Analysis of Children's Handwriting on Touchscreen Phones

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ABSTRACT
Drawing and handwriting play a central role in primary schools. So far handwriting is practiced mainly on paper and blackboards. Providing tasks on paper can be challenging in developing countries. With the potential availability of mobile phones in classrooms, there is a new medium that can be used. We determined the effect of different touch technologies on children's handwriting for 18 third grade and 20 sixth grade participants. Children drew and wrote using different input techniques. We measured their performance and asked teachers to assess the legibility. We show that writing on touchscreens is less legible and slower than on paper. Further, the comparison of touchscreen technologies indicates that capacitive screens operated with a stylus yield the highest readability and are faster to use for writing than resistive screens. In contrast to these quantitative findings participants from third grade indicated that they prefer resistive screens with a thin stylus compared to using capacitive screens with a stylus or fingers.

Author Keywords
Handwriting; touchscreen phones; children; school; stylus

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H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous. K3.1 Computers and Education: Computer Uses in Education

INTRODUCTION
Drawing and writing on paper are important in most subjects in elementary school. Often children write short texts, fill blanks in books, or solve arithmetic operations. While handwriting is the way children usually write and work in their classroom, computers play a minimal role in daily teaching. Keyboards, the traditional input modality in schools' computer labs, are not suitable for learning writing. In addition, computers are too costly and require too much infrastructure for primary schools in developing countries. In contrast, mobile phones are currently becoming more popular and robust. Recent devices with touchscreens support handwriting using styli and fingers. Phone manufacturers have started offering low-cost touchscreen phones for 50US$ or less which can make them affordable for users in developing countries.

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Figure 1. Study participant in a public primary school in Panama

In our previous work in developing countries [1] we showed that camera phones with touchscreens offer exciting opportunities. Children do not own their books and therefore cannot write or draw in them. Instead of distributing paper copies to pupils, teachers take photos of tasks from textbooks and distribute the images to the children via Bluetooth. The children fill in the tasks directly on their touchscreen phones. However, children's writing and drawing performance on touchscreen phones compared to writing on paper has not been investigated. Different touchscreen technologies exist, but it is not clear which technology has the best performance and legibility.

We compare writing on capacitive and resistive screens using stylus and finger to writing on paper. We measure writing speed, number of strokes per phrase, collect qualitative feedback and ask experts to assess the legibility. While the use of smartphones has apparent advantages, our results indicate that touchscreens are slower to use than paper and that the legibility of writing on paper is not achieved. Comparing the phones, capacitive screens used with a stylus are the best option for speed and legibility. However, subjective feedback suggests that younger children prefer resistive screens used with a thin stylus.

RELATED WORK
Read *et al.* compared children's text entry performance when using a Wacom tablet, speech, a mouse and a virtual keyboard, and a real keyboard [7]. They conclude that performance with tablet and keyboard is similar but note that

their study's small sample size precludes general statements about the techniques' usability. Read *et al.* further compared pen and paper, handwriting on a Wacom tablet, and using a keyboard with children [8] and conclude that writing with the tablet is as efficient as writing using pen and paper.

Only a few studies compared finger and stylus interaction. Holzinger *et al.* showed that the performance and accuracy of stylus interaction on a tablet PC for a medical application is superior to the use of a finger [6]. Tu *et al.* [2] compared singles stroke gestures using stylus or finger. They analyzed the strokes drawn by adult participants and show that using finger and stylus results in similar performance but using the fingers is faster. Oviatt *et al.* compared four technologies for solving mathematic operations with high school teenagers [10]. They compared pen and paper, digital stylus and paper, tablet with stylus, and tablet with multiple input modalities. Using a normal pen and using a digital pen with paper resulted in similar performance that was higher than that of the other conditions. McKnight and Cassidy explored the behavior and attitude of children using different touchscreen devices with stylus and with finger [5]. Here children showed a preference towards using a stylus.

While Read *et al.* showed that using large graphic tablets is comparable to using pen and paper [8] we are interested in much smaller touchscreen phones. In contrast to Holzinger *et al.* [6] and Tu *et al*. [2] we study writing and specifically address children that might have completely different requirements. Therefore we compare the performance of children writing and drawing on touchscreens using stylus and finger with a special focus on the legibility of their handwriting. As speed and legibility of handwriting are the main features assessed by teachers and pedagogics when monitoring progress of children [3, 4], we consider speed, the number of strokes, and legibility as the main performance measures.

METHOD OF THE STUDY

We conducted a repeated measures experiment to assess the effect of the input modality on children's writing and drawing performance. The study was conducted in two primary schools in Panama. We compared the following four conditions: *Pen and paper*, *capacitive screen with stylus*, *capacitive screen with finger*, and *resistive screen with stylus*.

We used a Samsung Galaxy Nexus for the capacitive conditions. An Amazon Basic stylus (8 mm tip and body) was used for the capacitive screen with stylus condition. We used a Nokia Xpress Music 5530 for the resistive screen with stylus condition (1 mm tip and 2 mm body).

Participants had to complete six tasks. We designed the tasks with teachers to develop tasks that are suitable for children with different ages. In task one, participants were asked to draw two parallel lines as quickly and accurately as possible. Given the same instructions as in task one, they were asked to draw a square in task two, a circle in task three, and a tree in task four. In the fifth task we asked them to write the numbers from 0 to 9 and in the last task they copied a sentence with five words. Figure 2 shows this sentence for each condition written by the same participant.

We assessed participants' writing performance using task completion time, number of strokes to complete a phrase, participants' preference and the legibility assessed by teachers. Sessions were recorded on video. For all conditions, we determined the task completion time using these videos. Screenshots or photos of all results were taken. According to teachers, pupils should write a word continuously without lifting the pen from the paper. Therefore, we counted the number of strokes to complete the given sentence. After the study each participant answered a guided feedback questionnaire. We evaluated the legibility afterwards by asking 13 school teachers to rate each of the 152 series of written numbers in an online survey.

20 male and 18 female pupils participated in the study (one left handed). Students from different grades participated to increase generalizability. 18 participants with an average age of 8.8 years from 3rd grade and 20 participants with an average age of 11.5 years from 6th grade. 37 were between 8 and 13 years old. One participant with learning disabilities was 15 years old. 92.1% had used a mobile phone before and 23.7% had experience with a touchscreen device (e.g. Nintendo DS, touchscreen tablet or phone).

Each participant repeated the six tasks using the four conditions resulting in 24 tasks. We used Latin square to counterbalance the order of the conditions. In total, the duration of the study was about 40 to 50 minutes per participant. Beforehand, each participant was given the same time to familiarize themself with both mobile phones and the use of finger and stylus.

RESULTS

In the following we analyze the participants' speed, the readability assessed by teachers, and participants' preferences. Furthermore we describe the observations made during the study. We used an Analysis of Variance (ANOVA) to analyze the means, and used t-tests to compare the conditions. We used a Holm–Bonferroni correction to prevent inflation of Type I errors in post-hoc analysis.

Handwriting Performance

Task completion time

The average time to complete each of the six tasks is shown in Table 1. Participants were slightly slower using pen and paper to draw lines, squares, and circles compared to the touchscreen devices. An ANOVA showed that the input modality had a significant effect on the time to draw a line ($F_{3,111}$=3.03, p<.05). Follow-up post-hoc tests did not reveal a significant difference between the conditions. We also did not find an effect of the input modality on the time to draw a circle ($F_{3,111}$=0.78, p=.51), a square ($F_{3,111}$=0.80, p=.51), or a tree ($F_{3,111}$=2.60, p=.06).

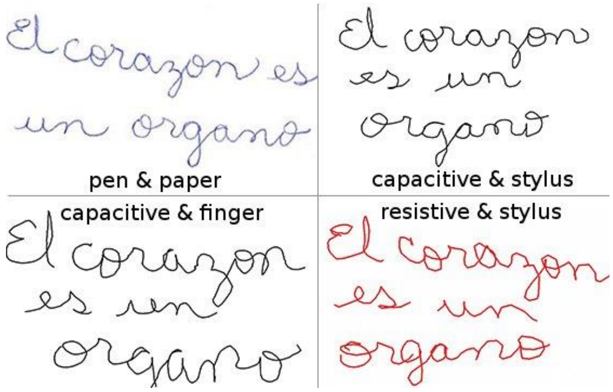

Figure 2. Phrases from one participant using the four alternatives.

The numbers were written fastest using pen and paper, followed by the capacitive phone with the stylus and the capacitive phone with finger. Using the stylus with resistive screen required the longest time. An ANOVA showed that the input modality had a significant effect on the time to write the numbers ($F_{3,111}$=8.13, p<.001). Post-hoc tests revealed significant differences between the conditions. Only the difference between resistive screen with stylus and capacitive screen with fingers is not significant (p=.83).

The phrases were written fastest using pen and paper, followed by using the capacitive screen with a stylus. The input modality had a significant effect on the time to write a phrase ($F_{3,111}$=5.29, p<.001). Participants were significantly faster using pen and paper than using the capacitive screen with their fingers (p<.01) or using the resistive screen with a stylus (p<.01). All other differences are not significant.

	pen and paper	capacitive and stylus	capacitive and finger	resistive and stylus
lines	1.9, σ=1.3	1.4, σ=0.9	1.5, σ=0.8	1.5, σ=1.0
square	4.5, σ=3.5	4.1, σ=2.9	3.5, σ=1.8	4.2, σ=3.5
circle	2.2, σ=1.4	2.0, σ=1.3	2.2, σ=1.4	2.1, σ=1.2
tree	13.0, σ=16.1	9.4, σ=7.3	12.9, σ=10.5	13.3, σ=11.4
numbers	22.1, σ=13.7	26.9, σ=9.6	33.8, σ=14.1	36.4, σ=13.9
phrases	18.3, σ=11.2	23.7, σ=8.5	27.8, σ=12.9	28.5, σ=10.5

Table 1. The average task completion time for the six tasks in seconds and the standard deviation (σ).

Number of strokes to complete the phrase

The analyzed sentence had 5 words, so there is a minimum of 5 strokes needed to write it. On average, participants needed 7.2 strokes (SD=3.7) using pen and paper, 7.5 strokes (SD=4.3) using the capacitive screen with a stylus, 8.6 strokes (SD=5.2) using the capacitive screen with their finger and 8.5 strokes (SD=8.6) using the resistive screen with a stylus. A Friedman test, however, did not reveal a significant difference X^2_3=1.82, p=.61).

Subjective feedback

Participants were asked to rate the touchscreen alternatives after completing all tasks. In general, they stated that drawing was easiest using the capacitive touchscreen with a stylus (37.7%) or the finger (40.5%). 21.8% preferred the resistive screen. For the writing tasks, 50.0% preferred to use the capacitive phone and the stylus followed by the resistive screen (39.0%) and the capacitive phone with finger (11.0%). However, the preferences changed among grades. Participants from the 6th grade preferred the capacitive screen with finger for drawing (50.0%), and the capacitive screen with stylus for writing (55.0%). Participants from the 3rd grade preferred the resistive screen for writing (50.0%), and both phones with the stylus were equally preferred for drawing (36.8%). Overall, young participants found it easier to grasp the resistive stylus than the capacitive stylus.

Further observations and qualitative findings

We observe two approaches in the way participants grasp the phone: participants who did not hold the device while writing, like the girl shown in Figure 1, and participants who secured the device on the table with their non-dominant hand. Only one participant held the phone with their non-dominant hand in the air, while attempting to write with the other hand. We observed in many cases that participants who initially followed the first approach experienced movement of the device. They also had to start using their non-dominant hand to hold the device on the table.

Some participants had problems while writing on the phones. In particular, unintentional lines were drawn when the border of the touchscreen was touched by the participants' hands. The following numbers of unintended lines were drawn: 20 on the capacitive screen with stylus, 29 on the capacitive screen with fingers, and 18 with the resistive screen. Participants unintentionally exited the application on the capacitive phone. Some participants attempted to write very close to the bezel of the screen. This was observed on both phones, in particular with the stylus. Further problems were, for example, using too much force when pressing the stylus against the capacitive touchscreen, holding the pen at an extreme angle or touching the screen at multiple points, which all resulted in failed writing attempts.

Legibility

Teachers commonly assess handwriting legibility by looking at the slant, letter formation, spacing, alignment and size [3]. Experts concur that legibility should consider the words as a unit rather than a set of singles strokes [3, 4]. Because of the large number of samples gathered during the study, we only used the numbers for comparison. Numbers were well known by all participants and could also be easily verified by teachers. We created an online survey and asked teachers to assess the legibility of the written numbers. We scanned the numbers written on paper and used screenshots for the other conditions. Each page of the survey showed the numbers one participant wrote using the four conditions. We labeled the conditions with *A*, *B*, *C*, *D*. Condition *A* showed the numbers written using pen and paper. The other conditions were randomly ordered. We asked teachers to rank the numbers from most legible to least legible. Teachers also compared the similarity of the phone-based writing with the ones created with pen and paper. In this case, teachers had to state which figure *B*, *C* or *D* was most similar to *A*. 10 female and 3 male teachers rated each of the writing samples (see Table 2). Half of the teachers considered the numbers written using the capacitive phone and stylus most similar to those written with pen and paper.

	most legible	2nd most legible	3rd most legible	least legible
pen & paper	91.9%	4.3%	0.8%	3.0%
capacitive & stylus	4.6%	46.3%	31.2%	17.9%
capacitive & finger	2.4%	26.0%	31.4%	40.1%
resistive & stylus	1.1%	23.3%	36.6%	39.0%

Table 2. Legibility of the handwriting assessed by teachers.

DISCUSSION AND LIMITATIONS

Handwriting using a finger was not well received by children. A potential reason is that writings with a stylus looked nicer. However, for drawing, the finger was preferred by the older children. The younger children preferred handwriting with the resistive phone. The thickness of the stylus seems to be a factor for handwriting in the case of children. Our observations and participants' feedback suggest that young children can control the thin resistive stylus better than the capacitive one. The tip of the resistive stylus resembles in size and shapes to the tip of a normal pen, while the capacitive stylus used do not. However, more studies have to be done to make further conclusions.

We used simple tasks that we designed with teachers. While this simplification limits the results, the tasks resemble the typical assignments teachers give to their pupils. Not all participants would have been able to complete more complex tasks. The study lasted as long as a lesson and we did not observe fatigue. The children, however, had more previous experience with paper and more training would have improved their performance with the touchscreen devices. We were mainly interested in the differences between the touchscreen technologies and used pen and paper as a baseline. Monitoring long-term effects would, however, certainly be interesting. We addressed a rather large age distribution and did not differentiate between age groups. We only observed subjective differences but leave a formal comparison to future work due to space restrictions.

To measure the difference between phone models while aiming to determine the difference between resistive and capacitive screens, we had to use phone models with different styli and screen sizes. Thus, we cannot ultimately be sure what causes the difference based on the quantitative results alone. By using standard devices that are ready to be used in schools we provide valuable insights to schools and can assess the effect compared to pen and paper and the difference between finger and stylus for capacitive screens.

CONCLUSION

Touchscreen phones offer exciting opportunities to improve education in developing countries. They are cheap, require little infrastructure, and offer the opportunity to support handwriting using fingers or styli. Touchscreen devices enable users to recreate common learning tasks [1, 9]. We compared different touchscreen technologies and input modalities to assess their effect on young children's handwriting. We show that children write phrases faster with pen and paper than with any tested touchscreen technology. In addition, number written with pen and paper are clearly more legible. Comparing the touchscreen alternatives suggests that writing on a capacitive screen with a stylus is faster and more legible than using the finger on the same device or using a different device's resistive screen.

Participants from the 3rd grade preferred writing on the resistive screen compared to the other touchscreen alternatives but all other measures favor capacitive screens using either finger or stylus. Schools that introduce touchscreen phones should therefore use phones with capacitive screens. Styli should be used for writing and fingers for drawing. Future work should investigate how to reduce unintended touch input. An interesting approach is implemented in the iPad app Studio Pen. After calibration, the software ignores touch contacts by the wrist. Future work should also investigate the effect of different styli sizes and grip styles.

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