place two months before the children started formal lessons in cursive handwriting at school.

[1] Note that the terms "training" and "instruction" are used in a quite undifferentiated manner.

[2] Concise evaluation scale for children's handwriting.

2.2. Material

The handwriting productions were collected using sheets of paper on which 16-cm long horizontal lines were printed, one line per letter. The distance between lines was 7 cm. There was a total of four cursive model letters (i.e., *f*, *l*, *m*, and *r*) to be copied, represented in Fig. 1. The model letter was displayed centred in the middle of the computer screen which was located in a distance of about 50 cm from the child. The height of the letters *f*, *l*, *m*, and *r* was 12, 8, 6, and 6 cm, respectively.

A Wacom Intuos2 A4 graphics tablet was used to record the children's handwriting movements. The tablet was equipped with an Intuos Ink Pen and linked to a PC computer. Data acquisition and analysis were run with the OASIS program (De Jong, Hulstijn, Kosterman, & Smits, 1996). The temporal resolution of the acquisition was 206 Hz, and the spatial resolution was of +/− 0.15 mm. A Butterworth band-pass filter (12–24 Hz) was used to filter the data.

2.3. Procedure

Children were tested individually with a procedure that varied, depending on the training group. In the visual-motor group, the model was with motion, that is, the letter produced beforehand by a handwriting expert, was displayed on moving on the screen. After a five-second period of observation, including the motion display of the letter, the child copied it on his/her sheet. The test was repeated six times in succession for the same letter, and then the next letter was presented, and so on. Thus, the children receiving visual-motor training saw each letter being written six times on the screen and copied them after each presentation, thus also six times (motor and visual training). The presentation of the letter was with motion in the visual group as well. The child watched six successive presentations with motion of five seconds each, and copied the letter once, at the end of the six demonstrations (no motor training). In the motor group, the presentation of the letter was still, that is, the letter was displayed already written on the screen. After having observed it for five seconds, the child copied it. This sequence was repeated six times in succession for each letter (no visual training). Finally, for the control group, the procedure was identical to that of the motor group, but each letter was only produced once (no motor or visual training).

In each group, after observing the model letter for five seconds, a sound signal indicated to the child that s/he could start to write, the model remaining on the screen. The child was asked to copy the letter in a cursive style without lifting the pencil off the paper.

The children in the three experimental groups received four training sessions. The children in the control group only took part in the first and last sessions. The procedure for the sessions was identical and the sessions were separated by a maximum of four days, except for the control group for which the maximum interval was 12 days. The choice of the number of sessions, as well as the length of time between sessions, was not our decision but was the result of a compromise reached between the school and the experimenters. A larger number of sessions would have been preferable, but that was not possible. Finally, the model letters were presented in a random order in each session for each participant.

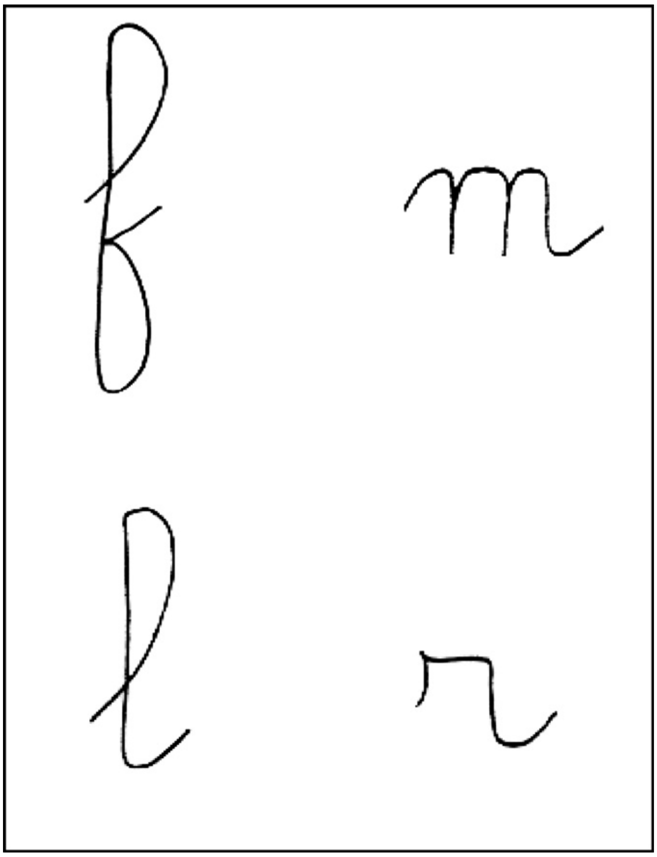

Fig. 1. Illustration of model letters (reduced size).

2.4. Data analysis

Only the productions that corresponded to a correct reproduction of the model shape were kept for the analyses. Out of all the data collected, 16% were eliminated for this reason. For the kinematical assessment of performance, the following variables were selected from the OASIS software: the duration of the movement (seconds), the length of the trajectory (centimetres), the mean velocity (centimetres/second) and the number of velocity peaks per letter stroke, which is a movement fluency index. For each variable, the mean obtained over the six repetitions for the motor and visual-motor groups, and over the four letters, for each child and session, was computed and the analyses were carried out on these means. Note that the overall results did not change when the statistical analyses were rerun selecting only the last repetition in the motor and visual-motor groups (and the unique repetition in the visual and control groups). Therefore, it was decided the results to be presented with the computed means.

With regard to the assessment of letter quality, two judges working independently were asked to judge the quality of the writing (focusing on shape accuracy and legibility) on a seven-point scale ranging from 1 (very bad quality) to 7 (high quality). The judges were ignorant as to the training group from which the writing was selected. They attributed a score letter by letter by child and session (i.e., 16 scores for participants in the motor and visual-motor groups, for instance). A mean score was computed by letter, child and session from these data. The inter-judge agreement was 81%, and disagreements were settled before analysis.

3. Results

To compare the impact of the training in the four groups, a series of 4(groups) x 2(1st and last session) ANOVAs was performed on the different variables. Group was the between subjects factor and session the within subjects factor. The training effects generated were, then, assessed more specifically by performing a 3(experimental groups) x 4(sessions) ANOVA. Group was the between subjects factor and session the within subjects factor.

3.1. Was there an advantage from the training method compared to the control group?

3.1.1. Trajectory length

The mean trajectory length did not vary as a function of group, $F(3, 44) < 1$, or of session, $F(1, 44) < 1$. The interaction between group and session, illustrated in Fig. 2A, was not significant either, $F(3, 44) = 1.3$, $p = .27$. However, in the motor group, there was a significant decrease of the trajectory lengths between the first and the last session, $F(1, 11) = 6.4$, $p < .05$, partial $\eta^2 = .37$, while in the visual-motor, visual, and control did not change. The lengths decreased only in the motor group, which practised as much as the visual-motor group but was not confronted with a moving model.

3.1.2. Movement duration

The mean movement duration differed between groups, $F(3, 44) = 3.7$, $p < .05$, partial $\eta^2 = .20$, and sessions, $F(1, 44) = 38$, $p < .001$, partial $\eta^2 = .46$. The interaction between group and session was also significant, $F(3, 44) = 3.3$, $p < .05$, partial $\eta^2 = .18$, indicating that the changes in movement time between the first and last session were not identical in the four groups. Newman–Keuls tests revealed that the durations were equivalent in all groups in the first session (in all cases, $p > .20$), and that, they decreased significantly between the first and last session (see Fig. 2B) in the visual-motor ($p < .01$), visual ($p < .001$) and motor groups ($p < .05$), but not in the control group ($p = .62$).

3.1.3. Velocity

Concerning the mean velocity per letter stroke, the effect of group was not significant, $F(3, 44) < 1$. However, mean velocity evolved from 1.45 cm/sec to 1.96 cm/s between the first and last session, $F(1, 44) = 22$, $p < .001$, partial $\eta^2 = .33$. The interaction between group and session was significant, $F(3, 44) = 3.3$, $p < .05$, partial $\eta^2 = .18$. As confirmed by Newman–Keuls tests (see Fig. 2C) there was an increase of velocity in the visual-motor ($p < .01$) and visual ($p < .01$) groups, but not in the motor ($p = .53$) and control groups ($p = .98$). The four groups performed similarly in the first session (in all cases, $p > .30$).

3.1.4. Velocity peaks

Regarding the mean number of velocity peaks per letter stroke, the main effect of group was not significant, $F(3, 44) = 1.6$, $p = .19$. However, the effect of session was significant, $F(1, 44) = 44$, $p < .001$, partial $\eta^2 = .50$. The mean number of velocity peaks decreased between the first and last session (9.15 vs. 6.89). The interaction between group and session was marginally significant, $F(3, 44) = 2.63$, $p = .06$, partial $\eta^2 = .15$. As indicated by Newman–Keuls tests (see Fig. 2D), movement fluency improved between the first and last session in the visual-motor ($p < .01$), motor ($p < .001$) and visual groups ($p < .05$), while it did not change in the control group ($p = .29$).

3.1.5. Letter quality

Finally, letter quality differed as a function of group, $F(3, 44) = 4.18$, $p < .05$, partial $\eta^2 = .23$, being higher in the visual group ($M = 3.92$, $SE = 0.18$) than in the motor group ($M = 2.96$, $SE = 0.32$, $p < .01$), the visual-motor group ($M = 3.19$, $SE = 0.09$, $p < .05$) and control group ($M = 3.30$; $SE = 0.10$, $p < .05$), as confirmed by Newman–Keuls tests (see Fig. 2E). Quality scores also evolved positively from the first ($M = 3.27$, $SE = 0.11$) to the last ($M = 3.42$, $SE = 0.12$) session, $F(1, 44) = 5.93$, $p < .05$, although the effect size was small, partial $\eta^2 = .12$. No significant interaction between group and session was found, $F(3, 44) = 1.29$, $p = .29$. However, the quality scores did not increase at all from the first to the last session in the control group (from $M = 3.31$, $SE = 0.13$, to $M = 3.3$, $SE = 0.11$, $p = .87$), while they increased in the three experimental groups considered altogether (from $M = 3.25$, $SE = 0.14$, to $M = 3.47$, $SE = 0.15$, $p < .05$). The means and standard errors associated with these different variables are reported in Table 1, as a function of Group and Session.

These results highlight an absence of change with respect to all the movement characteristics and to quality score in the control group. In contrast, in the groups receiving training, modifications of movement characteristics and of the quality score were observed, although they varied between groups. The absence of change in the different measured variables in the control group allows us to consider that the modifications shown in the experimental groups were linked to the trainings implemented. In the next section, we examine the specific effects of the visual-motor, motor, and visual training over the four training sessions, focusing on the interaction effects between group and session.

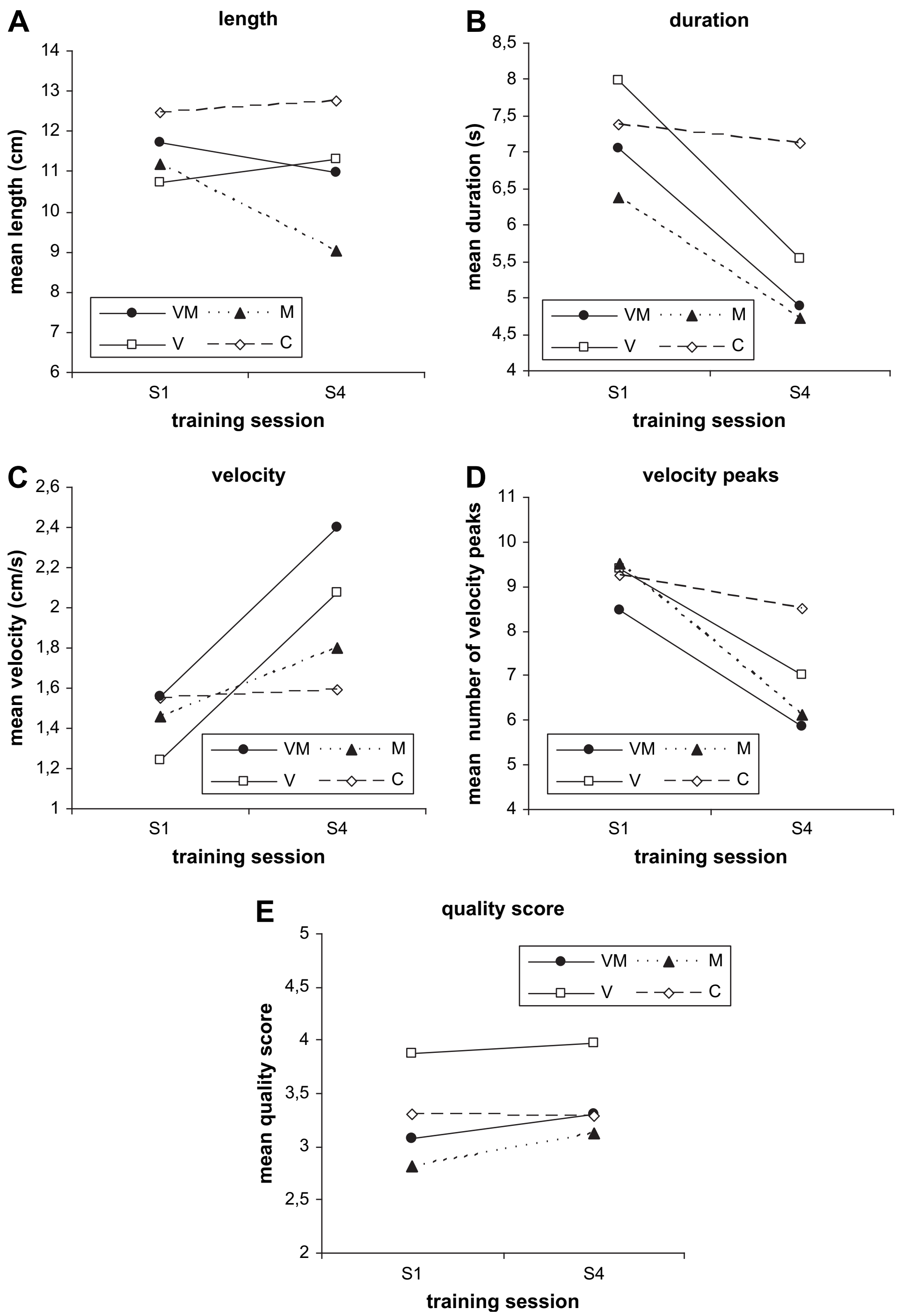

Fig. 2. Mean length (A), mean duration (B), mean velocity (C), mean number of velocity peaks (D), and mean quality score for the first and last training session in the three experimental groups and the control group. VM = visuo-motor group; V = visual group, M = motor group, C = control group. S1 = first session; S4 = last session.

3.2. Was there a specific impact of the visual-motor, motor, and visual training?

3.2.1. Trajectory length

Concerning the mean trajectory length, the 3(experimental group) x 4(session) ANOVA did not reveal a significant effect of group, $F(2, 33) = 1.03$, $p = .37$, or of session, $F(3, 99) = 1.3$, $p = .27$. However, there was a significant interaction between group and session, $F(6, 99) = 2.4$, $p < .05$, partial $\eta^2 = .13$. As illustrated in Fig. 3A, the decrease in length between the first and last session was significant in the motor group ($p = .04$), while this was not the case in the visual-motor or visual group (both $p > .30$). The low effect size of the interaction indicates, however, that the decrease of the lengths in the motor group was not high.

Table 1
Means (and standard errors) associated with the different measured variables as a function of Group and Session.

	Session 1	Session 2	Session 3	Session 4
	M (SE)	*M* (SE)	*M* (SE)	*M* (SE)
Visual-Motor group				
Length	11.72 (1.58)	12.77 (1.59)	11.02 (1.15)	1.10 (0.92)
Duration	7.04 (0.38)	5.68 (0.41)	5.07 (0.40)	4.89 (0.43)
Velocity	1.55 (0.20)	2.34 (0.35)	2.30 (0.24)	2.40 (0.26)
Velocity peaks	8.46 (0.54)	6.36 (0.61)	6.37 (0.67)	5.86 (0.64)
Quality	3.08 (0.10)	3.15 (0.14)	3.23 (0.11)	3.31 (0.19)
Visual group				
Length	10.73 (1.02)	11.70 (1.32)	12.60 (1.61)	11.30 (1.61)
Duration	7.99 (0.82)	7.00 (0.46)	6.77 (0.60)	5.54 (0.38)
Velocity	1.24 (0.14)	1.54 (0.24)	2.17 (0.41)	2.07 (0.42)
Velocity peaks	9.40 (1.30)	9.07 (0.86)	8.56 (0.95)	7.03 (0.48)
Quality	3.87 (0.18)	3.85 (0.21)	3.75 (0.19)	3.98 (0.20)
Motor group				
Length	11.18 (1.00)	9.57 (0.81)	9.23 (0.98)	9.00 (1.05)
uration	6.38 (0.43)	6.15 (0.44)	5.12 (0.45)	4.73 (0.34)
Velocity	1.46 (0.28)	1.37 (0.20)	1.75 (0.26)	1.80 (0.29)
Velocity peaks	9.50 (0.73)	8.10 (0.55)	6.40 (0.47)	6.10 (0.41)
Quality	2.81 (0.31)	2.83 (0.32)	2.98 (0.35)	3.12 (0.35)
Control group				
Length	12.48 (1.14)	–	–	12.75 (1.38)
Duration	7.37 (0.52)	–	–	7.11 (0.56)
Velocity	1.55 (0.10)	–	–	1.59 (0.10)
Velocity peaks	9.25 (0.88)	–	–	8.51 (0.64)
Quality	3.31 (0.12)	–	–	3.29 (0.13)

3.2.2. Movement duration

Concerning movement duration, the 3(experimental group) x 4(session) ANOVA showed a significant effect of group, $F(2, 33) = 4.02$, $p < .05$, partial $\eta^2 = .19$, movement duration being higher in the visual group than in the other groups (Newman–Keuls tests; in all cases, $p < .05$), which did not differ one from the other ($p > .30$). Movement durations progressively decreased throughout the sessions in all groups, $F(3, 99) = 24.8$, $p < .001$, partial $\eta^2 = .43$. The interaction between group and session was not significant, $F(6, 99) = 1$, $p = .36$ (see Fig. 3B). However, Newman–Keuls tests revealed that movement durations decreased earlier in the visual-motor group, between the first and second session ($p < .05$), than in the visual and motor groups in which the significant decrease occurred between the first and the third session ($p = .03$ and $p = .04$, respectively). As can be noted in Fig. 3B, durations were higher in the visual group than in the motor group already in the first session (Newman–Keuls test, $p < .05$).

3.2.3. Velocity

Concerning velocity per letter stroke, the 3(experimental group) x 4(session) ANOVA showed that velocity increased over the sessions, $F(3, 99) = 12.9$, $p < .001$, partial $\eta^2 = .28$, but differently across the groups, as indicated by the significant Group × Session interaction, $F(6, 99) = 2.5$, $p < .05$, partial $\eta^2 = .13$ (see Fig. 3C). The main effect of group was not significant, $F(1, 33) = 1.59$, $p = .22$. In the visual-motor group, the velocity increase was earlier, between the first and the second session (Newman–Keuls test, $p < .01$), while this increase occurred between the second and the third session in the visual group (Newman–Keuls test, $p < .05$). By contrast, Newman–Keuls tests failed to reveal any significant variation in the course of sessions for the motor group (in all cases, $p > .40$).

3.2.4. Velocity peaks

Regarding mean number of velocity peaks per letter stroke, the 3(experimental group) x 4(session) ANOVA showed that the number of peaks decreased progressively over training, $F(3, 99) = 22.8$, $p < .001$, partial $\eta^2 = .41$, and the effect of group was not significant, $F(2, 33) = 2.89$, $p = .07$. The interaction between group and session failed to reach significance, $F(6, 99) = 1.9$, $p = .09$. However, as revealed by Newman–Keuls tests (see Fig. 3D), the decrease in the number of velocity peaks occurred early in the visual-motor group, since it was significant already between the first and the second session ($p < .05$); in the motor group the number of velocity peaks decreased between the first and the third session ($p < .05$), and in the visual group between the first and the fourth session ($p = .03$).

3.2.5. Letter quality

Concerning the quality scores, the 3(experimental group) x 4(session) ANOVA revealed a significant effect of group, $F(2, 33) = 4.5$, $p < .05$, partial $\eta^2 = .21$, with these scores being higher in the visual group than in the other groups, as revealed by Newman–Keuls tests (visual vs. visual-motor, $p = .04$; visual vs. motor, $p = .02$). Moreover, the quality scores increased slightly over the sessions (see Fig. 3E), $F(3, 99) = 4.4$, $p < .01$, partial $\eta^2 = .12$, and the interaction between group and session was not significant, $F(6, 99) < 1$. The quality scores in the visual group exceeded those shown in the motor or visual-motor groups already in the first session (Newman–Keuls tests; in all cases, $p < .05$).

4. Discussion

This experiment focussed on the impact of different types of training in handwriting, namely visual-motor, visual, and motor, on the production of isolated cursive letters by 5 year-olds. The children had not yet started with systematic school handwriting instruction. The results revealed that the changes in the movement characteristics varied as a function of the type of training received. Children from the control group, who did not have any systematic training, did not show any modifications in the kinematical measures of their handwriting movements, that is, the mean movement duration, trajectory length, velocity, and number of velocity peaks per letter stroke remained unchanged between the first and last session. The same result appeared with respect to quality, that is, it did not increase at all. These findings confirmed Hypothesis 1 that predicted change only in the training groups. Therefore, improvement in performance in a writing task requires a systematic training process and can not be evoked by general

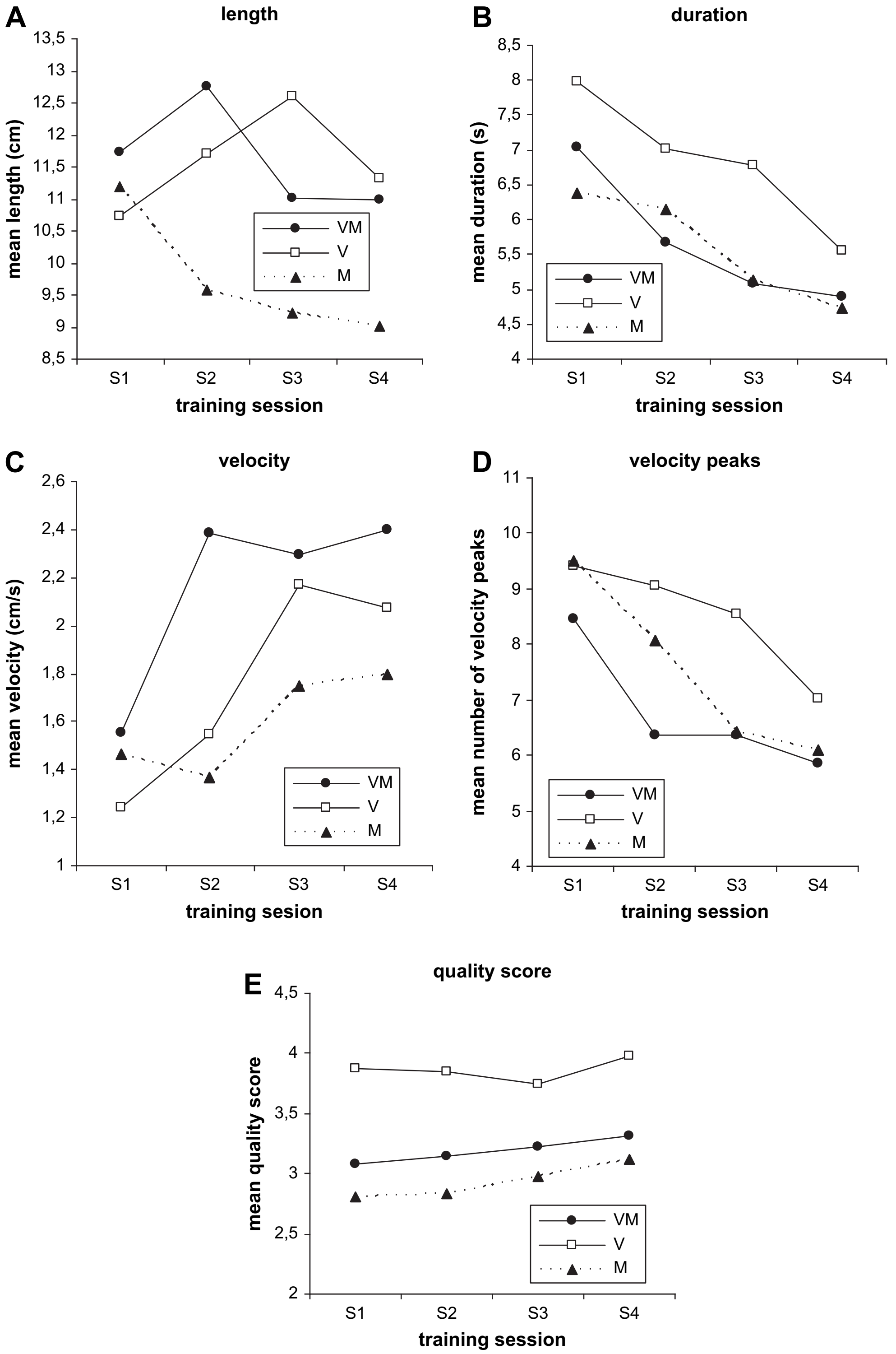

Fig. 3. Mean length (A), mean duration (B), mean velocity (C), mean number of velocity peaks (D), and mean quality scores (E) in the four training sessions as a function of the three experimental groups. VM = visuo-motor group; V = visual group, M = motor group. S1 = first session; S2 = second session; S3 = third session; S4 = last session.

graphic tasks as regularly proposed for preschool children; training is needed at least for a short period of time, as was done in the present experiment. In contrast, changes of parameters of handwriting measurements occurred following the three types of training tested, with differences depending on the specific training received. This finding is in line with Hypothesis 2. Of course, great caution should be taken when considering these data, because of the limited number of training sessions, and because we did not obtain the possibility to test the children in a further retention test. However, our results provide interesting indications in this up to now little explored domain of research.

Visual-motor training, which combines systematic motor exercise along with observation of letter model with motion, was expected to boost the transfer of information gained visually into motor knowledge. The efficacy of visual and kinaesthetic feedback on handwriting was indeed found in mentally disabled children (Lally, 1982). It should, therefore, be the most conducive to improvement of performance. Our results did support this hypothesis (Hypothesis 2). Children in the visual-motor group showed a decrease in movement duration and in the number of velocity peaks, which occurred earlier than in the other groups; they also showed an increase in velocity that occurred earlier than in the motor and visual groups, that is, between the first and second session. In this group, as in the others, the improvement in movement fluency, indicated by the decrease of the number of velocity peaks, can be seen as a consequence of the increased velocity. Indeed, the results of the study by Meulenbroek and Van Galen (1990) pointed out the existence of significant negative correlations between the number of velocity peaks and velocity, showing that the more fluent the movement, the greater the speed.

Only the trajectory length did not vary over the course of training in the visual-motor group, and this was also the case for the visual group. The absence of variation of trajectory lengths in visual-motor and visual groups could be the result of the repetitive impact of visual observation of the on-line writing of the model on the computer screen. Since the letter models presented were large-sized, the repetitive dynamic information present in the visual-motor and visual groups may have led the children to match their writing with these large sizes, taking into account that the space between the writing lines (see Method section), was rather large also and, hence, did not impose strong size constraints. This may suggest that one could lead young children to calibrate the size of their writing through dynamic learning methods. This could constitute an alternative method of training to that of imposing spatial constraints, like writing between lines (Chartrel & Vinter, 2008). However, this finding should be replicated with a broader sample and a bigger number of sessions.

The motor training generated an improvement of the kinematics of the handwriting movement that took place progressively over the course of the training sessions. The movements of the children who had received motor training became more fluent and they decreased in duration and in length. Through motor training, children have the opportunity to adapt their motor programs according to feedback from their sensorimotor experience, such as visual (Chartrel & Vinter, 2006; Zesiger, 1995) and proprioceptive information, as well through the efference copy generated by the movement (i.e., the proactive information linked to the planning and programming of the action). The motor exercise would enable the parameters of the movement to be adjusted. Longcamp's work (Longcamp et al., 2003, 2005) suggests that the writing movements themselves play a part in the memorisation, representation and visual recognition of letters and, therefore, emphasises the benefits of motor practice in the acquisition of writing. However, the production of the motor group was globally the worse from a qualitative point of view, throughout the sessions, though a slight gain in quality was observed between the first and last session. This is probably due to the fact that these children were given a static model deprived from any motion information, in particular, information about movement direction.

As for the visual training, this generated an improvement in performance similar to that elicited by the visual-motor training, although global performance, assessed in terms of kinematical parameters, was slightly behind that seen in the visual-motor group. Indeed, in the visual group, we observed a decrease of movement duration and in the number of velocity peaks as well as an increase of velocity, but these changes occurred later than in the visual-motor group. However, quality scores were higher in the visual group than in the visual-motor and motor groups. The visual training seems to have a fast impact on performance, with the quality scores being higher in the visual group than in the other groups from the first session. This immediate tendency to achieve a better letter quality had an effect on movement durations, which were the highest in this visual group from the first session. Learning by observation of motion thus led to an improvement in performance, even in the case of letter writing in pre-writers, with movements being more rapid and fluent. This is an important finding that calls for further systematic investigation, over longer periods of training. That the impact of visual training tended to be less effective than the impact of visual-motor training from a kinematics point of view indicates that the benefits of visual training are conferred with greater difficulty, which is in accordance with the results of Bard et al. (1995). In the visual group, it is plausible that the children learned something about how to produce a specific shape with a specific trajectory; yet, any improvements in performance were smaller than in the visual-motor group because children trained visually did not have the opportunity to practise the motor skills involved in executing the specific trajectories. Interestingly, the better performance in terms of quality in the visual group lends support to the view that learning by visual observation of motion facilitates letter trajectory learning. Previous studies have also shown the benefits linked to a dynamic presentation of the graphic model to be produced in terms of the quality of the production (Hayes, 1982; Sovik, 1976; Wright & Wright, 1980). We conjecture that the impact of visual training was linked to kinematical information, but it would be worth investigating this question more precisely in further experiments.

In conclusion, the three types of training tested here enabled improvements of pre-writers in handwriting over a very short training period. For the visual training there was even a quite immediate effect, in the course of the first session (on quality and duration scores) and between the first and the second session for the visual-motor training (on velocity and number of velocity peaks scores). These fast effects clearly argue in favour of the necessity to supply to the teachers clear instructions with regard to teaching handwriting. Whereas visual-motor learning appears to be the most effective, with motor and visual training, on the other hand, it is difficult to favour one instruction method over the other. The results of the present study seem to indicate that what is lost at the quality level (in favor of the visual training) seems to be gained at the fluency level (in favor of the motor training). It is very likely that a finer distinction might emerge between these types of training by increasing the number of sessions. The assessment of the effects of the various types of training also needs to be made after a longer time period. In fact, Press, Casement, Pascual-Leone, and Robertson (2005) have shown that the time delay between training sessions plays a role in the improvement of performance on a motor task. Whether such a gain is specific to motor training or concerns visual training as well needs to be investigated. Nevertheless, it is noteworthy that a marked improvement in handwriting performance could be elicited by visual training, even in children who had no systematic practice in cursive writing. Certainly, this study needs to be confirmed and expanded, but this initial demonstration suggests the effectiveness, in teaching handwriting, of an approach supplementing copying exercises.

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