2006

A Video Analysis of Eye Movements during Typing: How Effective is Handwriting during Note-Taking Tasks?

Muhd Dzulkhiflee Hamzah
The University of Electro-Communications, kifuri74@tlab.is.uec.ac.jp

Shun'ichi Tano
The University of Electro-Communications, tano@tlab.is.uec.ac.jp

Mitsuru Iwata
The University of Electro-Communications, miwata@tlab.is.uec.ac.jp

Tomonori Hashiyama
The University of Electro-Communications, hashiyama@tlab.is.uec.ac.jp

A Video Analysis of Eye Movements during Typing: How Effective is Handwriting during Note-Taking Tasks?

Muhd Dzulkhiflee Hamzah, Shun'ichi Tano, Mitsuru Iwata, and Tomonori Hashiyama
Information Media System Laboratory
Graduate School of Information Systems, The University of Electro-Communications
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, JAPAN
{kifuri74,tano,miwata,hashiyama}@tlab.is.uec.ac.jp

Abstract

Keyboard input for non-alphabetical languages, such as Chinese and Japanese, is problematic because it is labor intensive and imposes a high cognitive load. In our previous work, we measured the effectiveness of handwriting during a note-taking task in Japanese, and found that the input speed during note-taking was higher by hand than by keyboard. The results also showed that the quality of notes taken by hand was higher than that of notes taken by keyboard, and this might have been due to the higher cognitive load during typing. In addition, observation during the experiment revealed several problems subjects faced in the keyboard input task. To evaluate the significance of these observations, we had to obtain quantitative evidence through further study of participant behavior. Therefore, we repeated the experiment, this time with video analysis of the keyboard subtask. By analyzing the participants' eye movements and their behavior throughout the keyboard subtask we obtained quantitative evidence to support our findings from the previous study. Here, we describe this experiment and our findings in detail.

Keywords: Video analysis, eye direction movements, note-taking task, handwriting, and keyboard input problems.

1. Introduction

Digital document technologies clearly benefit the writing process by supporting information reuse and easy text modification as well as by providing specialized tools (O'Hara et al. 1997). Unfortunately, the keyboard input process for non-alphabetical languages, especially East Asian languages, is problematic and troublesome, because it is labor intensive and imposes a high cognitive load. Unlike English and most other European languages, many Asian languages such as Japanese, Chinese, and Korean are written using a huge number of characters, which greatly outnumber the characters in the Roman alphabet. A keyboard large enough to contain even the most commonly used characters would be impractical.

The most common approach to non-alphabetical text input is to use either a "radical-based" or a "phonetic-based" input method. With radical-based input methods, the component radicals (fundamental strokes) are typed in to produce a character. For example, the 11,172 Korean characters (Hangul) are entered by typing the corresponding 24 basic elements and combining them on a standard QWERTY keyboard. With phonetic-based methods, a character is produced by typing its syllables, generally using a Roman alphabet-based phonetic system such as "*pinyin*" in Chinese and "*romaji*" in

Japanese; unlike the radical-based method, these processes require a few steps before a character or word can be entered. Figure 1 shows a sample of Japanese text input using Roman characters with a QWERTY keyboard; a method widely used by Japanese users (Morita et al. 1987).

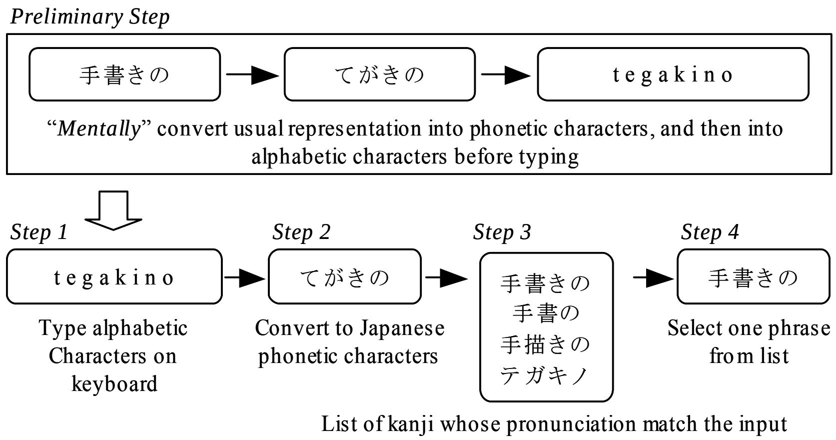


Figure 1. Japanese text input using Roman characters with a QWERTY keyboard

The heavy cognitive processing load this imposes can impair the user's mental functions, and is a bottleneck when text is input by keyboard in non-alphabetical languages, such as Chinese and Japanese. Our hypothesis is that keyboard input is not suitable for tasks requiring a lot of attention. This is especially the case for note-taking, where a person has to listen carefully while jotting down important statements or valuable ideas. We expected the quality of notes taken with keyboard input to be lower than that of hand-written notes because the keyboard user has to pay attention not only to the information they want to input, but also to the text-input process such as the conversion process in Japanese and Chinese. To test this hypothesis, we experimentally investigated the differences between the input of Japanese text by hand and input by keyboard during a note-taking task and quantitatively determined that handwriting was more effective than keyboard input (Dzulkhiflee et al. 2005, 2006). However, to support these findings further experiments were needed. Therefore, we repeated the experiment with video analysis included; that is, we analyzed the subjects' eye movements during keyboard input throughout the experiment.

This paper focuses on this video analysis and our findings based on it. We first briefly review related work regarding text input problems in the next section. Then we describe details of our previous work to determine the effectiveness of handwriting in non-alphabetical languages, since it is the foundation of this video analysis experiment. After that, we describe the video analysis experiment and our findings in detail.

2. Related Work

Since handwriting is thought to be the most natural and fastest way to annotate and jot down notes, there has been a growing interest in the development of both freeform annotation and note-taking systems (Shun'ichi et al. 2003; Ramos et al. 2003). Unfortunately, only a few studies have quantitatively investigated the effectiveness of input by hand.

One study related to text input speed in Japanese compared the speed of input by hand, by keyboard, and by cellular phone, where university students were the subjects (Hiroshi et al. 2003). This study considered the input speed during text entry tasks, not during note-taking tasks; since the task was significantly different, it does not directly apply to our aim of determining the effectiveness of handwriting during a note-taking task. Furthermore, the study did not address the cognitive load during text input. Since the cognitive load during input is a crucial factor affecting input efficiency, it is important to consider the cognitive load as well as the input speed when evaluating the effectiveness of the various input methods.

A study on inputting Chinese characters revealed that choosing the target character alone accounts for 36% of the total input time (Wang et al. 2001). A study of inputting Japanese text input showed that the kanji (Chinese character) conversion process takes almost 70% of the total input time (Ren et al. 2003), but this study focused mostly on the ways in which kanji candidates are displayed and used only one-letter kanji as the input target.

Our previous study to determine the effectiveness of handwriting in non-alphabetical languages (Dzulkhiflee et al. 2005, 2006) differs from these. To clarify the effectiveness of handwriting, we conducted a quantitative experiment to identify the differences between input by hand and by keyboard in Japanese during a note-taking task. We considered the ergonomics as well as the input speed, and focused on the imposed cognitive load to evaluate the effectiveness of handwriting during a note-taking task.

3. How Effective is Handwriting vs. Keyboard?

We first experimentally investigated the differences between input by hand and input by keyboard during a note-taking task in Japanese to quantitatively clarify the effectiveness of handwriting compare to input by keyboard. The details of this experiment are given below.

3.1 Experimental Design

The main goal for this study was to reveal the effectiveness of handwriting during the note-taking task and compare it with that of keyboard input. We designed a comparison experiment to answer three questions.

- *Which input method is faster?* Input speed is the most commonly used measure to compare the effectiveness of input devices.
- *Which input method imposes a larger cognitive load and how does the load affect mental functions?* A note-taking task itself imposes a high cognitive load; the note-taker must catch and remember an idea or important statements and almost simultaneously record them, and this is why it is important to understand the difference in the cognitive load between handwriting and keyboard input during a note-taking task.
- *How effective is input by hand for tasks that involve cognitive processes such as note-taking?* We expected that quality of notes taken with keyboard input in Japanese or other non-alphabetical languages to be relatively low, because the user has to pay attention not only to the important things that they want to input, but also to the text-input process such as the conversion process in Japanese or Chinese. It

was important to test this hypothesis and understand how this influence differs between handwriting and keyboard input during note-taking tasks.

3.2 Experimental Tasks and Procedures

The first two tasks were designed to determine the differences in speed and cognitive load between taking notes by hand and by keyboard. The third task was designed to determine the effectiveness of taking notes by hand during typical note-taking tasks.

- *Task 1:* Participants were shown a sentence in a reference window and asked to input the same sentence by hand or by keyboard into a task window as shown in Figure 2. There were two sets of subtasks, one for input by hand and one for input by keyboard. Each set consisted of 30 different sentences composed of 10, 20, or 30 Japanese characters (ten sentences for each).
- *Task 2:* During a note-taking task, the note-taker has to catch and remember ideas or important statements, and almost simultaneously record these. To simulate this behavior, we showed participants a sentence in a reference window for five seconds (Figure 3) and asked them to memorize it. After the sentence was cleared, they were asked to write the same sentence (as closely as possible) in a task window either by hand or keyboard; a kanji conversion process was not necessary for either subtask. As in Task 1, each subtask set (by hand and by keyboard) consisted of 30 sentences composed of 10, 20, or 30 Japanese characters (ten sentences for each).

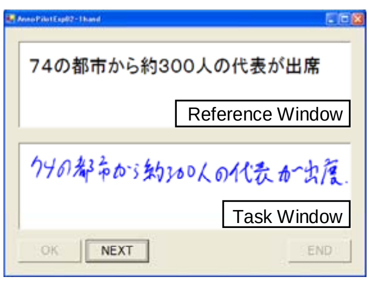


Figure 2. Sample of Task 1 UI

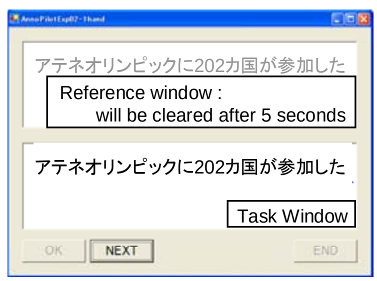


Figure 3. Sample of Task 2 UI

- *Task 3:* To produce the same situation as typical note-taking tasks in our daily life (for example, during a class or a meeting), we asked participants to watch a video file and take notes about its content, either by hand or keyboard, in a note window (Figure 4). Then, to estimate the subject's level of understanding and the quality of the notes taken, the subjects were asked to answer several questions related to the contents of the video file through a Q & A window (Figure 4). The video file could be played only once.

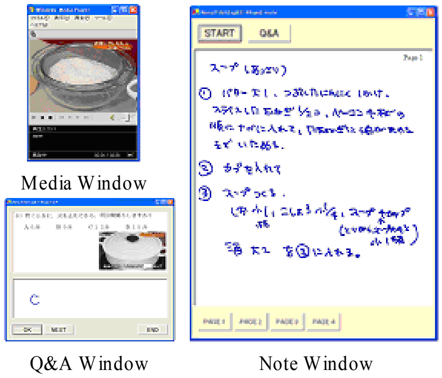


Figure 4. Sample interfaces for Task 3

Each task was done by each participant separately during a 90-minute session in a very quiet, controlled environment. The experimental task was first explained to the participant, and he or she was given a ten-minute practice session during which instructions were given on the use of the user interface and hardware. All tasks consisted of two subtasks (input by hand and by keyboard). Tasks 1 and 2 were done twice, while Task 3 was done three times because of the difficulty of the task. All samples were carefully collected to reduce all possible problems, such as the effect of the number of kanji in a sentence on input speed, and so forth.

3.3 Results

Fifteen postgraduate information system students (13 men and 2 women) who were 22 to 30 years old participated. All had at least five years of computer experience, and all spent a minimum of four hours a day using a computer. This study focused on both ergonomic and cognitive factors to estimate the effectiveness of handwriting. Results are summarized as follows:

- Notes can be input faster by hand than by keyboard (Figure 5). On average, input by hand was about 7.5% faster than by keyboard ($p < 0.05$), and twelve out of fifteen subjects were faster by hand than by keyboard. Since all participants were postgraduate students with much computer experience, we can safely assume that the gain in speed with handwritten input would be even greater for ordinary users (i.e., holders of the Japanese Word Processing Certificate - level 3, who should be capable of about 30 to 40 characters/minute). All inputted sentences were subjectively checked. We found that all sentences were correctly input, and almost all of those input by hand were legible, not only to the participant who wrote them but also to another person.

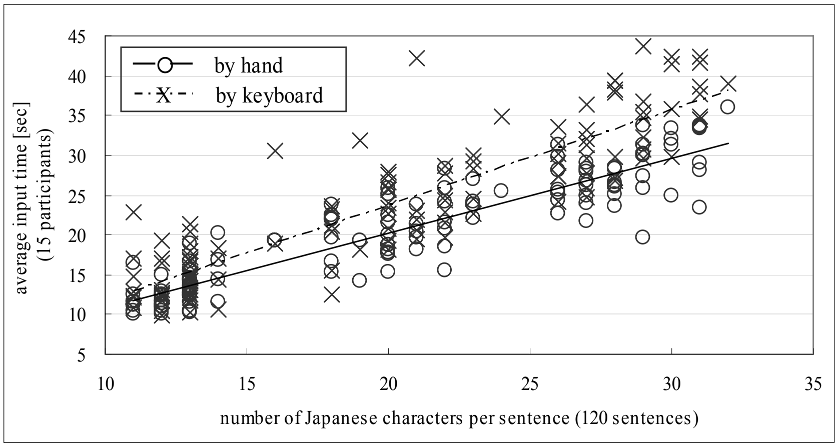


Figure 5. Average input speed for each sentence used in Task 1

- To clarify the effect of the cognitive load, we compared the sentences input for Task 2 with the contents (important words or concepts in a sentence) of the reference sentences. Our results show that input by keyboard imposed a heavier cognitive load than input by hand, and notes input by hand were much more accurate and complete than those input by keyboard. On average, there were about 28.5% more content items left out of the sentences input by keyboard than those input by hand ($p < 0.01$), and over 14.5% more perfectly input sentences by hand than by keyboard ($p < 0.01$). Figure 6 shows the average number of content items input by hand and by keyboard for each sentence. When the number of characters increased, more content items were input by hand than by keyboard, and the number of poorly input sentences tended to increase with keyboard input.

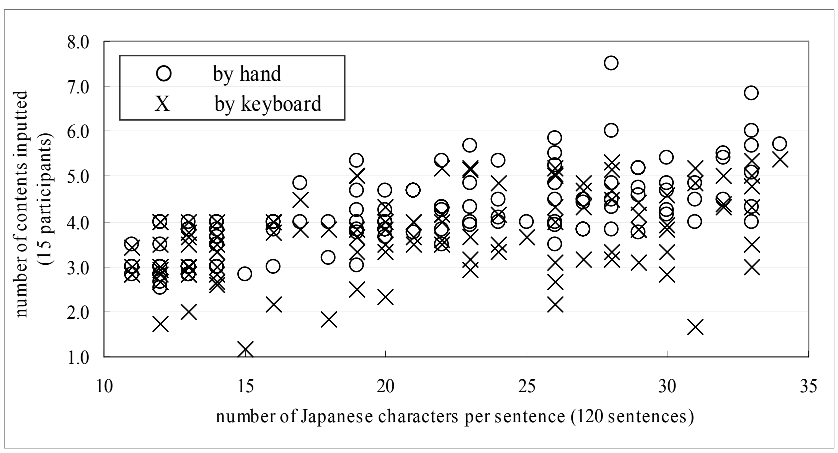


Figure 6. Average number of content items input for each sentence used in Task 2

- For Task 3, there were about 19.5% more correct answers on average when input was done by hand rather than by keyboard ($p < 0.01$). The results also showed that notes input by hand contained more content than those input by keyboard. On average, there was about 8% more content included in the notes taken by hand ($p < 0.01$).

These results suggest that notes in non-alphabetical languages are best recorded by hand rather than by keyboard. This is because keyboard input not only takes longer, but also interferes with tasks that involve cognitive processes. Our evaluation of the results revealed several factors that may explain this difference in input speed and cognitive load.

- Many special function keys, such as the space key and enter key, must be used during text input. On average, about 30% of the keys hit were special ones, and the "converting" keys accounted for almost 70% of the special keys used.
- Input misses occurred more frequently during input by keyboard than by hand, mainly because of the need to mentally convert phonetic characters into Roman characters before entering them. On average, the number of corrections in keyboard input was fourteen times the number in handwriting ($p < 0.01$); input misses frequently occurred even during the input of short sentences, and became more frequent when the number of characters increased (Figure 7).
- A major kanji conversion imposed a high cognitive load, overloading the participant's mental functions and sometimes causing the participant to forget the rest of the sentence. We observed that participants often suddenly stopped inputting the sentence after finishing a major kanji conversion. This shows that additional tasks imposed on the user when inputting by keyboard, such as kanji conversion, can distract the user from the main task of recording information, thus causing the participant to miss some of the information.
- Users often unconsciously glanced at the keyboard during keyboard input. This can affect the quality of notes taken while watching a video because some of the visual content might be missed.

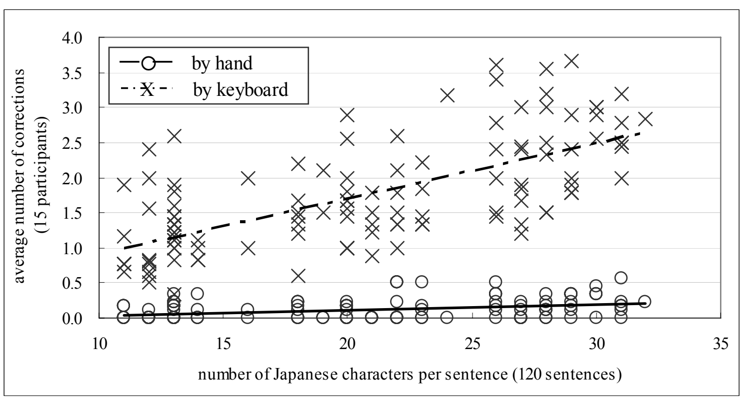


Figure 7. Average number of corrections for each sentence used in Task 1

Unfortunately, some of these findings were based on our observations during the experiment, but we did not have enough quantitative evidence to evaluate the impact of these factors. Therefore, in addition to analyzing the data recorded during the experiment, we decided to analyze the subjects' behavior during the entire time they performed the tasks. Of the various ways we could have done this, we chose to apply video analysis of the participants' eye movements. This approach allowed us to study their actual behavior in depth and determine what they really need to see while inputting text with a keyboard. The details of this study are described in the next section.

4. Video Analysis of Participants' Eye Movements

We performed the video analysis as part of a repetition of the experiment on keyboard subtasks. The goal for this experiment was to answer four questions (given below) so that we would be able to clarify the effectiveness of handwriting during note-taking tasks for a wide range of users.

- *What is the ratio of user eye movements directed towards the display and towards the keyboard?* Since users with poor keyboard input skills often need to look at the keyboard while typing, we wanted to understand how burdensome this task is and how it affects a user's ability to perform creative activities such as jotting down notes (i.e., recording valuable ideas or important statements as quickly as possible before they are forgotten).
- *Are any keys particularly difficult to use?* It is important to understand whether there are any keys that are difficult for even a skilled user to use.
- *During note-taking while watching a video, how much visual information is missed when inputting with a keyboard rather than by hand?* During our previous study, we noticed that participants often glanced at the keyboard, apparently unconsciously, during input by keyboard. This might be one reason why notes taken by keyboard while watching a video were poorer than those taken by handwriting; in this task, viewers would likely have to jot down important information provided through visual content as well as audio content. It is important to test this possibility to clarify the relative effectiveness of handwriting during typical note-taking tasks.
- *Do participants often suddenly stop typing after a long kanji conversion process?* During our previous study, we logged and analyzed all the keys typed by all participants. During task 2, we found that participants often suddenly stopped typing and moved to the next sentence after pressing the space key continuously. Since one use of the space key is to convert phonetic characters into kanji, this analysis suggested that a major kanji conversion imposed a high cognitive load, overloading the participant's mental functions and causing them to forget the rest of the sentence. To test this hypothesis, we analyzed the video recording of participants during Task 2 to find out whether they showed such behavior during the task.

4.1 Participants

Three postgraduate information system students who were 22 to 25 years of age participated in the video analysis experiment; none of them had participated in the previous study. Unlike the previous study, we selected participants according to their keyboard input skills so that we could examine the effect of keyboard input problems on users of different skill levels (skilled, intermediate, and low-level users). Table 1 summarizes the participants' skill levels.

Table 1. Summary of participants' typing skill

Participant	Speed (in Japanese)	Touch typing	Remarks
Skilled (KD)	> 70 Japanese char/min	Capable	Can input quickly without looking at the keyboard.
Intermediate (OU)	50-60 Japanese char/min	Capable	Average input speed for information system students, but capable of touch typing.
Low-skill (KT)	40-50 Japanese char/min	Not capable	Slow input speed, and had to look at the keyboard frequently while typing.

4.2 Experimental Environment

We used an eye direction detector (EDD) to record the participants' eye movements and one video camera to record each participant's up-down head movement from the left side. Figure 8 shows the experiment set-up. Figures 9 and 10 show photographs of the equipment used.

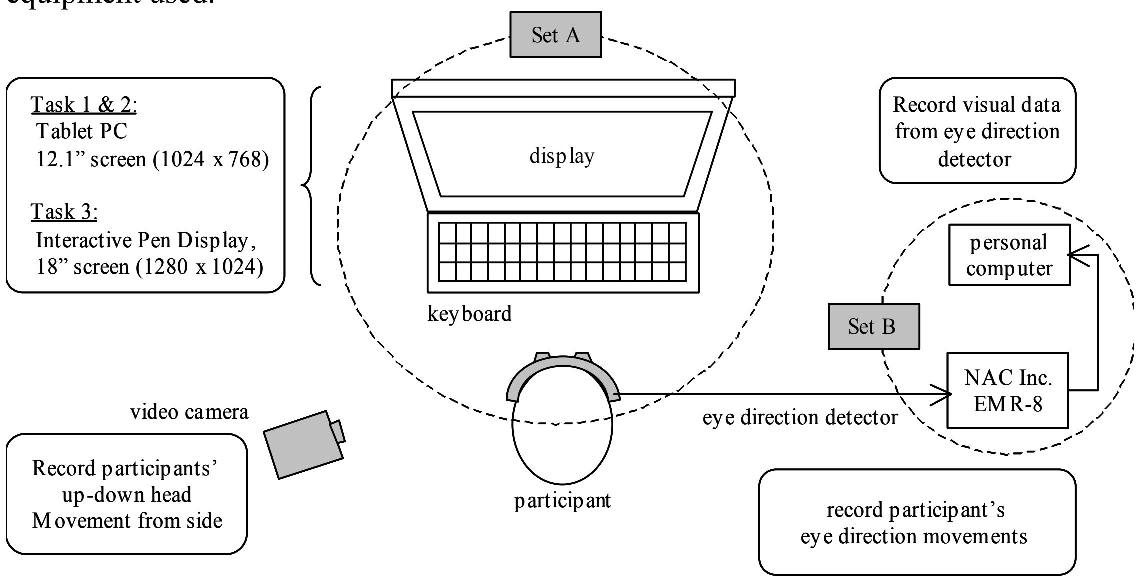


Figure 8. Experiment set-up

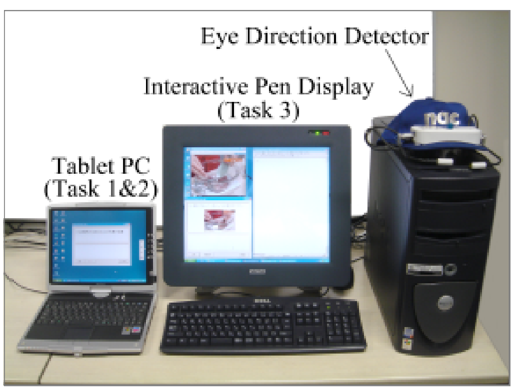


Figure 9. Experiment equipment (Set A)

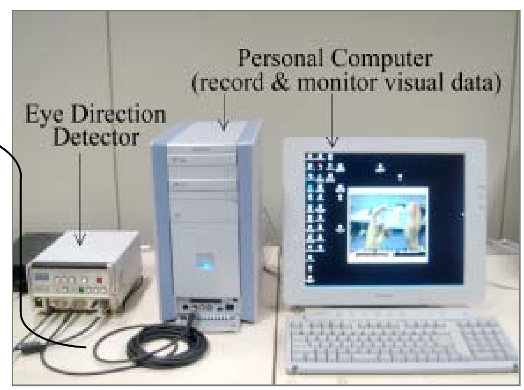


Figure 10. Experiment equipment (Set B)

4.3 Results

All keyboard subtasks for each task were done in the same way as in the previous study. Figure 11 shows a scene during the experiment. Task 1 was done twice, using 30 sentences each time (composed of 10, 20, or 30 Japanese characters, ten sentences for each; on average 600 Japanese characters). The participants' eye movements were detected by the eye direction detector (Figure 12), recorded 30 times per second (30 Hz), and sent to a computer in real-time. We recorded this visual data as a measurement item.

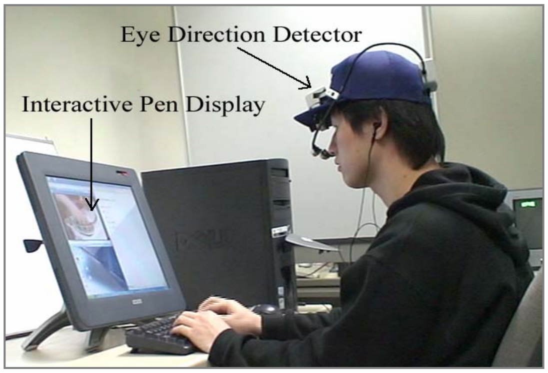


Figure 11. A scene from the experiment

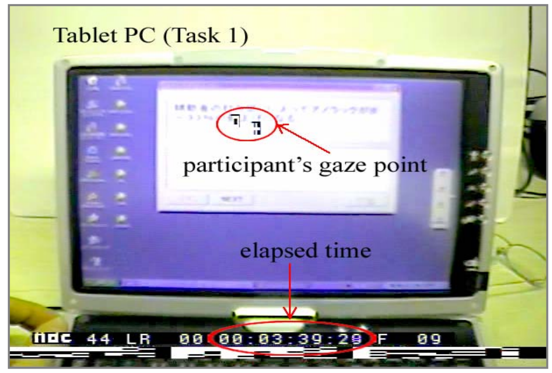


Figure 12. Virtual data recorded from the eye direction detector

First, by referring to the participant's gaze points and the elapsed time shown at the bottom of the recorded visual data (Figure 12), we calculated the average time every participant spent looking at the display or at the keyboard during Task 1. Figure 13 shows the results.

On average, the participant with low-level typing skill had to look at the keyboard for more than 55% of the entire input time. This suggests that during keyboard input, users with low-level typing skill will be mainly watching the keyboard rather than the display. This will seriously hinder their ability to make notes regarding important statements from video content that consists of both audio and visual information.

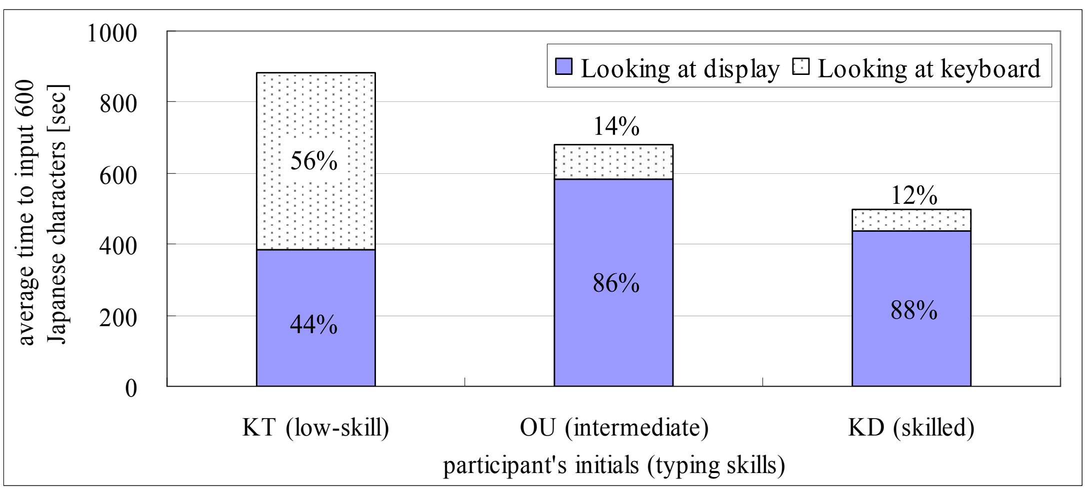


Figure 13. Ratio of participants' eye movements towards the keyboard or display

The participants capable of touch typing looked at the keyboard for less than 15% of the entire input time. This suggests that certain keys might be difficult to use, and to use these keys the participants had to look at the keyboard before typing. We will discuss this potential problem later in this section.

Figure 14 shows the low-skill participant's eye direction movements between the display and keyboard while he input three sentences composed of 10, 20, or 30 Japanese characters. As shown, the eye movements were too aggressive, and the participant spent more time looking at the keyboard than at the display.

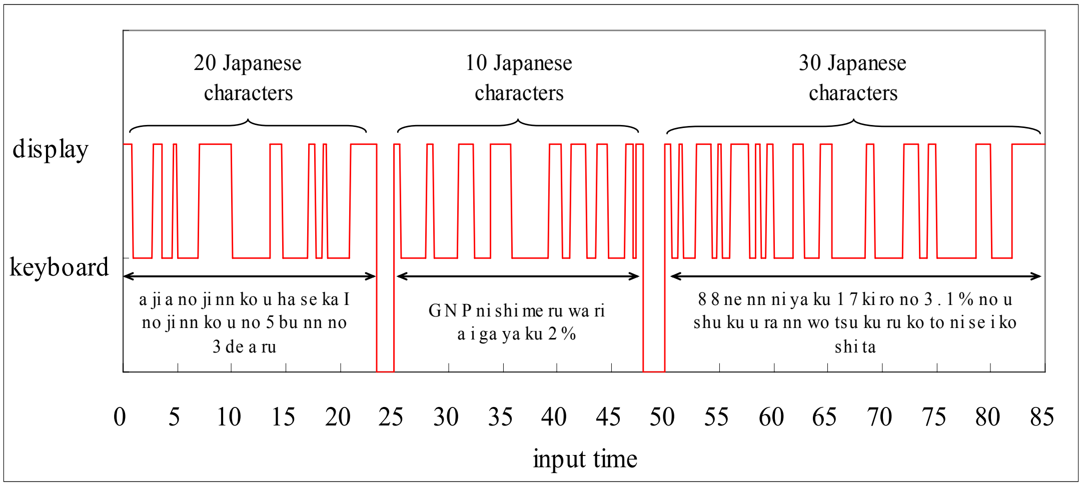


Figure 14. Low-skill participant's eye movements between display and keyboard when inputting three sentences consisting of 10, 20, or 30 Japanese characters

Second, during the experiment we observed that there were two ways in which participants looked at the keyboard while typing, each with different purpose:

- *Looking*: This was done when the participant had to *search for the keys* they wanted to use.
- *Glancing*: This often occurred when participants *wanted to make sure that their fingers were at the right position* to type and took only a short time (no longer than one second).

We separately calculated the number of times participants "looked" or "glanced" at the keyboard to find out the relation between these two behaviors and each participant's typing skill. The results (Figure 15) suggest two interesting possibilities:

- Although the intermediate participant could type without looking at the keyboard, he glanced at the keyboard about 2.5 times as often as the skilled participant. We think this is why his input speed was lower than that of the skilled participant even though both were capable of typing without looking at the keyboard.
- The skilled and intermediate participants looked at the keyboard almost the same number of times. Since both were capable of touch typing, this suggests that there were some keys that both had to search for before typing, and this could be the case for other skilled users.

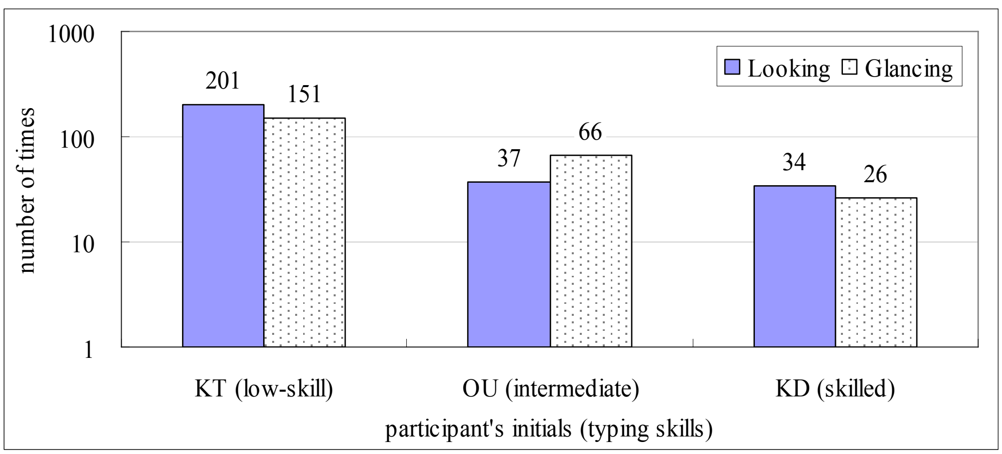


Figure 15. Number of times participants "looked" or "glanced" at the keyboard

Both of these analyses support our hypothesis that certain keys are difficult for even skilled users to use. To test this hypothesis, we divided the number of times participants looked at the keyboard into three categories depending on the key type being used: 1) alphabetical, 2) numeric, and 3) others (symbols and special keys such as function keys, arrow keys, etc.).

Since this was not the main problem slowing down the low-skill participant, only the intermediate and skilled participant were considered in this analysis. Figure 16 shows the results, and suggests that numeric keys are difficult to use. The distance of these keys from the home row (the ASDFGHJKL keys) might account for this result. Although use of a numeric pad might solve this problem for some users, mobile computer users (for example) will still face this difficulty.

Figure 17 shows the skilled participant's eye direction movements between the display and the keyboard while inputting three sentences composed of 10, 20, or 30 Japanese characters. As shown, this participant found it difficult to input numbers, which forced him to look at the keyboard before typing with the numeric keys.

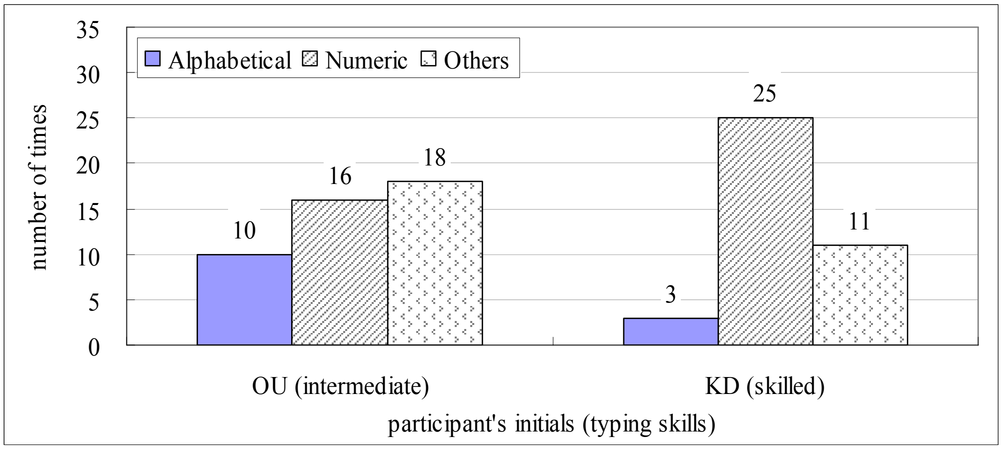


Figure 16. Number of times participants "looked" at alphabetical, numeric, and other specific keys while typing

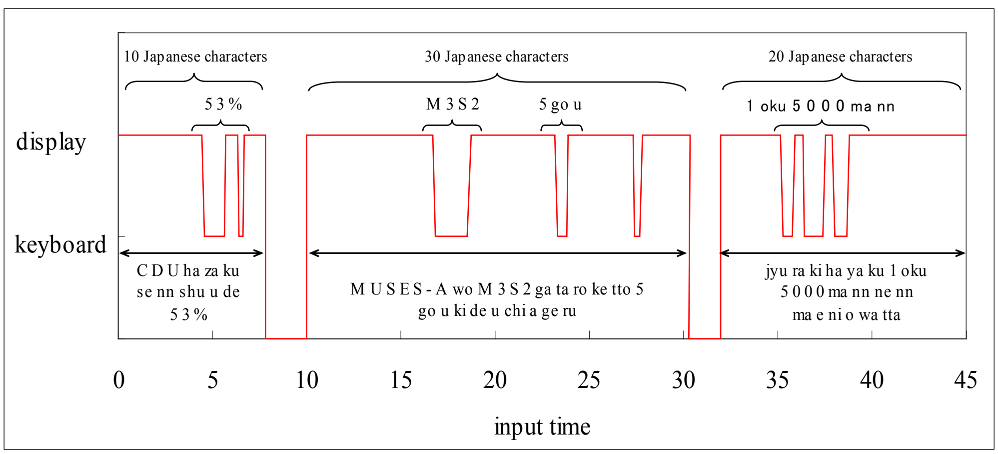


Figure 17. Skilled participant's eye movements between display and keyboard when inputting three sentences composed of 10, 20, or 30 Japanese characters

We next examined the participants' eye movements throughout task 3. This task was done three times by hand and three times by keyboard, using three types of video (a cooking show, a documentary, and an operating manual), each lasting an average of 230 seconds. We calculated the ratio of the participants' eye movements towards the media window, the note window, and the keyboard (see Figures 4 and 18) to estimate how much visual information they missed while taking notes with a keyboard.

Figure 18. Experimental environment for Task 3

Since there was only a small difference between the intermediate and skilled participants in the eye direction movement ratio (Figure 13), we only analyzed the difference between the low-skill and skilled participants. Figure 19 shows the results.

The low-skill participant looked at the media window for only 21% of the entire video length on average, and spent close to twice as much time looking at both the note window and the keyboard. This suggests that a note-taker with poor typing skills will miss a substantial amount of information provided through visual content if they input notes with a keyboard. In contrast, when taking notes through handwriting, this participant looked at the media window for 56% of the time, more than 2.5 times as long as when he used a keyboard.

Although the skilled participant's eye movement ratio for the keyboard was low (8%), this participant looked at the note window for 53% of the entire video length. Our observations during the experiment suggest that incorrect input while typing and the need to look for intended kanji during the kanji conversion process might account for this result. In addition, even the skilled participant looked at the media window only 39% of the time. This number is still too small compared to the average of 55% when taking notes through handwriting.

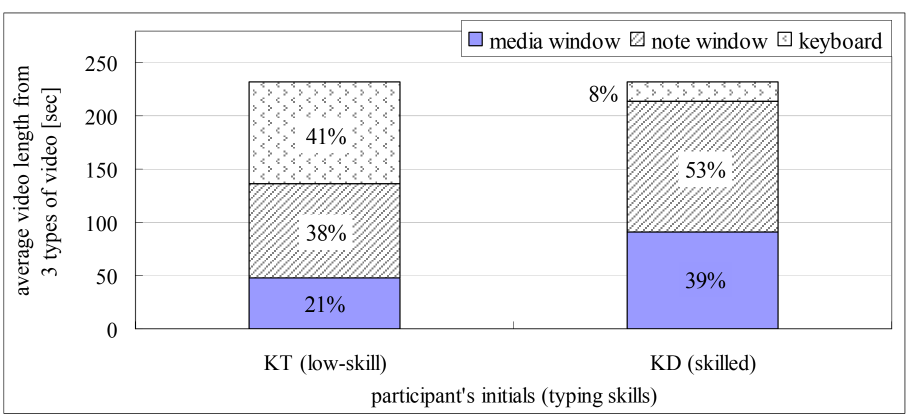
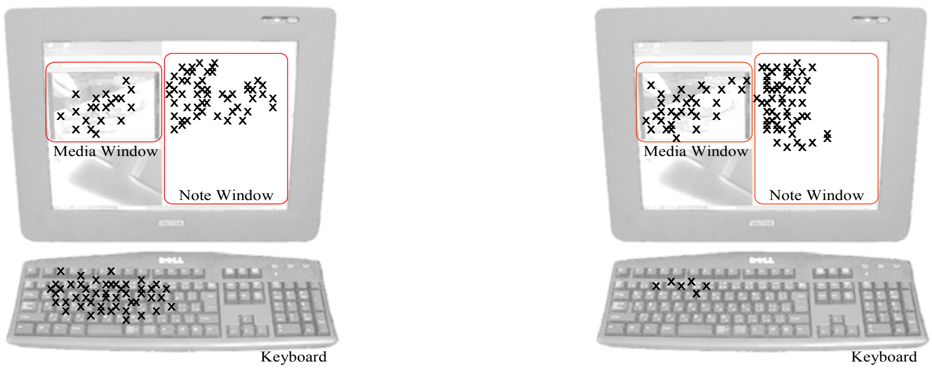


Figure 19. Participants' average eye movement ratio during Task 3

Figure 20 show the targets of eye movements recorded once a second over a two-minute period during the documentary video session. These results suggest that both participants found it difficult to constantly watch the media window because of the factors mentioned above, and this caused them to miss valuable information provided through the visual content.



(a) KT (low-skill) (b) KD (skilled)

Figure 20. Participant's eye movements during Task 3
(recorded each second over a two-minute period during the documentary video session)

We then analyzed the video recorded during Task 2, and found instances where participants suddenly stopped typing and moved on to the next sentence after facing a major kanji conversion process (Figure 21). We also found that after a major kanji conversion process, the participants would typically stop typing for 1 to 2 seconds. This suggests that the participants needed a moment to recall the memorized sentence because a major kanji conversion imposed a high cognitive load, thus momentarily overloading the participant's mental functions and causing them to forget the sentence.

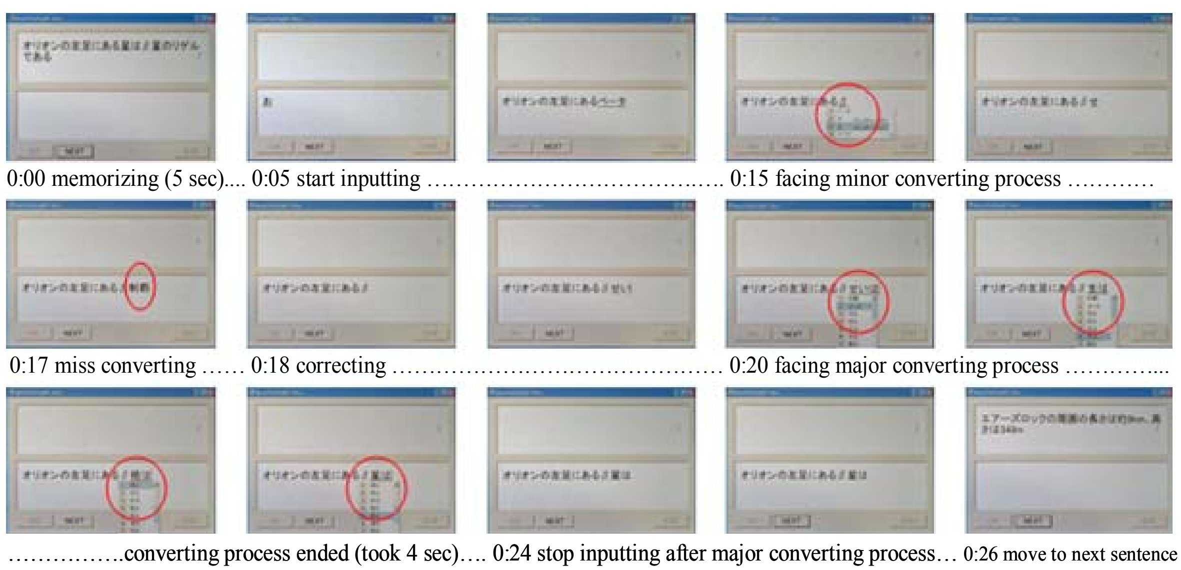


Figure 21. Snapshot (at 26 seconds) from the video recorded during Task 2 shows that a participant suddenly stopped typing after facing a major kanji conversion process

5. Conclusion

In our previous work, we experimentally investigated the differences between input by hand and input by keyboard during a note-taking task in Japanese to quantitatively clarify the effectiveness of handwriting compared to input by keyboard. We focused on both ergonomic and cognitive factors to estimate the relative effectiveness of taking notes by hand. Our results showed that

- Annotations and notes can be input more quickly by hand than by keyboard.
- Input by keyboard imposes a heavier cognitive load than input by hand. As a result, annotations and notes input by hand are much more accurate and complete than those input by keyboard.

Unfortunately, some of these findings were tentative, being based on our observation during the experiment but without quantitative evidence. Further study of participants' behavior was needed to determine if these findings were valid. Therefore, we repeated the experiment with the addition of video analysis. By recording the participants' eye movements during keyboard input, we found that

- The participant with limited typing skill had to look at the keyboard frequently and spent more time looking at the keyboard than at the content display. In addition, his eye movements between the display and keyboard were too aggressive.
- Numeric keys were difficult to use even for the highly skilled user.
- It was difficult for participants to look at video information while taking notes with a keyboard, causing them to miss some of the information provided by visual content.

This study shows that note-taking tasks in Japanese can be done more effectively by handwriting than by keyboard because keyboard input in Japanese is labor intensive and imposes a high cognitive load. We hope this study will impress upon computer users that not all tasks are best done by computer – some tasks that need a lot of attention and impose a high cognitive load, such as note-taking or producing and organizing ideas, are done better by handwriting than by keyboard. We also hope that this study will promote further research on pen-user interfaces, especially regarding ways to naturally support users during their creative efforts, such as note-taking tasks or when organizing and re-organizing their notes and ideas.

Much remains to be done. First, we need to increase the number of participants in our experiments to make our findings more generally applicable. We plan to repeat these experiments with at least five participants in each input skill group. We will also do further experiments to clarify the cognitive load limit during note-taking tasks with input by hand and by keyboard. In addition, we also hope to determine the extent to which keyboard input affects tasks that involve cognitive processes during text input in other East Asian languages, such as Chinese, and to determine whether note-taking by hand is also more effective in such languages.

References

Dzulkhiflee, H.M., Shun'ichi, T., Mitsuru, I., and Tomonori, H. "Qualitative Analysis of Effects of Handwritten Annotation on Intelligent Work," *Proceedings of the 11th International Conference on Human-Computer Interaction: HCII 2005, Las Vegas*.

Dzulkhiflee, H.M., Shun'ichi, T., Mitsuru, I., and Tomonori, H. "Effectiveness of Annotating by Hand for non-Alphabetical Languages," *Proceedings of the Conference on Human Factors in Computing Systems CHI 2006*, Montreal, pp. 841-850.

Hiroshi, T., and Masami, C. "Text Input Speed of the Student in University Classes," *Proceedings of Human Interface 2003*, Tokyo, pp. 81-84.

Morita, A. "Quantitative Comparisons on Performances of Various Japanese Text Input Systems," *Trans. Inst. Electron. Inf. Commun. Eng.*, J70D(11), 1987, pp. 2182–2190.

O'Hara, K., and Sellen, A. "A Comparison of Reading Paper and On-Line Document," *Proceeding of the Conference on Human Factors in Computing Systems: CHI 1997*, Atlanta, pp. 335-342.

Ramos, G., and Balakrishnan, R. "Fluid Interaction Techniques for the Control and Annotation of Digital Video," *Proceedings of User Interface Software and Technology 2003*, Vancouver, pp. 105-114.

Ren, X., Tamura, K., Kong, J., and Zhai, S. "Candidate Display Styles in Japanese Input," *Proceedings of Human-Computer Interaction: INTERACT 2003*, Zurich, pp. 868-871.

Shun'ichi, T., Daisuke, O., Mitsuru, I., and Yusuke, S. "DynaGraffiti: Hand-written Annotation System for Interactive and Dynamic Digital Information," *Proceedings of the 10th International Conference on Human-Computer Interaction: HC11 2003*, 2 (2003), Greece, pp. 781-785.

Wang, J., Zhai, S., and Su, H. "Chinese Input with Keyboard and Eye-Tracking: An Anatomical Study," *Proceeding of the Conference on Human Factors in Computing Systems CHI 2001*, Seattle, pp. 349-356.