Does modifying visual feedback facilitate learning to write?

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Abstract. The purpose of handwriting is to produce a legible trace quickly and fluently. Learning to write therefore rely on the efficient integration of visual and proprioceptive feedback, with a transition from a control based on the written trace in writing beginners to a progressive switch to a control based mainly on writing movements in expert writers. The aim of this study was to test the effect of a partial deletion of the written trace, as well as the effect of added visual information on handwriting kinematics in a learning task. Twenty-four adults learned to write with their non-dominant hand six new pseudoletters on a touch screen digital tablet. The participants trained to trace three pseudoletters with modified visual FB conditions and the other three without any visual modification (control condition). Results revealed that, on the short-term, the pseudoletters learned with modified visual feedback were traced faster and more fluently than those learned in the control condition, without spatial accuracy reduction. This method seems to be efficient, at least in proficient adults, and is currently being tested with children with dysgraphia.

1. Introduction

Digital tablets in school classrooms encourage the development of new methods to help students learn to write, thanks to real-time computer-assisted feedback (FB). For example, it is possible to change the digital trace on the screen in order to add customized visual information. Danna & Velay (2015) have listed several strategies, one of which is changing the color of the trace in order to inform on the writing speed or the trace's thickness depending on the pressure exerted by the pen on the tablet. Both strategies have been tested in adults and appear to be promising (Loup-Escande et al., 2017). However, the possible overload of the visual information processing must be considered. Indeed, in the beginning of the handwriting learning process, visual control predominates, then gradually decreases, making way for a more predictive type of control. An efficient strategy for optimizing the learning or the rehabilitation of handwriting could rely on the facilitation of this transition from control based on the visualization of the written trace to control based on the handwriting movement. To implement this transition, it is possible to decrease the visual perception of the written trace, totally or partially, leading the writer to focus on the ongoing movement. The total deletion of visual FB has already been tested in adults who were asked to write without being able to see their hand. The authors reported a positive effect on writing speed and fluency, but the effect on the legibility of the trace has not been evaluated (Portier & van Galen, 1992). The latter was tested more recently by Bara & Bonneton-Botté (2021) who asked young children to learn isolated cursive letters without seeing the written trace. They confirmed a positive effect on the kinematics of handwriting, but the total trace deletion impacted the quality of the written trace. This deterioration can be explained by the participants' lack of knowledge about the outcome after the trial.

To our knowledge, the effects of a partial deletion of the written trace has never been tested. This method is inspired by the *Light Drawing* (or *Light Painting*, e.g., Hu et al., 2020), a photographic technique that consists on moving a light source while taking a long exposure photograph to "draw" with a light source in the air. The drawer only sees a light point at the pen tip (equipped with a light emitting diode) during the trial and sees the product of his/her performance after tracing. During tracing, the light point becomes a luminous trail that follows the moving pen. This luminous trail results from the retinal persistence, and lasts several tens of milliseconds after of a disappearance of a stimulus. As a result, the length of this luminous trail depends on the movement velocity: the longer the trail, the faster the movement. Therefore, this technique provides a real-time visual FB on both the position of the written trace and the movement velocity. We have transposed this technique on a digital tablet and tested this method of decreasing visual FB with participants who were learning to write new pseudoletters. A pilot study showed the limited effect of this strategy (Connan et al., 2021). Another condition was thus added, based on supplementary visual FB on movement fluency given after the trial. In this case, the trial was produced without modification of the written trace. The present study aims at testing the effect of this mixed method on learning to write. Since we were not sure whether such method has a positive effect on learning, we preferred to first conduct a study among adults, in whom a possible negative effect would have less impact than in children. In order to put the adults in a more difficult situation, we asked them to write new pseudoletters with their nondominant hand.

2. Method

2.1 Participant

Twenty-four right-handed adults (mean age: 24,6 +- 6,32 SD years, 22 women) volunteered for the experiment. None of the participants presented any known neurological or attentional deficits, as determined by a detailed questionnaire filled prior to the experiment. They all had normal or corrected-to-normal vision. All participants signed a written informed consent before starting the experiment.

2.2 Task and procedure

The task consisted in learning to write six new pseudoletters with the non-dominant hand (see Figure 1B). Participants were asked to write the pseudoletters on a touch screen digital tablet (Windows surface pro® 12.3 inches; sampling rate at 60 Hz) with a stylus (surface pen, HB lead). They were required to trace the pseudoletters in 4x4 cm a square placed under the model to reproduce, which remained displayed during the trial.

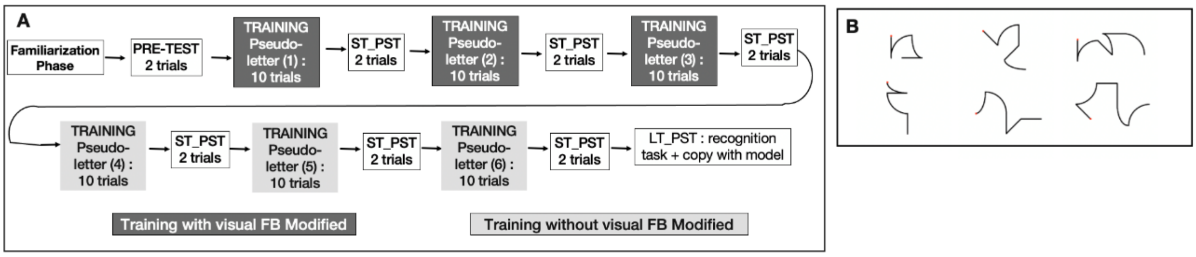

Figure 1. Description of the experimental design (A) and pseudoletters (B). The pseudoletters were created from the combination of elementary strokes. The pseudoletters were divided into two sets of three. Each set included a 4-strokes pseudoletter, a 5-strokes pseudoletter, and a 6-strokes pseudoletter. The participants learned one set in the control condition and the other one in the modified visual FB condition.

The experiment began with a short familiarization with the tablet and the two modified visual FB. The learning task included a pre-test, a training session, and two post-tests. In the pre-test (PRE), the participants had to reproduce six pseudoletters twice without FB modification. During the training session, participants wrote 10 times one of the six pseudoletters, with or without modified visual FB according to the experimental condition. Just after each training session, the participant had to reproduce twice the trained pseudoletter without FB modification (short-term post-test -ST_PST). The following day (T0 + 24h), two post-tests were performed. First, the participants had to recognize the six learned pseudoletters from a set of twenty-four pseudoletters (recognition task). The second long-term post-test (LT_PST) was exactly the same the PRE and ST_PST. The presentation order of the six pseudoletters was the same between the PRE and LT_PST. In both training and test sessions, the model remained displayed during the trial.

2.3 Visual FB Modification

During the training session under the experimental condition, two visual FB modifications were applied, a real-time visual modification during the trial (called “snake”) and a postponed additional visual FB after the trial (called “enriched postponed”). Both the snake and the postponed feedback were shown to all participants.

Snake (trials 1, 3, 5, 7, 9): The black trace of the pen's movement remained displayed for a time window of 192 ms and then disappeared. This condition created a real-time animation of a *black snake* following the pen tip movement, whose size varied according to the velocity of the pen’s movement and disappeared when the pen stopped moving. This time window has been chosen empirically from a pilot experiment (Connan et al., 2021), so that the writer is able to see the last stroke of the letter he is writing. At the end of the trial, the pseudoletter produced by the participant appeared in its entirety and the model remained displayed on the screen for visual comparison.

Enriched postponed (trials 2, 4, 6, 8, 10). During an enriched postponed trial, the writer wrote the pseudoletter with a usual visual FB of the written trace. At the end of the trial, the model and the pseudoletter produced by the participant remained displayed on the screen. Over the pseudoletter, red dots appeared wherever the movement was less fluent. These red dots corresponded to the abnormal velocity peaks determined by the Signal-to-Noise velocity peaks difference (SNvpd, Danna et al., 2013).

As can be seen in Figure 1A, three pseudoletters were trained with both “snake” and “enriched postponed” trials (modified visual FB condition) and three others were trained in control condition (without visual FB modification). The conditions and pseudoletters orders were counterbalanced between the participants.

2.4 Data analysis

Based on the position and the axial pressure of the stylus, we segmented the written signal to distinguish the tracing segments from the pen lifts. We only analyzed the written trace and computed five variables, namely a) the mean velocity (millimeters/second), b) the number of abnormal velocity peaks, c) the mean stylus pressure (arbitrary unit – A.U. – normalized between 0 and 1), d) the trace length (millimeters) that corresponds to the total distance traveled by the stylus from the contact point with the tablet up until the pseudoletter was completed and the pen was lifted from the writing surface, and e) the spatial error between the produced pseudoletter and a reference pseudoletter (for more details, see Connan et al., 2021).

A total of 2304 data were collected. Fifty trials (2.17%) were excluded for the statistical analysis because of recording problem or outliers. A comparison of performance during the tests with Omnibus tests based on a Linear Mixed Model (LMM) (LMM, GAMLj module, Galluci, 2019) were conducted with JAMOVI® (The jamovi project, 2020; R Core Team, 2019). Omnibus tests were carried out with three "Test" conditions (PRE, ST_PST, and LT_PST) and two "FB" conditions (with or without modified visual FB) as fixed factors with repeated measures, and with the "participants" and "pseudoletters" as random factors. All significance levels were set at $p = 0.05$. Fisher LSD post hoc tests with Bonferroni correction were applied for multiple comparisons.

We also tested whether the “FB” condition had an impact on the recognition of learned pseudoletters in a recognition test. No significant difference was established between the pseudoletters learned with or without the modified visual FB.

3. Results

The average evolution of velocity, movement dysfluency, and stylus pressure during the tests and the training were presented in Figure 2.

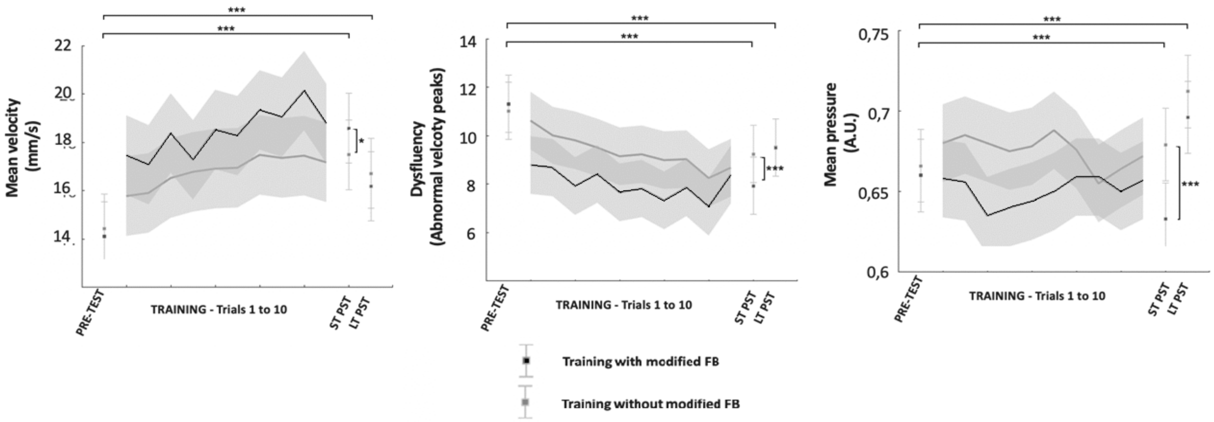

Figure 2. Mean velocity, dysfluency, and stylus pressure during the test (PRE-TEST, ST PST and LT PST) and training phases. Error bars correspond to the standard error. *Abbreviations:* ST PST: short-term post-test; LT PST: long-term post-test

Velocity: The analysis revealed a main effect of Test on velocity ($F(2,806) = 82.72$, $p < 0.001$) and a FB*Test interaction ($F(2,806) = 4.39$, $p < 0.05$). The post hoc tests revealed, both between the PRE and the ST_PST and between the PRE and the LT_PST, a significant increase for the pseudoletters learned in the control ($p < 0.001$ for both comparisons) and the modified ($p < 0.001$ for both comparisons) conditions. Interestingly, as can be seen in Figure 2 (left), the velocity at ST_PST was higher for pseudoletters learned in the modified condition than in the control condition ($p < 0.05$).

Movement dysfluency: The analysis revealed a main effect of Test ($F(2,806) = 44.79$, $p < 0.001$) and a FB*Test interaction ($F(2,806) = 6.82$, $p < 0.001$). The post hoc comparisons between PRE and ST_PST revealed a significant decrease of dysfluency for the pseudoletters learned both in the control ($p < 0.001$) and the modified ($p < 0.001$) conditions. The comparisons between PRE and LT_PST revealed a significant decrease for the pseudoletters learned in the modified condition ($p < 0.001$) whereas this difference did not reach the significant threshold for the pseudoletters learned in the control condition ($p = 0.06$). Finally, as displayed in Figure 2 (center), the dysfuency at ST_PST was lower for the pseudoletters learned in the modified condition than those learned in the control condition ($p < 0.001$).

Trace length: The analysis revealed a main effect of Test ($F(2,806) = 3.997$, $p < 0.05$). The post-hoc tests revealed that the trace length tends to increase between the PRE and the ST_PST ($p = 0.06$) and increases significantly between the PRE and LT_PST ($p < 0.05$). No difference was observed between the two post-tests. Finally, the analysis did not reveal a significant effect of FB, nor any interaction between factors.

Stylus pressure: The analysis revealed main effects of Test ($F(2,806) = 29.8$, $p < 0.001$) and FB ($F(1,806) = 16.5$ $p < 0.001$), and a significant FB*Test interaction ($F(2,156) = 4.75$, $p < 0.01$). As can be seen in Figure 2 (right), the post hoc tests revealed a significant increase of pressure between the PRE and LT_PST ($p < 0.001$) for the pseudoletters learned both in the control and the modified conditions ($p < 0.01$ for both comparisons). Surprisingly the pseudoletters learned in the modified condition was produced with a lower pressure than those learned in the control condition in the ST_PST ($p < 0.001$).

Spatial error: The analysis revealed a main effect of Test ($F(2,806) = 3.84$, $p < 0.05$). The post-hoc tests did not reveal any differences between the PRE and the two post-tests. A decrease of spatial error between ST_PST and LT_PST was observed ($p < 0.05$). The analysis did not reveal a significant effect of FB and interaction between factors.

4. Discussion

This study aimed to evaluate the effect of visual modification of the trace on a digital tablet in a pseudoletter learning task. The results revealed a short-term effect in favor of our mixed visual modification method. Writers wrote the pseudo-letters faster and more fluently, while remaining accurate, when trained with the modified visual FB than those trained in a control condition.

In this experiment, we chose a mixed FB modification strategy. In one of two trials, the partial deletion of the trace decreased spatial information but increased writing speed information (the faster the subject the longer the trace). Furthermore, we hypothesized that not seeing the shape of the letter during execution would increase the movement speed due to a decrease in online adjustments related to the visual back and forth verification between the model and the production. This hypothesis is in line with Van Doorn and Keuss (1992) who observed an increase in latency in the case of writing without being able to see the hand and stylus. This increase in latency could be consequent to the additional processing of information prior to the action, i.e. a pro-active strategy. In contrast to Bara & Bonneton's (2021) study with children, the writer had access to the full shape of the pseudoletter after the performance to verify if the shape is correct. For the following trial, we added visual information relating to the fluency of the movement once the pseudoletter was written in usual condition (without modification of the trace). The writer thus had different visual FB depending on the trial, but in both cases, the modification led the writer to focus on the writing movement. The results of our study suggested that the mixed strategy facilitated the learning process at the kinematic level (speed and dysfluency) without affecting spatial accuracy. We assume that the alternation of visual FB modifications limits the dependency phenomena, as Winstein & Schmidt (1990) already showed in the field of motor learning.

Surprisingly, we also observed that pseudoletters learned in the modified visual FB condition were produced with less pressure than those trained in the control condition. This finding is not in line with the literature. Indeed, many authors suggested that an increase in pen pressure would result from a proprioception maximizing strategy when visual FB are minimized (Van Doorn, 1992). In the present study, we deem that the partial vision of the trace allowed the participants to see the contact between the pen and the surface. This might have refrained them to press harder. Another complementary hypothesis is that the modification of the trace, which informs on the movement speed, gives a visual kinesthetic information that overrides the somatosensory channel.

On the long term, the specific benefits of the visual modification disappeared, with a positive effect of the training, regardless of the condition. It is possible that the number of trials was not important enough to obtain long term effects. In conclusion, this method seems to be efficient, at least in proficient adults. Consideration must be taken to ensure that such suppression of FB does not come at the expense of trace quality in younger children for whom visual FB is crucial, until the letter's shape representation is complete (Chartrel & Vinter, 2006). We are currently testing this method in a rehabilitation protocol with children with dysgraphia.

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