Effects of Paper on Page Turning: Comparison of Paper and Electronic Media in Reading Documents with Endnotes

Hirohito Shibata and Kengo Omura

Research and Technology Group, Fuji Xerox Co. Ltd.
6-1 Minatomirai, Nishi-ku, Yokohama, Kanagawa, 220-8668, Japan
{hirohito.shibata,kengo.omura}@fujixerox.co.jp

Abstract. This study compares the performances of paper and electronic media during a reading task that includes frequent page turning. In the experiment, 18 subjects read multi-page documents aloud while referring to endnotes using paper, a large display, and a small display. Results revealed that reading from paper was 6.8% faster than reading from a large electronic display and 11.4% faster than reading from a small electronic display. No difference was found between scores of recognition tests of important words of documents among the three conditions, which indicates that paper is the most effective medium for people to read text speedily without reducing comprehension. Detailed analyses of the reading process show that, in the Paper condition, people perform both text reading and page-turning simultaneously. However, when using computer displays, reading and turning pages were divided completely and performed separately.

Keywords: paper, reading, page turning.

1 Introduction

This study performed a quantitative comparison of the performance of reading multi-page documents with endnotes between paper and electronic media.

Since the 1980s, many experiments have been conducted to evaluate the readability of text documents on paper and displays [1–10]. They mainly focused on presentation properties such as the resolution of a medium, the size of a medium, text font, and the document format, and examined how the difference of these properties affect reading performance. In addition, their experiments addressed sequential reading, whose processes include less movement back and forth between pages of a document or among documents.

However, as Sellen and Harper [11] described based on an observation of real-world reading, only rarely did workers read documents sequentially from beginning to end with turning pages one-by-one, at least in work situations. Readers often refer to the table of contents or references frequently, skim documents, and move back and forth between pages repeatedly while reading. O'Hara and Sellen [12] observed the reading processes used for scientific articles and reported that readers frequently navigated among pages of a document or among multiple documents. They skim

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articles to grasp the flow of text, move to previous pages to confirm definitions of terms, and turn pages to refer to figures or tables. Additionally, O'Hara et al. [13] observed the professional writing process and reported that writers move attention across documents, lay out documents spatially, and freely annotate documents during writing. They also described that physical paper, as a material artifact, supported these operations effectively.

However, the effect of operability in such operations for reading has been only scarcely investigated quantitatively. This study specifically examines the operation of page turning and quantitatively compares reading performance with frequent page turning using paper and electronic media.

In electronic media, various user interface tools can be used to switch pages, such as scrolls, page-turning buttons (e.g., "previous buttons" and "next buttons"), overview using thumbnails of pages (e.g. the "page navigation panel" of Adobe Reader), physical buttons [14], and gestures [15, 16]. Among them, we specifically examine the operation of scrolling and page-turning buttons because they are common and widely used features that are used to switch pages. Some studies have compared reading performances of scrolls and page-turning buttons [6, 17, 18]. However, the studies were aimed at improving the user interfaces of electronic environments and therefore compared the different user interfaces of electronic media. In contrast, the present study compares reading performance achieved when using paper and electronic media.

2 Hypotheses

As described earlier, in the reading of work situations, readers frequently move back and forth between pages. The aim of the experiment is to analyze how the operability of a medium affects reading performance. For the experiment, we use multi-page documents with endnotes as reading materials. We require subjects to read aloud to follow where the subjects read in documents at each time of reading. By analyzing the discontinuity of reading aloud associated with page turning, we can separate the reading of the main text only, which does not include referral to notes listed on another page, from the reading of whole documents that accompany repeated page turning. Furthermore, we can measure the time used to refer to notes and the time used to turn back to the main text. Hypotheses examined using this experiment are the following four.

First, if reading processes do not include page turning, then we expect that reading from paper is as fast as reading from computer displays. According to an experiment conducted by Gould et al. [5] in the late 1980s, no difference exists between reading speeds attained when reading from paper and when reading from CRT displays. Although the display used in their experiment was a high-performance one in those days (the display resolution was 1024 × 1024), the performance of current up-to-date TFT displays is better than the display that Gould et al. used in their experiment. Consequently, it is apparently natural that the reading speed from displays does not differ from the reading speed achieved when using paper.

Second, if reading accompanies frequent page turning, then we expect that reading from paper is faster than reading from a computer display. Previous observational studies [11, 13, 19] show that paper is preferred for use in the reading of work situations. Adler et al. [20] categorized work-related reading as 10 kinds. Among them, frequently observed reading was reading for cross-referencing, reading to search for answers to questions, reading to support discussion, and skimming. In such reading, people often must turn back and forth between pages. We think that one reason why people prefer paper in work-related reading is that paper supports such reading with frequent page turning.

Third, we expect that people can understand the contents of documents more deeply when reading from paper than when reading from a display. The difference of operability between media is attributable to the difference of cognitive load. During reading with frequent page turning, the cognitive load is less when reading from paper than it is when reading from displays. We expect that this load affects the degree of document comprehension.

Fourth, we hypothesize that people can read documents with endnotes rapidly when reading from paper because people perform both reading and turning pages simultaneously. When reading from paper, people can switch pages with the feeling of hands without using vision. Consequently, people need not look away from the text of documents while turning pages. However, when reading from displays, people must look away from document text to use page turning buttons or scroll bars. We think that this makes it difficult to read and turn pages simultaneously using PC displays.

3 Method

Design and subjects. The experimental design was a 3×2 within-subjects design. The first factor was media (paper, a large display, and a small display); the second factor was parts of reading (reading without page turning and reading with page turning). Each subject performed all conditions of tasks. They performed two trials in each condition. The order of the media and types of reading in the series of subjects' trials were counterbalanced to cancel the effects of the trial order overall.

Subjects were 18 people (9 male, 9 female). Their ages were 20–39 years (avg. 29.1). Each had three or more years' experience of using a PC. The power of vision of each after correction was better than 0.7.

Materials. We created documents for the experiment based on columns of a Japanese newspaper. The documents consisted of two pages: The first page was a main text with eight annotation numbers; the second page was a list of annotation notes. The annotation notes were originally created based on the contents of dictionaries and Wikipedia. We created six documents for the experiment and two documents for a training session. For the six documents used in the experiment, the average length of the main text of the first page was 622.3 characters, and the average length of annotation notes of the second page was 246.8 characters.

Procedure. The task of the experiment was to read the documents aloud. When reading, subjects were required to move to annotation notes immediately after reading words with annotation numbers (*referring*). Subjects were required to return to the former position in the main text and commence reading after reading the annotation notes (*returning*), as presented in Fig. 1.

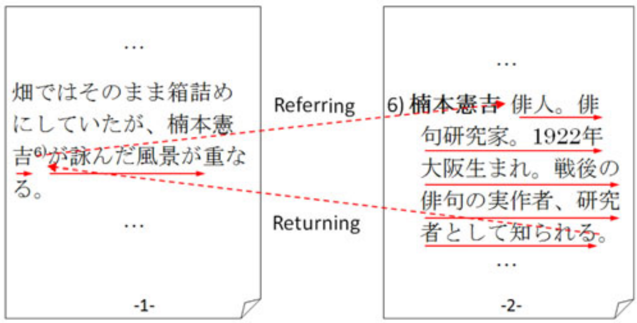

Fig. 1. How to read text documents

We videotaped the images and sounds produced while subjects were reading. To measure the time for referring and returning by specifying the start and the end of continuous sound of voice, we required subjects to read aloud. It might seem that the task setting was artificial because people usually read text without uttering a word. However, a previous study shows that a strong positive correlation exists between silent and oral reading speed: those who speedily read aloud also read rapidly in silence [21].

When reading from paper (Paper condition), documents were printed on one side of B5 paper in black and white and stapled in the upper left corner. When reading from the large display (LD condition), documents were displayed in a 20.1-inch TFT monitor (Diamondcrysta RDT201L, 1600×1200; Mitsubishi Electric Corp.). When reading from the small display (SD condition), documents were displayed in a 10.4-inch TFT monitor (Let's note CF-R3, 1024×768; Panasonic). In electronic conditions (LD condition and SD condition), the OS was Windows XP (Microsoft Corp.). Electronic documents were all PDF format and displayed with Adobe Reader 9 (Adobe Systems Inc.).

In the Paper condition, subjects turned pages using both hands. In the electronic conditions, subjects turned pages using scroll bars or page-turning buttons.

We adjusted the character size of electronic documents to be the same size as those of paper documents. We prohibited changing of the size of displayed characters. In this situation, a single whole page was displayed in the LD condition and about half of a page was displayed in the SD condition. Prior to the experiment, subjects adjusted the position of displays and display preferences to their preference.

We instructed subjects to read documents with comprehension of the contents of the documents. We encouraged subjects to read at a natural speed. However, we required fast and smooth reading when referring to notes and returning to the main text to the greatest extent possible.

After reading all documents, we conducted a recognition test of important words of documents to check how well subjects remembered brief summaries of documents. We did not announce this test for subjects in advance. In the test, for each document, we presented 16 words selected from the document and 16 words as distracters, which were not used in the documents. We required subjects to answer whether or not given words occurred in the documents. In the process of selecting the 16 words, at first two experimenters separately selected 20 important words for each document. The agreement rate was 55.2%. Finally, we selected 16 important words for each document based on discussion between the two experimenters.

4 Results and Discussion

Fig. 2 presents comparison of the reading speed (the number of characters that subjects read per minute) in each condition. The time required for reading the main text was calculated by eliminating the time from the end of reading aloud before referring to notes to the start of reading aloud after returning to the main text. The timing of discontinuity of reading aloud was identified by visual judgment using audio waveform presented by Windows Movie Maker (Microsoft Corp.).

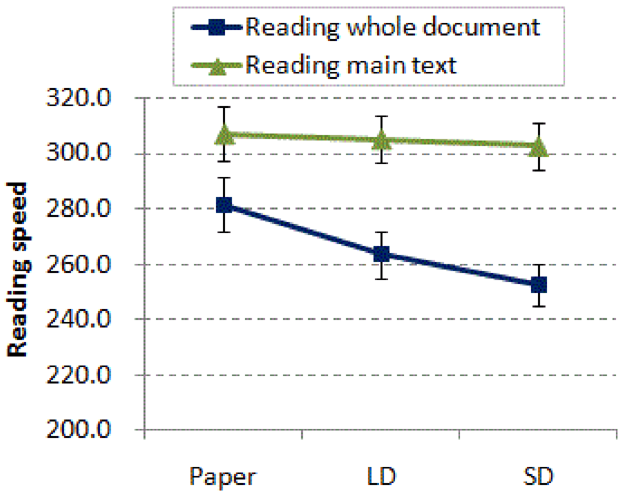

Fig. 2. Reading speed in each condition. Reading of whole documents includes page turning and reading of main text only does not include page turning.

A two-way repeated measures analysis of variance was conducted to assess the reading speed according to the medium used (Paper, LD, and SD) and parts of reading (whole documents and only main text). Results show that the main effects of the medium [$F(2, 34)=5.08$, $p<0.05$] and the parts of reading [$F(1, 17)=151.17$, $p<0.001$] were significant. Interaction of the two factors was significant [$F(2, 34)=11.37$, $p<0.001$]. Then we tested the simple main effects of the medium for each part of reading. Although the simple main effect was significant for the reading of the whole document [$F(2, 34)=15.57$, $p<0.001$], the simple main effect was not significant for the reading of only the main text [$p>0.1$]. According to multiple comparison using the LSD method, reading in the Paper condition was significantly faster than the reading in the LD condition, and the reading in the LD condition was also significantly faster than the reading in the SD condition [$p<0.05$]. Regarding reading documents with frequent page turning, reading from paper was 6.8% faster than reading from large displays and 11.4% faster than reading from small displays.

Regarding the recognition test of important words, no significant difference was found in the scores for different media, which indicates that paper is a medium that enables rapid reading without deterioration in the level of understanding. Our second hypothesis was not supported in the experiment. However, the relation between reading speed and the level of understanding is complementary; subjects might have adjusted the speed of reading to achieve a certain degree of understanding.

No significant difference was found for the main text reading speed. Therefore, reading speed is independent of the medium if reading does not include page turning. However, reading from paper was faster than reading from the displays (LD and SD) in this experiment because the act of referring and returning is performed more rapidly in the Paper condition than in the LD and SD conditions.

Fig. 3 presents a comparison of the processing time of referring to notes and returning to the main text in each condition.

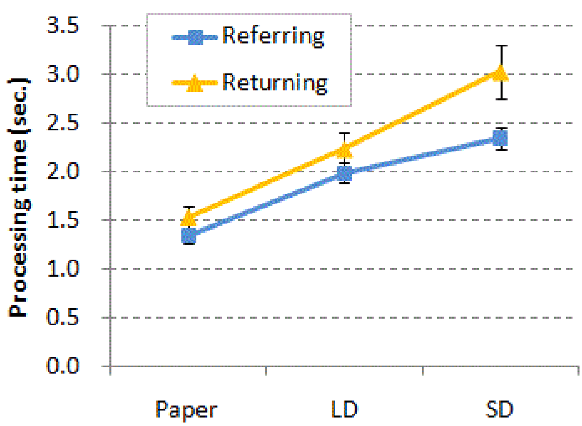

Fig. 3. Time for referring notes and returning to the main text

A two-way repeated-measures analysis of variance was conducted to assess the reading speed according to the medium used (Paper, LD, or SD) and the direction of referring (referring and returning). Results show that the main effects of the medium [$F(2, 34)=69.75$, $p<0.001$] and the direction of referring [$F(1, 17)=9.95$, $p<0.01$]. Interaction of the two factors was also significant [$F(2, 34)=7.426$, $p<0.01$]. Then we tested the simple main effects of the medium for each direction of referring and found that simple main effects were significant for both referring and returning [$F(2, 34)=83.24$, $p<0.001$; $F(2, 34)=42.98$, $p<0.001$]. According to multiple comparison using the LSD method, in both cases, the processing time of the Paper condition was significantly shorter than in the case of the LD condition and the processing time of the LD condition was significantly shorter than in the case of the SD condition [$p<0.05$].

Referring to notes using paper was 32.7% faster than in the case of large displays that can display a whole single page, and 43.0% faster than in the case of small displays that can display half of a single page. Furthermore, returning to the main text from notes using paper is 31.3% faster than in the case of large displays, and 49.2% faster than in the case of small displays.

Turning back to the main text from notes takes more time than referring to notes in all conditions. A reason for this is apparently that it takes time to find the start position of reading after returning to the main text. In the second page of documents, all annotation numbers and annotation words are positioned to the left of lists. Therefore, when referring to notes, people can find the start position of reading easily. However, annotation numbers in the main text are small and scattered in text. Therefore, when returning to the main text, people seem to have difficulty finding the start position of reading.

Fig. 4 presents a comparison of the percentage of page turning in which subjects had started to turn pages before finishing reading the text, where we call these phenomena *simultaneous operations*. For each referring and returning, we judged whether or not two actions of turning pages and reading were performed simultaneously by analyzing the videotapes.

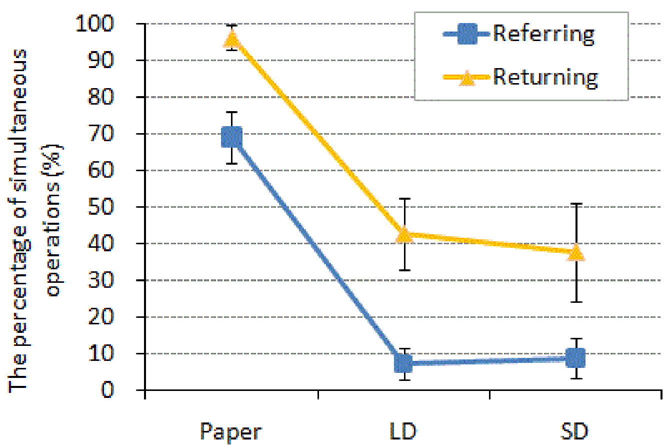

Fig. 4. The percentage of simultaneous operations

A two-way repeated measures analysis of variance was conducted to assess the reading speed according to the medium (Paper, LD, or SD) and the direction of referring (referring and turning back). Results show that the main effects of the medium [$F(2, 34)=130.43$, $p<0.001$] and the direction of referring [$F(1, 17)=98.94$, $p<0.001$]. Interaction of the two factors was not significant [$p>0.1$]. According to multiple comparison by the LSD method, more simultaneous operations existed in the Paper condition than in both the LD condition and the SD condition [$p<0.001$]. When reading from paper, readers frequently perform simultaneous operations more than 7.8 times on referring and more than 2.3 times on returning in comparison with the case of reading from an electronic medium.

Fig. 4 shows that when reading from paper, readers perform reading and turning pages simultaneously, i.e., two different actions are mutually overlapping. However, when reading from an electronic medium, readers often turn pages after finishing the reading of text, i.e. the two actions are completely separate. As Sellen and Harper [11] described, computer operations heavily rely on visual cues. To turn pages, people need to look away from text to page-turning buttons or scroll bars. It makes difficult to perform two actions of reading and turning pages simultaneously. On the other hand, when reading from paper, people can turn pages with the feeling of hands without vision. It allows to interweave two different actions. It seems that this engendered rapid reading in the Paper condition.

We next consider the reasons for reading speed differences between the LD condition and the SD condition. In the LD condition, people can view a single whole page at a glance, but in the SD condition people can view only half of the page in a display area. Therefore, we expect that people must perform more operations such as clicks or drags on a scroll bar in the SD condition than in the LD condition.

Fig. 5 shows the number of operations such as clicks on a scroll bar (Click), drags of a scroll bar (Drag), and clicks of page-turning buttons (Button) per instance of referring to notes and returning to the main text. A two-way repeated measures analysis of variance was conducted to assess the reading speed according to the medium (LD and SD) and type of operation (Click, Drag, and Button). Results show that the main effects of the medium [$F(1, 17)=8.87$, $p<0.01$] and type of operations [$F(2, 34)=4.04$, $p<0.05$] were significant. Interaction of the two factors was also significant [$F(2, 34)=5.75$, $p<0.01$]. We tested the simple main effects of the medium for each type of operations. The simple main effect was significant only for Drag [$F(1, 17)=19.25$, $p<0.001$]. Additionally, we observed a tendency by which the number of button operations in the LD condition was greater than that of the SD condition [$F(1, 17)=3.70$, $p<0.1$].

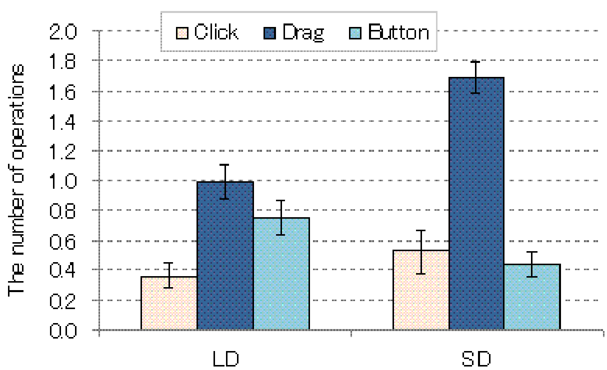

Fig. 5. Number of operations for page-turning

Using the large display, people frequently used page-turning buttons that enabled page-turning with a single click. However, with the small display, people frequently dragged a scroll bar, which seemed to take much time. Apparently, the difference of time required for referring to notes and turning back to main text between the LD condition and the SD condition is attributable to the difference of window operations.

5 Conclusion

We quantitatively compared subjects' reading performance using three media: paper, a large electronic display that presents a whole page, and a small electronic display that presents half of a page. The reading speed using paper was equal to those of both displays if the reading included no page turning. However, in the case of reading with frequent page turning, the reading speed for paper was 6.8% faster than for the large display and 11.4% faster than for the small display. A recognition test of important words of documents, we found no difference among media. Results showed that people were able to achieve the same level of comprehension as that achieved with computer displays for a short time.

To determine why reading from paper is faster than computer displays, we analyzed the process of reading in detail. Results show that subjects were able to refer to notes and return to the main text efficiently when reading from paper. Furthermore, when reading from paper, subjects frequently performed reading and page-turning simultaneously: they interwove two actions while reading. We think that this brought smooth fast reading in paper.

The results presented in this paper indicate that, when reading documents with frequent page turning, reading time could be reduced up to 11.4% without sacrificing comprehension if a person were able to select the appropriate medium. Examples of reading during which readers frequently move back and forth between pages are the following:

- reading of books with numerous notes,
- reading of documents with many references (e.g., academic paper and reports),
- reading of documents for which figures and tables are listed in the end of documents (e.g. patent descriptions), and
- proofreading while checking terminology.

We think that it is valuable to reconsider the use of paper in such instances of reading.

We are currently conducting a series of experiments to compare the performance of paper and electronic media. We intend to investigate reading of other types such as cross-reference reading using multiple documents, skimming, and reading with frequent annotation, as future research.

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