

Reconsideration of the Effects of Handwriting: Comparing Cognitive Load of Handwriting and Typing

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Abstract Handwriting is preferred when people take notes or annotate during listening to lectures or reading documents. This paper proves the effects of handwriting experimentally. Two experiments using a dual task method revealed that the cognitive load of handwriting was smaller than that of typing and typing interfered with memorization more than handwriting. Moreover, this tendency was also observed for people who can type fast with touch typing. This indicates that handwriting has a strong advantage in keeping information without interfering with other cognitive activities regardless of people's typing skill.

Keywords: Handwriting, Typing, Cognitive load, Dual task method, Memorization.

1. Introduction

A computer is widely used as a writing tool. Writing text documents takes place using word processors or editors of PCs, where keyboards are used to input text, especially if the documents are formal or long and are read by other people. As a typical example of long formal documents, many college graduates have written a graduation thesis before graduation. According to our survey¹⁾, 100% of graduation theses have been written using digital tools since 2005.

However, handwriting has not disappeared. According to our survey¹⁾, people think that, when using handwriting, they can memorize words, write something easily, start writing quickly, take notes while listening to other people's speech, and write anything in a free form anywhere. Handwriting is widely used as means for note-taking²⁾⁻⁴⁾ or annotating⁵⁾⁻⁷⁾.

Note-taking is an activity to write or draw short sentences or rough figures to retain information usually on a blank page. Mueller et al.³⁾ examined how note taking methods affect the comprehension of lectures. In their experiments, students who took notes with handwriting got better score than those who took notes with laptop PCs, in tests conducted after lectures. When analyzing the students' notes, students who used PCs

took many notes and they had a tendency to write what a teacher said as it is without changing the teacher's words or sentences. On the other hand, students who used handwriting had tendency to take notes on what the teacher did not say. They rephrased what the teacher said with their own words or they wrote what they considered after listening to the lectures. This indicates that handwriting would promote thinking, and typing is apt to make people concentrate on inputting information without thinking like an input machine.

Annotating is an activity to add symbols (e.g., circles, underlines, or arrows), short text, or figures in margin areas or line spaces of printed or digital documents^{1),5)}. It takes place frequently during active reading, which is characterized as a combination of reading with critical thinking or learning⁹⁾. In annotation, the relative positional relation between written results and original text often has important meanings.

From the observation of reading and summarizing multiple documents, O'Hara et al. reported that paper and pen effectively integrated two different activities of reading and writing^{1),8)}. When using digital tools, participants in their experiment could perform both reading and writing. However, low manipulability of digital tools using a mouse and a keyboard interfered with smooth integration of reading and writing. They strongly preferred to use paper and pen for annotating when they devoted themselves to active reading.

In fact, many digital tools to support active reading provide digital pens to support annotation during reading⁹⁾⁻¹⁵⁾. Additionally, many commercially available

Received March 28, 2018; Revised August 10, 2018; Accepted August 27, 2018

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slate-type devices, such as Microsoft Surface, Apple iPad Pro, or Sony Digital Paper, support handwriting with digital pens. It seems that the importance of pen input is empirically recognized for the support of reading.

As we described above, handwriting is preferably used in note-taking or annotating. In such a situation, written notes are for own use and are not looked by other people. Therefore, people do not have to write notes or annotations beautifully so that other people can read them. Instead, note-taking or annotating usually takes place with other activities such as thinking, listening, speaking or looking in parallel. Therefore, it is desirable that note-taking or annotating should not interfere with those other activities.

In such situations, why is handwriting preferred over other digital input methods? In this paper, we experimentally investigate the reasons*. To begin with, we introduce the concept of cognitive load, which is an important notion to examine the effect of input methods, and describe an experimental framework to measure the cognitive load. Next, we report two experiments conducted to compare the cognitive load of handwriting using a pen and typing using a keyboard.

2. Cognitive Load and Related Work

Cognitive load is the load for working memory when people perform a task^{17),18)}. It may be easy to understand, if we say that the cognitive load is the amount of working memory in use to perform the task.

The capacity of working memory is restricted. We can memorize only 7 ± 2 semantic chunks in our working memory¹⁹⁾. Human working memory is very limited in comparison with computer memory, which has more than gigabytes. Moreover, human working memory cannot be extendable like computer memory. To perform intellectual activities, we must use this small memory space efficiently.

Although a subjective evaluation is developed to measure cognitive load of tasks^{20),21)}, it is well known that the subjective evaluation largely differs among individuals and is sometimes lack of consistency within each individual¹⁸⁾.

As an objective method to compare the cognitive load among tasks, a dual task method is often used. In a dual task experiment, participants are required to perform two different tasks (a main task and a secondary task) simultaneously. The degree of the cognitive load of the main task can be estimated based on the performance of

the secondary task. If the secondary task showed low performance, this indicates that people spent many mental resources for the main task and they could not allocate sufficient resources for the secondary task, which means the cognitive load of the main task was large. On the other hand, if the secondary task showed high performance, this means the cognitive load of the main task was not large.

This method has been used to measure the cognitive load in various situations²²⁾⁻²⁴⁾. However, they have not examined the cognitive load of typing and have not compared the cognitive load of typing and handwriting.

Hamzah et al.²⁵⁾ examined how handwriting and typing affect cognitive tasks. In their study, participants looked at a short sentence and wrote it down with handwriting and typing. Results showed that there were fewer mistakes with handwriting and they concluded that the cognitive load of handwriting was smaller than that of typing. However, their results cannot eliminate the usability effect of tools. To measure the cognitive load, it is desirable to use a dual task method using different types of tasks.

3. Framework of Experiments

In this study, we compare the cognitive load of handwriting and typing using the dual task method. As a secondary task, we adopt a memorization task. Consequently, we can also examine the interference effect of the two input methods on memorization.

In the dual task experiment, we present two types of words by turns. Participants are required to remember one type of words and are required to input the other type of words. We examine how inputting words affect the performance of remembering words.

The cognitive load of typing may strongly depend on individual typing skill. We estimate that the cognitive load of typing may be small for people who can type without looking at a keyboard (i.e. touch typing). If they need to look at a keyboard while typing, they must look at the document and the keyboard by turns to input text. This will increase the cognitive load and also take much time to perform the task. Therefore, we recruited two types of people whose typing skills are different and compare the cognitive load between them.

In the first experiment, we compare handwriting speed and typing speed for both those who can do touch typing and those who cannot. In the second experiment, we compare the cognitive load of handwriting and typing using a dual task method.

* This paper is the revised version of a previous one¹⁶⁾.

4. Experiment 1: Typing Speed

In the first experiment, we measure the typing speed of participants to obtain basic data for the next experiment.

4.1. Method

Design. The experimental design was a two-way mixed design. The between-subjects independent variable was typing skill (touch typing group and non-touch typing group). The within-subjects independent variable was input method (handwriting and typing). A dependent variable was input speed, i.e. the number of characters that participants wrote per minute.

The order of conditions of each trial was counterbalanced over all participants.

Participants. Participants were 24 people (11 men, 13 women). They all were in their 20s or 30s. Each had three or more years' experience using PCs. Their corrected visual acuity was better than 14/20. The half of the participants mastered touch typing (touch typing group) and the remaining did not (non-touch typing group), based on their self-report.

Devices. We used two PCs. The first one was a laptop PC with a 12-inch display (Lenovo Thinkpad X61 Tablet7762B6J). We used it to present instructions and stimulus of the experiment. The other one was a desktop PC (DELL Dimension C521) with 23-inch display (Nanao EV2302W-TBK) and a keyboard (DELL E145614). We used this to perform a task of the experiments. The laptop PC was placed in the left of the desktop PC.

Materials and the task. The task of the experiment was to input given 50 words with the two input methods as fast and accurate as possible. The words were all Japanese three-letter nouns and were written in Japanese Hiragana. They were selected from the list created by Koyanagi et al.²⁶⁾, where the familiarity values of the words were 3.50–3.99 of 1.00–5.00.

The words were displayed in the laptop PC with 18 point MS Mincho. The 50 words were arranged in 10 lines, where each line contained five words.

In the handwriting condition, the participants transcribed the words on an A4 paper sheet. They were allowed to change lines as they like. They were instructed that they did not have to write words neatly.

In the typing condition, they input the words to the desktop PC using Microsoft Word. The participants did not have to use Kana-Kanji conversion because all the words did not include Kanji.

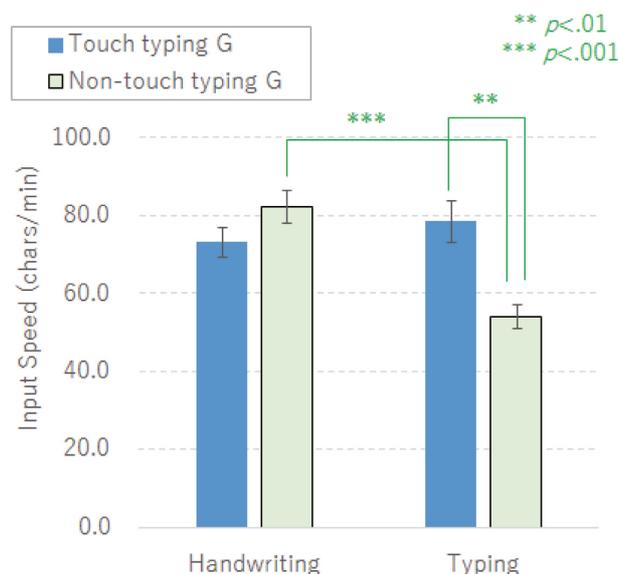


Fig.1 Input Speed.

Procedure. Before the experiment, the participants adjusted the position and presentation properties of the displays to their preferences. They input 10 words with both input methods as training.

In the experiment, they performed one trial in each condition.

4.2. Results and Discussion

Figure 1 presents the input speed in each condition. Throughout the paper, error bars in graphs present plus or minus one standard error from the average.

We performed a two-way mixed ANOVA. The interaction between the typing skill and the input method was significant ($F(1, 22)=20.35, p<.001$). Therefore, we examined simple main effects for every typing skill and for every input method. As a result, in the non-touch typing group, the handwriting method was faster than the typing method ($F(1, 22)=28.85, p<.001$). And in the typing method, the Touch typing group was faster than the non-touch typing group ($F(1, 22)=15.72, p<.01$).

In the handwriting condition, no significant difference was found in the input speed between the Touch typing group and the non-touch typing group. This means the validity of selecting participants in both groups.

For people mastering touch typing, typing speed was almost the same as handwriting speed. In Hamzah et al.'s experiment²⁵⁾, people who were good at typing were able to input text faster when typing than when handwriting. However, text used in their experiment included Kanji with many strokes.

For people who cannot do touch typing, typing was significantly slower than handwriting.

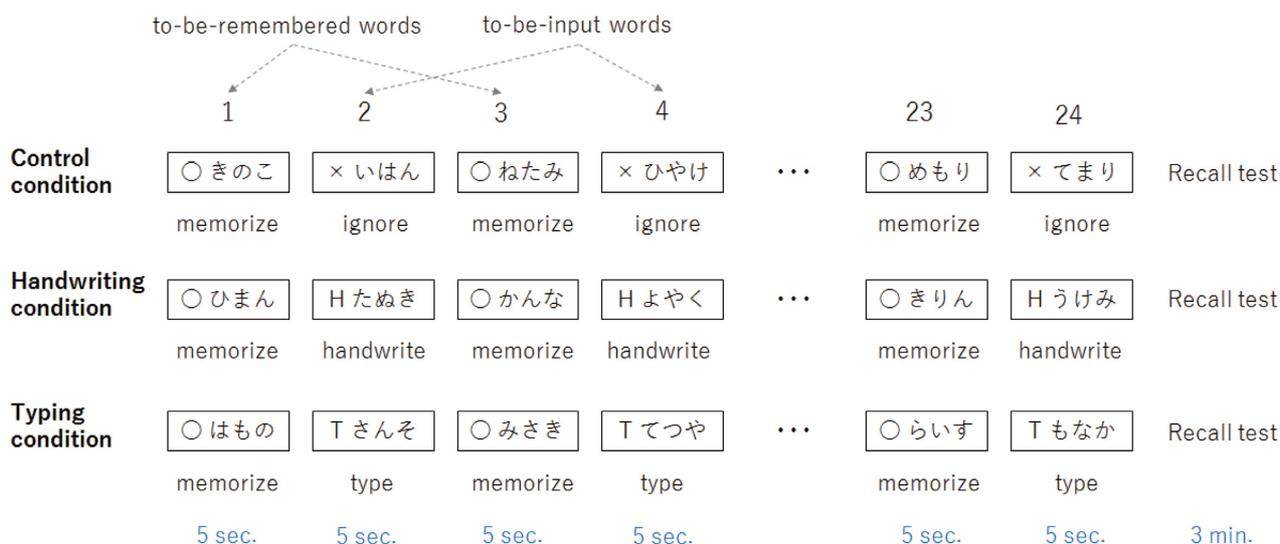


Fig.2 Procedure of each trial of Experiment 2.

5. Experiment 2: Cognitive Load

Next, we compare the cognitive load of handwriting and typing using a dual task method.

5.1. Method

Design. The experimental design was a two-way mixed design. The between-subjects independent variable was typing skill (touch typing group and non-touch typing group). The within-subjects independent variable was input condition (control, handwriting, and typing). A dependent variable was the recall rate of to-be-remembered words, which we describe later.

The order of conditions of each trial was counterbalanced over all participants.

Participants. The same as Experiment 1.

Devices. The same as Experiment 1.

Materials and the task. We selected 144 words from the Koyanagi et al.'s list²⁶). The familiarity values of the words were 3.00–3.49 of 1.00–5.00. The words were all Japanese three-letter nouns and were written in Japanese Hiragana.

We created 6 lists containing 24 words. The words were divided into two types: to-be-remembered words and to-be-input words. In each list, both words were presented one-by-one by turns, as shown in Figure 2. Each word was displayed for 5 seconds.

The participants had to memorize the to-be-remembered words and they must recall them in a test conducted after each trial. The participants did not have to memorize the to-be-input words and their behaviors are different depending on the input condition.

In the control condition, the participants were asked to ignore the to-be-input words. The symbol "X" was

written in front of the to-be-input words (e.g. "Xつきみ" (Tsukimi)) so that the participants could easily understand that they do not have to do anything.

In the handwriting condition, they were asked to write the to-be-input words on a paper sheet with a pen. In this case, the symbol "H" was written in front of the to-be-input words (e.g. "Hよみち" (Yomichi)) so that they do not forget to handwrite.

In the typing condition, they were asked to type the to-be-input words on the desktop PC. In this case, the symbol "T" was written in front of the to-be-input words (e.g. "Tあやめ" (Ayame)) so that they do not forget to type.

In all conditions, the symbol "O" was written in front of the to-be-remembered words so that the participants could easily understand that they need to memorize the words.

The task of the experiment was to memorize to-be-remembered words as much as possible.

In the control condition, the participants did not have to do anything for to-be-input words. Therefore, they could use this time for memorizing to-be-remembered words. This condition was a baseline for other two conditions.

On the other hand, in the other two conditions, they had to input to-be-input words by handwriting or typing. This works as a distraction for memorizing to-be-remembered words. The aim of this experiment is to examine how these input methods deteriorate the memorization of to-be-remembered words.

Procedure. Before the experiment, the participants adjusted the position and presentation properties of the displays to their preferences. They performed a trial

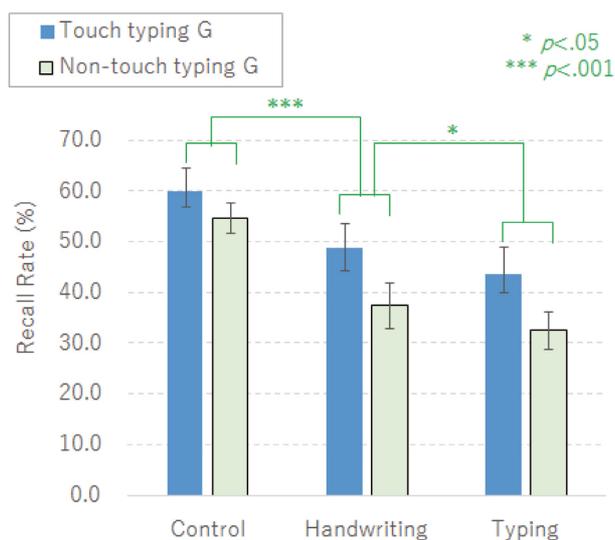


Fig.3 Recall rate.

once in each input condition as training. The materials used in the training were not used in the experiment.

In each trial, 24 words were displayed in the laptop PC one-by-one by turns every 5 seconds. In the control condition, the participants can ignore words with "×". In the handwriting condition, they must handwrite words with "H". In the typing condition, they must type words with "T".

After each trial, the participants took a recall test. They were required to recall all to-be-remembered words and write them in a paper sheet in a free order. The test time was 3 minutes.

5.2. Results and Discussion

Figure 3 presents the recall rate conducted after each trial in each condition.

We performed a two-way mixed model ANOVA. The interaction between the typing skill and the input condition was not significant ($F(2, 44)=1.10, p>.1$). The main effect of the input skill was not significant ($F(1, 22)=2.70, p>.1$), which means there was no statistical difference between the touch typing group and the non-touch typing group. The main effect of the input condition was significant ($F(2, 44)=35.73, p<.001$). According to the multiple comparison of the Tukey's method, the recall rate of the control condition was higher than that of the handwriting condition ($p<.001$), and the recall rate of the handwriting condition was higher than that of typing condition ($p<.05$).

To sum up, although the recall rate of the non-touch typing group was lower than that of the touch typing group in the figure, there was no significant difference between the two groups. The participants of both groups showed similar behavior for all the three input

conditions. Regarding the input conditions, the recall rate was higher in the following order: the control condition, the handwriting condition, and the typing condition.

The recall rate was the highest in the control condition. The reason is very clear. The participants did not have to do anything while to-be-input words are displayed. They could use this time for encoding to-be-remembered words.

The recall rate in the handwriting condition was lower than that of the control condition, but higher than that of the typing condition. Handwriting interfered with memorizing to-be-remembered words, but the degree of interference was smaller than the typing condition.

The recall rate in the typing condition was the lowest in all three conditions. Typing interfered with memorizing to-be-remembered words, and the degree was larger than the case of handwriting. This means the cognitive load of typing was larger than that of handwriting.

Contrary to our expectation, there was no significant difference between the touch typing group and the non-touch typing group. Both two groups showed similar trend in all three input conditions. It is reasonable that there is no significant difference between these two groups in the control condition and the handwriting condition because the participants did not type at all in these two conditions. And this fact means the validity of selecting participants.

At first, we expected that, in the typing condition, recall rates were completely different between two groups. Or, we even thought that, in the touch typing group, the recall rate of the typing condition could be higher than that of the handwriting condition. However, the results did not support our hypothesis.

Interestingly, even for people who can do touch typing, typing interfered with memorizing words more than handwriting. From Experiment 1, for people who mastered touch typing, typing speed was not significantly different from handwriting speed. Therefore, it seems that the time interrupted by inputting words was almost the same in the handwriting condition and the typing condition for the participants of the touch typing group.

However, the recall rate was higher in the handwriting condition than in the typing condition even for people who mastered touch typing. We think that is because the participants could perform two different tasks of memorizing words and typing simultaneously

when handwriting. In other words, we think that they could rehearsal and encode words during inputting other words. On the other hand, there is a possibility that the participants' memorizing activity was completely interrupted during typing. It seems that handwriting enables performing other activities simultaneously.

6. General Discussion and Future Work

The two experiments showed that the cognitive load of typing was larger than that of handwriting and this was true regardless of typing skill. That is, even for people who mastered touch typing, typing was more cognitively demanding than handwriting. Handwriting did not interfere with thinking or memorizing, so much. We think this is one of the most important reasons why people prefer handwriting with a pen when they perform intellectual activities such as listening to lectures or reading and why many systems to support active reading provide pen input.

We think that many people understand this phenomenon intuitively. Let's consider about a scene of lectures. Even for people who are good at typing very much, it is difficult to speak and give a lecture during typing. In addition, it is difficult to find anyone who cannot do both speaking and writing on a blackboard simultaneously. Considering this example, we can realize a big difference between the cognitive load of typing and that of handwriting. In this study, we proved this phenomenon experimentally.

Generally speaking, new input technologies have been mainly evaluated from perspectives of input speed and error rate^{27)–29)}. Additionally, in a mobile situation, device size, display space, and users' use scenarios (e.g., inputting with single hand or inputting while walking) are also used as evaluation criterion^{30)–32)}. However, cognitive load is also an important factor when we perform cognitively demanding intellectual activities. As we have shown in this study, input speed does not affect memorization performance so much. Input speed and cognitive load are two different things.

This indicates the importance of pen-input support when we take notes or annotate during cognitive activities. To support reading and writing on electronic displays, it is important to improve the user interaction of digital pens as a means of retaining information with low cognitive load.

There are also some remaining challenges in this study. In the experiments, we used only Hiragana to input Japanese text. However, Japanese text usually

includes Hiragana, Katakana, and Kanji (i.e. Chinese characters). Generally, Kanji has much strokes compared to Hiragana and it takes more time to write Kanji²⁵⁾. It is desirable to examine how the cognitive load of inputting Kanji differs among different input methods.

However, we expect that inputting Kanji would be more cognitively demanding than inputting Hiragana when typing. To input Kanji text in digital environments, we must use a Kana-Kanji conversion software. In this process, at first we must input Hiragana, and next we must convert it to Kanji by selecting appropriate one from popped up words. The procedure to input Kanji is cumbersome and it requires users to use vision.

Mobile devices provide text input methods without using a keyboard. The most popular example is a flick input method, which is frequently used in Japanese mobile phones. We also need to compare the cognitive load of such input methods with handwriting and typing.

However, we expect that the cognitive load of the flick input would be larger than typing using a keyboard. People skilled in typing can type without looking at a keyboard. However, even for people who are accustomed to the flick input, it is impossible to input text without using vision. Most input methods in mobile devices heavily rely on vision.

7. Conclusion

We measured the cognitive load of handwriting and typing. We also examined how typing skill affects cognitive load of typing. Results showed that handwriting interfered with memorization, but its degree was lower than the case of typing. The cognitive load of handwriting was not zero, but it was smaller than that of typing.

To our surprise, even for people mastering touch typing, the interference effect for memorization was higher in typing than in handwriting. This indicates that people should use handwriting for remaining information while performing other activities regardless of their typing skill.

This study shows that handwriting has a strong advantage compared to typing in that it allows to retain information without interfering with other cognitive activities so much. For digital reading devices used in academic or work situation, providing stylus pen and allowing handwriting are important to support

intellectual activities.

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