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Author(s)	Wei, Jianning; Nishimoto, Kazushi; Takashima, Kentaro
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SwaPS: A Method for Efficiently Relearning Chinese Characters Just by Reading Documents Including Incorrectly Shaped Characters

Jianning Wei, Kazushi Nishimoto, Kentaro Takashima

Japan Advanced Institute of Science and Technology, Ishikawa 9231292, JAPAN
jianning.wei@jaist.ac.jp

Abstract. Character amnesia is a recent phenomenon in which native Chinese or Japanese speakers forget how to write Chinese characters (*kanji* in Japanese), although they maintain the ability to read them. To solve this problem, we previously proposed a novel pronunciation-based input method called G-IM (Gestalt Imprinting Method), which is effective in preventing the loss of character shape memory. G-IM sometimes outputs GIM characters whose shapes are slightly incorrect, which forces users to pay close attention to character shapes and thus strengthens retention and recall. However, the task of finding and correcting such slight errors in writing documents is an originally high cognitive load act that is burdensome and discourages users from using G-IM. Therefore, in this work, we focus on the act of reading behaviors and propose a novel method for generating incorrect character shapes named SwaPS, which can effectively correct and strengthen the memory of character shapes by simply reading a document without increasing the user's workload. SwaPS generates incorrect characters named PS characters by using a deformation method that swaps the position of the semantic radicals and phonetic radicals of the phonogram characters, which account for 80% of all Chinese characters. By reading a document that includes PS characters, the user's attention is drawn to the character shapes, which is expected to correct and strengthen his or her memory of the character shapes. In the future, we aim to build an e-book reader that automatically generates and presents PS characters. In this paper, we conducted a basic investigation by printing manually created incorrect characters on paper and presenting them to users. The results of the user study confirmed that reading a document that includes PS characters significantly strengthens character shape memory compared to reading a document that contains only correct characters or slightly different incorrect characters used in the G-IM system. We also confirmed that reading a document that includes PS characters does not increase the user's load compared to reading a normal document that contains only correct characters.

Keywords: Character Amnesia, Incorrect Character Shapes, Phonogram Characters, (Re)building Retention and Recall of Character Shapes, Relearning Support

1. Introduction

Character amnesia is a recent phenomenon manifested by the inability of native Chinese or Japanese speakers to recall how to write Chinese characters (*kanji* in Japanese), although they know these characters well and can still read them [1] [2]. It is generally believed that the constant use of computers and mobile phones equipped with pronunciation-based Chinese character input systems is the cause of character amnesia [3]. For example, if a Japanese person wants to get the character “歳” (“age”), he/she only needs to input its pronunciation “sai” in Japanese and checks that the character is not converted to a homophone, such as “再” (“re-”) and “最” (“the most”). If the correct character “歳” is outputted, he/she just glances at it but does not check its detailed shape. As a result, the memory of the exact form of a Chinese character gradually fades, and he/she eventually falls into a state in which he/she can recognize the approximate form of the character but does not remember the exact form, that is, a state of character amnesia in which he/she can recognize the form of the character but cannot reproduce it. Thus, the existing pronunciation-based input methods are convenient tools, but they also have the characteristic of “harms of convenience” [4] in terms of weakening the memory of Chinese character shapes. We should avoid the intellectual loss of forgetting the knowledge of Chinese characters that we have acquired.

To solve this problem, we previously proposed a novel pronunciation-based input method called G-IM (This is an acronym of “Gestalt Imprinting Method”, and, at the same time, “IM” is usually also an acronym of “Input Method” of Chinese characters), which is effective in preventing the loss of character shape memory. While the usual input methods of Chinese characters always output characters with correct shapes, G-IM sometimes outputs GIM characters whose shapes are slightly incorrect. By being made to forcibly correct the errors, users must pay close attention to the character shapes, which leads to strengthening retention and recall. User studies have demonstrated that G-IM significantly strengthens the retention and recall of character shapes compared to conventional input methods and writing by hand [5].

G-IM is a typical example of “intellectual activity support by interference” [6] promoted in our laboratory as well as of “the benefit of inconvenience” [4]: G-IM improves the user’s intellectual ability through an obstructive function that outputs incorrect characters during the inputting process. However, the task of finding and correcting slight errors in writing documents that is an originally high cognitive load act is too burdensome and discourages users from using the system [5]. Therefore, a method that can support the correction and enhancement of character shape memory with a lighter (preferably negligible) load is required.

In this research, we propose an efficient and low-burden support method for correcting and reinforcing Chinese character shape memory just by reading documents. To this end, we propose a novel deforming method for Chinese characters based on the characteristics of Chinese character structures. Incorporating incorrectly shaped Chinese characters generated by the proposed deforming method into the document to be read can help achieve effective relearning of Chinese characters without increasing the workload. The final goal of our research is to build an e-book reader that automatically generates incorrect characters and incorporates them into documents. In this paper, as a basic investigation toward this final goal, we conducted a user study by using printed documents on paper that included manually created incorrect characters.

The rest of this paper is organized as follows. Section 2 reviews related studies on the learning and recognition of Chinese characters. Section 3 describes the proposed method. Section 4 shows preliminary experiments on the Chinese character amnesia problem for the types of Chinese characters handled by the proposed method (i.e., phonogram characters). Section 5 presents the results of the user studies, and Section 6 discusses the effectiveness of the proposed method. Section 7 concludes the paper.

2. Related Works

In recent years, many learning support systems for Chinese characters have been proposed. For example, a Chinese character learning system with the integrated use of a computer, projector, and camera can aid learners in understanding the meaning, cultural background, and formation structure of Chinese characters using morphological and phonetic animation projection and handwriting instruction [7]. Ito et al. [8] generated a song for learning Chinese characters comprehensively that uses sounds to represent the formation structure of the character and lyrics that represent the meaning and usage. Fan et al. [9] proposed a Chinese character learning support system using augmented reality technology with learning cards. In these research cases, support functions that focus on the structure of Chinese characters and related information were adopted.

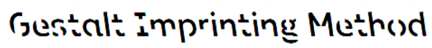

Fig. 1. An example of the Sans Forgetica font (see the Sans Forgetica website: https://sansforgetica.rmit.edu.au/)

As the target of these conventional methods is basically “not yet learned” Chinese characters, they are not suitable for correcting and reinforcing the memory of “already learned” Chinese characters. Additionally, these systems require users to take time out of their busy schedules to use them, which leads to the problem of low utilization. To the best of our knowledge, there are no Chinese character learning support methods specializing in correcting and reinforcing already learned Chinese characters other than the G-IM system we developed [5].

Bjork pointed out that making the learning process harder for the learner results in better (long-term) retention than conventional learning, which is called “desirable difficulties” in cognitive psychology [10]. Based on the principle of desirable difficulties, RMIT University in Australia developed Sans Forgetica, a font that has the effect of retaining learning content in memory [11] (Fig. 1). This font was designed to make texts difficult to read, thus increasing the memorization effect of the written information. User studies have shown that information written in the Sans Forgetica font is more memorable than information written in normal fonts. G-IM [5] can also be regarded as a method for correcting and enhancing Chinese character shape memory based on the principle of desirable difficulties. However, as the characters used in G-IM were slightly incorrect, with only one or more strokes different from the correct ones, they were not easy to detect. In addition, because of the specification that the document file cannot be saved if even only one incorrect character is left unnoticed, the user was forced to check the shapes of all the output Chinese characters. Thus, G-IM imposes a high cognitive load on users. Therefore, the difficulties set by G-IM, although desirable, were considered somewhat excessive.

3. Proposal Method: SwaPS

In this research, we aimed to create a method for correcting and reinforcing character shape memory by introducing a “desirable and appropriate degree of difficulties”. To this end, we propose an improved method called SwaPS for solving the character amnesia problem. In SwaPS, we modified two points based on the findings of the G-IM study [5].

Fig. 2. An example of a correctly shaped “蟀” (left), slightly incorrectly shaped character (middle) named the GIM character, and the proposed PS character (right).

The first point is that G-IM targets the act of “writing”, while SwaPS targets the act of “reading”. It is generally said that the problem of character amnesia has arisen because the act of writing characters by hand has been replaced by Chinese character input systems [3]. Therefore, in the G-IM study, we attempted to embed a way of solving the character amnesia problem in the act of “writing”. However, writing documents is an originally high cognitive load action. G-IM embeds an additional high cognitive load task into another high-load task; this design concept violates UI design principles [12]. In this work, therefore, we focus on the act of “reading”, which is generally less cognitively demanding than writing, and embed a means of solving the character amnesia problem within it. Furthermore, because the act of reading a document is an everyday activity that is more widely performed than the act of writing, it is expected to be able to solve the character amnesia problem for a wider range of people than G-IM.

The second point is the method of generating incorrect characters. Fig. 2 shows an example of the correct form of a Chinese character (Normal), an example of an incorrect character used in G-IM (GIM), and an example of an incorrect character newly used in SwaPS (PS). The GIM characters are incorrect characters that contain only minor errors, such as the deletion or addition of one stroke from the normal characters (in the GIM character in Fig. 2, one stroke [“丶”] is missing). The reason for adopting such a slight error in G-IM is to make the reader pay more attention to the shape of the characters. However, such slight errors are likely to be easily overlooked in the act of “reading”, and it is necessary to create conspicuous incorrect characters. At the same time, it is necessary to be able to provide all shape information about the correct form of the character, although it is incorrect. In the case of G-IM, when a user pointed out an incorrect character as “incorrect”, it was immediately replaced with the correct form of the character. This function allowed G-IM users to know the correct form of the character, which was useful for correcting and reinforcing their memory of character shapes. Therefore, it is necessary for SwaPS to realize a method of generating incorrect characters that includes all the shape information to ascertain the correct character shapes, rather than wildly incorrect characters.

Thus, we focused on phonogram characters. A phonogram character is a combination of a semantic radical (meaning) and a phonetic radical (pronunciation). For example, "雲" (it means "cloud" and is pronounced "un") is composed of the semantic radical "雨" ("rain") and the phonetic radical "云" ("un"). Phonogram characters account for a very high percentage of Chinese characters. Of the approximately 7,000 simplified Chinese characters used in the Chinese language, 81% are phonogram characters [13]. Of the approximately 3,500 Chinese characters in common use, 2,523 are phonogram characters, accounting for 72% of the total [14]. In addition, 91.1% of the phonogram characters in Chinese characters in common use have a structure in which the semantic radicals and phonetic radicals are aligned vertically or horizontally, such as in "雲" ("cloud") and "銅" ("copper") [14]. Focusing on these characteristics, we devised a method for generating incorrect characters by swapping the positions of the semantic radicals and the phonetic radicals of the phonogram characters with a structure in which the semantic radicals and the phonetic radicals are aligned vertically or horizontally. The incorrect characters generated in this way are named "PS characters" because they are generated by swapping Semantic radicals and Phonetic radicals. The PS characters shown in Fig. 2 were generated by swapping the "虫" (means "insect") and the "率" (is pronounced "ritsu") of the Chinese character "蟀" ("cricket"). Although the PS character is incorrect, it contains all the information regarding the correct shape. It can be converted to the correct character by switching the positions of the semantic radical and the phonetic radical.

By the way, even if we embed PS characters in a document, it will be meaningless if readers skip over them without noticing. A phenomenon called typoglycemia in which readers can comprehend text without any problem, even if the order of letters in the word is changed under certain conditions (e.g., "Document" to "Documnet") is known to exist in English [15]. The same phenomenon occurs in Japanese, especially in *hiragana*. It is possible that a similar phenomenon may also occur in Chinese characters when PS characters are used. Although the issue of the processing mechanism of the semantic radicals and the phonetic radicals in phonogram character recognition has long been a major concern of psycholinguists [16][17], to the best of our knowledge, there are no studies on the recognition of characters with interchangeable semantic radicals and phonetic radicals. Therefore, it is necessary to verify the possibility of similar phenomena, such as typoglycemia, in PS characters.

4. Preliminary Experiment

A preliminary experiment was conducted to investigate the forgetting status of the shapes for phonogram characters.

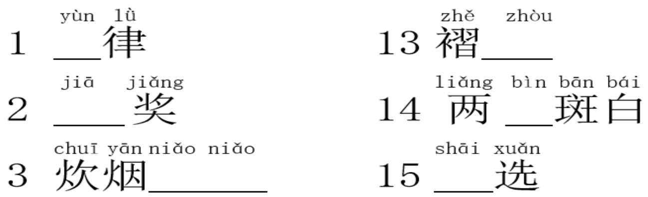

Fig. 3. Examples of the problems in the dictation test of the preliminary experiment.

Table 1. Results of the preliminary experiment in different point scales.

	All characters (points)		Characters in common use (points)		Characters in non-regular use (points)	
Perfect score	20	100	13	100	7	100
Average score	7.5	37.7	6.0	46.2	2.0	26.2

Table 2. Distribution of the dictation test results of the preliminary experiment.

Result (points)	All characters		Characters in common use		Characters in non-regular use	
	Number of people	Ratio	Number of people	Ratio	Number of people	Ratio
≧ 80	0	0	1	4.20%	0	0
79 − 60	2	8.30%	7	29.2%	0	0
< 60	22	91.7%	16	66.7%	24	100%

4.1 Procedure

A dictation test of the phonogram characters was administered to 24 Chinese students at our institution. The test was composed of 20 phonogram characters: 13 phonogram characters in common use selected from the list of frequently used characters in modern Chinese [18] and seven phonogram characters in non-regular use that are easy to misspell. Fig. 3 shows part of the dictation test in the preliminary experiment. In the test, the participants were asked to refer to the pronunciation of the Chinese characters written in pinyin and to handwrite the underlined missing Chinese characters.

4.2 Results

The results of the experiment are shown in Table 1. The average score for the dictation test was 7.5 on the 20-point scale (37.7 on the 100-point scale). The average score for the phonogram characters in common use was 6.0 on the 13-point scale (46.2 on the 100-point scale), and the average score for the phonogram characters in non-regular use was 2.0 on the 7-point scale (26.2 on the 100-point scale). Table 2 shows the distribution of the number and percentage of each score band. Of the 24 participants, 91.7% received a score of less than 60 points on the 100-point scale for all characters, 66.7% for the characters in common use, and 100% in non-regular use characters. The results show that the percentage of students who did not memorize the correct shape of the characters was quite high, indicating that the problem of character amnesia still exists, even in the case of phonogram characters.

5. User Study

A user study was conducted to demonstrate the usefulness of the proposed SwaPS method.

5.1 Outline of the Experimental Procedure and Hypotheses

Twenty-four postgraduate Chinese students at our institution who did not participate in the preliminary experiments participated in the experiment. The experiment was conducted in three steps:

- Step 1. Pre-examination: A dictation test of 90 Chinese characters, including 40 target Chinese characters.
- Step 2. A task of reading material printed on paper that included target characters whose character is one of the three characters (PS character, GIM character, and Normal character) shown in Fig. 2.
- Step 3. Post-examination: A post-examination of the Chinese character dictation test (the same question as the pre-examination), reading comprehension questions, and ex post facto survey.

Based on the pre-examination results, we divided the participants into three groups (SwaPS group, GIM group, and Normal group) of eight to equalize the distribution of the pre-examination scores of the groups. Then, we evaluated the improvement in performance by comparing the score differences between the pre-examination and the post-examination for each of the three groups.

The hypothesis for this experiment was that the improvement in performance would be in the order of Normal ≤ GIM < SwaPS. We assumed that the improvement in the GIM group would be greater than that in the Normal group because the recognition of incorrect characters in the GIM group would correct and strengthen the memory of the character shapes. However, as stated above, because GIM characters have only slight errors, there was a high possibility that the errors would not be noticed and would be skipped as Normal characters, in which case there would be no difference between the GIM group and the Normal group. Therefore, the overall improvement in the GIM group was expected to be slightly larger than or equal to that of the Normal group. However, as PS characters are more likely to be noticed as errors, the SwaPS group was expected to show the greatest improvement.

5.2 Details of the Experiment

In the pre-examination conducted in Step 1, we prepared 90 phonogram characters consisting of 60 characters in common use selected from the list of frequently used

① the document including PS characters

天冷极了，下着雪，又快黑了。这是一年的最后一天——平安夜。在这又冷又黑的晚上，一个没戴帽子、没戴手套、也没穿鞋子的小女孩，在街上哆哆[illegible]地走着。凛[illegible]的寒风吹过她幼小的脸[illegible]，她的衣服又旧又破，脚上穿着一双妈妈的大拖鞋在街上走着。她的口袋里装着许多盒火柴，一路上不住口地叫着："卖火柴呀，卖火柴呀！"人们都在买节日的食品和礼物，有谁会理她呢?

② the document including GIM characters

天冷极了，下着雪，又快黑了。这是一年的最后一天——平安夜。在这又冷又黑的晚上，一个没戴帽子、没戴手套、也没穿鞋子的小女孩，在街上哆哆嗦嗦地走着。凛冽的寒风吹过她幼小的脸颊，她的衣服又旧又破，脚上穿着一双妈妈的大拖鞋在街上走着。她的口袋里装着许多盒火柴，一路上不住口地叫着："卖火柴呀，卖火柴呀！"人们都在买节日的食品和礼物，有谁会理她呢?

③ the document including Normal characters

天冷极了，下着雪，又快黑了。这是一年的最后一天——平安夜。在这又冷又黑的晚上，一个没戴帽子、没戴手套、也没穿鞋子的小女孩，在街上哆哆嗦嗦地走着。凛冽的寒风吹过她幼小的脸颊，她的衣服又旧又破，脚上穿着一双妈妈的大拖鞋在街上走着。她的口袋里装着许多盒火柴，一路上不住口地叫着："卖火柴呀，卖火柴呀！"人们都在买节日的食品和礼物，有谁会理她呢?

Fig. 4. Part of a document, which included characters in three different types.

characters in modern Chinese [18] and 30 characters in non-regular use with a relatively large number of strokes. The experimental method was the same as that used in the preliminary experiment, as shown in Fig. 3.

Before Step 2, we divided the 24 participants into three eight-person groups (the SwaPS group, GIM group, and Normal group) based on the pre-examination results. The participants were assigned so that the distribution of the pre-examination scores in each group would be even. To confirm this, we performed ANOVA at the one-factor, three-level with no correspondence. The analysis result showed that the main effect of the groups was not significant ($F(2, 21) = 0.002, p = 0.998 > 0.05$). There were no significant differences in the group assignments.

Next, we selected 40 target Chinese characters from the 60 characters in common use employed in the pre-examination in Step 1, transformed them into the PS or GIM character, and then embedded the PS or GIM character into the documents. Fig. 4 shows part of each document: The SwaPS group was given a document embedded with the PS character of the target characters (① in Fig. 4), the GIM group was given a document embedded with the GIM character of the target characters (② in Fig. 4), and the Normal group was given a document consisting entirely of the Normal correct form of the target characters (③ in Fig. 4). All the materials were printed on paper, and the participants in each group were required to read the materials. In Fig. 4, the target characters embedded in the documents are shown in red for the convenience of readers, but the documents provided to the participants were in black.

The document used in the experiment was "The Little Match Girl" [19], which is a text from a Chinese textbook for third graders in elementary school. The total number of characters in the document was 2,233, and it contained all 60 characters in common use employed in the pre-examination in Step 1. The document used the SimSun font in 10.5 point, which is the standard character and character size for Chinese paper books. All incorrect characters were created by the first author of this paper using the Microsoft private character editor on Windows 10.

Table 3. Results of the pre-examination and the post-examination for the three groups.

Group	Step 1		Step 3		Step 3-Step 1	
	Average	StdDev	Average	StdDev	Average	StdDev
SwaPS	58.96	16.67	78.54	9.910	19.58	14.14
GIM	59.58	17.55	73.13	16.38	13.54	9.380
Normal	59.58	22.73	68.96	22.14	9.380	5.400

The instructions given to the participants before the reading task in Step 2 were only to write down the start and end times on the provided paper. They were not allowed to ask any questions about the experiment during or after the task.

As all 40 target characters in Step 2 were included in the dictation test in Step 1, there was a possibility that the dictation test in Step 1 may have had some unexpected influence on the results for Step 2. To eliminate such effects as much as possible, Step 2 was conducted 15 days after Step 1. In addition, we mixed 20 other characters in common use (these 20 characters were also included in the Step 2 document) and 30 non-regular use characters (these 30 characters were not included in the Step 2 document) on the Step 1 dictation test.

Step 3 was conducted immediately after Step 2. After the reading materials were collected, participants were required to answer a reading comprehension test form (five questions), a dictation test form, and a questionnaire form in turn. The reading comprehension test was a single-choice question with four response options. The dictation test in Step 3 consisted of the same 60 characters in common use employed in the pre-examination in Step 1. The experimental method was the same as that used in the preliminary experiment. The questionnaire was administered only to the SwaPS and GIM group participants. The contents of the questionnaire were about the participants' impressions of the incorrect characters in the documents they read in Step 2.

5.3 Results

5.3.1 Dictation Test Results

Table 3 presents the average scores and standard deviations (StdDevs) for the pre-examination and post-examination of only 60 characters in common use for each of the three groups with a perfect score of 100. The 60 characters were very basic characters included in the third-grade Chinese textbook. In Step 1, participants were also given a dictation test of 30 highly difficult characters in non-regular use, but the results shown in Table 3 do not include them. The "Step 3-Step 1" column in the table shows the average of the difference between the pre-examination and post-examination scores.

The average score for Step 1 was around 59, which is very low for a graduate student's performance on Chinese characters at the third-grade level of elementary school. This result indicated the existence of the character amnesia problem here as well as in the preliminary experiment in Section 4. For all participants, the results for Step 3 were higher than those for Step 1. A paired t-test was conducted on all participants' Step 1 and Step 3 scores, and the score difference was significant at the 1% level ($t\ (23) = 6.32,\ p = 0.00 < 0.01$). The post-examination scores were significantly better than the pre-examination scores.

The hypothesis of this experiment was that the improvement in performance would be in the order of Normal ≤ GIM < SwaPS. The mean of the difference between Step 3 and Step 1 in Table 3 shows that the hypothesis was basically true. Based on the difference between Step 1 and Step 3 scores, we conducted William's test with the Normal group as the control group under the hypothesis above. The results were as follows:

- The test statistic between the difference in the performance of the Normal group and the SwaPS group was *1.93*. Significant differences ($p < 0.05$) were found between the Normal group and the SwaPS group. The improvement in the SwaPS group was significantly greater than that of the Normal group.
- The test statistic between the difference in the performance of the Normal group and the GIM group was *0.79*. No significant difference was found between the two groups. The improvement in the GIM group was not significantly greater than that in the Normal group.

5.3.2 Reading Time and Comprehension Performance

In the case of English, it is known that sentences with transposed letters result in some cost in reading speed and comprehension [20]. Therefore, we verified whether inserting incorrect characters in a Chinese-language document affected reading speed and comprehension, as in the case of English.

Table 4. Average required time in minutes to read the document in Step 2 for the three groups.

Group	Average (min.)	StdDev
SwaPS	7.25	2.99
GIM	7.25	3.73
Normal	7.13	2.52

Table 5. Results of the reading comprehension in Step 3 for the three groups.

Group	Average	StdDev
SwaPS	80.0	12.5
GIM	75.0	17.2
Normal	80.0	12.5

The average times taken to read the documents for the three groups are shown in Table 4, and the results of the reading comprehension for the three groups (20 points for one question, 100 points in total) are shown in Table 5. We performed ANOVA tests at the one-factor, three-level with no correspondence based on the results of Tables 4 and 5. The analysis results in Table 4 show that the main effect of the groups was not significant ($F(2, 21) = 0.316, p > 0.05$), and the analysis results in Table 5 also show that the main effect of the groups was not significant ($F(2, 21) = 0.452, p > 0.05$). Therefore, there were no significant differences in reading time and comprehension performances among the three groups.

5.3.3 Questionnaire Results

The questionnaire about the participants' impressions of the incorrect characters in Step 2 was administered only to the SwaPS and GIM group participants. Table 6 shows the percentage of participants who noticed the incorrect characters in the documents,

Table 6. Percentage of participants in the SwaPS group and the GIM group who reported noticing the presence of incorrect characters in the documents.

Group	Percentage
SwaPS	100%
GIM	50%

Table 7. Responses to the question about how much the presence of incorrect characters in the documents affected the post-examination.

Options	SwaPS group		GIM group	
	Number of people	Ratio	Number of people	Ratio
1. Very useful.	5	63%	4	100%
2. Useful.	3	37%	0	0
3. I can't say either.	0	0	0	0
4. Not very useful.	0	0	0	0
5. Useless.	0	0	0	0

Table 8. Responses to the question about whether the incorrect characters in the documents in Step 2 affected participants' understanding of the documents or the reading time.

Options	SwaPS group		GIM group	
	Number of people	Ratio	Number of people	Ratio
1. It affected me a lot.	0	0	0	0
2. It affected me to some extent.	0	0	0	0
3. I can't say either.	0	0	0	0
4. It didn't affect me very much.	3	38%	2	50%
5. It didn't affect me.	5	62%	2	50%

Table 7 shows the subjective impression of the participants who noticed the incorrect characters regarding how much the presence of incorrect characters in the documents affected the post-examination in Step 3, and Table 8 shows the subjective impression of how much the presence of incorrect characters affected the comprehension and reading speed of the documents.

As shown in Table 6, all participants in the SwaPS group noticed the incorrect characters (PS characters) in the documents in Step 2. However, only half of the participants in the GIM group noticed incorrect characters (GIM characters). As shown in Table 7, all participants who noticed the incorrect characters indicated that their presence was helpful in the post-examination. As shown in Table 8, all participants who noticed the incorrect characters indicated that their presence did not affect the participants' comprehension of the content or their reading time.

6. Discussion

As shown in Section 5.3.1, the overall performance in the post-examination was significantly better than that in the pre-examination. This result indicates that reading documents has a beneficial effect on correcting and reinforcing the memory of character shape. In other words, reading materials such as books can improve the character amnesia problem to some extent.

This result also suggests that character amnesia is caused not only by the constant use of computers and mobile phones equipped with pronunciation-based Chinese character input systems but also by the decrease in opportunities to read documents. Alternatively, the quality of documents read daily may be declining due to the spread of social networking services. However, this explanation is only speculation. According to the results of a survey of elementary school children, a positive correlation between the amount of reading and vocabulary (which is different from Chinese character aptitude) was observed, but the correlation was not strong [21]. As far as we know, there are no studies on the relationship between the amount of reading and Chinese character aptitude among adults who have completed character learning, and further investigation is needed.

As stated above, reading documents was shown to be beneficial for solving the character amnesia problem, but the results shown in Section 5.3.1, that the improvement from pre-examination to post-examination was significantly larger in the SwaPS group than in the Normal group, illustrated that embedding PS characters in documents is more effective in solving the character amnesia problem. However, not just any incorrect characters can be used. In fact, the improvement in the GIM group using GIM characters was not significantly greater than that of the Normal group.

One possible reason is that it is difficult to notice embedded incorrectly shaped characters when GIM characters are used. Table 6 shows that all participants in the SwaPS group were aware of the existence of PS characters, while only half of the participants in the GIM group were aware of the GIM characters. In other words, a phenomenon similar to typoglycemia in English occurs in the case of GIM characters, but it is less likely to occur in the case of PS characters. The results shown in Table 7 indicate that all participants who noticed the incorrect characters found their presence useful in the post-examination (i.e., effective in correcting and reinforcing their character shape memory). If the incorrect characters were not noticed, the effect was equivalent only to that of the Normal group. Therefore, although the improvement in the GIM group was slightly larger than that of the Normal group (Table 3), it did not reach a level where a significant difference could be observed.

As described above, we found that the PS characters, which are incorrect characters created by swapping the position of the semantic radicals and phonetic radicals of the phonogram characters, are effective in making the reader aware of the presence of incorrect characters. Moreover, PS characters have all shape information about the correct form of the character. As a result, embedding PS characters in a document effectively corrects and strengthens character shape memory.

Although G-IM is effective in preventing the loss of character shape memory, users are reluctant to use it because of the excessive workload required to find and correct slightly different incorrect characters [5]. It is necessary to confirm whether a similar situation of avoiding the use of SwaPS occurred.

The results in Table 4 show the time taken to read the document in Step 2, and Table 5 shows the results of the reading comprehension in Step 3; no significant differences were found between the three groups. Table 8 shows the results regarding whether the presence of incorrect characters affected the comprehension and reading speed of the documents. There were no significant differences between the SwaPS and GIM groups.

These results indicate that embedded incorrect characters in either PS or GIM characters do not impede document reading: Users did not feel reluctant as they did when they used the G-IM system. Based on these results, the SwaPS method, which targets the task of reading a document and embeds PS characters, can be regarded as a kind of "desirably and appropriately difficult factor" [10] that works effectively to correct and strengthen the memory of character shapes. Note that the SwaPS method is a *relearning* method for those who have already mastered Chinese characters in their daily activities. People who are learning Chinese characters for the first time cannot determine whether the PS characters are correct or incorrect, and there is a risk that they will rather learn the PS characters as correct characters.

7. Conclusion

In this paper, we proposed a method called SwaPS, which can correct and strengthen the memory of character shapes just by reading documents that include incorrectly shaped characters called PS characters. The PS characters are generated by swapping the position of the semantic radicals and phonetic radicals of the phonogram characters with a structure in which the semantic radicals and phonetic radicals are aligned either vertically or horizontally.

To verify the effectiveness of the proposed SwaPS method in correcting and enhancing the memory of Chinese character shapes, we performed a user study under three conditions: reading a document that included the PS characters proposed in this study, reading a document that included the GIM characters with slight errors used in our previous study [5], and reading a document that included no incorrect characters. We compared and analyzed the score differences between the pre-examination and the post-examination for the three groups. A significant difference was found only between the PS group and the Normal group. For the GIM group and the Normal group, no significant difference could be found. We also checked whether the presence of incorrect characters affected reading time and comprehension. There were no significant differences in either reading time or the results of the comprehension questions. These results are consistent with the participants' subjective findings in the ex post facto survey. Therefore, the proposed SwaPS method using PS characters is an effective method for relearning character shapes for people who have already learned Chinese characters without placing an unnecessary burden on them.

We are currently developing an e-book reader system that automatically generates PS characters and embeds them in documents. As shown in this paper, the proposed method is effective for paper media. However, when considering its use in the real world there is concern, for example, that printing academic papers with embedded incorrect characters, such as PS characters, may have a negative impact on the quality evaluation of the papers. If an e-book reader that has a function for generating and replacing PS characters can be implemented, readers, not authors or publishers, can embed PS characters into documents at will. The previously described problems of usage scenarios can be solved. By embedding the PS characters into the reading materials, it would give the user a sense of "vujà dé", which makes the user feel as if he or she is seeing a character for the first time. This is expected to change the shallow cognitive act of recognizing well-known characters into a deeply cognitive act. In the future, we would like to verify the effectiveness of the proposed method on e-book readers. It has been reported that the degree of concentration and comprehension of content is lower when using electronic media, such as tablets, than when using paper media [22], and it will be necessary to verify whether the same effect can be observed in the proposed method. Furthermore, the same effect can be expected to be obtained by embedding PS characters into arbitrary visible text. For example, displaying the PS characters instead of the correct characters in the choice box of any existing pronunciation-based input method can make the user pay attention to the character shape. After the PS characters are selected, the correct character shape is displayed in the document. We would like to discuss such a different usage pattern in the future.

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