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Using tablet computers to teach preschool children to write letters: Exploring the impact of extrinsic and intrinsic feedback

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ABSTRACT

With the increasing popularity of touchscreen devices, using technology to support young children's learning has become more accessible. However, given the relative novelty of tablet computers, the research regarding their effectiveness in education is limited. The current study extends findings of current research demonstrating that tablet computers helped students improve writing, reading, and math abilities of elementary students by examining how tablet computers could support the development of preschool children's writing ability. We explored the effects of two types of feedback afforded by tablet computers: concurrent, extrinsic feedback (i.e., feedback provided by a tablet computer as soon as an error was made) and intrinsic feedback (i.e., naturally occurring sensory information resulting from practicing writing with one's finger). Preschool children (ages 41–65 months) learned to write eight uppercase letters in small groups three times a week for eight weeks in one of three ways: paper and pencil, tablet computer and finger, or tablet computer and stylus. The number of letters correctly written on a paper-and-pencil posttest depended on the instructional condition. Those who practiced writing with a stylus on a tablet computer wrote a similar number of letters correctly at posttest as those who practiced using paper and pencil. This result suggests that concurrent, extrinsic feedback did not provide an additional benefit over the visual feedback in this context. More interestingly, those who practiced writing with their finger on a tablet computer wrote more letters correctly at posttest than those who practiced using a stylus on a tablet computer. This finding indicates that an enhanced tactile experience was more beneficial for learning to write on a tablet computer than increasing the similarity between the practice tasks and the transfer task. However, whether the use of tablet computers is superior to practicing with one's finger on paper worksheets remains an open question. Several future directions are offered.

1. Introduction

Over the past three decades, more educators and researchers are recognizing the significance of the preschool years for the development of later academic skills. Alarmingly, as many as 35% of children in the United States enter public schools with

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such low levels of skills and motivation that they are at substantial risk of early academic difficulties (Boyer, 1991; Zill & West, 2001). These early academic difficulties have serious, long-term consequences. For example, children who experience early difficulties in learning to read and write are likely to continue experiencing problems with reading and writing throughout their school years (Aram & Levin, 2004; Felton, 1998; Shatil, Share, & Levin, 2000), and these problems permeate into adulthood (Bruck, 1998). Thus, the broad goal of the current study is to consider how the ways we provide support to young children shape their development.

1.1. Supporting learning with technology

Many children are exposed to technology at an early age, and exposure to mobile devices in particular is growing across the world. For example, access to mobile devices in the homes of US families with young children is increasing—mobile device usage increased by 23% from 52% in 2011 to 75% in 2013, and specifically tablet computer usage increased by 32% from 8% in 2011 to 40% in 2013 (Rideout, 2013). Moreover, as reported by Rideout (2013), children were using mobile devices for longer periods of time (45 min a day in 2011 to 67 min a day in 2013). Children have similar access to technology in schools—81% of US PreK-12 teachers reported using personal computers or laptops in their classroom, 58% using interactive whiteboards, and 52% using tablet computers (PBS LearningMedia, 2015). Given the pervasiveness of technology in young children's lives, we are particularly interested in how technology can support young children's development—and more specifically, emergent writing.

Prior research on technology benefits in preschool classrooms in the US, Australia, and Greece has demonstrated that computers can be used to improve a variety of skills, including early literacy skills and early mathematical skills (Moxley, Warash, Coffman, Brinton, & Concannon, 1997; Shute & Miksad, 1997; Vernadakis, 2005). These benefits have been attributed to several features afforded by technology, including computer animations, immediate and targeted feedback, increased locus of control, and increased engagement with the instructional material (R. Shute & Miksad, 1997).

With the introduction of Apple's iPad in 2010, the popularity of tablet computers in educational institutions has increased in many countries including, the US, United Kingdom, Australia, New Zealand, and South Korea (W. Clark & Luckin, 2013; Heinrich, 2012; Henderson & Yeow, 2012; Johnson, Adams Becker, Estrada, & Freeman, 2015; Neumann & Neumann, 2013, 2015; Plumb, Kautz, & Tootell, 2013; Saenz, 2011). However, as noted in these reviews, research regarding the effectiveness of tablet computers in education is limited given the novelty of the technology.

Prior research has demonstrated how tablet computers could be used in the classroom (Beschorner & Hutchison, 2013; Hutchison, Beschorner, & Schmidt-Crawford, 2012). For example, in Norway, preschool children used tablet computers to create digital books, and teachers used tablet computers to check the weather during their opening routine (Sandvik, Smerdal, & Osterud, 2012). Prior research also examined the usability of tablet computers with young children, finding that children from a London nursery school interacted with the technology in ways that differed from the interactions with traditional materials (Crescenzi, Jewitt, & Price, 2014). Although several gains and losses associated with tablet computers were identified, tablet computers in general promoted an increase in mark making similar to traditional materials with images (Price, Jewitt, & Crescenzi, 2015). Overall children from a primary school in the UK were able to easily execute a variety of touch-screen gestures (e.g., ‘click’, ‘slide’, ‘swipe’), however they had some difficulty with others that typically involved timing, like ‘select’, ‘long click’, and ‘double-click’ (McKnight & Fitton, 2010). These children also experienced problems with unintentional movements and touches. Despite numerous technical issues, US children as young as preschool were not easily frustrated, and many children commented that using the tablets was easier than using traditional materials (Couse & Chen, 2010).

Surprisingly, only two studies to date have empirically tested the effectiveness of using tablet computers for instruction. In fourth through ninth grades located in the US, students with diagnosed specific learning disabilities significantly improved their handwriting, spelling, and syntax abilities after completing 36 h of writing lessons on tablet computer (Berninger, Nagy, Tanimoto, Thompson, & Abbott, 2015). In first and second grades located in the US, students showed greater improvement in both reading and math when tablet computers were incorporated into their lessons (McKenna, 2012).

Although these initial results look promising, more research is needed to determine if and how tablet computers support learning. In the current study, we explore two types of feedback that are likely to support learning to write letters with tablet computers: 1) scaffolding and extrinsic feedback and 2) intrinsic feedback. Furthermore, we consider the importance of task similarity for transfer to other classroom activities.

1.2. Scaffolding & extrinsic feedback

Scaffolding and feedback are often seen as critical components to the learning process (Chi & Wylie, 2014; Hattie & Timperley, 2007; Kluger & DeNisi, 1996; Koedinger, Corbett, & Perfetti, 2012; Nelson & Schunn, 2009; Shute, 2008; VanLehn, 2011; Wood, Bruner, & Ross, 1976). Despite the importance of scaffolding, this one-on-one instruction is often impractical in classroom settings. Rather than adjusting the level of scaffolding to match an individual child, the teacher must try to meet the needs of multiple children simultaneously. For example, preschool teachers tended to utilize low support strategies that were less suitable for children who struggle with a task (Pentimonti & Justice, 2009).

Provided the continual advancements in technology, researchers have been investigating how technology in general can be used in the classroom to support learning and deliver more individualized, one-on-one instruction (for a recent review, see

Van der Kleij, Feskens, & Eggen, 2015). Using theories of learning and cognition as well as observations of human tutors, computer tutors have been used to improve a variety of skills throughout the elementary grades, including mathematics (Arroyo, Beck, Beal, Wing, & Woolf, 2001; Hwang, 2003; Rau, Aleven, & Rummel, 2009, Rau, Aleven, & Rummel, 2012), literacy (Kegel & Bus, 2012; Mayo, Mitrovic, & McKenzie, 2000; Steinhart, 2001), and science (Luckin & du Boulay, 1999).

Information provided by an external source (coming or operating from outside) during and after one performs a task, is often referred to as extrinsic or augmented feedback—henceforth referred to as 'feedback' (Schmidt & Wrisberg, 2008). This type of feedback differs from visual feedback, which also derives from an external source. Unlike extrinsic feedback, visual feedback occurs naturally, and it requires some internal processing before the learner detects an error. Therefore, visual feedback is considered to be a form of intrinsic feedback rather than extrinsic feedback. The conditions that influence feedback effectiveness are complex, and specific features of effective feedback have been largely disputed (for a review, see Mory, 1996, 2004).

One such factor is the timing of feedback. From a reinforcement perspective, feedback that closely follows a response would be most effective, however, it is unclear how closely the feedback should follow the response. Although several studies have found that a delay in feedback was effective, these effects might be limited to special experimental circumstances (Dempsey, Driscoll, & Swindell, 1993; Kulhavy, 1977; Kulik & Kulik, 1988). For the acquisition of motor skills, immediate terminal feedback (i.e., feedback that is provided immediately after completing a task) can be effective, however, there is a risk that learners will become dependent on the feedback and struggle when feedback is no longer available (Schmidt, Young, Sinnen, & Shapiro, 1989). Similarly, concurrent feedback (i.e., feedback that is provided during the actual motor action) has improved performance during the practice of motor skills and with computer tutors (Dyer, Stapleton, & Rodger, 2015; Mononen, 2007; Schmidt, 1997; VanLehn, 2011). However, as with the immediate terminal feedback, a learner might become overly dependent on the feedback and perform even worse on posttests than those who practiced without this feedback (Schmidt, 1997). A recent review of the effects of concurrent feedback revealed that it was not possible to make any general conclusions about the efficiency of concurrent feedback (Sigrist, Rauter, Riener, & Wolf, 2013). Although earlier studies found that concurrent feedback was less helpful for simple tasks, more recent studies found that concurrent feedback was more helpful for complex tasks, especially when provided earlier in the learning process.

Given the importance of scaffolding and extrinsic feedback in tutoring and for young children in particular, we wanted to further examine how these supports provided by educational technology could shape preschool children's writing development. The findings about concurrent, extrinsic feedback in particular inform our first hypothesis.

Hypothesis 1. *Concurrent, extrinsic feedback will best support young children's writing development, such that preschool children who receive feedback from a tablet computer as soon as an error is made while practicing writing uppercase letters will write more letters correctly on a paper and pencil, letter writing task at posttest than those who did not receive this concurrent, extrinsic feedback (see* Fig. 1-*H*1).

To make this comparison more robust, we compared students who practiced writing using a stylus versus pencil. Thus, differences between these conditions could be attributed to the feedback provided by the tablet computers rather than the utensils needed to perform the tasks (Clark, 1983).

1.3. Intrinsic feedback

Learning how to write is unique from learning to read or learning math in that it includes a motor component. For handwriting, success requires visual information about the letter (i.e., orthography), fine motor control, as well as visual-motor integration. Given the need to coordinate information from multiple senses while writing, intrinsic feedback is also likely to be important. Intrinsic feedback refers to the naturally occurring sensory information resulting from movement (Schmidt & Wrisberg, 2008). There are two types of intrinsic feedback. First, exteroception refers to feedback from sources outside of the body or at a distance from the body. For example, visual feedback would result from seeing the product of one's

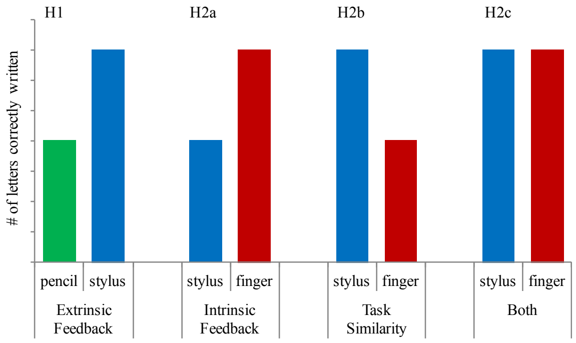

Fig. 1. Predictions for hypothesis 1 and hypothesis 2.

writing. Second, proprioception refers to feedback that occurs inside the body. For example, kinesthetic feedback would result from feeling one's hand move in a particular direction while writing.

Evidence demonstrating how even expert writers rely on this intrinsic feedback can been seen in studies that varied paper smoothness. For example, adults experienced difficulty writing on surfaces with low friction (e.g., coated paper), which resulted in writing slower with more pressure (Chan & Lee, 2005; Wann & Nimmo-Smith, 1991). Similar difficulties could occur when writing on tablet computers—that is, using a plastic or rubber tipped stylus on the smooth surface would likely produce very little friction. Indeed, legibility was reduced when writing with a stylus on a tablet computer compared to writing with paper and paper (Alamargot & Morin, 2015). Moreover, the more experienced writers (i.e., ninth grade students) adjusted for this difficulty by writing faster and using more pressure, while the less experienced writers (i.e., second grade students) paused longer between strokes. How these adjustments might affect children just learning to write is still unclear.

These studies inform our hypothesis that young children's writing development may be best supported while using their finger on tablet computers—that is, children using their finger on tablet computers will not only experience similar visual and kinesthetic feedback as those writing with a pencil on paper, but they will also have an enriched tactile experience. The additional proprioception information (i.e., haptic feedback) resulting from direct contact of one's finger while writing is also expected to strengthen one's memory of the letter in comparison to the sensation that would be mediated by a pencil or stylus. Moreover, using one's finger rather than a stylus would likely result in more friction, and thus change the intrinsic information available while writing. For young children, using a stylus could result in longer pauses between strokes and possibly disrupt connections between the visual and haptic information.

One possible limitation to practicing writing with a finger would be how well the skill transfers to other writing activities that involve writing with a utensil, such as a pencil. The success of transfer often depends on the overlapping units between the learning task and the transfer task (Anderson & Singley, 1993; Kieras & Bovair, 1986; Taatgen, 2013; Thorndike & Woodworth, 1901). For novel and complex situations, both adults and children tend to focus on surface similarities, which leads to poor transfer on tasks that have a similar underlying structure but differ on the surface (Anderson, 1987; Brown, 1988; Chi, Feltovich, & Glaser, 1981). Although explicit training or instruction that encourages reflection upon relational similarities can improve the probability of transfer, this training is often less successful with young children (Bransford, Brown, & Cocking, 2003; Chen & Klahr, 2008). These findings inform our hypothesis that young children's development of handwriting may best be supported while using a stylus on tablet computers.

We therefore contrasted ways to use tablet computers: one that emphasized an enriched tactile experience (i.e., using a finger) and one that emphasized the similarity to other classroom writing activities (i.e., using a stylus). Three hypotheses emerged from this prior research:

Hypothesis 2a. *Intrinsic feedback (i.e., enriched tactile experience resulting from direct contact of one's finger while writing) is more important to young children's development than task similarity, such that preschool children who practice writing uppercase letters using their finger will write more letters correctly on a paper and pencil, letter writing task at posttest than those who practice writing using a stylus (see Fig. 1-H2a).*

Hypothesis 2b. *Task similarity is more important to young children's development than intrinsic feedback, such that preschool children who practice writing uppercase letters using a stylus will write more letters correctly on a paper and pencil, letter writing task at posttest than those who practice writing using their finger (see Fig. 1-H2b).*

Hypothesis 2c. *Both intrinsic feedback and task similarity are equally important to young children's development, such that preschool children who practice writing uppercase letters using their finger will write the same number of letters correctly on a paper and pencil, letter writing task at posttest as those who practice writing using a stylus (see Fig. 1-H2c).*

2. Method

2.1. Participants

Participants were recruited from 10 classes in six preschools. A range of socioeconomic status (SES) backgrounds was represented. Two preschools were low-SES with more than 75% of the students receiving subsidiaries, one preschool was mid-SES with 25–49% of the students receiving subsidiaries, and three preschools were high-SES with less than 25% of the students receiving subsidiaries.

As part of the screening process, a pretest assessing children's letter knowledge was administered to all the children in attendance. To be eligible for participation, children had to demonstrate that they were just beginning to write using conventional letters, which was determined using two criteria. First, since instruction involved teaching children to write eight target letters, children who were able to write most of the letters at pretest (i.e., more than 18 letters) were not eligible to participate. Out of the 113 preschool students who were screened, 84 students met this requirement. Second, children should be able to write at least three letters at pretest or correctly name at least 17 letters at pretest. A total of 65 students met both requirements. Because instruction was provided in small group format, groups of two or three children were formed from these potentially eligible children. Children from the same preschool were matched with other children who had no prior writing knowledge of the same eight target letters. Children whose writing knowledge did not overlap with any of the other eligible children in their school were excluded from the study. This selection process resulted in a total of 54 participants in 21 small groups.

Each small group was randomly assigned to one of the three conditions: iPad finger, iPad stylus, and paper and pencil. During the eight weeks of instruction, eight children moved—four from the iPad finger condition, two from the iPad stylus condition, and two from the paper and pencil condition. Thus, of the 46 participants who completed the study, 16 children practiced writing with an iPad and their finger, 14 children practiced writing with an iPad and a stylus, and 16 children practiced writing with paper and pencil. These participants ranged in age from 41 months to 65 months ($M = 51.9$, $SD = 5.4$) with 57% of the children being female. The sample included 48% Caucasians, 46% African-Americans, 4% Hispanic, and 2% Asian.

2.2. Measures & coding process

Prior to and following the instruction period, all participants completed two individual assessments: letter naming and letter writing. Assessments were conducted in the students' classroom using paper and pencil and took approximately 15 min per child. The assessments were administered and scored by trained research assistants (RAs).

2.2.1 Letter naming. To measure children's letter naming knowledge, they were asked to name all 26 letters of the alphabet presented individually in a random order. The letter naming score was the number of correct responses out of 26.

2.2.2 Letter writing. To measure children's letter writing knowledge, they were asked to write the uppercase form of each letter presented verbally in a random order. The letter writing score was the number of correctly written letters. A letter was considered correct if it demonstrated complete or partial knowledge (e.g., reversal or inverted letters, missing or extra strokes) of the letter. To examine scoring fidelity, 15% of the writing assessments were double-coded. Inter-rater reliability was high (90% agreement).

2.3. Procedure

Trained RAs provided instruction to the children three times a week for eight weeks. A different letter was taught each week for a total of eight target letters. Each of the 21 small groups was taught a different set of eight letters depending on the letter writing knowledge of the children in the group. Across the small groups, all 26 letters of the alphabet were taught. To confirm that this variation was not confounded by condition, the average letter writing difficulty was calculated for each participant using the difficulty parameter (i.e., higher values represent more difficult letters) estimated by Puranik, Petscher, and Lonigan (2012). A one-way, between-subjects ANOVA revealed that there was a significant difference between the conditions, $F(2, 32) = 7.22$, $p = 0.002$. Least Significant Difference (LSD) post-hoc tests confirmed that children in the paper and pencil condition were taught easier letters than the iPad stylus condition (see Fig. 2). This difference only sets a high bar for the experimental conditions.

Each lesson lasted approximately 20 min. The lesson began with the RA introducing or reviewing the letter of the week, including the name, sound (along with several words that begin with the letter sound), and how to write the letter. The RA modeled writing the letter three times while verbally describing the strokes. To model writing for all three conditions, the RA used a dry erase marker and a large laminated poster that was propped up on an easel.

Then the children practiced writing the letter for 5 min. Participants in the iPad conditions used the Writing Wizard app by L'Escapadou. After the appropriate letter was selected, the app first modeled how to write the letter, and then the child attempted to write the letter. If the child strayed too far from the model, the app stopped the child and provided scaffolding by placing an arrow where the student should restart. Upon successful completion of the letter, the child touched the refresh button to try again. The app also provided the option to hide the model so that the children could practice writing freehand. Those in the iPad finger condition practiced writing with their finger, while those in the iPad stylus condition practiced writing with a chunky stylus that resembled a fat pencil commonly used with preschoolers. Participants in the paper and

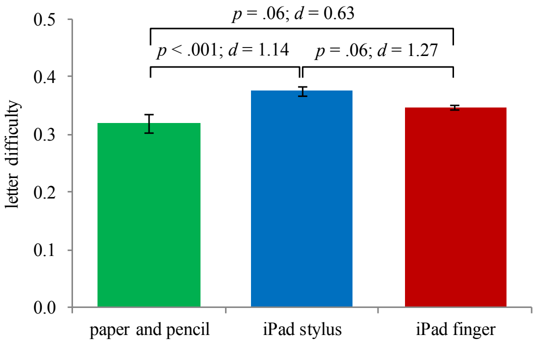

Fig. 2. Average letter instruction difficulty by condition.

pencil condition practiced writing the letter using worksheets typical of preschool writing instruction that were created using an add-on feature of the Alphabet Tracing app by FunLittleApps. Practice involved both tracing model letters as well as writing the letter freehand. During this practice, the RA spent most of her time keeping the children focused on the task. For example, children in the paper and pencil condition needed encouragement to continue writing, whereas children in the iPad conditions needed reminders to push the refresh button after completing the letter. Occasionally, children needed help with forming the letters, and the RA was careful to provide similar support across the conditions. This support typically involved repeating the verbal instructions that described the strokes in the letter and pointing where to start.

After the children finished the first writing session, they completed a supplemental activity that either focused on the letter name (e.g., identifying the target letter among foil letters by tapping it with a fly swatter), the letter sound (e.g., creating 'My Alphabet Books' by pasting pictures that started with each target letter sound), or the letter shape (e.g., using bingo daubers to fill in the letter on a worksheet). Then the children practiced writing for five more minutes. At the conclusion of the lesson, the RA reviewed the letter name, letter sound, and verbal instructions describing how to form the letter.

Within one week of the last writing lesson, the children again completed the letter naming task and the letter writing task. These posttests were conducted individually in the students' classroom using paper and pencil.

3. Results

A series of one-way, between-subjects ANOVAs revealed no preexisting differences between the instructional conditions on any of the pretest measures nor were there differences in age or gender. Chi-Square tests also revealed no differences in SES or ethnicity. The only variables significantly correlated with the posttest letter writing scores were the pretest letter naming scores, $r\,(44) = 0.42$, $p < 0.001$, and the pretest letter writing scores, $r\,(44) = 0.33$, $p < 0.001$. Therefore, we included these measures of pretest as covariates.

A between-subjects ANCOVA revealed that there was a significant difference between the conditions for the posttest letter writing score, $F\,(2, 41) = 7.07$, $p = 0.002$. LSD post-hoc tests were used to test our hypotheses. Hypothesis 1 was not supported—children in the stylus condition wrote a similar number of letters correctly as children in the paper and pencil condition (see Fig. 3-H1). Hypothesis 2a was supported—children in the iPad finger condition wrote more letters correctly than children in the iPad stylus condition (see Fig. 3-H2). This pattern of results was also consistent when analyzed without the covariates. A between-subjects ANCOVA revealed that there was no significant differences between the conditions for the posttest letter naming score ($M = 5.9$; $SD = 2.3$), $F\,(2, 41) = 1.55$, $p = 0.22$.

A one-way, between-subjects ANOVA of the average number of practice trials per letter confirmed that these differences were not just the result of more practice (see Fig. 4). The children in the paper and pencil group practiced writing each letter more often than children in both iPad conditions, and there was not a significant difference between the iPad conditions, $F\,(2, 43) = 42.9$, $p < 0.001$.

4. Discussion

The goal of the current study was to consider how technology could support young children's emergent writing skills. In particular, only a few prior studies empirically tested the effectiveness of using tablet computers for instruction and found a benefit for students in first through ninth grades in writing, reading, and math (Berninger et al., 2015; McKenna, 2012). The current study provides additional support for using tablet computers to teach preschool children how to write their uppercase letters. We further examined the influence of two factors afforded by tablet computers (i.e., extrinsic and intrinsic feedback) on the development of children's writing ability.

First, we expected that the concurrent, extrinsic feedback provided by a tablet computer would best support preschool children learning to write uppercase letters because it was provided while the child was still thinking about the form of the

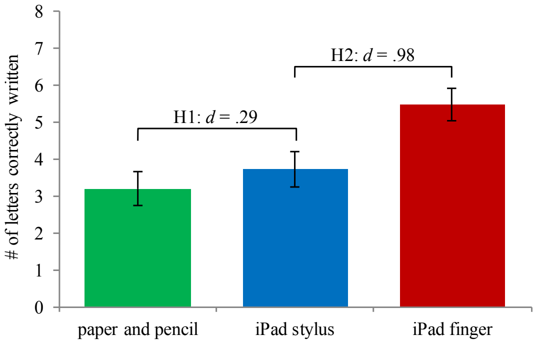

Fig. 3. Average number of correctly written letters by condition for hypothesis 1 (H1) and hypothesis 2 (H2).

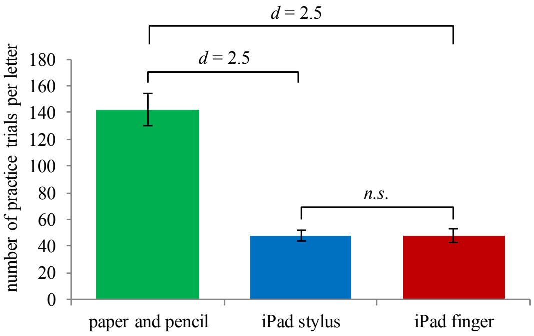

Fig. 4. Average number of practice trials per letters by condition.

letter. As suggested by recent research on motor learning, correcting errors as they occur could help a child adjust his or her mental representation of that letter and support performance during the early learning process (Sigrist et al., 2013). Surprisingly, this hypothesis was not supported—the children in the iPad stylus condition wrote a similar number of letters correctly at posttest as the children in the paper and pencil condition. Perhaps, additional extrinsic feedback might not be necessary to support the development of writing skills—that is, the visual feedback the children experienced when they saw that their letters strayed from the model while tracing might be sufficient. Additionally, by providing feedback as soon as an error was made, the tablet computer could have disrupted the encoding process. Therefore, although the feedback might have corrected formation errors, it might have also caused inefficient learning. Perhaps, receiving feedback after completely writing a letter would have been more helpful than being interrupted as soon as a mistake was made.

Second, we examined whether intrinsic feedback or the task similarity better supported children's learning. The results supported hypothesis 2a—children in the iPad finger condition wrote more letters correctly at posttest than the children in the iPad stylus condition. This result suggests that enhancing a child's tactile experience during learning was more beneficial than increasing the similarity between the practice tasks and the transfer task. The success of transferring knowledge or skills from the learning task to a transfer task often depends on the overlapping units between the two tasks (Anderson & Singley, 1993; Kieras & Bovair, 1986; Taatgen, 2013; Thorndike & Woodworth, 1901). However, in this context, task similarity was not a critical factor—that is, using a stylus, which is more similar to the other writing utensils used in the classroom (e.g., pencils, crayons, markers), did not help children write more letters correctly on a posttest that involved paper and pencil. This finding suggests that the critical component for handwriting is something different than the particular motor movement differences between using a stylus and finger.

More important for this context was the child's tactile experience. This finding relates to theories of embodied cognition, also known as ‘grounded’ or ‘situated’ cognition, which postulate that knowledge stored in memory contains rich, multimodal representations, and all of these representations are reactivated when a particular concept is retrieved (Barsalou, 2008; Barsalou, Simmons, Barbey, & Wilson, 2003). Several studies have supported this embodiment of writing knowledge (Kiefer & Trumpp, 2012). Recent research has supported the use of multisensory letter training for improving handwriting (Bara & Gentaz, 2011; Labat, Ecalle, Baldy, & Magnan, 2014; Vinter & Chartrel, 2010). In addition, children made greater gains from learning to write using paper and pencil than typing on a keyboard (Kiefer et al., 2015; Longcamp, Zerbato-Poudou, & Velay, 2005). These studies suggest that haptic or kinesthetic perception has an effect on learning to write. Indeed, Yu, Howe, and Hinojosa (2012) found that haptic perception (i.e., sense of touch) influenced children's handwriting speed, while kinesthetic perception (i.e., sense of movement and position) influenced children's handwriting legibility.

Further evidence was provided in several fMRI studies. Although children were equally likely to recognize a letter after either practicing writing the letter or observing a teacher write the letter, connections to sensori-motor networks only developed after active motor experiences in which children practiced writing (Kersey & James, 2013). Similarly, activation in brain regions associated only with reading occurred after handwriting training but not after typing or tracing (James & Engelhardt, 2012). In these multi-sensory tasks, additional sensory-motor information is likely to be encoded along with the visual form information, and these multiple types of information can strengthen one's memory of the letter (Guan, Liu, Chan, Ye, & Perfetti, 2011).

However, in the current study, there is only a subtle difference between using a stylus and using a finger. Both conditions have similar visual and kinesthetic input as well as some form of tactile input. With the stylus, input is collected by pushing or pulling the stylus in a particular direction, whereas with the finger, input is collected through friction. Perhaps this input from the finger is richer than the input from the stylus. Alternatively, surfaces with low friction can make writing more difficult for even more experienced writers (Alamargot & Morin, 2015; Chan & Lee, 2005; Wann & Nimmo-Smith, 1991). As indicated by past research with second grade students, when using a stylus, children are more likely to pause longer between strokes, which may have disrupted the connection between the visual and haptic information. The visual information might be better combined with the haptic information when the finger directly touches and follows the letter's shape rather than indirectly with the stylus. Thus, the richer information and better connection between the visual and haptic information from using one's finger while practicing writing could strengthen one's memory of the letter (Guan et al., 2011).

4.1. Limitations & future directions

One limitation to the current study is the relatively small sample size (i.e., 46 participants across three conditions). Despite this lower sample size, significant differences between the conditions were observed. However, significant effects may also have been missed. For example, although the difference between the iPad stylus condition and the paper and pencil condition was not statistically significant (indicating that concurrent, extrinsic feedback was not helpful in this context), the effect size indicated a small effect, which might be practically important. Perhaps a larger sample would reveal a significant difference. Furthermore, a lower sample size limited our ability to examine whether SES moderated the effects. Given that lower SES students tend to perform at lower levels than higher SES students, these students might benefit more from concurrent, extrinsic feedback. Similarly, the benefit of using one's finger while practicing writing may be stronger for the lower SES students. We also did not collect data on the students' phonological awareness at pre-test which has been shown to positively contribute to letter writing (Puranik, Lonigan, & Kim, 2011).

Additionally, in the current study, participants were not screened for learning disabilities, or attention deficit hyperactivity disorder, which could be factors that influence potential learning gains. Because the participants were randomly assigned to conditions, the likelihood that these factors confounded the findings is minimal. Future research should examine these populations specifically.

Finally, the current study did not examine the effects of writing practice that involves an enriched tactile experience without the concurrent, extrinsic feedback (e.g., tracing letters in colorful substances or writing in sand). To further isolate the importance of the tactile experience from the additional benefits of the tablet computers, future research could incorporate a tactile handwriting task that does not involve technology. For example, similar writing instruction could involve worksheets rather than a tablet computer, and if the tactile experience continues to be an important factor, we would expect similar differences for those children who traced letters with their finger versus those who used a pencil. Furthermore, the amount or quality of the tactile sensation could be manipulated by using different materials (e.g., paper vs. sandpaper) to better understand the degree to which haptic perception supports learning. Future research could also explore the benefits of multisensory learning. Are other senses just as supportive as the sense of touch (e.g., sound vs. touch)? Is there an additive effect to multisensory instruction (e.g., sound + touch vs. touch only)? Do these benefits depend on the nature of the task or skill being learned?

The finding that children who received concurrent, extrinsic feedback did not write more letters correctly than those who did not receive this type of feedback was somewhat surprising. Although early research has found that the benefit of concurrent, extrinsic feedback did not extend to tasks without that feedback (Schmidt, 1997), more recent research suggests that concurrent, extrinsic feedback could be more beneficial earlier in the learning process compared to later in the learning process (Sigrist et al., 2013). For preschool children who are just learning to write, concurrent feedback could guide their movements, help minimize errors, and possibly prevent cognitive overload. However, future research should further examine how to best fade this type of feedback so that children are able to successfully write without continuous support (e.g., when should concurrent feedback transition to terminal feedback?). Given the advances in technology, tablet computers could easily support this adaptive learning environment.

Future research should examine how technology, and tablet computers in particular, supports learning among other populations. For example, given that technology can increase students' motivation and help sustain their attention, instruction utilizing tablet computers could be especially useful for teaching children with disabilities.

4.2. Conclusion

The current study explored two aspects of tablet computers that could support young children's development—that is, providing concurrent, extrinsic feedback as well as intrinsic feedback through an enriched tactile experience. In the context of learning to write uppercase letters, the concurrent, extrinsic feedback did not provide an additional benefit. There was no general benefit of tablet computer-based training. However, the intrinsic feedback made salient by the enriched tactile experience did enhance children's learning. There was a benefit of practicing writing with one's finger on a tablet computer. Whether the use of tablet computers is superior to finger writing on paper worksheets remains an open question. Importantly, more practice was not necessarily better. Although children who practiced with a paper and pencil wrote each letter almost three times more than children who practiced with the tablet computers (i.e., 142 vs. 48), they did not perform better at posttest. Clearly more work is warranted in understanding how tablet computers can be used effectively to enhance instruction.

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