Investigation into the Discrepancies Between Writing on Paper and Writing on a Touchscreen Device

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Abstract. Due to the complexity of text in Asian languages and hence the complexity of input methods, demand for stylus-type input is higher in Asian than the Western world, prompting Asian tech brands such as Samsung and Sony to introduce smart devices with in-built stylus to cater to this group of consumers. To account for general usage, this research has opted to employ mobile devices with built-in stylus as test equipment. In addition, in order to account for the difference between various sizes of devices, the researchers have chosen three device dimensions: 5.7 in, 9.7 in, and 12 in, for the tests, and each size of device is compared to an identically sized piece of paper. In consideration of the locality of the behavior of users, the subjects are asked to input using Traditional Chinese text only. Results from the experiment showed, in terms of writing behavior, that almost all subjects put the device flat on a table for writing, and that the habit of spinning the paper to an angle for writing is transferred to writing on a device. The finger positions on a stylus change depending on the properties of the device, especially when writing on the 5.7 in, the smallest device, touching the stylus at the smaller supporting points or completely dangle the pen away from the palm occurs much more often than on the bigger device sizes. In terms of writing performance, writing time on a device is generally longer than that on paper. The words written on a device are bigger and grow in size as the device size increases on the devices, but on the different sizes of paper the words stay relatively the same size. Words written on a device are generally less legible than those written on paper.

Keywords: Mobile device · Touchscreen · Stylus · Writing performance

1 Purpose

Recent technology has brought about a new type of computer interface enabling new modes of operation which have impacted the user experience of computers. Since the pen was modified into an input instrument known as a stylus, a most quickly accepted and easily adapted type of pre-learned input instrument which has proven to be more effective at the task of selecting items than the computer mouse [1]. In addition to the mouse-like operations, the stylus provided a more intuitive way of computer input, and

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for certain parts of computer operation, the combination of voice and writing input were more efficient than the combination of the keyboard and the mouse [3].

The advancement of technology, however, has not affected people's dependence on the pen [11]; studies have likewise shown that writing with a pen is better for learning than the keyboard, exhibiting increase in cognitive understanding and longer memorative duration [10]. Mobile devices in recent years have reverted back to using handwriting as a primary means of operating the product, such as the Samsung Galaxy Note, the Microsoft Surface, or the iPad Pro, which have stressed handwriting and drawing as their primary features.

Nevertheless, due to technical limitations and tactile distinctions, a significant discrepancy in perception is still present between writing with a stylus on a mobile device and writing with a pen on paper. This research investigated the differences between writing Chinese text on various sizes of mobile devices and paper. Due to the structural complexity of Chinese characters, Typing in Chinese is much more complex than Western languages causing greater demand for stylus based writing than western countries. In addition, this research was conducted in Taiwan, and all of the participants use Chinese as their primary language. This research thus focused on the performance of Chinese text writing. The observations were divided into two criteria:

(1) Writing behavior: posture and habits, how the user holds the writing instrument, the points of pivot while writing, and the angle of rotation of the writing surface.
(2) Writing performance: writing time, the size of written Chinese text, neatness and legibility.

2 Literature

2.1 The Ergonomic of the Use of Stylus

Stylus-based input works by employing the habits of pen use onto a computer interface, which, when compared to using a mouse, is not only more intuitive, but also far more comfortable. While holding a stylus the elbow angle is about 45 degrees less than when holding a mouse, contributing to more relaxed muscles. The operating process also benefits from being able to utilize more parts of the arm for motor control, avoiding Repetitive Strain Injury (RSI) or Carpal Tunnel Syndrome which can result from overuse of wrist muscles. In addition, the development of multi-touch interface has made stylus use even more flexible and more preferable than the mouse [4]. Luo's [9] comparison of the dimensions of styluses on the market revealed that those with the combined dimensions of 140 mm long and 8 mm thick are ideal for use for all operating tasks on a screen, perhaps due to this specification being closest to that of pen and paper writing. Luo further suggests that the shaft of the stylus should be longer than 100 mm in order for users to hold it at the three optimal points of the hand: the thumb, index finger, and the crevice between the thumb and index finger. In addition, Huang's [5] investigation into the stylus shape concluded that styluses with a circular cross-section performs best for writing, ovals are best for drawing stability, and hexagonal are best for firm holding.

2.2 Writing Behavior

Stylus-based interface works by emulating writing with pen and paper on a device screen with a stylus, transferring the habits of holding a pen and writing with it on paper onto doing the same on a digital surface [3, 12]. Conventional writing can be discussed in three categories: writing environment, position of paper, and method of holding the pen. For a person to have a suitable writing environment, the following criteria need to be met: (1) consolidate the height of the seat (chair) and the writing surface (table) for the table height to be no taller than the elbow. (2) the body should be 10 cm away from the edge of the table, the distance between the eyes and the paper should be maintained at around 30 cm, and the forearm should rest halfway on the table. (3) A sufficiently bright light source should be to the above-left of the paper (above-right for left-handed individuals).

The position of the paper should have a rotation of 10–20º to the left. so that the upper-right corner is slightly higher than the upper-left corner, in order to compensate for how the arm exerts force according to ergonomics, where the wrist tilts to the upper-right instead of being parallel to the upper edge of the table [7]. The pen should be held with a three-point pinch for normal sized pens, and a lateral pinch would be used for styluses with smaller dimensions [14]. In addition, when writing with the stylus, the user typically avoids contact between the screen and the palm or finger, resulting in two primary pivot points of the hand on the screen which differs with the writing surface (Fig. 1). Luo [9] therefore proposes the design of dedicated supports to improve stylus writing.

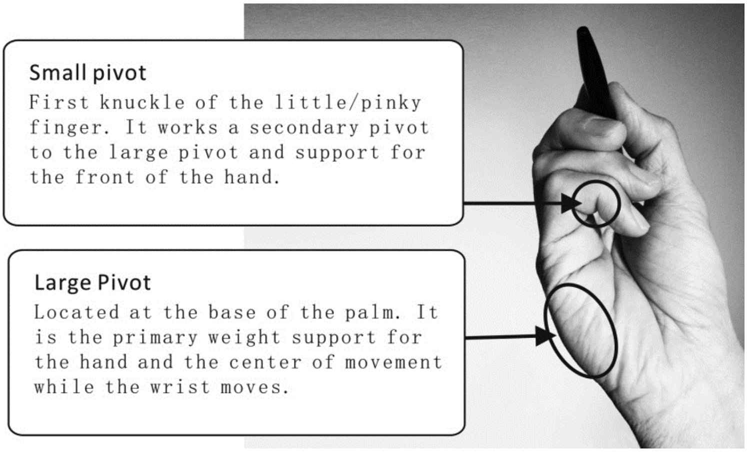

Fig. 1. Two pivot points used for writing

According to Chien’s [2] research, 72% of stylus users will retain the way they hold conventional pens when holding a stylus, but the positions they hold the stylus may be somewhat lowered, with increased muscle intensity to maintain stability. In addition, the wrist and the pinky may be used as support to keep minimum contact between the screen and the palm and the screen.

2.3 Writing Performance

Henderson's [13] research discovered that when the written content is more simplistic, readability is not affected by writing pace, but when content complexity or quantity of writing increases, the pace of writing can affect the quality of the words written as well as the flow of writing. Li [8] also discovered in her research that the speeds of transcribing common words and uncommon words are significantly different. Discretion was therefore prudent during design of the writing performance test, otherwise the experiment result would be adversely affected. In terms of readability, Chinese character strokes are not simply made up of a combination of stroke lines; when the strokes are out of order, the writing speed and aesthetics can be affected. The readability of Chinese text is associated with the Chinese character structure and the continuity between the characters. Character structure can affect readability by having incorrect overlapping, addition, or omission of strokes, or the spread of character blocks or their incorrect position or proportioning. Continuity between characters pertains to the text size, text spacing, the horizontal evenness, and general layout neatness [6].

3 Research Method

This research is divided into writing behavior and writing performance for investigation.

(1) Writing behavior: pertains to how the user holds the writing instrument, the points of pivot while writing, and the angle of rotation of the writing surface.
(2) Writing performance: pertains to the writing duration, size of characters written, and the quality of characters written.

3.1 Experiment Procedures

Three sizes of writing surface were selected for comparison, each size given its experiment group (mobile device and stylus) and control group (paper and pen). Each test subject was asked to write a string of Chinese characters while timed with a stopwatch while a camera recorded the writing behavior. Afterwards, they were given a brief interview to gather feedback on writing behavior and basic personal information.

3.2 Hardware and Software

Equipments. Various stylus based products exist on the market with a wide variety of hardware. In order to minimize the hardware variable, our researchers have selected Samsung mobile devices which include electromagnetic induction styluses for the experiment. Their specifications are as Fig. 2.

Fig. 2. Mobile devices for the experiment

Software used for experiment. This research selected ‘MyScript Smart Note’ for the experiment as depicted in Fig. 3. Compared to the free-writing app ‘S Note’ pre-installed in all Samsung devices, ‘MyScript Smart Note’ provides a superior writing experience, whether it be decreased lag-time or smoother pen-stroke display. The app has an additional ‘write mode’ which recognizes written character and is therefore able to digitize the written content and save it as a text file. The stylus included in the device is also fully compatible and functionally supported. The above reasons resulted in the app’s selection for use in the experiment.

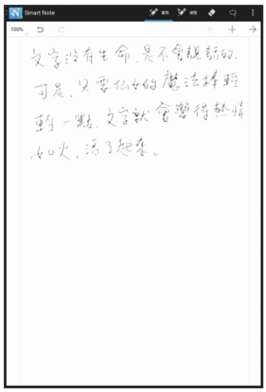

Fig. 3. MyScript smart note interface image

Writing instruments. The selection of writing instruments require a digital writing instrument and a paper based writing instrument. For writing on paper, the popular ‘Penrote NO.6506’ black ballpoint pen was chosen to match the color of stroke trails displayed by the digital app [2]. For digital writing, the ‘S pen’ stylus built into each of the three mobile devices was used, as depicted by Fig. 4.

Fig. 4. The writing instruments for the experiment (left: S pen, right: Penrote NO.6506)

Environment and participants. The experiment took place in a well lit interior prepped with desks and chairs for the participants. The seat of the backrest-equipped chairs is 430 mm off the ground. The seat surface area is 360 mm x 420 mm. The desk is 730 mm tall. The experiment contains three sets of dimensions of writing surfaces, each dimension is assigned 30 participants for a total of 90 participants who conducted the writing task on both pen and paper as well as stylus on mobile device. The participants consist of college graduates and post-graduates between the ages of 18 and 24, whom have all had at least one year of experience on a mobile device or tablet PC, and all of whom are right handed and without visual impairment.

Experiment text. Due to the research having been conducted in Taiwan, the primary language used for the participants is Chinese, the complexity of which is ideal for researches to observe during writing how the character strokes and structural form change when writing Chinese. It has therefore been selected for this experiment even though most participants are sufficiently fluent in English as well. In order to ensure the straightforwardness of the test content, a word string was chosen from a sixth grade elementary Mandarin supplementary text book ‘Smart Lifestyle’ from Chapter 1 ‘The Magic of Words’ consisting of 40 characters, not counting punctuation, as shown in Fig. 5.

Experiment Procedure.

(1) The participants were seated followed by a briefing on the experiment purpose and necessary precautions.
(2) A projector screen displays the experiment text for every participant to see and transcribe once on to a mobile device, and once on to paper, for a total of two transcriptions. To minimize familiarity, the order of paper and device is randomized. A break of 5 min is taken before the second transcription.
(3) After the writing experiment is completed, the participants are given a brief interview to gather feedback.

文字沒有生命的，
是不會說話的，
只要仙女的魔法杖輕輕一點，
文字就會變得熱情如火，
活了起來。

Fig. 5. Writing experiment text (translated into English: *"Words are lifeless; they don't talk. However, with the tap of the fairy's magic wand, the words become passionate and alive"*)

Data collection and analysis. The experiment supervisors performed observations and measurements, and corroborated information gathered using the recorded videos. The observations made emphasized the following:

(1) Writing habit: the pivots of the hand on the writing surface, whether pivots were used and where they were.
(2) Rotation: Observations were made as to whether the participants rotated the writing surface, and videos were made and used to determine the angle of rotation, whereby rotation within 5° were considered none.
(3) Size of written text: a font size chart is used to determine the size of text produced by the participants.
(4) Quality of written text: In order to maintain an objective standard of critique of the quality of written text, this research employed a focus group consisting of four Mandarin instructors to evaluate the written text in 3 categories: strokes, proportion, blank space.
    Stroke: pertains to the correct stroke order of the written text as well as neatness of the strokes.
    Proportion: pertains to the size and position of the character blocks in relation to each other.
    Blank Space: pertains to the straightness of the written words and their indentation to other strokes. In short, neatness of layout.

The panel of four Mandarin experts were asked to score the writings from each group from 1-point to 5-points.

4 Results

Of the 90 participants of the experiment, 41 individuals have had experience in writing or drawing with a stylus (45.5%) while the other 49 individuals have not (54.5%). The results of the observations and measurements are as following.

4.1 Writing Behavior

Rotation of writing surface. 90 participants produced 180 text samples, of which 133 samples (74%) were written while rotated. Tilted papers consisted of 72 samples, 80% of all paper samples, and tilted devices consisted of 61 samples, 68% of all device samples, revealing a 12% higher ratio of rotation of paper to that of devices (see Fig. 6). The results also revealed that those with the habit of tilting the paper while writing were the ones who rotated the device, with 85% of paper rotaters maintaining the habit while writing on the device. In addition, medium-sized surfaces were rotated the most, followed by small and then large surfaces. This revealed that the habit of rotating the device can present on either digital or paper surfaces, but participants are slightly less likely to rotate a digital surface. Furthermore, no participant was found who rotated the digital device without also rotating the paper. 9.7 in writing surfaces experienced the least variation; participants given medium sized writing surfaces exhibited the least change in habit of rotation between the two surfaces.

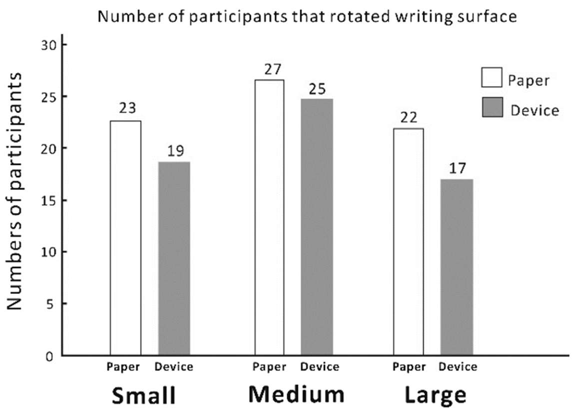

Fig. 6. Number of times writing surface was rotated

Use of pivots. When writing on paper, all participants used both large and small pivots of the writing hand, which is resting almost the entire bottom edge of the hand on the paper. When writing on a digital device, on the other hand, 19 participants used only the small pivot or suspended the hand entirely. The ratio of changing pivoting patterns from small to large devices were 40%, 10%, and 13% respectively, revealing the highest change in pivoting habits happened on small devices. The small devices group had 9 participants who used only the small pivot for writing, which is much greater than other device groups (see Fig. 7).

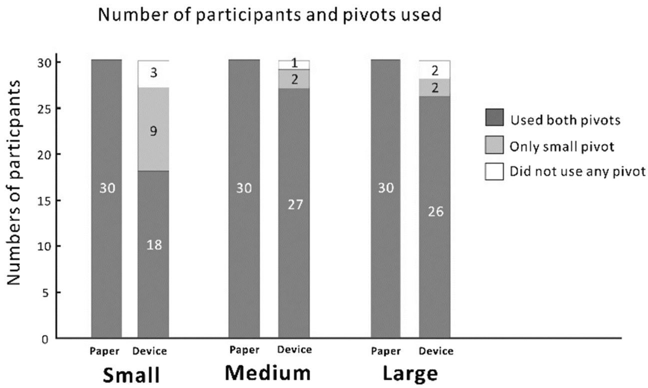

Fig. 7. Participants usage of large and small pivots during writing for various sizes of devices

4.2 Writing Performance Results

Writing time. The average writing time for each groups are indicated in Fig. 8. Comparing the same sizes together, writing on paper was faster than writing on a screen for each size, and the difference in speed on paper increased as surface size became smaller, while 9.7 in device screen performed best in terms of speed. ANOVA analysis of surface size to writing speed did not reveal a significant difference, but T- test analysis of the difference in writing time revealed a significant difference between small and medium sized surfaces, indicating the effect of the properties of the writing surface were more prominent on these two sizes, but not as much on the large devices (Table 1).

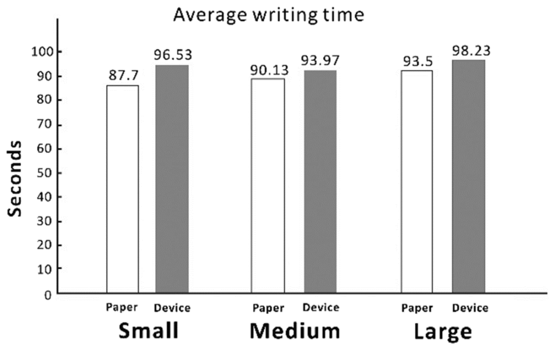

Fig. 8. Writing time of various sizes of both surface types

Table 1. Pair T test for writing time of paper and device

Paper vs device	M	SD	t	Sig.
Large size	−4.733	20.596	−1.259	0.218
Medium size	−3.833	8.175	−2.568	0.016*
Small size	−8.833	10.011	−4.833	0.000*

* P < 0.05 significant

Written text size. The changes in the written text size of the groups are as indicated in Fig. 9. The change in paper surface area did not have a significant effect on text size. The average in text size from small to large paper surfaces were 21.5 → 21.6 → 21.9 exhibiting a growth of less than 0.4 pts. A significant growth of average written text size is experienced, however, on digital devices as screen size increased. Average text size from small to large devices was 25.9 → 31.5 → 36.1 exhibiting a growth of over 10pts. In addition, text sizes on digital devices were significantly larger than text sizes on paper overall, making this finding the most significant as well as the most interesting difference between paper and digital device. Further ANOVA comparing the text sizes revealed that the difference between text sizes on paper was not significant ($F(2, 87) = 0.095$, $p = 0.910$), indicating no effect of paper size on text size, but that difference on digital devices was significant for all sizes ($F(2, 87) = 16.105$, $p < 0.001$) as the text size increased with the size of digital device (Tables 2, 3). T-test analysis also revealed a significant difference between paper and digital device for each of the three tested sizes, where the text size on digital devices were all significantly larger than that on paper, consistent with findings (Table 4).

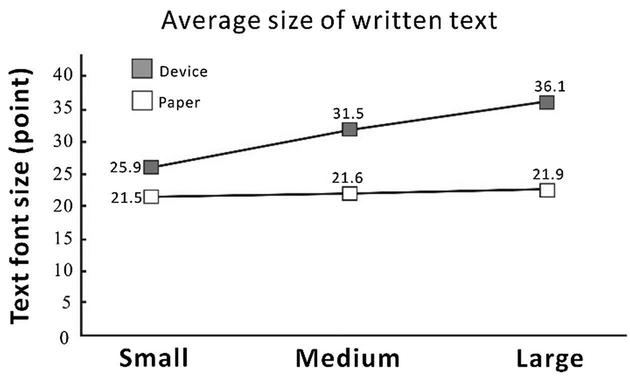

Fig. 9. Text size results for all test groups

Table 2. ANOVA analysis for written text size

		SS	df	MS	F	Sig
paper	Between groups	2.156	2	1.078	0.095	0.910
	Within groups	988.167	87	11.358		
	Total	990.322	89			
Devices	Between group	1565.600	2	782.800	16.105	0.000*
	Within groups	4228.800	87	48.607		
	Total	5794.400	89			

*The mean difference is significant at 0.05 level

Table 3. Post hoc test by Tukey for written text size of device

	Size (I)	Size (J)	Mean Difference(I-J)	Sig.
Paper	Large	medium	0.267	0.950
		Small	0.367	0.907
	Medium	Large	−0.267	0.950
		small	0.100	0.993
	small	Large	−0.367	0.907
		medium	−0.100	0.993
Devices	Large	medium	4.600*	0.033
		small	10.200*	0.000
	Medium	Large	−4.600*	0.033
		small	5.600*	0.007
	Small	Large	−10.200*	0.000
		medium	−5.600*	0.007

*The mean difference is significant at 0.05 level

Table 4. T-test for written text size for paper and device in different size

Size	M	SD	SEM	t	p
Small	−4.367	2.606	0.476	−9.177	0.000*
medium	−9.867	5.361	0.979	−10.081	0.000*
Large	−14.200	8.310	1.517	−9.359	0.000*

* $P < 0.05$ significant.

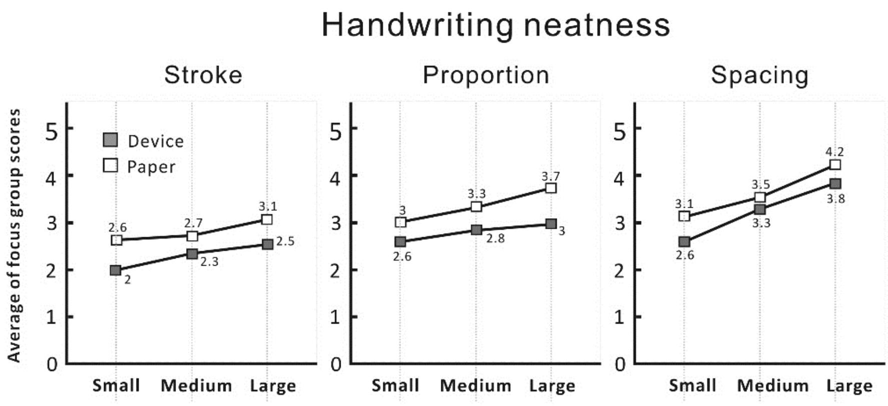

Fig. 10. Comparison of writing neatness

4.3 Writing Neatness

The scores of the categories of neatness of handwriting is as depicted in Fig. 10. From the scores of the three categories it can be seen that paper based writing groups performed superior to the digital writing groups. In addition, increase in size of both paper and digital device produced ever better neatness. It can thus be speculated that the size of the writing surface directly affects writing neatness, even though writing on paper is still superior to writing on digital device.

5 Discussions

5.1 Smaller Screen Has Greater Change to Influence Writing Behavior

From the experiments in this research, it can be observed that a large portion of users have the habit of rotating the writing surface (around 70–80%) and those with the habit of rotated writing may transfer the habit onto writing on a digital device. It is interesting to note that there were no participants who rotated the digital device but not the paper. The medium writing surface (9.7 in) showed the least change of behavior, suggesting that it is the size that least alters the habit of rotated writing. As to how the writing instrument is held, results from this research were similar to the study conducted by Chien [2], where the majority of users held a stylus the same way they held a pen. This research further found that when writing on a digital device, particularly for small device users, more than half of the participants write with only the small pivot or even a suspended hand. The subsequent interview revealed the reason to be an apprehension to unintentionally triggering unwanted functions if the palm makes contact with the device screen. Therefore, it is suggested that this psychological element be taken into account during the design of small devices to alleviate the accidental triggering of functions in order to avoid forcing a change of writing habit for the user.

5.2 The Size of the Device Affects Writing Time

In all size groups, writing on digital surface cost more time than writing on paper, with writing on a medium digital surface taking the least amount of time. On the other hand, the larger the paper surface size, the longer the writing time became. Our researchers speculate that the techniques and habitual motions of writing on paper were the same, and therefore the size of the text characters would be similar, meaning that the additional time was due to the increase in paper size enlarging the spacing between words, prompting increased displacement between characters, increasing total writing time. Due to the properties of writing on a digital device, users may change writing behavior resulting in bigger characters being written in a less fluidic manner, slowing down writing speed. The small screen can be challenging to use if the user tries to avoid triggering unwanted functions by using different hand pivots or none at all. On the other hand, a large screen surface prompted the production of larger fonts and bigger displacement of the strokes as well as the hand position, producing the slowest writing speed of all the groups. Our researchers speculate that the apprehension of touching the screen undesirably, the non-rotated writing surface due to the bulk of the larger device, and the abundance of screen writing space on the larger device prompted the user's writing behavior to produce larger writing. All in all, writing on screens too small can cause difficulty, and writing on larger screens suffered from enlarged text and increased displacement of the hand, making the medium sized digital interface the most suitable size for writing.

5.3 Stylus Based Writing Needs to Be Provided with More Writing Space

This research has shown that writing on different sized paper resulted in consistent written text size, with text size having variation of less than 1.8% and the text size between 21.5 pt and 21.9 pt. Comparatively, writing on digital devices can cause unintentional enlargement of text size, increasing with screen size. Compared with paper of the same size, words on 5.7 in, 9.7 in, and 12.2 in devices grew by 20%, 46%, and 66%, respectively. It can therefore be speculated that when writing with a stylus on a device, the properties of such constraints forced users to make maximum use of available space, and when not given lines or a grid to write on, will adjust writing according to one's own intuition, as can be seen by how the text size of writing on digital devices grew from 20% to over 60% depending on the device size. Interface designers are therefore encouraged to consider this phenomenon and provide more fitting interface features, such as suitably sized writing lines similar to paper notebooks, or space for signatures or making notes on e-books.

5.4 Paper Based Writing Is Superior to Digital Device Writing Overall

Overall, results indicate that writing performance can be affected by the constraints of the properties of the writing hardware as well as the digital interface, such as when the apprehension of unintentional screen contact alters how the stylus is held for writing, or when the bulk of the writing device stops users from rotating it to a more suitable angle for writing, which can all result in the decrease of writing speed on digital devices to that of on conventional paper. In terms of writing neatness, writing on paper is superior to writing on digital surfaces as well, possibly also due to the way the stylus is held and the properties of digital devices. However, the writing neatness on both paper and digital devices improved with the increase of size, which our researchers speculate to be related to the ample available space which allowed users to more freely conduct movements of the hand for writing and thus produced smoother and more proportional pen strokes to form the Chinese characters. The factor of making text more immaculate is therefore the size of the writing surface, and larger surfaces allow users to write neater characters.

6 Conclusion and Recommendations

Despite technology having advanced greatly closing the gap between digital device and paper, The properties of digital devices as well as user habits continue to keep the performance gap of the two types of writing open. All in all, writing on paper is significantly better than writing on screen; writing speed on paper can decrease with increasing size of paper, meaning that smaller paper sizes are better for writing, while medium sized digital devices can be the quickest device for writing. For writing neatness, paper based writing produces better looking texts than digital writing for any size, but both paper and digital device can result in neater writing with increase in size. What's more interesting to note is the difference in text size, where the increase in digital device size can inadvertently trigger an increase in text size, as an increase between 20% to over 60% was observed in the experiment.

Designs henceforth would benefit from consideration of this phenomenon, and include into different devices an interface more suitable for writing, such as properly spaced lines for guidance and a more suitable blank area for writing. This paper was focused on Chinese text due to cultural constraints. In the future research can be done in the language of English or observing writing neatness for different specs of styluses.

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