Can tablet apps support the learning of handwriting? An investigation of learning outcomes in kindergarten classroom

Nathalie Bonneton-Botté, Sylvain Fleury, Nathalie Girard, Maëlys Le Magadou, Anthony Cherbonnier, Mickaël Renault, Eric Anquetil, Eric Jamet

CRediT author statement

Nathalie Bonneton-Botté*:** Conceptualization- Methodology -Writing-Reviewing and Editing; **S. Fleury.**: Data curation- Methodology- vizualisation; ***Nathalie Girard: Software; Vizualisation-Reviewing; ***Maëlys Le Magadou***: Data Curation- Investigation. ***Anthony Cherbonnier***: Data curation- investigation ***Mickaël Renault***: Software, ***Eric Anquetil*:** Conceptualization- vizualisation- Reviewing; ***Eric Jamet***: Conceptualization, Methodology, vizualisation, Reviewing.

Can Tablet Apps Support the Learning of Handwriting? An Investigation of Learning Outcomes in Kindergarten Classroom

Nathalie Bonneton-Botté[a*], Sylvain Fleury[b], Nathalie Girard [c], Maëlys Le Magadou [d], Anthony Cherbonnier[a], Mickaël Renault [c], Eric Anquetil [c], Eric Jamet[a]

[a] Psychology of Cognition, Behavior and Communication Laboratory (LP3C), University of Rennes, Rennes, France.

[b] Arts et Metiers, LAMPA, 2 Bd du Ronceray, 49000 Angers – France

[c] University of Rennes, CNRS, IRISA, F-35000 Rennes, France

[d] Department of clinical neurosciences, University of Geneva, Geneva, Switzerland

The authors declare that they have no conflict of interest.

* Corresponding author:

Nathalie Bonneton-Botté

LP3C, Equipe d'accueil 1285, Université de Bretagne Occidentale, 29000 BREST.

nathalie.bonneton@gmail.com /0603195445

Can Tablet Apps Support the Learning of Handwriting? An Investigation of Learning Outcomes in Kindergarten Classroom

Abstract

Digital technologies are increasingly being used to support school learning, but few studies have assessed the effectiveness of these new teaching methods for very young students**.** The aim of the present study was to assess the impact of implementing a digital notebook application designed for a stylus-oriented tablet in kindergarten classrooms. This digital notebook was dedicated to the acquisition of handwriting skills by beginning writers. Using artificial intelligence to finely analyze the spatiotemporal characteristics of handwriting (i.e., shape, order and direction of the segments), the exercises were personalized, and extrinsic feedback was delivered at the end of each trial to inform learners of their results. A total of 22 kindergarten classes participated in a 12-week teacher-implemented program, half working exclusively with paper and pencil, and half partially undertaking their handwriting training with the digital notebook. A paper-and-pen writing task was administered as a pre-test and post-test to assess the progress of all the children. Data analysis showed that learning outcomes with the digital notebook were contingent upon the students' initial handwriting level, as the benefits of training with the app were only demonstrated for children with a medium level at the start of the study. The results are discussed in the light of the literature on the impact of extrinsic feedback and learners' initial levels.

Keywords: tablet apps; early years education; improving classroom teaching; handwriting.

Highlights

- We studied the impact of a digital notebook on handwriting learning in preschoolers.
- Results were compared according to pupils' initial pen-and-paper handwriting level.
- The notebook's added value was only shown for pupils with a medium initial level.
- The lack of added value for children with a high or low initial level is discussed.

1 Introduction

The acquisition of fluid, rapid and legible handwriting is key to achieving academic success and preventing problems at school (Berninger et al., 2002; Medwell & Wray, 2008). Adopting a grounded cognition perspective, several studies have found that handwriting skills seem to play a decisive role in building reading skills (Bara, Gentaz, Colé, & Sprenger-Charolles, 2004; Bartolomeo, Bachoud-Levi, Chokron, & Degos, 2002; Velay & Longcamp, 2013), and pupils with weak handwriting skills remain at a disadvantage throughout their schooling, particularly when they undergo written assessments (Rosenblum, Goldstand, & Parush, 2006). Current digital learning environments such as tablet apps are designed to scaffold the teaching and learning process (Berninger, Nagy, Tanimoto, Thompson, & Abbott, 2015; MacKenna, 2012). Nonetheless, more studies are needed to assess the beneficial effects of digital learning environments, especially when it comes to handwriting skills. Given the complexity of handwriting development and its associated difficulties and disorders, it is very important to investigate interventions such as training programs featuring a digital learning environment and to measure their efficiency. These interventions have to enable children to acquire fast and legible handwriting, in order to free up cognitive resources for higher order writing processes such as spelling (Fayol & Miret, 2005; Pontart et al., 2013; Puranik, Lonigan, & Kim, 2011).

The main purpose of the present study was to gauge whether a tablet application (digital notebook) can viably support the learning of handwriting gestures for all students equally. To consider this very topical question, we conducted a study in a school setting with an experimental pre-test-post-test design for two groups of students who practiced handwriting either in the traditional way (paper and pencil) or in the traditional way but using a tablet app for some of the activities. Handwriting progress was measured with a paper-and-pencil task, and the digitalized data were then analyzed, taking the students' initial graphomotor skills into account.

1.1 Handwriting Skills Acquisition

Handwriting can be described as a rapid and precise motor action that begins with the progressive construction of visual and motor representations of letters. At the beginning of learning, young children mainly use intrinsic and extrinsic feedback (i.e., visual and kinesthetic information about the body and the handwriting trace) from their own movements (necessarily slow, so sensory information is collected and used) to produce and control the graphic traces (Danna & Velay, 2015). As with all motor learning, they can also potentially take account of information about the result generated by self-evaluation or contained in their teacher's verbal feedback, which can be considered as extrinsic feedback (Patchan & Puranik, 2016; Schmidt & Lee, 2005). As a result of learning and development, a form of complementarity is gradually established between motor programs and movement control processes, through the processing of sensory information and knowledge about the result. This complementarity is only really achieved at around 10 years, at which point handwriting becomes increasingly rapid and fluid (Danna & Velay, 2015; Zesiger, Deonna, & Mayor, 2000).

Thibon, Gerber, and Kandel (2018) recently clarified this developmental sequence, showing that the motor programs of children under 8 years mainly contain information about a single segment, whereas children aged 8 years and older use motor programs that contain information about several segments. This modification of the motor programs is generally referred to as *chunking*. The automatization of low-level handwriting processes gradually leads to the simultaneous control of high-level orthographic, lexical or syntactic processes (Alamargot, Plane, Lambert, & Chesnet, 2010), allowing for the development of expertise in handwriting production.

To sum up, young novice writers are initially highly dependent on feedback to control their handwriting movements, but with learning and training, they gradually construct a motor memory for letters (i.e., motor programs) with increasingly large chunks. Although this developmental sequence of handwriting acquisition is now quite clearly defined, less is known about the role of learning, and more especially the role of extrinsic feedback (i.e., results about the static and dynamic characteristics of the writing product) during the learning process.

1.2 Learning and Teaching Handwriting

The amount of practice and training determines handwriting quality (Hoy, Egan, & Feder, 2011). However, the amount of time spent teaching handwriting in elementary schools varies from two minutes to one hour per day, at least in the United States (Graham et al., 2008). In France, since 2002, the syllabus for kindergarten has stated that by the end of their final year, children must be able to write some words with cursive allographs. In 2006, official literacy documents highlighted the importance of the teacher's presence during the learning process: "Cursive writing is used in situations monitored by the teacher, who will check each child's progress in stroke direction, and letterforms and their ligatures" (MEN, 2006; p.111 [translated from the French]). In the scientific literature on motor training, recommendations refer to the beneficial role of feedback in the form of knowledge of results (KR), and consequently of one-to-one instruction in the motor learning process (Salmoni, Schmidt, & Walter, 1984; Schmidt & Lee, 2005). However, this demand constitutes a challenge for French teachers, given their large class sizes (up to 30 children) and their pupils' widely diverging rates of learning (X et al., 2019).

As with all motor learning, the development of handwriting skills depends to some extent on the quantity and quality of sensory and KR feedback (Danna & Velay, 2015; Schmidt & Lee, 2005). The *guidance hypothesis* suggests that increasing KR feedback to an optimum level helps adult learners to correct their movements (Salmoni et al., 1984). Moreover, it seems that during motor learning, partial reinforcement of trials forces adults to actively engage in a problem-solving process. By contrast, giving too much feedback may render individuals passive, at the expense of learning. Another hypothesis put forward to explain the negative impact of systematic augmented feedback is that its inherent cognitive load prevents the processing and exploitation of intrinsic sensory feedback (Wulf & Shea, 2004). Although the guidance hypothesis promotes augmented feedback during motor skill practice as a means of improving adult learners' motor learning, the same benefits do not necessarily extend to child learners. Sullivan, Kantak, and Burtner (2008) exposed young adults and 10-year-old children to motor learning of a discrete arm movement with specific spatiotemporal parameters. Participants were randomly assigned either to systematic augmented feedback (100% of trials reinforced) or to reduced feedback (62% faded). Unlike the adults, the children who received gradually reduced feedback performed more poorly on a retention test. The authors concluded that children use feedback in a different way from adults, and may require longer periods of practice to optimize their motor learning. These results underline the extent to which**,** at least for a gross motor activity**,** the modeling of feedback effects requires a better understanding of the interactions between intrinsic and extrinsic feedback during motor learning. The authors concluded that the contribution of each type of feedback should be examined with regard to the specificity of the task (e.g., gross or fine motor task) and the developmental abilities of the learner.

To be effective in motor learning, KR must either inform pupils of their errors and provide the correct answers (Kluger & Denisi 1996) or inform them about their progress and/or how to proceed (Hattie & Timperley, 2007). Quick and immediate access to KR allows pupils to adapt their learning in real time. Children can receive KR in the form of production feedback (e.g., teacher's debriefing covering the static and dynamic aspects of the written product), but regulation by teachers is probably the type that is most often delayed, and logistical constraints mean that the static (i.e., legibility and size) and dynamic (kinematics of motion including production rules, speed or fluidity of writing gesture) aspects of the written product are rarely taken into account at the same time (Bonneton-Botté et al., 2019). By contrast, digital tablets enable data to be analyzed automatically and so provide near realtime feedback. When equipped with a stylus, they can potentially be used as a handwriting teaching aid, delivering augmented feedback in the form of KR (Simonet, Anquetil, & Bouillon, 2017).

1.3 Digital Tablet Apps for Learning to Write

For several years now, new technologies have been emerging to scaffold pupils' learning (Berninger et al., 2015; MacKenna, 2012; Puntambekar & Hübscher, 2005; Warschauer, 2007). In the field of educational research, assistive technologies and software have been designed to teach specific aspects of literacy and to facilitate the teaching-learning process through one-to-one instruction (Chickering & Ehrmann, 1996; Van Der Kleij, Feskens, & Eggen, 2015). However, a recent critical review completed by Haßler, Major, and Henessy (2015), concerning the effectiveness of learning on tablets at school, highlighted a lack of rigorous studies measuring learning outcomes and a lack of assessments involving the use of tablet technology by practitioners and their students over a sustained period of time.

To date, literacy studies investigating the effectiveness of digital tools have mainly addressed this issue in terms of text production. As a teaching aid, these technologies offer new opportunities by facilitating collaborative writing (Choi, Kang, & Lee, 2008; Warschauer, 2007) and self-assessment (Dragemark-Oscarson, 2009). Researchers have also observed increased commitment to the task, compared with the written production of text on paper (Rogers &

Graham, 2008). Berninger et al. (2015) found that students with learning difficulties in Grades 4-9 made significant progress in writing, spelling, and syntax after undergoing 36 hours of tablet writing sessions.

These issues should be considered in relation to the use of stylus-equipped digital tablets for the teaching and learning of writing gestures by beginning writers. Some studies have shown that because it involves less friction than a sheet of paper, writing on a tablet can disrupt the control strategies of young children (Alamargot & Morin, 2015) and, to a lesser extent, those of adults (Gerth et al. 2016). To our knowledge, only one recent study has so far explored the impact of extrinsic feedback on 4 year-old preschoolers learning to write uppercase letters with pencil and paper or on a tablet with a stylus or finger. Although Patchan and Puranik (2016) did not find any positive effect of extrinsic feedback provided by a tablet on pupils learning to write with a stylus versus pupils learning with pencil and paper, they did find a significant and positive effect for the group who learned to write letters on a tablet using their finger. This study focused on the number of correctly written uppercase letters (i.e., letter shape) and not on the dynamic properties of handwriting movements (i.e., number, order and direction of strokes). Moreover, the chosen app (“L’escapadou” for iPad) systematically provided feedback as soon as an error was made, which may, in the opinion of the authors, have disrupted the encoding process.

1.4 The current study

Digital learning environments could be designed to assist the teaching process, by 1) allowing for one-to-one personalized instruction, and 2) systematically providing immediate augmented feedback in the form of explicit KR. Just such an application was designed as part of our IntuiScript project. This app, based on the use of a tablet with stylus, can provide realtime feedback to children by automatically analyzing their writing. This feedback is delivered immediately after a trial, in the form of KR (i.e., information about the legibility, size, order and direction of the letterstrokes), and so does not interrupt the writing movement (Chickering & Ehrmann, 1996; Hattie & Timperley, 2007; Simonnet et al., 2017; Van Der Kleij et al., 2015). We worked on the assumption that augmented feedback is beneficial for learners who are experiencing difficulties (Kluger & Denisi, 1996; Salmoni, Schmidt, & Walter, 1984), as our digital environment can quickly deliver KR on both static (i.e., letter quality) and dynamic (i.e., gesture quality) aspects of handwriting, whereas teachers' feedback is generally delayed, and logistical constraints (i.e., high number of students in a class) mean that the static and dynamic aspects of writing are rarely taken into account at the same time (Bonneton-Botté et al., 2019).

In the particular case of handwriting on a tablet, the processing of perceptual and motor information may be disturbed by the nature of the medium (Alamargot & Morin, 2015; Gerth et al., 2016) and the writing instrument (Patchan & Puranik, 2016). However, these studies only evaluated the impact of the medium in a short session, thus making it impossible to consider the children's ability to adapt their motor strategy over a longer period. Quasi-experimental studies designed to measure the benefits of a handwriting app in a school context should allow teachers and students plenty of time to familiarize themselves with the tool (Haßler, Major, & Henessy, 2015; Van der Kleij et al., 2015). This was done in Patchan and Puranik (2016)'s study, but the authors raised the issue of the handwriting movements being interrupted by the augmented feedback. As a consequence, the first aim of the present study was to resolve this issue by evaluating the long-term (12 weeks) use of tablets in the classroom with an app providing real-time-but less intrusive-feedback.

Our review of the literature also revealed that learners' initial level was not considered in previous studies of handwriting, in contrast to other types of motor learning (Sullivan et al., 2008). And yet their initial level may interact with the effect of the medium, as well as with the ability to benefit from increased feedback during a handwriting task. Given the potentially antagonistic effects of feedback and moderate writing difficulties, the present exploratory study sought to extend current understanding of the effects of writers' initial level on learning gain with tablets or traditional instruction.

Lastly, the digital handwriting environment should be designed to ensure the transferability of learning to the paper medium. The final evaluation in our study therefore took the form of a transfer task.

In sum, the aim of the current research was to broaden our understanding of the efficiency of handwriting learning programs by evaluating the effects of an app providing immediate augmented feedback on the writing skills of 5 to 6 year-olds, an age at which French preschoolers begin to learn cursive writing. These effects were assessed in three original ways with regard to the state of the art, by 1) undertaking a lengthy study in a natural setting to compare two teaching programs, one featuring traditional handwriting instruction, the other traditional handwriting instruction that included activities with the app, 2) considering the influence of the writers' initial level in this comparison, and 3) assessing writing skills at the end of the program with a pencil-and-paper transfer task.

2 Methods

2.1 Participants

A total of 233 preschoolers (111 girls and 122 boys) aged 5-6 years (mean age = 5;4) took part in the experiment. They were recruited from 22 preschools in the region of Brittany in France**.** All participants were in their final year of kindergarten (kindergarten lasts 3 years in France). All were typically developing children, recruited from schools in a medium-sized city. None of them had visual or motor impairments. We obtained written informed parental consent for each child. All the schools were attended by children with medium socioeconomic status.

2.2 School Context for Tablet Group and Traditional Group

Before the study, the researchers conducted interviews with the children’s teachers to establish their handwriting teaching practices and their use of digital learning environments. Before the study, none of the classes had used tablets for teaching pupils. All the teachers stated that they followed the French syllabus, according to which pupils should be taught the names and sounds of the letters of the alphabet and how to write them. In September, at the start of the school year, all the teachers had focused on the writing of capital letters. In December, they had introduced cursive writing into writing activities. Letters were presented either in isolation or in context (i.e., in a word, usually a firstname or a short word linked to an ongoing project). Activities dedicated to the teaching of handwriting were done either on paper with a pencil or pen, or on a slate or whiteboard with an erasable felt-tip pen. From September to November, the weekly time allocated to teaching and writing was 20 minutes on average. Cursive was introduced between November and December, depending on the teacher, and the weekly time allocated to teaching and practicing handwriting was 40 minutes on average from December onwards.

2.3 Material

2.3.1 Tablet and Stylus

The stylus-oriented tablet we used was a Galaxy Tab A 10.1 (WUXGA display with a resolution of 1920 x 1220 pixels, multi-touch screen, Marshmallow 6.0 android operating system, 1.6 GHz octo-core processor). The stylus was an S Pen (2048 pressure points, wireless connectivity: 802.11a/b/g/n, Bluetooth 4.2).

2.3.2 Application

The Kaligo[1] app was installed on each tablet. This app, developed during the IntuiScript[2] project for the Script&Labs LabCom[3], is a digital workbook providing extrinsic feedback (i.e., KR). By using the workbook on the tablet, children can work autonomously, as they are given online and realtime feedback each time they have to write a letter, digit, or word. The basic feedback concerns shape, direction, order of the strokes and continuity (intra-stroke pen lifts), and is materialized by a colored gauge (Simonnet et al., 2017; Simonnet, Girard, Anquetil, Renault, Thomas, 2019; see Fig. 1). This gauge indicates the overall quality of production (in the form of a horseshoe colored from red to green, with a star in the middle if the letter or set of letters is sufficiently like the model; see Fig. 1 for different colored horseshoes for the letter *a*). When the teacher wants the student to respect the proportions between the letters in a word, she/he chooses to have them written in spaces, in which case additional feedback is produced: pink rectangles show where a letter is taller or shorter than expected, and a tag inserted in the colored horseshoe indicates that there is a size problem (e.g., see Fig. 2 for feedback delivered for the letters *l* and *i* for the bigram *li* in the word *lion*). This feedback was systematically delivered on completion of each letter, so as not to interrupt the child’s activity. During the latter, the part of the model to be

---

[1] https://www.kaligo-apps.com/en_GB/homepage.html

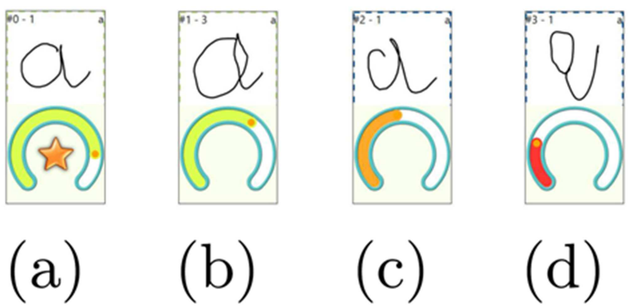
[2] https://www-intuidoc.irisa.fr/en/projet-intuiscript%E2%80%AF-cahier-numerique-pour-laide-a-lapprentissage-de-lecriture-a-lecole/

[3] https://scriptandlabs.irisa.fr/en/

copied (i.e., letter, bigram, trigram or word) was shown in bold and located at the top of the screen and at the side (left side for right-handed students and right side for left-handers). Before the children started writing in the dedicated (and customizable) space, the model was first displayed dynamically, in order to help them write in the right way. Each model could be replayed whenever the child clicked on it (see Fig. 3).

[Insert Fig. 1: colored figure]

Figure 1: Four trials for the letter *a*, with different levels illustrated by the colored horseshoes.



[Insert Fig. 2: color figure]

Figure 2: Three trials and their feedback for the bigram *li* in the word *lion.*

[Insert Fig. 3: color figure]

Figure 3: Dynamic models with the stylus showing the right way to write *lun* at the top of the screen, and also to the left of the writing area.

The automatic analysis of handwriting allows children's graphomotor level to be assessed, so that the pedagogical scenarios can be automatically adapted and different exercises given. Several handwriting features are evaluated, especially letter shape, handwriting direction and stroke order in cursive handwriting. When capital letters are analyzed, the order of the strokes is also taken into account, in order to check that the writing goes from left to right (Simonnet et al., 2017) and to look for intra-stroke pen lifts (a lift occurs when the pressure within a stroke is equal to 0). Unexpected pauses in the middle of a stroke are considered in the analysis, but not inter-letter pen lifts**.** For the purpose of the present study, the analysis process was tuned to respect the French Education Ministry's recommendations. This automatic analysis has been demonstrated to be equivalent to assessment by a teacher (Simonnet et al., 2019). The scoring was identical for all children and all schools. During a written activity on Kaligo, the app's artificial intelligence checks whether the child has been successful. If not, the requested task is simplified. For example, if a child fails to join two letters in a bigram, the app automatically suggests working on each letter separately first. Pupils each work at their own pace. The children's successful and unsuccessful productions are stored in a notebook and their teachers can visualize them at any time via a dashboard. This dashboard enables teachers to manage the pedagogical scenarios they want to follow in their teaching activities. They can select several exercises (writing letters/words in capital/cursive letters, writing numbers), and in each exercise they can either choose from a stock of available words or add new words, depending on the topics tackled in class.

2.4 Procedure

The children were divided into two experimental conditions: the children in nine of the schools (n = 138) used the Kaligo app (tablet group), while the children in the remaining 13 schools (n = 95) did not use the app (traditional group). The teaching programs were implemented by the children's regular teachers. Teachers were school employees, and none were affiliated to this university research project prior to the study. We deliberately chose to implement the instructional programs in the children's normal learning setting, in order to strengthen the link between innovative research and typical teaching activities. It is rare for teachers to directly implement research interventions, even though two meta-analyses (Ehri et al., 2001; Piasta & Wagner, 2010) have shown that, in the literacy domain, teachers are just as effective as researchers. Additionally, when researchers do the teaching, their involvement is typically limited to the duration of the research, whereas when teachers introduce new interventions, they are apt to internalize the educational goals of the research and continue using the program to benefit future students (Piasta & Wagner, 2010). Finally, Haßler et al. (2015) strongly recommended relatively long periods of experimentation: “if successful pedagogical approaches are to be comprehensively documented, that future evaluations involve use of tablet technology with practitioners and their students over a sustained period of time” (p. 150).

At the end of the study, the teachers in the tablet group were interviewed to evaluate how they had used the app during the experimental period in the pilot classes. Five teachers had used the tablet app several times a week, and four had used it once a week. Teachers estimated the mean duration of a writing on the tablet to be 20 minutes per child and per week (i.e., 50% of the time allocated to handwriting training). All the teachers had used both training modules ("I write in capitals" and "I write in cursive”), but they also reported supplementing the tablet app’s activities with writing activities on paper or whiteboard. All nine teachers we interviewed stated that the modules were in line with their educational objectives.

Interviews with the teachers in the traditional group allowed us to check the amount of time they had allocated to handwriting learning and the learning conditions. The teachers stated that, like the teachers in the tablet group, they had spent an average of 40 minutes per child per week on teaching handwriting. Their students had worked individually or in workshops of three or four students, depending on the class. None of the teachers reported using a digital medium to teach writing during the experimental period.

2.5 Pre- and Post-tests

This study was a between-groups comparative study featuring the classic experimental design: pre-test–training–post-test. Both groups underwent the pre-test, administered by two experimenters, between November and December of their last year in kindergarten. Over the subsequent 12 weeks (from the beginning of December to mid-April, excluding the holiday periods), they received either traditional education or traditional education that included activities on the digital notebook. The post-test was conducted at the end of April by the same experimenters, 2 weeks after the end of the experimental period. Children performed the pre- and post-tests in groups of five or six, quietly in their school classroom. During a short test session (approx. 30 minutes) led by two experimenters, the children had to copy letters, bigrams, words and pseudowords (*a*/*t*/*o*/*b*/*ti*/*la*/*co*/*le*/*muet*/*beurre*/*hulle*/*cemi*) in cursive allographs in a pen-and-paper condition (the sheet of paper was placed on a digital notepad). To limit the influence of the child’s handedness, the model was displayed above the box in which children had to copy the item. Given the age of the children, the box did not contain any lines to write on. To control for an effect of fatigue or learning effects during the task, we created two protocols to counterbalance the order of the items. The tests were carried out on a sheet of paper attached to a Wacom notepad (Bamboo Slate Large). This digital notepad converted the handwritten traces into digital files, and the quality of the children’s productions was then evaluated using an algorithm that yielded a score (between 0 and 1) taking different characteristics related to legibility and kinematics into account (Dinehart, 2015**;** Simonnet et al., 2017). This score reflected the overall quality of the child's production, and the higher the score, the closer the production was to the model. It reflected the shape of the written trace (legibility), its direction, the order of the letters, and the pencil lifts inside each stroke (kinematic; i.e., writing process). Each item (i.e., letter, bigram, word or pseudoword) was scored between 0 and 1. We averaged each child’s scores separately for the pre-test and the post-test. As we assumed that the app would have a differential effect, depending on the learners’ initial graphomotor level, we segmented the initial scores into three parts: 0.28 < low ≤ .37, n = 68 (including 44 students from the tablet group); .37 < medium ≤ .46, n = 107 (including 59 from tablet group); and 0.46 < high < .56, n = 58 (including 35 students from the tablet group).

3 Results

3.1 Group Balance

There were 73 boys and 64 girls in the tablet group, and 49 boys and 47 girls in the traditional group. Left-handers accounted for 7.3% of the children in the tablet group, and 8.3% of those in the traditional group (handedness was determined by the teachers and verified during the pre-test). The equivalence of the two experimental groups was verified using chi-square tests. This analysis revealed that the tablet group and traditional group did not differ on either sex, $\chi^2(1) = .11$, $p = .419$, or handedness, $\chi^2(2) = 2.99$, $p = .224$. Moreover, a *t* test comparing their writing levels before the beginning of the experiment revealed that the two groups did not differ, $t(231) = -1.24$, $p = .217$. Mean scores were 0. 41 (*SD* = 0.061) for the tablet group and 0.42 (*SD* = 0.062) for the traditional group.

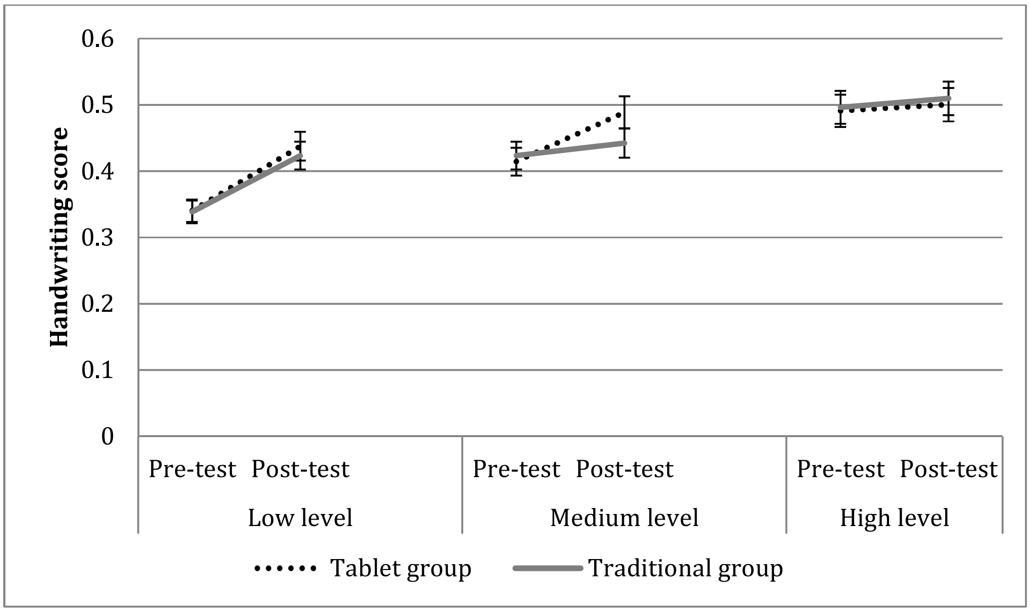
3.2 Group Comparisons According to Beginning Writers' Initial Level

Figure 4 shows the mean handwriting scores and standard deviations for the two groups according to the participants' initial mean score (low, medium, or high).

To compare the impact of teaching program (including digital tablet vs. pen-and-paper only) between pre- and post-testing, we subjected these scores to a 2 (teaching program) x 3 (initial level) x 2 (time) analysis of variance (ANOVA). Teaching program and initial level were the two between-participants factors, and time (pre-test vs. post-test) was the within-participants factor. This analysis failed to reveal a main effect of experimental condition, $F(1, 231) = 1.26$, $p = .261$, but there were significant main effects of time, $F(1, 231) = 106.78$, $p < .001$, and initial level, $F(1, 231) = 114.14$, $p = .001$. There was no interaction effect between experimental condition and initial level, $F(1, 231) = 0.006$, $p = .16$. There was an interaction effect between time and experimental condition, $F(1, 231) = 4.78$, $p = .03$, and between initial level and time, $F(1, 231) = 19.66$, $p = .001$. Finally, analysis revealed a three-way interaction effect between experimental condition, initial level and time, $F(1, 231) = 3.95$, $p = .03$. Post hoc tests were performed using Tukey's honestly significant difference (HSD) set at the .05 level. These revealed a significant effect of experimental condition, but only for children with a medium initial level. No learning effect was observed for students with a high initial level in either experimental group. Students with a low initial score made significant progress between the two measures, whatever the experimental condition.

[Insert Fig. 4: no color]

Figure 4: Mean handwriting scores and standard deviations at pre- and post-test for the two groups (tablet and traditional) according to participants' initial mean score (low, medium, or high).



4 Discussion

For many years, digital learning environments have been developed for education and learning, and have found their place across all education levels, from kindergarten to university (PBS Learning, 2015). These technologies provide a means of enriching the learning environment, especially when they allow for learning to be personalized. Personalization makes it possible to take the individual learner's interests, abilities, procedures and possibilities into account (Traxler & Whishart, 2011). Among these technologies, tablets have a special place in the field of education, owing to their maneuverability, low cost, and appeal to students (Haßler et al., 2015). As the new stylus-oriented tablets allow the palm of the hand to rest on the screen while writing on the screen with the stylus, they are quite suitable for handwriting learning. They could therefore potentially provide a useful learning environment for beginning writers, especially if the tablets are equipped with an app that uses artificial intelligence to analyze the production and give the writer feedback in the form of KR (XX et al., 2017). However, studies allowing tablet learning outcomes to be objectified are scarce (Dirh, Gahwaji, & Nyman, 2013). In the field of handwriting, results are scant and quite mixed, and the methodologies and digital devices used are very different, thus making it impossible to reach firm conclusions (Patchan & Puranik, 2016). The goal of the current study was to extend our understanding of learning to write when traditional instruction includes activities with a tablet app providing immediate augmented feedback and personalized guidance. We assumed that improving the one-to-one instruction and delivering immediate feedback in the form of KR would help to develop handwriting skills (i.e., improve the legibility and kinematic characteristics of cursive letters), as measured with a pencil-and-paper writing transfer task after a 12-week series of classroom training sessions for kindergarten pupils. However, given Sullivan et al. (2008)'s recommendation to examine the effect of feedback in terms of learner level, and the potentially antagonistic effect between feedback and moderate writing difficulties, we predicted that differential effects would be observed, depending on the initial handwriting level of the novice writers. Although KR usually benefits learning, adults who receive systematic feedback become passive and learn less efficiently than when they receive reduced feedback (Sullivan et al., 2008). However, this outcome may depend on the level of the learner, as these authors found that 10-year-olds did not benefit from reduced feedback and instead learned better when they were given systematic extrinsic feedback. In our study, learning was evaluated by considering the learners' level at the beginning of the experiment, as measured by the overall score delivered by the app. Three levels (low, medium, high) were considered for this analysis, and revealed some contrasting effects of the app. The scores of students with a high initial performance level remained unchanged, regardless of the experimental condition. There may have been a threshold effect, such that the tasks in the pre- and post-tests did not make it possible to highlight the progress made during the experimental period. A study with more complex items might have allowed us to identify a difference between the two groups. Moreover, it would be useful to assess the value of providing reduced feedback to students with a high initial level of handwriting. For participants with a medium graphomotor level at the beginning of the study, progress measured by a paper-based test was significantly greater when learning was done partially with the tablet app than when it was done entirely traditionally. This result is far from trivial, for to our knowledge, no experiment has so far shown that young children can practice their handwriting gestures using a tablet app equipped with a stylus, and that this learning is transferable to a paper task. A critical review conducted by Haßler et al. in 2015 highlighted a dearth of studies focusing on learning outcomes for tablet use by schoolchildren, as most studies primarily examined the motivational affordances of tablets. Of the 23 relevant studies (i.e., focusing on learning outcomes) reviewed by the authors, only 16 reported positive learning outcomes, and none concerned handwriting gestures. Furthermore, tablets' low degree of friction, compared with paper, may hinder the learning of handwriting by young children, as observed by Alamargot and Morin (2015) in a short training session. The positive learning outcomes measured in our study mean that students with a medium initial level managed to adapt their strategy of control to the tablet's degree of friction, probably owing to the length of the learning period (i.e., 12 weeks) and the characteristics of the app. In any event, this particular feature of the tablet did not prevent them from learning. Our results differ from those obtained by Patchan and Puranik (2016), who failed to observe a positive effect of letter-writing training with a stylus-oriented tablet for children aged 4 years. It should be stressed that the students in this study were younger and their initial level was not taken into account. Furthermore, the authors used an app that did not analyze all the essential characteristics of the written product (i.e., shape, direction, number of strokes) and which interrupted the child's writing activity as soon as a mistake occurred. Moreover, in our opinion, the many animations that were added to entertain the learners may have disrupted the learning process. Finally, in contrast to our digital notebook, the learning process was not personalized, and children did not receive precise KR after writing a letter or a word. KR provided at the end of a performance (Danna & Velay, 2015; Hattie & Timperley, 2007; Schmidt & Lee, 2005) and one-to-one instruction (Chickering & Ehrmann, 1996; Van Der Kleij et al., 2015) are both critical factors identified in the literature that could potentially explain the positive effects we observed with our tablet group.

Pupils with the lowest scores at the beginning of the study significantly improved their writing performance, as measured by the transfer task, whether they were in the tablet group or the traditional (control) group. As the effects were comparable, it is not possible to conclude that the use of the tablet app specifically enhanced learning over the period we assessed. However, as the students in the tablet group made substantial progress between the pre- and post-tests, our experiment at least allowed us to conclude that the app can provide teachers with a viable way of allowing students with a low graphomotor level to train independently with Kaligo during some of the time devoted to teaching handwriting. The absence of a difference between the two conditions suggests that the students gave too little consideration to the feedback they received. If the feedback given to the students was too demanding, some of them may have become resigned themselves and ceased to consider it. A differentiated score setting that allows feedback to be delivered according to the children's initial graphomotor level could be considered in future experimental protocols. In addition, these students with low graphomotor level may not be able to handle composite feedback that incorporates both spatial and kinematic indicators. Additional studies are therefore needed to assess the effects of presenting these two forms of feedback separately, and students' ability to interpret their meaning. It is also important to consider the impact of the pen/stylus, as the stylus had a smaller diameter than that of a conventional pen, making it harder to hold. Although there has been little research in this area and results regarding the pen's impact on writing performance are contradictory (Schwellnuss et al., 2013), Patchan and Puranik (2016) reported that children performed significantly better when they wrote letters on a tablet with their finger rather than with a stylus. Our group of beginning writers may therefore have been more sensitive than other groups to the characteristics of the writing tool. A criterion-based observation of this tool (Schneck and Henderson, 1990) during the training and test phases would have shed light on this point, and a complementary study comparing Kaligo learning with a finger versus stylus would allow us to extend our understanding of the mechanisms elicited by the test. A longer training time (Haßler et al., 2015, recommend 1 year) might have revealed significant differences between students in the two groups, similar to those observed in intermediate-level students.

To sum up, using a pencil-and-paper transfer task, we showed that a digital environment providing one-to-one instruction and delivering KR to learners can bring added value in complex motor learning such as handwriting, but this benefit depends on the characteristics of the learners, and in particular their initial graphomotor level.

The present study had the advantage of being conducted over a relatively long period (i.e., 12 weeks) and in a natural, real-life situation at school during handwriting lessons. Nevertheless, it also had several limitations. First, an observation across an entire school year would have been more relevant for objectively estimating the impact of using this type of app in class. This amount of time is needed for practitioners to find the pedagogical organization that suits them best and learn how to use the teacher's dashboard to program personalized exercises, and for students to really take advantage of working autonomously. Second, although we chose to measure children's performance before and after using a digital notebook in class, the present study did not allow us to precisely analyze the types of exercises and the degree of personalization achieved for each child during the digital notebook activities. Our large sample would in any case have generated too great a volume of data over the 12 weeks for us to process. In addition, the tablet connection times were not reliable enough for us to infer durations of use, as students could leave the tablet connected without using it. A complementary study with a didactic aim would make it possible to study the ways in which teachers use the potentialities of the digital notebook to optimize the didactic and pedagogical organization of the sessions.

Finally, although the objective of the study was to show that it is worthwhile using a tablet app to support the teaching of handwriting, we acknowledge that we are not currently able to say precisely why we observed the effects we did. One-to-one instruction, KR augmented with spatial and/or kinematic indicators, availability of the dynamic handwriting model, and the appeal of tablets could all, either separately or combined, explain the positive effects we observed for students with a medium initial level. Further studies are needed to isolate and measure the impact of each of these four factors when a tablet app is used. Indeed, an ongoing experimental study is evaluating the specific impact of augmented feedback on writing performances.

5 Conclusions

Most research indicates that practitioners see digital tools as being potentially useful in the context of emerging literacy (Burnett, 2010; Flewitt, Messer, & Kurcirkova, 2014; Lankshear & Knobel, 2003). However, some professionals remain unconvinced, while others assume that digital learning is systematically beneficial. Some assessments of tablet use in schools show strong resistance on the part of French teachers, who fail to grasp the potentialities (X et al., 2019; Ferrière, Cottier, Lacroix, Lainé & Pulido, 2012). Although policies recommend the use of tablets in kindergarten, studies providing evidence of their effectiveness are extremely scarce, especially in the field of handwriting for beginning writers. More studies need to be conducted, in order to provide tangible evidence of learning on a tablet, both to help teachers objectively consider the limits and advantages of assisted learning, and to deepen our understanding of the relationships between students' developmental level and their learning potential. Our study showed that a stylus-oriented tablet app (i.e., Kaligo) can support handwriting learning in kindergarten pupils. Depending on the children's initial graphomotor level, learning is either comparable or superior to learning with traditional methods. From this point of view, by objectifying the added value of a digital learning environment, we hope that this research will encourage teachers to take the characteristics of their students into account when using a tablet app for educational purposes. During tablet learning, the amount of feedback and the nature of the medium (degree of friction of the touchscreen) and the writing instrument may well be destabilizing factors for some students. Future research should allow us to better understand the conditions under which young learners, regardless of their characteristics, can benefit from these digital devices.

Acknowledgments

This study was part of a 3-year research project (IntuiScript; http://intuiscript.com/) funded by the French Government as part of its innovative projects initiative (BPI). It was also supported by the Script&Labs LabCom funded by the French National Research Agency (ANR-16-LVC2-0008-01). The authors are grateful to their industrial partner (Learn&Go), the education experts of Rennes local education authority, ESPE, Brittany Regional Council and the LOUSTIC laboratory for their collaboration.

References

Alamargot, D., & Morin, M.-F. (2015). Does handwriting on a tablet screen affect students' graphomotor execution? A comparison between Grades Two and Nine. *Human Movement Science*, *44*, 32–41. doi:10.1016/j.humov.2015.08.011

Alamargot, D., Plane, S., Lambert, E., & Chesnet, D. (2010). Using eye and pen movements to trace the development of writing expertise: Case studies of a 7th, 9th and 12th grader, graduate student, and professional writer. *Reading and Writing*, *23*(7), 853-888.

Bara, F., Gentaz, E., Colé, P., & Sprenger-Charolles, L. (2004). The visuo-haptic and haptic exploration of letters increases the kindergarten-children's understanding of the alphabetic principle. *Cognitive Development*, *19*, 433-449.

Bara, F., Morin, M.-F., Alamargot, D., & Bosse, M.-L. (2016). Learning different allographs through handwriting: The impact on letter knowledge and reading acquisition. *Learning and Individual Differences*, *45,* 88–94. doi:10.1016/j.lindif.2015.11.020

Bartolomeo, P., Bachoud-Lévi, A. C., Chokron, S., & Degos, J. D. (2002). Visually- and motor- based knowledge of letters: Evidence from a pure alexic patient. *Neuropsychologia*, *40*, 1363-1371.

Berninger, V. W., Nagy, W., Tanimoto, S., Thompson, R., & Abbott, R. D. (2015). Computer instruction in handwriting, spelling, and composing for students with specific learning disabilities in grades 4–9. *Computers & Education*, *81*, 154–168. doi:10.1016/j.compedu.2014.10.005

Berninger, V. W., Vaughan, K., Abbott, R. D., Begay, K., Coleman, K. B., Curtin, G., & Graham, S. (2002). Teaching spelling and composition alone and together: Implications for the simple view of writing. *Journal of Educational Psychology*, *94*(2), 291-304. doi:10.1037/0022-0663.94.2.291

Bonneton-Botte, N., Beucher-Marsal, C., Bara, F., Muller, J., Corf, L. L., Quéméneur, M., & Dare, M. (2019). Teaching cursive handwriting: A contribution to the acceptability study of using digital tablets in French classrooms. Journal of Early Childhood Literacy, 146879841983858. doi:10.1177/1468798419838587

Burnett, C. (2010). Technology and literacy in early childhood educational settings: A review of research. *Journal of Early Childhood Literacy*, *10*(3), 247–270. doi:10.1177/1468798410372154

Chickering, A. W., & Ehrmann, S. C. (1996). Implementing the seven principles: Technology as lever. *AAHE Bulletin*, *49*, 3-6

Choi, S. Y., Kang, Y. S., & Lee, H. (2008). The effects of socio-technical enablers on knowledge sharing: An exploratory examination. *Journal of Information Science*, *34*(5), 742-754

Danna, J., & Velay, J. L. (2015). Basic and supplementary sensory feedback in handwriting. *Frontiers in Psychology*, *6*. doi:10.3389/fpsyg.2015.00169

Dhir, A., Gahwaji, N. M., & Nyman, G. (2013). The role of the iPad in the hands of the learner. *Journal of Universal Computer Science*, *19*(5), 706-727.

Dinehart, L. H. (2015). Handwriting in early childhood education: Current research and future implications. *Journal of Early Childhood Literacy*, *15*, 97–118.

Dragemark Oscarson, A. (2009). Collaboration in understanding results – Self-assessment of EFL Writing. (n.d.). *Collaboration in Language Testing and Assessment*. doi:10.3726/978-3-653-01526-3/15.

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, D. M., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read: Evidence from the National Reading Panel's meta-analysis. *Reading Research Quarterly*, *36*, 250‑287.

Fayol, M., & Miret, A. (2005). Écrire, orthographier et rédiger des textes. *Psychologie Française*, *50*(3), 391-402

Ferrière, S., Cottier, P., Lacroix, F., Lainé, A., & Pulido, L. (2012). Dissémination de tablettes tactiles en primaire et discours des enseignants: Entre rejet et adoption. *Sciences et Technologies de l'Information et de la Communication pour l'Éducation et la Formation*, *20*, 153-176

Flewitt, R., Messer, D., & Kucirkova, N. (2014). New directions for early literacy in a digital age: The iPad. *Journal of Early Childhood Literacy*, *15*(3), 289–310. doi:10.1177/1468798414533560

Gerth, S., Dolk, T., Klassert, A., Fliesser, M., Fischer, M. H., Nottbusch, G., & Festman, J. (2016). Adapting to the surface: A comparison of handwriting measures when writing on a tablet computer and on paper. *Human Movement Science*, *48*, 62–73. doi:10.1016/j.humov.2016.04.006

Graham, S., Harris, K. R., Mason, L., Fink-Chorzempa, B., Moran, S., & Saddler, B. (2008). How do primary grade teachers teach handwriting? A national survey. *Reading and Writing*, *21*(1-2), 49-69.

Haßler, B., Major, L., & Hennessy, S. (2015). Tablet use in schools: A critical review of the evidence for learning outcomes. *Journal of Computer Assisted Learning*, *32*(2), 139–156. doi:10.1111/jcal.12123

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112. doi:10.3102/003465430298487

Hoy, M. M. P., Egan, M. Y., & Feder, K. P. (2011). A systematic review of interventions to improve handwriting. *Canadian Journal of Occupational Therapy*, *78*(1), 13–25. doi:10.2182/cjot.2011.78.1.3

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: A historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin*, *119*(2), 254–284. doi:10.1037/0033-2909.119.2.254

Lankshear, C., & Knobel, M. (2003). New technologies in early childhood literacy research: A review of research. *Journal of Early Childhood Literacy*, *3*(1), 59–82. doi:10.1177/14687984030031003

McKenna, C. (2012). There's an app for that: How two elementary classrooms used iPads to enhance student learning and achievement. *Education*, *2*(5), 136–142. doi:10.5923/j.edu.20120205.05

Medwell, J., & Wray, D. (2008). Handwriting–a forgotten language skill? *Language and Education*, *22*(1), 34-47.

Ministère de l'Education Nationale (2006). Documents d'accompagnement: Le langage au cœur des apprentissages [Accompanying documents: Language at the heart of learning]. Retrieved from http://eppee.ouvaton.org/spip.php?article66

Patchan, M. M., & Puranik, C. S. (2016). Using tablet computers to teach preschool children to write letters: Exploring the impact of extrinsic and intrinsic feedback. *Computers & Education*, *102*, 128–137. doi:10.1016/j.compedu.2016.07.007

PBS Learning Media (2015). The future of digital learning. Retrieved from https://gpb.pbslearningmedia.org/resource/26524f73-498a-4607-ae61-66d6a8903e1f/the-future-of-digital-learning

Piasta, S. B., & Wagner, R. K. (2010). Developing early literacy skills: A meta-analysis of alphabet learning and instruction. *Reading Research Quarterly*, *45*(1), 8‑38.

Pontart, V., Bidet-Ildei C., Lambert E., Morisset, P., Flouret, L., & Alamargot, D. (2013). Influence of handwriting skills during spelling in primary and lower secondary grades. *Frontiers in Psychology*, 4, 818. 10.3389/fpsyg.2013.00818

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, *40*(1), 1–12. doi:10.1207/s15326985ep4001_1

Puranik, C., Lonigan, C. J., & Kim, Y. S. (2011). Contributions of emergent literacy skills to name writing, letter writing, and spelling in preschool children. *Early Childhood Research Quarterly*, *26*, 465‐474. doi: 10.1016/j.ecresq.2011.03.002

Rogers, L. A., & Graham, S. (2008). A meta-analysis of single subject design writing intervention research. *Journal of Educational Psychology*, *100*(4), 879–906. doi:10.1037/0022-0663.100.4.879

Rosenblum, S., Goldstand, S., & Parush, S. (2006). Relationships among biomechanical ergonomic factors, handwriting product quality, handwriting efficiency, and computerized handwriting process measures in children with and without handwriting difficulties. *American Journal of Occupational Therapy*, *60*(1), 28-39.

Salmoni, A. W., Schmidt, R. A., & Walter, C. B. (1984). Knowledge of results and motor learning: A review and critical reappraisal. *Psychological Bulletin*, *95*(3), 355–386. doi:10.1037/0033-2909.95.3.355

Schneck, C. M., & Henderson, A. (1990). Descriptive analysis of the developmental progression of grip position for pencil and crayon control in nondysfunctional children. *American Journal of Occupational Therapy*, *44*(10), 893–900. doi:10.5014/ajot.44.10.893

Schmidt, R. A., & Lee, T. D. (2005). *Motor control and learning. A behavioral emphasis* (5th ed.). Champaign, IL: Human Kinetics.

Schwellnus, H., Carnahan, H., Kushki, A., Polatajko, H., Missiuna, C., & Chau, T. (2013). Writing forces associated with four pencil grasp patterns in grade 4 children. *American Journal of Occupational Therapy*, *67*(2): 218–227. doi:10.5014/ajot.2013.005538

Simonnet, D., Anquetil, E., & Bouillon, M. (2017). Multi-criteria handwriting quality analysis with online fuzzy models. Pattern Recognition, 69, 310–324. doi:10.1016/j.patcog.2017.04.003

Simonnet, D., Girard, N., Anquetil, E., Renault, M., & Thomas, S. (2019). Evaluation of children cursive handwritten words for e-education. Pattern Recognition Letters, 121, 133–139. doi:10.1016/j.patrec.2018.07.021

Sullivan, K. J., Kantak, S. S., & Burtner, P. A. (2008). Motor learning in children: Feedback effects on skill acquisition. *Physical Therapy*, *88*(6), 720–732. doi:10.2522/ptj.20070196

Thibon, L. S., Gerber, S., & Kandel, S. (2018). The elaboration of motor programs for the automation of letter production. *Acta Psychologica*, *182*, 200–211. doi:10.1016/j.actpsy.2017.12.001

Traxler, J., & Wishart, J. (2011). *Making mobile learning work: Case studies of practice.* Bristol: ESCalate, HEA Subject Centre for Education, University of Bristol. Retrieved from http://escalate.ac.uk/8250

Van der Kleij, F. M., Feskens, R. C., & Eggen, T. J. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research*, *85*(4), 475-511.

Velay, J. L., & Longcamp, M. (2013). Motor skills and written language perception: Contribution of writing knowledge to visual recognition of graphic shapes. In Y. Coello & A. Bartolo (Eds.), *Language and Action in Cognitive Neuroscience*, 161-176. doi:10.4324/9780203095508

Warschauer, M. (2007). The paradoxical future of digital learning. *Learning Inquiry*, *1*(3), 219–219. doi:10.1007/s11519-007-0022-0

Wulf, G., & Shea, C. H. (2004). Understanding the role of augmented feedback. *Skill Acquisition in Sport: Research, Theory and Practice*, 121-144.

Zesiger, P. E., Deonna, T., & Mayor, C. (2000). L'acquisition de l'écriture. *Enfance*, *53*(3), 295-304.

Acknowledgments

This study was part of a 3-year research project (IntuiScript; http://intuiscript.com/) funded by the French Government as part of its innovative projects initiative (BPI). It was also supported by the Script&Labs LabCom funded by the French National Research Agency (ANR-16-LVC2-0008-01). The authors are grateful to their industrial partner (Learn&Go), the education experts of Rennes local education authority, ESPE, Brittany Regional Council and the LOUSTIC laboratory for their collaboration