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Gouagout, Philippe; Gentaz, Edouard

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A Visuo-Haptic Device - Telemaque - Increases Kindergarten Children's Handwriting Acquisition

R. Palluel-Germain^{*}

B. Hennion[‡]

F. Bara[†]

P. Gouagout[‡]

A. Hillairet de Boisferon^{**}

E. Gentaz^{**}

(^{*})Moss Rehabilitation Research Institute, Philadelphia, USA

([†])Department of Educational Sciences, Sherbrook University, Canada

(^{**})Psychology and Neurocognition Laboratory, CNRS UMR-5105, Grenoble II, France

([‡])FranceTelecom Division Research Development, Grenoble, France

E-mail: germainr@einstein.edu, anne.hillairet@upmf-grenoble.fr, edouard.Gentaz@upmf-grenoble.fr

Abstract

The objective of the present research was to show that incorporating a visuo-haptic device 'Telemaque' may increase the fluency of handwriting production of cursive letters in kindergarten children i.e., before formal handwriting learning begins. Forty two 5 year-old children were assigned an intervention involving either Telemaque (experimental training; VH group) or not (control training; C group). The fluency of handwriting was tested before and after both interventions. Fluency was analysed by kinematic parameters: Average velocity, number of velocity peaks, and number of breaks during the production of six cursive letters (a,b,f,i,l,s). The results showed that the fluency of handwriting production for all letters was higher after the VH training than after the C training: The movements were faster, exhibited less velocity peaks and children lifted the pen less often during the letter production. These results showed that the Telemaque device may help kindergarten children to increase the proactive strategy to control handwriting movements.

1. Introduction

This study examined the effects of incorporating a visuo-haptic device -named Telemaque- in a training program designed to develop handwriting acquisition among pre-handwriting kindergarten children. Handwriting acquisition consists in learning the visual representations of letters, which are used to guide their production, and the motor representations specific to each one. This acquisition is generally slow and difficult: Several years of formal instruction are necessary before young children master this skill [1, 2]

and differentiate the path for writing and the path for drawing (they copy letters according to a model) [3, 4]. Although handwriting acquisition begins upon entry into school, handwriting skills become satisfactory only by the end of primary school. Handwriting gradually changes during learning [5, 6]. From grade 1 to grade 3, quality and speed improve steadily with age and schooling. After grade 4, a decrease in legibility and an increase in speed were observed. The developmental changes in the product and the process of handwriting could be the consequence of a change from retroactive control of movement (based on sensorial, visual and kinaesthetic feedback) to proactive control (based on an internal representation of motor acts) [1]. Indeed, at the beginning of learning, movements are slow and guided by visual and kinaesthetic feedback. With practice, writing becomes automatic and the control of movement is mostly proactive.

We argued that there is a crucial interest to understand and propose some assessment methods in order to improve this learning acquisition. Indeed, studies revealed strong links between handwriting of single letters and both reading acquisition and spelling skills [7, 8, 9, 10, 11]. Thus, handwriting plays an important role in literacy acquisition: Children must develop enough fluency so that the mechanisms of producing text do not interfere with the processes of composing and spelling. When the low-level processes of handwriting become automatic, working memory resources are freed up for the constructive high level aspects of composing [12, 13]: If the writer has to pay considerable attention to the motor constraints of handwriting, planning and text generation will be disrupted.

A way of teaching handwriting is to explain the form and the order of letter strokes in additional to

copying exercises [14, 15, 16]. Children must be able to both perceive the shape of the model and evaluate the deviation between their own handwriting product and the standard. In addition, if the process of handwriting acquisition is -at least partially- the consequence of a change from retroactive control of movement to proactive control [1] exercises developing proactive strategies would increase this skill.

Therefore, we propose that a good way to improve handwriting acquisition is to provide a letter standard that is not only static (the shape) but also dynamic (rules of motor production) in order to help children to increase the proactive strategy to control handwriting movements. Consequently, we developed an original ergonomic visuo-haptic device, named *Telemaque* [17], involving a force-feedback programmable pen. This device permitted to teach children how to reproduce a letter according to a correct shape and also to a correct movement. The kinematics applied to *Telemaque* was built according to the rules of motor production described by Viviani [18], and Lacquaniti, Terzuolo, and Viviani [19]: (1) There is a proportional and direct relationship, called *isochrony*, between the trajectory length and movement velocity (whatever the size of a letter, the time taken to write it remains constant); (2) Handwritten letters keep their spatial characteristics even if the size of the letter changes (the shape remains the same whatever the size); (3) Shape determines the movement dynamic, called the *two-thirds power law*. It means that the tangential velocity and the curvature of the trajectory are inversely related in a manner specified by this law. In a preliminary study [20] we evaluated the effects of the *Telemaque* device on twenty-two first grade children (6 years-old). Results showed that the movement time and the number of velocity peaks during the handwriting production of four cursive letters (*b, f, k, s*) decreased more after training involving *Telemaque* than after classical control training (without *Telemaque*).

The first objective of the present study was to show that incorporating this visuo-haptic device may also increase the fluency of handwriting production in kindergarten children i.e., before formal handwriting learning begins. Fluency was analysed by kinematic parameters: Average velocity, number of velocity peaks, and number of breaks during the letters production. The second objective was to examine the effects of *Telemaque* with a larger number of children (forty-two) and letters (six) than in our first study [20]. Consequently, in order to show that the *Telemaque* device may help kindergarten children increase the proactive strategy to control handwriting movements, we used a classical training design on 5-year-old children. The fluency of handwriting was tested before

and after an intervention involving *Telemaque* (experimental training) or not (control training).

2. Method

2.1. Participants

Forty-two children between the ages of 5;1 and 6;1 months at the beginning of the study (20 boys and 22 girls, $M=5;5$) from a preschool in Grenoble participated in this study. All participants spoke French as their first language and no child had a statement of special educational needs. Permission for recruitment was gained from the head teacher of the school, and written informed consent for the participation of the children was obtained from their parents.

2.2. Material and procedure

2.2.1. Pre- and post-tests

Between 1 and 2 weeks before and after the training intervention, children were individually assessed in order to measure their handwriting performances. These two sessions were carried out by the same experimenter. Children were seated comfortably in front of a table, upon which a digital tablet (Wacom®) was placed. In this measuring system, the positions of the pen were sampled at a frequency of 50 Hz and at a spatial resolution of about 0.1 mm. The pen used in order to write on the tablet was a ball-point pen (Intuos Ink Pen, Wacom®) allowed to receive feedback of the written samples. A white paper was placed on the digital tablet. After a familiarization phase in which we asked children to write on the paper their name and to produce a drawing, we asked them to copy six cursive letters (*a, b, f, i, l, s*). These letters were chosen in accordance with the teachers and in order to have some “difficult” letters (e.g., *f*) and some easier ones (e.g., *l*). Each letter was presented separately on a paper placed in front of the child. There were no time and size constraints. The order of letter presentation was counterbalanced across participants. Each test lasted approximately 15 min.

A large number of quantitative and qualitative measures may assess handwriting production. However, because *Telemaque* was built in order to improve the fluency of movement, we based our measures only on kinematic parameters. In addition, some computerized studies showed that the differences between children with and without handwriting difficulties lie not only in the written products, but also in the dynamics of handwriting performance [21, 22, 23, 24]. According to these studies, the main temporal and spatial features that differentiate the handwriting process of poor writers from proficient writers include movement

velocity, pauses at greater frequencies and a lack of continuity and fluency. Therefore, we have calculated for each letter production, the mean movement velocity, the number of velocity peaks and the number of breaks during execution. We expected that the movement production would be more rapid and would present less velocity peaks and breaks after the intervention involving Telemaque than after the control intervention (without Telemaque).

2.2.2. Training sessions

Two equivalent groups of 21 children each were formed using the criteria of handwriting performances. Therefore, twenty one children were assigned to the Visuo-Haptic (VH) intervention and twenty one to the Control (C) intervention. An intervention consisted of 6 training sessions (one per week). A specific letter (*a, b, f, i, l, s*) was learned in each session. Consequently, the intervention took 6 weeks. In each session, children were asked to perform four exercises which were proposed in a counterbalanced order across subjects. These exercises lasted approximately 20 min. Two exercises were common to the two interventions. In the first exercise, children were asked to colour the target letter represented with two borders. In the second exercise, children were asked to make a 4-piece jigsaw puzzle that represented the target letter. The size and the shape of the letter were the same in the two exercises and the same as the one produced by Telemaque (see Table 1). The two exercises specific to each intervention are described below.

Table 1. Size (in mm) of the letters produced by Telemaque in *x* (horizontal) and *y* (vertical).

Letter	Size (mm)		Letter	Size (mm)	
	<i>x</i>	<i>y</i>		<i>x</i>	<i>y</i>
<i>a</i>	24	25	<i>i</i>	20	35
<i>b</i>	20	75	<i>l</i>	18	75
<i>f</i>	20	123	<i>s</i>	17	22

2.2.2.1. The two specific exercises of the visuo-haptic (VH) intervention

In the VH intervention, children were comfortably seated in front of a table and were asked to hold a pen (14 cm in high) in a “natural” way. This pen was attached to a force-feedback arm (Phantom®) controlled by a software (see Fig.1). This working station is named Telemaque.



Fig. 1. Global and schematic view of the Telemaque working station. Children were seated in front of a table upon which the letters generated by the visuo-haptic interface were displayed on a horizontal computer screen. Children had to hold a pen attached to force-feedback arm controlled by the Telemaque software.

The letters generated by the visuo-haptic interface were displayed on a horizontal computer screen (30 cm X 22 cm). The distance between the child chest and the horizontal screen displaying the letters was constant across participants. It is to note that the pen never touched the video screen but was maintained approximately at a distance of 1.5 cm. After a familiarisation phase in which we asked children to write their name and to produce a drawing which appeared in real time on the computer screen, each child performed two exercises generated by Telemaque: the circuit game and the dynamical tracing of letters. The order of these two exercises was counterbalanced across subjects.

The circuit game. This exercise was focused on the “correct” order of a letter production. In this exercise, a letter appeared with two borders representing a road on the computer screen (see Fig. 2). Children hold the Telemaque pen and were asked to stay between the two borders. The line produced by the child appeared in real time on the screen. A force generated by Telemaque attracted the pen on the correct direction if the child veered off the correct trajectory or did not produce the letter in a correct order. In this case, the pen was attracted towards the nearest point of the letter, perpendicularly to the curve. This force was progressively reduced during the exercise. Each child executed 10 trials for each letter. For the first four trials, the strength was equal to 500g/cm. For the next two trials, the strength was 250g/cm, and it was 125g/cm for the seventh and the eighth trial. Finally for the last

ones, no strength was applied. The size of the letters produced by Telemaque and projected on the computer screen is indicated in Table 1. The distance between the two borders was 0.8 cm.

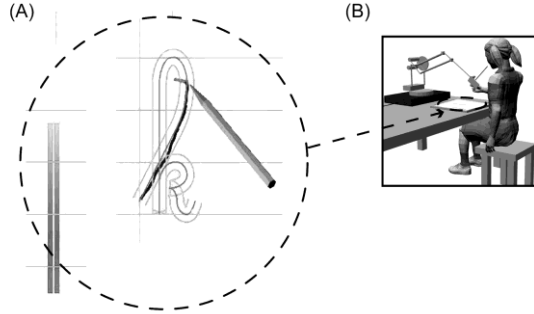


Fig. 2. The circuit game. (A) A letter appeared with two borders representing a road on the computer screen. (B) The child held a pen - represented on the video screen by a lead pencil- attached to a force-feedback arm. Children were asked to stay between the two borders. A force generated by Telemaque attracted the pen on the correct direction if the child veered off his production on the correct trajectory or did not produce the letter in a correct order.

The dynamic tracing of letters. This exercise was precisely dedicated to the dynamical aspect of handwriting. In it, children held the pen, a letter appeared on the video screen and the pen moved “alone”. The size of the letters produced by Telemaque and projected on the computer screen is indicated in Table 1. The dynamical font was used here to drive the pen at the right place in the right time in a natural way (Fig. 3): The movement generated by Telemaque followed the basic principles of writing production i.e., isochrony principle and the two-thirds power law (see Introduction).

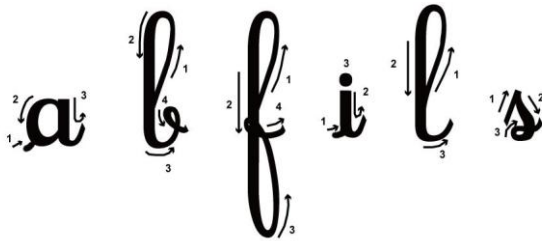


Fig. 3. The typography of each letter produced by Telemaque. The numbers inscribed above the arrows indicates the order of the production in the dynamic tracing of letters exercise.

Ten trials were performed for each letter. As in the circuit game, the Movement time production of the letter was reduced during the session (Table 2).

Table 2. Movement duration (in s) used in the Dynamic tracing of letters exercise according to the letter and the trials.

	Movement Duration (s)				Movement Duration (s)		
	Trial 1-4	Trial 5-7	Trial 8-10		Trial 1-4	Trial 5-7	Trial 8-10
<i>a</i>	5.7	4.2	3.2	<i>i</i>	5.2	3.9	2.9
<i>b</i>	6.4	4.8	3.6	<i>l</i>	4.2	3.1	2.3
<i>f</i>	11.6	8.7	6.5	<i>s</i>	3.0	2.2	1.6

2.2.2.2. The two specific exercises of the Control (C) intervention

Regarding the C intervention, we proposed one exercise in which children wrote the target letters and one exercise involving a computer as in the VH intervention. In the first exercise children sat in groups of four around a table and were asked to copy the target letter ten times on a sheet of paper and to judge which one had the “best form”. The second exercise was carried out individually as in the VH intervention. Children were comfortably seated in front of a laptop computer and they had to type on text software a sentence in which the target letter appeared frequently.

3. Results

For each parameter a three-way analysis of variance (ANOVA) was performed with repeated measures on the period (pre-and post-test) and the letters (*a*, *b*, *f*, *i*, *l* and *s*), and with an independent measures on the group (VH or C). For each analysis a significance level of 0.05 was chosen. As we hypothesised a benefit of the VH intervention on handwriting acquisition, we expected a significant interaction between the period and the group with a higher performance for the VH group in the post-test situation.

3.1. Average Velocity

Figure 4A shows the average velocity for each group according to the period. A significant interaction between the period and the group was observed, $F(1,40) = 13.96$, $p < 0.01$. In the pre-test session, the average velocity was 1.62 cm/s and 1.60 cm/s for the control and the Visuo-Haptic groups, respectively. In the post-test session the average velocity was 1.94 cm/s for the Control group and 3.23 cm/s for the Visuo-Haptic group. Furthermore this effect did not depend on the letter since no significant interaction between the group,

the period and the letter was observed, $F(5,200) = 1.08$, $p = 0.37$.

3.2. Number of velocity peaks

Regarding the number of velocity peaks during the execution of letters, a significant interaction between the period and the group was observed, $F(1,40) = 6.63$, $p < 0.02$ (see Fig. 4B). In the post-test session the number of velocity peaks was indeed less important for the VH group (7.67) as compared to the C group (10.44). In the pre-test session, the average number of velocity peaks was 13.64 and 13.04 for the VH and The C group, respectively. Finally we can notice that the interaction between group, period and letter was not significant, $F(5,200) = 0.37$, $p = 0.86$. Therefore the interaction between period and group did not depend on the letter produced.

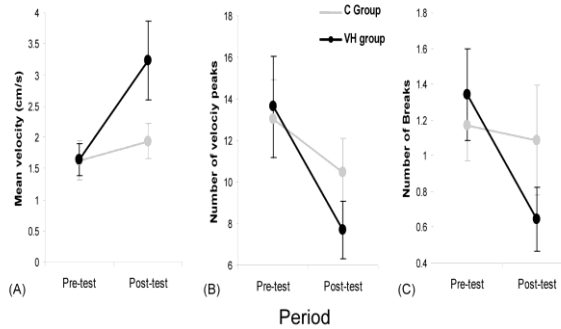


Fig.4. Results. Mean Velocity (A), Number of velocity peaks (B), Number of breaks (C) and 95% confidence intervals according to the period (pre-and post-test) and the group (VH or C).

3.3. Number of breaks

The number of breaks i.e., the number of time when children lifted the pen off the digital tablet are presented in Fig. 4C. A significant interaction between the period and the group was observed, $F(1,40) = 6.71$, $p < 0.02$. In the VH group, children made on average 1.34 pauses in the pre-test and 0.64 in the post-test. In the C group, the number of breaks was 1.16 and 1.08 in the pre- and the post-test session respectively. This effect seems did not depend on the letter since no significant interaction between the group, the period and the letter was observed, $F(5,200) = 0.91$, $p = 0.47$.

4. Discussion

The goal of the present study was to evaluate whether the use of a visuo-haptic interface (Telemaque) could improve the handwriting of cursive letters

performances in kindergarten children (5 years-old). To test this hypothesis, we used a classical training on 6 target letters (*a, b, f, i, l, s*). The results indicated that the fluency of handwriting production was improved after the VH intervention, for each letter. Indeed, after the training sessions the performances of the VH group were better than those of the control group: The average velocity improved after intervention, the movements exhibited less velocity peaks and children lifted the pen less often during the execution. Consequently, movements executed after a training involving Telemaque were more fluent. It is known that the differences between children with and without handwriting difficulties lay not only in the written products, but also in the dynamics of their handwriting performance [21, 22, 23, 24]. Therefore we can admit that the visuo-haptic intervention increases the handwriting production of cursive letters. Moreover, it is noteworthy that the results are the same whatever the difficulty of the letters. It would be interesting to verify whether this increase would be observed not only with the target letters but also with some letters not trained in the visuo-haptic intervention. Further studies were needed to examine this “cross-letter transfer” question.

At the beginning of handwriting, motor control is retroactive (based on sensorial feedback). Movements are slow and guided by visual and kinaesthetic feedback [1]. With practice, writing becomes automatic and the control of movement is mostly proactive (based on an internal representation of the motor act). Consequently, we may think that the use of Telemaque helps the motor system to incorporate the basic rules of motor production and therefore leads children to use proactive strategy to control handwriting movements. Indeed, as the Telemaque software is able to guide fingers via the pen both in spatial and dynamical movements, its aims at improving both the visual perception of the letter and the motor act which have to be produced for tracing a letter or a word.

However, in the present study, we asked participants to copy the cursive letters, a task that can be considered similar to drawing. We may wonder, therefore, whether the same results would be obtained in a spelling task i.e., a task when it is necessary to retrieve the letter stored in memory, to access the corresponding motor program, to set the parameters for the program and to execute the program. Finally, we think that this interface may be a solution in order to improve handwriting in dysgraphic children. More precisely, this remediation program should effectively act on problems of handwriting distortion, including incorrect letter forms, disconnected letters, wavy lines,

lack of loops, touched-up letters, irregular letter shapes, and incorrect size proportions among letters.

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