Paper

Evaluating Digital Slate Devices from Users’ Behavior: Electronic Paper Devices as Stationery

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This paper evaluates people’s conscious for digital devices from their behavior for the devices. Fourteen people performed tasks using four media: a sheet of A4 paper, an A4-size tablet PC, and two types of A4-size electronic paper devices. We analyzed how they handled these media. Results showed that they frequently handled electronic paper devices with a single hand and slid them on a desk surface like a sheet of paper. This indicates that they considered electronic paper devices as analog stationery rather than as digital devices.

Keywords: Electronic paper, Tablet PC, Paper

1. Introduction

This paper describes experiments to examine how people behave digital devices including electronic paper devices.

When we use digital devices and analog devices, our behavior for the former seems to be different from that for the latter. We have a preconceived feeling that electronic devices are expensive and fragile. Therefore, when we hold an electronic device, we usually hold it firmly with both hands not to drop it down. Moreover, when we move it on a desk, we usually hold it up from the desk, move it to the target position in air, and put it on the desk softly, without sliding it on the desk surface. They are actions to avoid troubles of precision instruments and to protect causing bruised on the desk surface or the digital device.

On the other hand, when we use analog stationery such as paper sheets or notebooks, our behavior of handling them seems to be rough and lack of carefulness. When we hold a notebook, we usually hold it roughly with a single hand without paying careful attention. When we move it on a desk, we usually slide it on the desk surface without holding it up. We know very well from our experience that it is rare that a notebook as a typical example of analog devices gets out of order or it scratches the surface of it or the surface of the desk.

In 2017, a new A4-size electronic paper device came into market. When we got hold of it for the first time, we felt as if it were stationery rather than a digital device. It was lightweight, thin, and easy to handle. The panel is completely flat and it looks like a sheet of paper or a notebook. Moreover, the material of the panel is not a glass unlike tablet PCs. Therefore, the panel does not glare and our fingerprint is not clearly remained on the panel after touching it. Through our experience of using it, we also found ourselves that we handled it like analog stationery without careful caution.

We think that we can understand how users feel about a device from their behavior for the device. In this paper, we analyze human behavior for various devices and examine how people consider the electronic paper device. We also hypothesize that the human behavior for the A4-size electronic paper device will be close to the human behavior for a sheet of paper rather than that for other digital devices.

Besides, when we read documents in academic or work situations, we frequently move documents, arrange them spatially, or show them to others by pointing to contents. We expect that digital reading devices that we can handle like analog stationary would support reading well in such situations.

2. Related Work

There have been many studies on the evaluation of e-readers with electronic paper panels. They are divided into two types: field studies and laboratory experiments.

Regarding field studies, fifty-one students at Princeton University used Kindle DX of Amazon.com Inc. to browse handouts of lectures. The paper consumption of these students was less than half of that of other students who did not use the Kindle DX. They required an annotation function and smooth page navigation as additional features of the Kindle DX to be used in academic activities.

Maynard* investigated how young children felt about digital

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1 This paper is the revised version of our previous article.
reading devices (Kindle of Amazon.com Inc., Nintendo DS of Nintendo Co., and iPod touch of Apple Inc.) through their actual use of the devices for children’s books. The children subjectively evaluated the Kindle highly with respect to its presentation quality and device size compared to other devices. They also reported that they could read books faster with the Kindle than with other devices.

Hupfeld et al. observed how people used digital reading devices (Kindle and iPad of Apple Inc.) for leisure-based reading. Users complained about the difficulty of page navigation and browsing of the Kindle.

Shibata et al. used Digital Paper (DPT-S1) with A4-size electronic paper panel in their actual work and tried to use less paper as much as possible. In this study, users reported the difficulty in exchanging data between the device and a PC, problems of the usability of the device, and the difficulty in page navigation.

Regarding laboratory experiments, some of them measured reading speed, level of understanding, and subjective evaluation for reading novels. They evaluated reading from paper and reading from e-book readers with electronic paper panels (LIBRIs of Sony Co.). As a result, significant difference was not found among these conditions. This indicates that electronic paper devices provide high-quality document presentation which is not inferior to paper, at least from the perspective of the effect for such objective indicators.

Visual fatigue is also examined. Generally speaking, paper is subjectively regarded as giving less fatigue. However, no significant difference was found between reading from paper and reading from e-book readers in terms of objective indicators such as regulatory function of eye muscles, contrast sensitivity, flicker values, and the frequency of blink.

Szalavitz described his experience that it was difficult to remember character names when reading mystery novels with Kindle. Mangen et al. compared children’s reading from paper books and reading from e-books with the Kindle. Results showed that the children were able to reconstruct the order of the story events more correctly with the paper books than with the e-books. They considered the reason was that people understand the order of stories in accordance with hand movement of page turning with paper books.

Shibata et al. compared the speed to search answers from a text manual using a paper book, a desktop PC with a mouse, and a tablet PC. In their study, the tablet condition was significantly slower than the other two conditions. That was because the tablet PC had difficulty in navigating pages and it took time to turn pages continuously. Although they did not deal with an electronic paper device in their study, we can easily expect that results would be getting worse when using an electronic paper device in this situation, because page turning speed is slower in electronic paper devices than in tablet PCs.

According to the above laboratory experiments, electronic paper devices were inferior to paper books in page access. However, significant difference was not found in other aspects such as effects on reading speed, understanding, or visual fatigue. If the reading does not include any page turning, is not there any difference between reading from paper and reading from electronic paper devices? In this study, we pay attention to people’s actions such as holding or moving devices and make clear how these devices gives different impressions and experiences to users.

3. Method

We conducted an experiment to analyze the behavior for various A4-size slate devices. We required participants to do tasks and video recorded their actions for these devices.

Design and participants. The experimental design was a one-way within-subjects design. The independent variable was a media condition with four levels: a sheet of A4 plain paper for photocopier (Paper), a tablet PC with a LCD panel (Tablet), an A4-size electronic paper device of the first version (DP1), and the second version (DP2).

Participants were 14 people (13 males and 1 female). Their ages were from 22 to 63 years. The system condition order among the participants was randomized.

Apparatus. Specifications of the four media are summarized in Table 1. The device of Tablet (iPad Pro) is covered with a glass, its bezel color is black, and its weight is relatively heavy (677 g). The device of DP1 (DPT-S1) is covered with plastics and its bezel color is black. It has a tiny step between the bezel and the panel. The device of DP2 (DPT-RP1) is also covered with plastics, but its bezel color is white and its panel is completely flat. The weight of DP1 (358 g) and DP2 (349 g) is nearly half of the Tablet.

Tasks, materials, and setup. Experimental tasks were following four. In all the tasks, text was shown in the same font and the same size in all medium.

(1) Transcribing task: The participants transcribed text shown in each medium (text document) on a sheet of paper (memo paper). Four texts were selected from a short novel of Haruki Murakami. The length of the texts was from 36 to 40 characters. The percentage of Chinese characters (i.e., Kanji) in the text was from 25.6% to 30.0%. The memo paper was A4 size (294 × 210 mm) and included seven horizontal lines for transcribing the text. The line width was 15 cm and line distance was 2.5 cm. The participants were encouraged to transcribe text along with the lines.

At first, in each medium, the text document was
Table 1  A4–size media used in the experiment.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Product</th>
<th>Release</th>
<th>Device size</th>
<th>Panel</th>
<th>Weight</th>
<th>Device feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>A4 PPC paper</td>
<td>—</td>
<td>210 × 294 mm</td>
<td>—</td>
<td>4 g</td>
<td>Fibers, White, Flat</td>
</tr>
<tr>
<td>Tablet</td>
<td>iPad Pro (Apple)</td>
<td>2016</td>
<td>220.6 × 305.7 × 6.9 mm</td>
<td>12.9 inch</td>
<td>677 g</td>
<td>Glass, Black, Flat</td>
</tr>
<tr>
<td>DP1</td>
<td>DPT–S1 (Sony)</td>
<td>2013</td>
<td>233 × 310 × 6.8 mm</td>
<td>13.3 inch</td>
<td>358 g</td>
<td>Plastic, Black, Non–flat</td>
</tr>
<tr>
<td>DP2</td>
<td>DPT–RP1 (Sony)</td>
<td>2017</td>
<td>224 × 302.6 × 5.9 mm</td>
<td>13.3 inch</td>
<td>349 g</td>
<td>Plastic, White, Flat</td>
</tr>
</tbody>
</table>

Fig. 1  Document layout on a desk.

placed in the left position of Fig. 1 and the memo paper was placed in the central position of Figure 1. After starting the task, they could freely change the position of these documents. They were not encouraged to write characters beautifully. They were encouraged to transcribe text as fast and accurate as possible. They could use strike out to correct writing errors.

Inputting task: The participants input text shown in each medium (text document) on a PC with typing. As a PC, we used Surface Pro 3 and its accessory keyboard to input text. The OS was Windows 8.1. Four new text was created in the same manner as in the first task. The length of the text was from 38 to 40 characters. The percentage of Chinese characters in the text was from 25.0% to 30.0%.

At first, in each medium, the text document was placed in the left position of Figure 1 and the PC to input text was placed in the central position of Figure 1. After starting the task, they could freely change the position of the document. They were encouraged to input text as fast and accurate as possible.

Moving task: The participants moved each medium. At first, it was placed in the central position shown in Figure 1. They moved it to the right position, to the left position, and to the central position again. They were not encouraged to move each device fast. Each position was marked on the desk as shown in Figure 1.

Showing task: The participants showed a document displayed on each device to an experimenter sitting on the chair of the participants' left 100 cm far from the participants' chair. At first, the document was placed in the central position of Figure 1.

Procedure. Before the experiment, the participants sat at the location marked by a small red triangle on the desk edge as shown in Figure 1. They remained seated during the experiment. They were allowed to change their upper body posture during the experiment.

The participants performed all the four tasks from Task 1 to Task 4 in this order. In each task, they performed the task with all media. They performed the paper condition at first, because we used the paper condition as a baseline to evaluate media subjectively. After the paper condition, they performed other media. The order of media except for paper and the order of documents used in each task was randomized.

After performing all media in each task, they subjectively evaluated the usability of media. They scored the usability of each media from 0 to 200, where 0 was the lowest usability of tools and 200 was the highest usability of tools. The score of the paper was fixed to 100. They scored other media relatively compared to the paper.

We asked participants to evaluate the usability of all media in all tasks. We did not tell them to analyze their behavior during the tasks. We video recorded how the participants performed tasks to analyze their behavior later.

After all the tasks were ended, we conducted an interview and asked how they felt about each medium for every task. The experiment lasted about 40 min.

Analysis. We used following dependent variables in the analysis of the experiment:
- participants' subjective scores for each medium,
- the percentage of actions performed with a single hand, and
- the percentage of actions that included sliding a medium on the desk.

We considered that the latter two actions (single–hand actions and sliding) as typical rough actions that are frequently performed for analog media. The latter two variables were measured by analyzing video data. On counting the action for a medium, every time participants released their
Fig. 2 All results of Task 1 to 4: Subjective scores (A) and the percentage of single-hand actions and sliding (B).
finger from the medium or changed the position of the finger on the medium, we considered that a new action started.

### 4. Results

**Fig. 2** shows subjective scores and the percentage of characteristic actions (single-hand actions and sliding) for all the tasks. To test the results statistically, we conducted repeated measures ANOVA (analysis of variance). Post-hoc analysis of multiple comparisons was performed with Tukey’s method.²

#### 4.1 Task 1: Transcribing Task

Regarding subjective scores, the repeated measures ANOVA showed a significant effect on media \((F(3, 39) = 7.32, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 1 (A). The class difference is summarized as follows: Tablet < DP1 = DP2 < Paper.

Regarding the two actions (single-hand actions and sliding), we conducted a two-way repeated measures ANOVA. The interaction of the two actions was significant \((F(3, 39) = 3.96, p < .05)\). Therefore, we conducted simple main effects for every action. For single-hand actions, the simple main effect was significant \((F(3, 39) = 11.08, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 1 (B). The class difference is summarized as follows: Tablet < DP1 = DP2 < Paper. For sliding, the simple main effect was not significant \((F(3, 39) = 2.00, ns \text{ (non significant)})\).

#### 4.2 Task 2: Inputting Task

Regarding subjective scores, the repeated measures ANOVA showed a significant effect on media \((F(3, 39) = 6.81, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 2 (A). The class difference is summarized as follows: Tablet < DP1 = DP2 < Paper.

Regarding the two actions, we conducted a two-way repeated measures ANOVA. The interaction of the two actions was significant \((F(3, 39) = 1.38, ns)\). Therefore, we conducted simple main effects for every action. For single-hand actions, the simple main effect was significant \((F(3, 39) = 8.86, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 2 (B). The class difference is summarized as follows: Tablet < DP1 < DP2 < Paper. The class difference was significant as follows: Tablet < DP1 \((p < .05)\), Tablet < DP2 \((p < .01)\), and Tablet < Paper \((p < .001)\). For sliding, the simple main effect was not significant \((F(3, 39) = 1.09, ns)\).

#### 4.3 Task 3: Moving Task

Regarding subjective scores, the repeated measures ANOVA showed a significant effect on media \((F(3, 39) = .4169, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 3 (A). The class difference is summarized as follows: Tablet < DP1 = DP2 < Paper.

Regarding the two actions, we conducted a two-way repeated measures ANOVA. The interaction of the two actions was not significant \((F(3, 39) = 4.20, p < .05)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 3 (B) for both actions. The class difference is summarized as follows: Tablet < DP1 = DP2 < Paper.

#### 4.4 Task 4: Showing Task

Regarding subjective scores, the repeated measures ANOVA showed a significant effect on media \((F(3, 39) = 10.17, p < .001)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 4 (A). The class difference is summarized as follows: Tablet < Paper < DP1 = DP2.

Regarding the two actions, we conducted the two-way repeated measures ANOVA. The interaction of the two actions was not significant \((F(3, 39) = .621, ns)\). The post-hoc analysis showed significant differences as shown in Figure 2 Task 4 (B) for both actions. The class difference is summarized as follows: Tablet < Paper < DP1 < DP2.

### 5. Summary and Discussion

All the significant differences are summarized in Table 2. Regarding the Tablet condition, the subjective scores of Tablet were the lowest in all the four tasks. In Task 1 and 2, single-hand actions in Tablet were fewer than that in other conditions. In Task 3 and 4, both single-hand actions and sliding in Tablet were fewer than that in Paper and DP2.

Most participants reported that the tablet device was heavy and they needed to use both hands to handle it. Moreover, they reported that its glass cover of the panel gave an impression that they had to handle it carefully not to cause a bruise on the device and on the desk. When people put the tablet on the desk, it sometimes causes big metallic sound. Some participants

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² The terminology and notation of this paper are based on the Mori and Yoshida’s textbook on psychological statistics.
reported that they put it on the desk carefully not to cause big sound. From the observation, we had a feeling that some participants avoid touching the glass panel. Additionally, they were handling the device with touching thin side area of the device when they held or put it. They might feel a psychological barrier to touch a glossy hard glass with their hand directly. We inferred that they did not want to remain their fingerprints on the panel to read. A participant commented that they disliked remaining their fingerprints on the glass surface. We think that such features of the tablet made it difficult to handle.

Regarding DP1, the subjective evaluation was higher than Tablet and was close to Paper. Although the score of DP1 was lower than that of Paper in Task 3, 10 of 14 participants gave more than 100 scores to DP1. In Task 1 and 2, single-hand actions and sliding were performed more frequently in DP1 than in Tablet.

Many participants reported that the device of DP1 was thin, light-weight, and easy to handle. Moreover, it uses plastic to cover the panel. Participants reported that they did not have to pay careful attention to hold or slide it. A participant described this situation. “It does not give me a feeling of elaborate digital equipment. I can use it at ease like a clear plastic folder. Moreover, when I hold it, I can easily insert my finger easily from the side of it (because its side is curved roundly). It is sort of more than a clear plastic folder.”

Regarding DP2, the subjective evaluation was the almost same as DP1 in all tasks. For actions, in the percentage of single-hand actions and sliding of Task 1 and 2, no significant difference was found between DP1 and DP2. However, in Task 3 and 4, participants performed more single-hand actions and sliding in DP2 than in DP1.

Similar to DP1, many participants reported that the device of DP2 was thin and light and they did not have to pay careful attention to handle it. Some participants reported that the device of DP2 did not give an impression of an electronic device. The panel of DP2 is flat and we think they considered it as an analog slate rather than an electronic device. For this point, one of the participants described, “The material of the device looks like a cardboard. And its panel is completely flat. It seems like a slate of a cardboard.” We found that DP2 did not give an expensive impression to users and therefore they could use it without special care.

Additionally, some participants reported that they felt the DP2 device was lighter than the DP1 device. However, as a matter of fact, the difference of the weight of the both devices was just 9 g as shown in Table 1. It is well-known that dark-colored objects look heavier than brighter-colored objects. It seems that white color of the DP2 device made people think it was lighter than the DP1 device.

To sum up, the participants’ behavior for the DP2 device was closer to that for a sheet of paper than that the DP1 device does. This indicates that they handled the DP2 device like a stationery of an analog tool.

The visual feature of the presentation panels (i.e. resolution or contrast of electronic paper panels) of DP1 and DP2 was very similar. The difference of participants’ behavior was caused by the device features (e.g., non-flat or flat, and black or white). This indicates that the design of devices is also an important factor that affects users’ behavior.

Next, we want to discuss the importance of ease of handling devices to support work-related reading or academic reading. Different from reading novels, during such reading, people frequently move or arrange documents spatially, show them to others by pointing to contents, or changing the orientation of documents. If such actions are restricted during reading in digital environments, previous experiments have shown that the performance of reading (i.e. reading speed or understanding) might be deteriorated compared to the use of paper. We expect that electronic paper devices like DP1 or DP2 would decrease such problems because they can be roughly handled like a sheet of paper.

Subjective evaluation is an easy method to know how users felt about devices, but it is apt to be affected by experimenter’s expectation-effect, where participants unintentionally respond to what experiments expect. We have a prospect that the analysis of participants’ behavior for devices would be an effective objective method to evaluate users’ conscious for devices. We would like to examine the possibility of such use of this method as our future work.

6. Conclusion

In this study, we evaluated people’s conscious for digital devices from their behavior for the devices. Our experimental results showed that the behavior for digital paper devices were similar to that for paper sheet in comparison with tablet PCs. This indicates that they considered electronic paper devices as what was near analog paper rather than delicate digital devices. Moreover, the behavior for the second version of the A4-size electronic paper devices was closer to that for a sheet of paper than that the first version does. The important difference of device features was the color of the device and the flatness of the presentation panel. We think that white color and flat panel of the device contributed to what makes people consider them as analog media.

As our future work, we would like to design a digital reading device to support work-related reading or academic reading. In such situations, it is desirable to be able to handle the device like analog stationary during reading. We would like to use this evaluation framework to confirm how the device is close to analog stationary.
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