Paragraph-based Faded Text Facilitates Reading Comprehension

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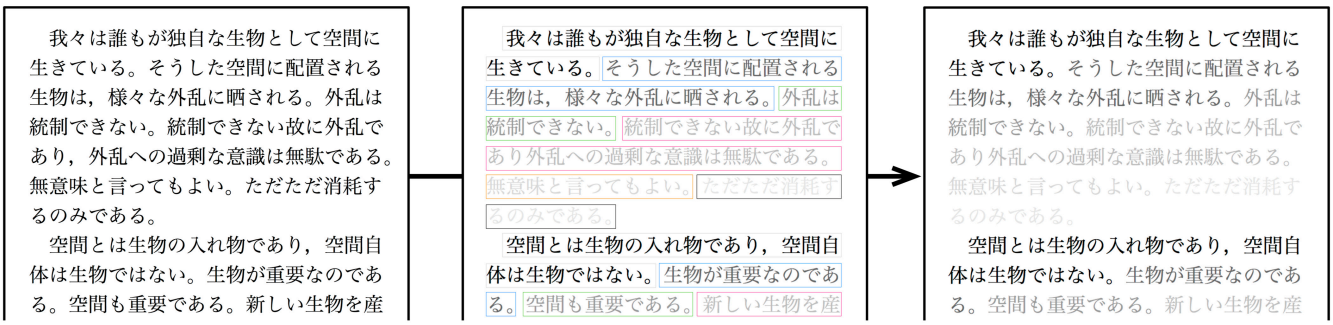

Figure 1: Paragraph-based faded text highlights the paragraph structure of the entire text and the relative positions of its sentences by sequentially fading out characters sentence-by-sentence from the beginning of each paragraph.

ABSTRACT

We propose a new text layout that facilitates reading comprehension. By sequentially fading out characters sentence-by-sentence from the beginning of each paragraph, we highlight the paragraph structure of the entire text and the relative positions of the sentences. To evaluate the effectiveness of the paragraph-based faded text in a reading comprehension, we measure the comprehension, eye movements, and recognition for both the proposed method and a conventional standard method. In the proposed method, rates of correct answers to text comprehension questions are improved. Moreover, the proposed method leads to slower reading speeds and better recognition rates for the first sentences of paragraphs, which are displayed in a relatively thicker mode. With the paragraph-based faded text, the reader is naturally facilitated to pay attention to the first sentence of each paragraph, suggesting that this reading style could result in a more accurate text comprehension.

CCS CONCEPTS

• **Human-centered computing** → **E-book readers**; *Visualization techniques.*

KEYWORDS

reading, text layout, eye movements, text comprehension

ACM Reference Format:
Jumpei Kobayashi and Toshio Kawashima. 2019. Paragraph-based Faded Text Facilitates Reading Comprehension. In *CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019), May 4–9, 2019, Glasgow, Scotland UK*. ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3290605.3300392

1 INTRODUCTION

Considering the amount of information currently conveyed through texts, an improvement in electronic reading in terms of intelligibility and better text layout methodologies would lead to a dramatic effect. So far, several methods aiming at improving the intelligibility of texts have been proposed and

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CHI 2019, May 4–9, 2019, Glasgow, Scotland UK

ACM ISBN 978-1-4503-5970-2/19/05…$15.00
https://doi.org/10.1145/3290605.3300392

evaluated. Reports have shown that a text layout methodology that provides a prior presentation of text contents, methods that allow the visualization of the structure or content of texts, or methods that draw attention to specific parts of texts facilitate an understanding of a text content. They include, for instance, methods that stress on specific character information (typographical cuing), which change sizes and weights of the characters or use an underline or bold face [15, 25]; methods that provide an advance organizer, containing prior conceptual knowledge related to the contents of the text [2, 34, 40]; methods that provide an outline that shows the structure of the entire text [11, 19]; methods that provide a summary that organizes and summarizes the contents of the text [22, 24, 41]; methods that show figures depicting the central persons and objects appearing in the text [43]; and methods that create schematic figures related to the structure of the entire text [20].

However, these methods have some issues regarding their strategies in generating information to be added to the text or in dealing with the reader's burden about their understanding of the additional information. For instance, if diagrams and schematic figures are to be used, it is not guaranteed that a third person would be able to precisely represent with images the contents expressed by the author in the text. In addition, the reader is expected to understand diagrams and schematic figures in the text, which exceeds the ability involved in just reading a text. Even if the additional information consists of characters containing summarized information, a remaining issue is to precisely understand the summarized sentences. On the other hand, typographical cuing is the most common method adopted by users who insert information themselves, without requiring special training [13, 38]. Therefore, if we can find an efficient method to embed typographical cuing into the text, it would enhance text comprehension without requiring users to change their usual reading styles.

In this study, we focus on the construction-integration (C-I) model, developed by Kintsch et al. [31–33], to enable a greater understanding of the models of text comprehension. The model demonstrates that text comprehension can be explained by an interactive combination of top-down (knowledge-driven) and bottom-up (word-based) approaches [46], serving as the most computationally explicit [52]. According to this model, text comprehension results from a mutual interaction between the "textbase construction phase" and the "integration phase." In the textbase construction phase, a network of propositions — the component elements of a text — is formed through a bottom-up approach that starts from the language input. On the other hand, in the "integration phase," textbases are integrated and considerations on context and knowledge are introduced, resulting in the formation of a stable situational model after several inference actions. A textbase construction comprises the phase where the relations among propositions are clarified and associated with meanings. During the construction of a situational model, the propositional textbase is re-integrated based on the reader's previous knowledge to make the entire situation described in the text to be understood. This is important for an accurate understanding of a text, which enhances the accurate extraction of propositions embedded in the sentences and the relations among propositions, which form the basis of the construction and integration processes.

Understanding the propositions and naturally grasping the connections between propositions would result in a more accurate comprehension of texts. In this study, we expand the typographical cuing method to the entire text and propose a new text layout to highlight the paragraph units of the text and the order of sentences using character fading. We also evaluate the effectiveness of the proposed method in text comprehension.

2 BACKGROUND

Text layout methodologies

In previous studies, several methods for improving the intelligibility of texts were proposed and evaluated [2, 11, 15, 19, 20, 22, 24, 25, 34, 40, 41, 43, 49]. In this study, we focus on typographical cuing [15, 25, 49] because it is the most conventional method that does not require users to change their usual reading styles [13, 38].

A unique aspect of typographical cuing is that it stresses specific characters. Various techniques have been proposed in optimizing electronic text reading. They include, for instance, techniques known as rapid serial visual presentation (RSVP), where text is displayed one word at a time at the same screen location [3, 7, 8, 14]; techniques that emphasize eye movement destinations by arranging or vibrating the characters [30, 35–37]; and techniques that use hard-to-read fonts [12, 16]. While these techniques are effective, issues have also been reported. RSVP technique increases reading speed; however, it increases cognitive load and reduces comfort [4, 10, 39, 48]. The technique that emphasizes eye movement destinations improves reading speed and efficiency; however, it does not increase comprehension levels [30, 35–37]. The hard-to-read font technique improves memory recall; however, the text becomes difficult to read because the fonts are created based on concept of desirable difficulty. In this study, we aim to develop a method that improves text comprehension without requiring users to change their usual reading styles and without being subjected to cognitive load.

Text comprehension studies

In various text comprehension studies [1, 5, 6, 18, 21, 29, 32, 33, 50, 51, 53], much of the experimental research was

stimulated [9] and propelled [46] by Kintsch et al.'s theory [31–33, 51]. The C-I model we focus on was developed by Kintsch et al. [31]. As mentioned in the introduction section, proposition is the key component of C-I models. In this study, we aim to develop a text layout method that allows readers to understand the propositions of each sentence and naturally grasp the connections between such propositions.

The measurement of reading comprehension has various indicators and methods. We focus on the definition and classification of the Programme for International Student Assessment (PISA) [42], which is an international research program for assessing reading comprehension. In this study, we define text comprehension as the ability to accurately understand the gist of the "continuous text" with reference to PISA definition and classification. The continuous texts are formed and organized into sentences and paragraphs, not including figures and tables.

Eye movement characteristics

Eye movements in reading consist of repeated fixations and saccades [47]. During fixation, the foveal vision recognizes the characters, while the peripheral vision selects the next fixation position. The saccade is a rapid eye movement between fixation positions. The saccade direction basically follows the character arrangement (left-to-right). Eye movements can be recorded using an eye-tracking device. In this study, we analyzed the reading speeds and fixation positions based on eye movement data.

3 PROPOSED METHOD

We propose a new text layout method that facilitates reading comprehension by fading out characters sequentially, sentence-by-sentence, starting from the first sentence of each paragraph (hereafter, the "proposed method").

The proposed method, shown in Figure 2, highlights the paragraph structure of the entire text and the relative positions of its sentences. First, the text is divided into paragraph units, which in turn are subdivided into sentences. Then, a fading degree is set to each resulting sentence. As shown in Figure 2, the fading degree for the first sentence of a paragraph is set to zero and increased by one toward the end of the paragraph. In total, six fading degrees are set so that the color of the characters becomes fainter as the fading degree increases. The character colors are set as follows: `#000000` for fading degree 0 (black), `#545454` for fading degree 1, `#888888` for fading degree 2, `#B0B0B0` for fading degree 3, `#CFCFCF` for fading degree 4, and `#E0E0E0` for fading degree 5. If more sentences exist beyond the sentence of fading degree 5, the fading degrees for all remaining sentences are set to 5. Note that, even for fading degree 5, which is the highest value, we verified through interviews to readers and eye

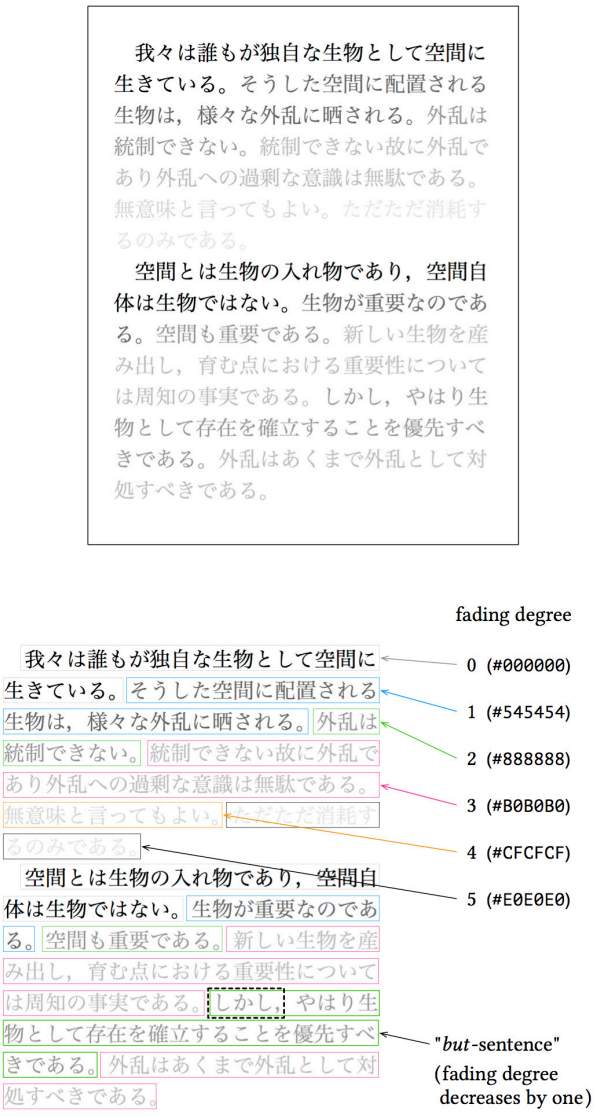

Figure 2: Example of a paragraph-based faded text and fading configuration.

movement analysis based on an eye-tracking device that this character color still permits reading without any problem.

As an exception, when one of the four types of conjunctions (expressing result, such as in "therefore"; paradox, in "but"; comparison, in "rather"; and summarization, in "in other words") is placed at the beginning of a sentence, the fading degree decreases by one with respect to the previous sentence and the sentence is displayed in a thicker color, as shown in the sentence containing "but" in Figure 2. In what follows, we denote such sentences as "*but*-sentences."

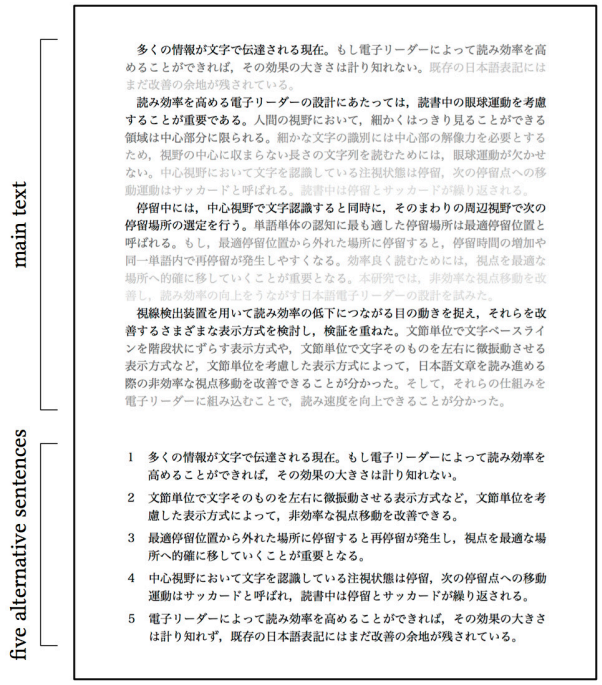

Figure 3: Example of text comprehension question comprising the main text and five alternative sentences.

4 EXPERIMENT I (TEXT COMPREHENSION)

We examined the influence of the proposed method on the rates of correct answers to text comprehension questions.

Method

Design. We compared the proposed method to the reference methods in terms of rates of correct answers to text comprehension questions. The reference methods were the "standard method (control group)," where fading degree 0 is assigned to all sentences, and the "random fading method," where a fading of 0 to 5 is applied to each sentence at random.

Stimuli. The stimuli were Japanese text comprehension questions (Figure 3), extracted from Japanese civil service entrance examinations. In this study, we define text comprehension as the ability to accurately understand the gist of the "continuous text." We researched stimuli under the conditions such as "suitable difficulty for participants," "examination questions answered by many candidates," and "examination questions opened to the public." As a result of several preliminary experiments, we decided to use the Japanese civil service entrance examinations as an evaluation method for text comprehension. The questions were extracted from the examinations that were prepared considering subjects with the equivalent of an university education level. All questions were written in Japanese, containing approximately 1000 characters and consisting a main text and five alternative sentences. The main text was descriptive expository text, structured as a continuous text. The participants read the main text and selected the most suitable alternative to "expressing the central idea of the main text." Even if the selected sentence could be found in the main text, if it did not convey its central idea, the choice was considered incorrect. We prepared seven questions: two questions belonged to the preliminary experiment and five to the main experiment. The questions were displayed serially on a 9.7-in screen with 264-ppi resolution of an iPad tablet computer (Apple Inc.).

Participants. The participants were 39 undergraduate students who had no prior knowledge or experience of this experiment.

Procedure. To test three text layout methods, including the proposed method and two reference methods, the participants were divided into 3 groups of 13 randomly selected people. The groups were named Group A, Group B, and Group C. Then, the participants answered two text comprehension questions prior to the experiment, and all text comprehension questions were displayed using the standard method. The mean rates of correct answers in the preliminary experiments were 46 ± 7 % for Group A, 46 ± 10 % for Group B, and 54 ± 10 % for Group C. In the results of the analysis of variance, no significant difference among the groups was detected. In the main experiment, the participants answered five text comprehension questions, which were displayed in this phase using the "proposed method" for Group A, the "random fading method" for Group B, and the "standard method" for Group C. The questions were presented in a random order.

Results

We analyzed the influence of the proposed method on the rates of correct answers to the text comprehension questions.

Figure 4 shows the mean rates of correct answers for each text layout and each question. The error range corresponds to the standard error. In Figure 4, the rates of correct answers to text comprehension questions when using the proposed text layout method is higher than that obtained using the random fading and the standard methods. The mean rate of the correct answers for the proposed method was 60 ± 6 %, as compared to the values of 35 ± 5 % for the random fading method and 35 ± 4 % for the standard method. According to the results of Dunnett's test, a significant difference was found between the proposed and standard methods ($p = 0.007$). On the other hand, no significant difference was found between the random fading and standard methods.

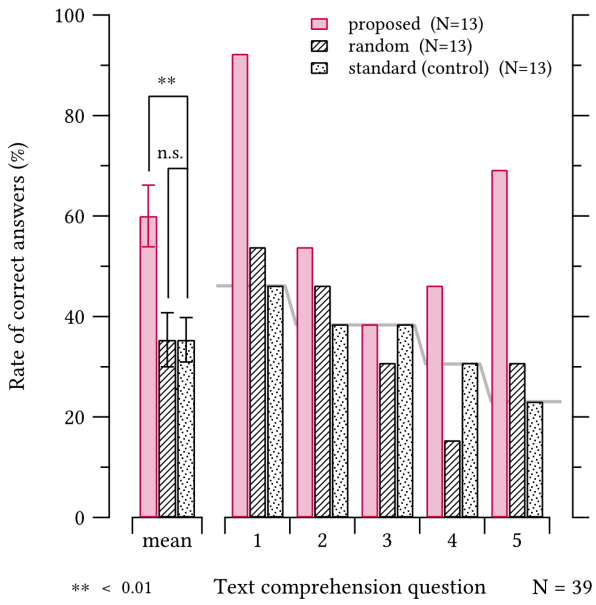

Figure 4: Rates of correct answers to text comprehension questions according to text layout method. Error bars show standard error.

Regarding the rates of correct answers by question, the proposed method achieved the highest rate in all questions. On the other hand, the rates of correct answers in the random fading method showed the same level as compared to the standard method. Therefore, we concluded that fading in random points in the text has no effect.

In Experiment I, we found that the proposed method improved the rates of correct answers of text comprehension questions.

5 EXPERIMENT II (EYE MOVEMENTS)

We found in Experiment I that the proposed method improved text comprehension. To investigate the reasons in Experiment II, we analyzed the effect of the proposed method on eye movements. Note that, the random fading method in Experiment I was removed for Experiment II because it was found to have no effect.

Method

Design. We compared the proposed method with a reference method in terms of eye movement during the answering process. The reference method was the "standard method (control group)," where fading degree 0 is assigned to all sentences.

Apparatus. The eye movement was measured at 1/60-s intervals using an EMR-9 eye-tracking recorder (nac Image Technology Inc.).

Stimuli. As in Experiment I, the stimuli were Japanese text comprehension questions (Figure 3). We prepared six questions: two questions for the preliminary experiment and four for the main experiment. The questions were displayed serially on a 9.7-in screen with 264-ppi resolution of an iPad tablet computer.

Participants. The participants were 18 undergraduate students who had no prior knowledge or experience of this experiment.

Procedure. First, a preliminary experiment was performed to allow the participants to familiarize themselves with the experiments. Thereafter, the main experiment was performed. In the preliminary experiment, the participants answered two questions common to all participants, which were displayed using the standard method. In the main experiment, the participants answered four questions, two displayed using the proposed method and two using the standard method. The questions and text layout methods were combined in a random order. The preliminary and main experiments were conducted seamlessly, and the participants were not given any clue as to whether they were participating in the preliminary or the main experiment.

Result I (Comprehension and re-reading action)

First, we obtained the rates of correct answers to text comprehension questions by using the proposed and standard methods.

Table 1 shows the rates of correct answers related to text comprehension questions, using the proposed and standard methods. It is revealed that the mean rate of correct answers for the proposed method is higher than those of the standard method. According to the result of the t-test, a significant difference was found between the proposed and standard methods ($t\,[17] = 2.3,\ p = 0.03$).

Next, we analyzed eye movements during the reading comprehension questions.

We found that the participants first read the main text and then the alternative sentences. If needed, they read the main text again before finally selecting an alternative. No participant read the alternative sentences before the main text. In this study, we refer to the act of "going back to the main text during the reading of an alternative sentence" as "re-reading." Note that the "re-reading" term differs from "backward saccade," which is the act of "returning to a few words or sentences during the reading of the main text."

Table 2 shows the rates of correct and incorrect answers and re-reading occurrences in text comprehension questions, using the proposed and standard text layout methods. From Table 2, both the rates of correct answers *without* and *with* re-reading increased when using the proposed method as

Table 1: Rates of correct answers to text comprehension questions according to the proposed and standard methods.

	Proposed method	(control) Standard method	Sig. diff.
Mean rate of correct answers	61 ± 9 %	36 ± 9 %	*
N = 18			* $p < 0.05$

Table 2: Rates of correct/incorrect answers and re-reading actions related to text comprehension questions according to the proposed and standard methods.

		Proposed method	(control) Standard method	Difference
Mean rate of **correct** answers	without re-reading	22 ± 8 %	6 ± 4 %	+16
	with re-reading	39 ± 10 %	30 ± 9 %	+9
Mean rate of **incorrect** answers	without re-reading	28 ± 9 %	42 ± 10 %	−14
	with re-reading	11 ± 5 %	22 ± 7 %	−11

N = 18

compared to the case of using the standard method. Moreover, both the rates of incorrect answers *without* and *with* re-reading decreased, using the proposed method as compared to the standard method.

The above suggests that the proposed method may improves the rates of correct answers both "when re-reading of the main text occurs during the choice of alternatives" and "when the main text is read only once." Therefore, we analyzed the re-reading eye movements during the choice of alternatives (Result II) and the eye movements during the reading of the main text *without* re-reading (Result III).

Result II (Re-reading eye movements)

We analyzed the re-reading eye movements during the choice of alternatives.

Table 3 shows the re-reading eye movements when selecting alternatives of the displayed text comprehension questions according to the proposed and standard methods. The number of re-reading movements is like the number of re-readings of the main text until an alternative is selected. The number of re-reading sentences is the number of sentences re-read before an alternative is selected. According to Table 3, approximately 50 % of the questions were answered by re-reading for both the proposed and standard methods. In addition, in questions where re-reading occurred, re-reading was performed approximately two times for both the proposed and standard methods. Regarding the number of re-read sentences, the results were four sentences for the proposed method and six sentences for the standard method. No significant difference was found in any of the cases. However, in the proposed method, we noticed that re-reading occurred mostly around sentences close to the beginning of the paragraph.

Figure 5 shows the relation between mean of re-readings of text comprehension questions and sentence position displayed according to the proposed and standard methods. The vertical axis corresponds to the mean of re-readings, and the horizontal axis corresponds to the position of the sentence counting from the beginning of the paragraph. Sentence position 0 means that the sentence is located at the beginning of the paragraph (first sentence of the paragraph). Sentence position 1 denotes the sentence that follows the first sentence. As the sentence position increases, it gets closer to the end of the paragraph. The error range corresponds to the standard error. Figure 5 shows that, for the proposed method, re-reading occurs mostly in positions close to the beginning of the sentence. On the other hand, in the standard method, the range where re-reading occurs is broader than that in the proposed method. We can also see that, in the standard method, re-reading occurs in sentences in the middle of the paragraph toward the second half, where re-reading does not occur often with the proposed method. In other words, using the proposed method, re-reading tends to concentrate in sentences located closer to the beginning of the paragraph as compared to the standard method.

We found that the rate of re-reading and the number of re-reading movements were approximately the same for both the proposed and standard methods. We also found that, in the proposed method, re-reading tended to concentrate on sentences located closer to the beginning of the paragraph, compared to the standard method.

Table 3: Re-reading eye movements during the choice of text comprehension questions displayed according to the proposed and standard methods.

	Proposed method	(control) Standard method	Sig. diff.
Mean re-reading rate	50 ± 10 %	53 ± 10 %	n.s.
Mean of re-reading movements	2.1 ± 0.3	2.3 ± 0.4	n.s.
Mean of re-read sentences	4 ± 1	6 ± 1	n.s.

N = 18

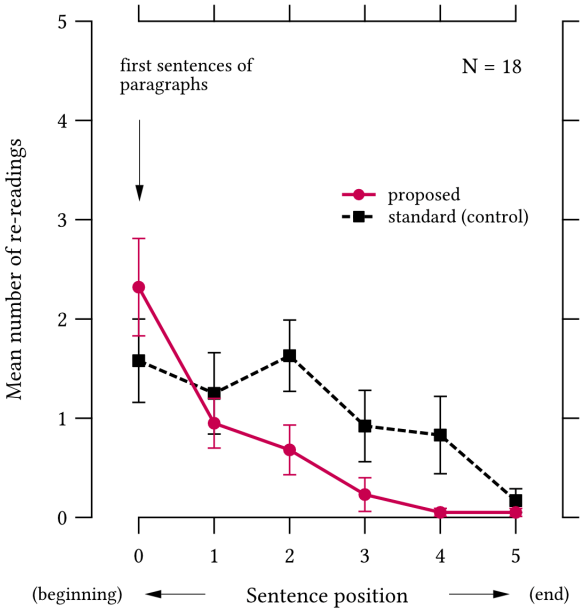

Figure 5: Relation between number of re-readings and position of the sentence displayed according to the proposed and standard methods. Error bars show standard error.

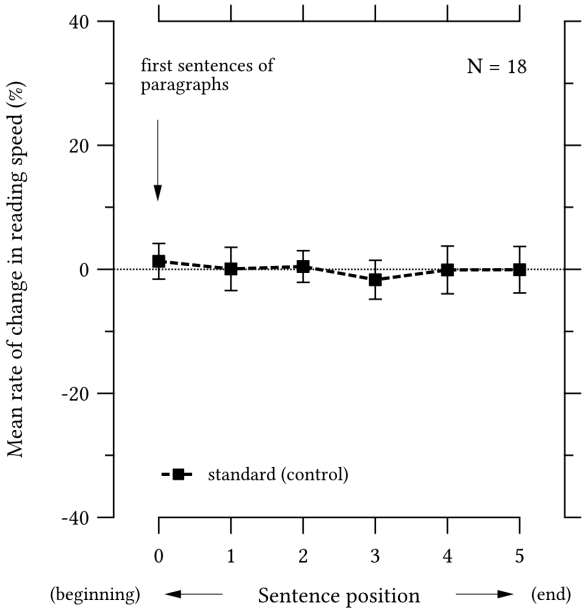

Figure 6: Relation between reading speed and sentence position for the standard text layout method. Error bars show standard error.

Result III (Reading speed)

Next, we analyzed the eye movements during the reading of the main text.

Figure 6 shows the relation between the reading speed and sentence position for the standard method. The vertical axis corresponds to the mean rate of increase or decrease in the reading speed, and the horizontal axis corresponds to the sentence position. The error range corresponds to the standard error. Figure 6 suggests that the rate of change in the reading speed of the standard method is approximately 0 % regardless of the sentence position. In other words, the mean reading speed for the standard method is approximately the same irrespective of being at the top or at the last sentence of the paragraph.

Figure 7 shows a relation between the reading speed and fading for the proposed method. The vertical axis corresponds to the mean rate of increase or decrease in the reading speed, whereas the horizontal axis represents the fading degree. The error range corresponds to the standard error. Figure 7 suggests that sentences with fading degree 0 (black) show the slowest reading speed. According to the result of the t-test, a significant difference was found between the reading speed for sentences with fading degrees 0 and 1 ($t\,[17] = 2.72$, $p < 0.01$). On the other hand, the reading speed for sentences in which the fading degree is in the range of 1 to 5 tended to be relatively constant.

Figure 8 shows the relative reading speeds for sentences located at the beginning and end of paragraphs, as well as in *but*-sentences, using the proposed and standard methods. The vertical axis corresponds to the relative reading

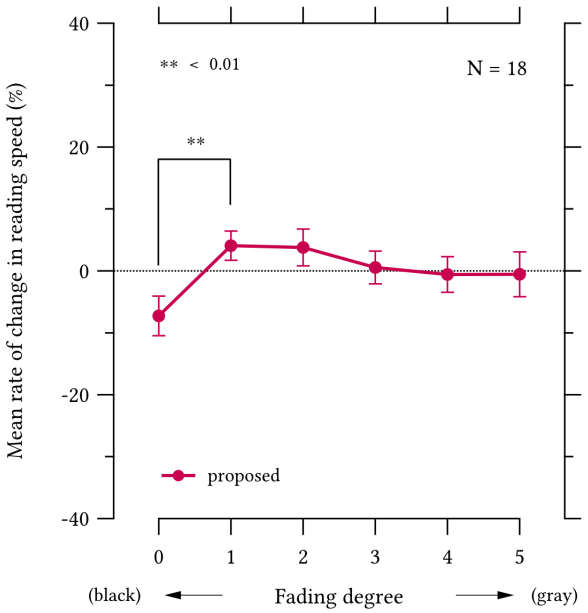

Figure 7: Relation between reading speed and fading degree in the proposed text layout method. Error bars show standard error.

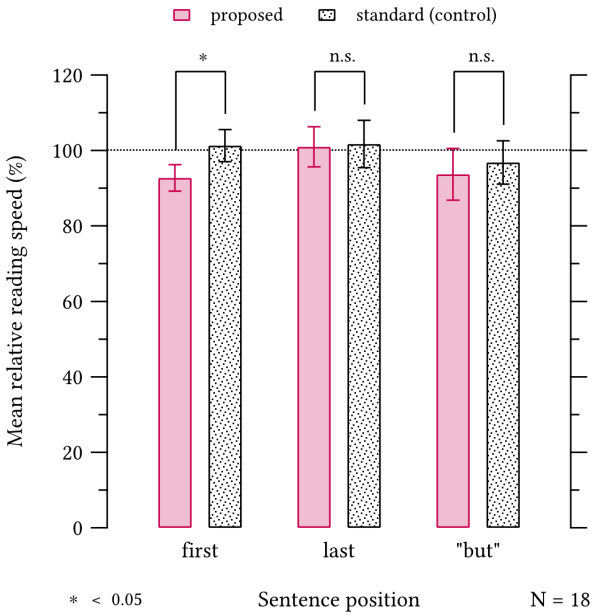

Figure 8: Relative reading speeds for the proposed and standard methods for the first and last sentences of paragraphs and *but*-sentences. Error bars show standard error.

speed, considering that the mean reading speed of the entire text is 100 %, and the horizontal axis corresponds to the type of sentence. The error range corresponds to the standard error. As revealed in Figure 8, the first sentences of the paragraph for the proposed method tended to be read relatively more slowly than those for the standard method. According to the result of the t-test, a significant difference was found between the reading speeds for the proposed and standard methods for the first sentences of paragraphs ($t\,[17] = 2.1$, $p < 0.05$). In the case of reading speeds for the last sentences of paragraphs and *but*-sentences, no significant difference was found between the proposed and standard methods.

In Experiment II, we found that re-reading tended to concentrate mostly on sentences close to the beginning of the paragraph in the proposed method. In addition, we found that sentences located at the beginning of paragraphs tended to be read relatively slower than other sentences in the proposed method.

6 EXPERIMENT III (MEMORIZATION)

We found in Experiment II that the reading speed for the proposed method tended to slow down for the first sentences of paragraphs. To investigate such influence in Experiment III, we analyzed the influence of the proposed method on the memorization of the first sentence in a paragraph.

Method

Design. We compared the proposed method with the reference method in terms of recognition rates of the first sentences of the paragraphs. The reference method was the "standard method (control group)," where fading degree 0 is assigned to all sentences. After reading the presented text, using the proposed and standard methods, sentences were displayed serially and the participant was asked to respond whether the given sentence "belongs to the text that was read (target stimulus)" or "does not belong to the text (destructor stimulus)." Then, the rates of correct answers for the proposed and standard methods were compared.

Stimuli. As in Experiment I, the stimuli were Japanese text comprehension questions (Figure 3). However, only the main text was used in this experiment, without using the five alternative sentences. We prepared 10 main texts written in Japanese that contain about 700 characters. The target stimuli were extracted from the above 10 main texts. A total of 30 sentences were selected: 10 sentences located at the beginning of paragraphs, 10 located at the end, and 10 were *but*-sentences. The destructor stimuli were extracted from 30 texts that appear in Japanese civil service entrance examinations. A total of 50 sentences were selected, including those located at the beginning and at the end of paragraphs and *but*-sentences, comprising those that did not contain proper names and other peculiar words. The presented main

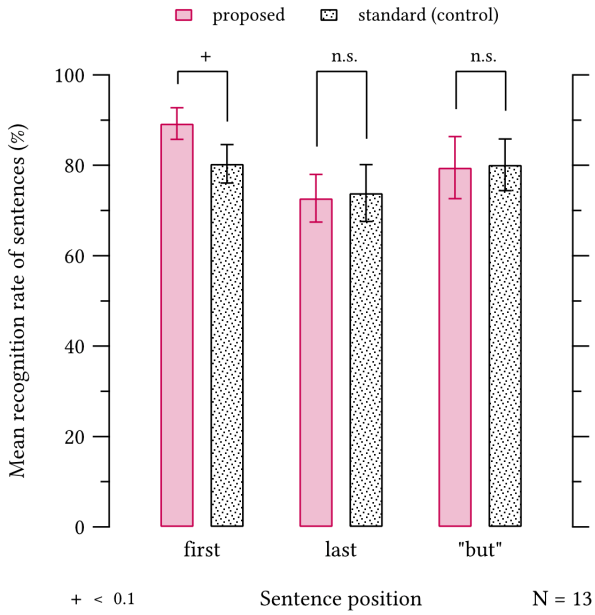

Figure 9: Recognition rates of the proposed and standard methods for the first and last sentences of paragraphs, and *but*-sentences. Error bars show standard error.

texts were displayed serially, while the target and destructor stimuli were displayed sentence-by-sentence. They were displayed on a 12.9-in screen with 264-ppi resolution of an iPad Pro tablet computer (Apple Inc.).

Participants. The participants were 13 undergraduate students who had no prior knowledge or experience of this experiment.

Procedure. First, the participants read 10 texts, five using the proposed method and five using the standard method. After that, in response to the sentences presented sequentially, the participants indicated whether such sentences consist of the target or destructor stimuli. The stimuli and text layout methods were combined randomly. The presentation order of the target and destructor stimuli was also random.

Results

We analyzed the influence of the proposed method on the memorization of the first sentences of the paragraphs.

Figure 9 shows the recognition rates of sentences located at the beginning and the end of paragraphs, as well as *but*-sentences, using the proposed and standard methods. The vertical axis indicates the success rate for recognizing the stimulus, and the horizontal axis indicates the extracted position of the target stimulus sentence ("first" stands for sentences located at the beginning of paragraphs, "last" stands for those located at the end, and "but" stands for *but*-sentences). The error range corresponds to the standard error. As revealed in Figure 9, the recognition rate of the first sentences of paragraphs for the proposed method tended to improve as compared to the standard method. From the result of the t-test, a marginal difference was found between the recognition rates of the proposed and standard methods for the first sentences of paragraphs ($t\,[12] = 1.9$, $p = 0.07$). On the other hand, in the case of recognition rates for the last sentences of paragraphs and *but*-sentences, no significant difference was found between the proposed and standard methods.

In Experiment III, we found that the recognition rates of the proposed method tended to improve for sentences located at the beginning of paragraphs.

7 DISCUSSION

Here, we discuss the effect of the proposed method on text comprehension based on the results of Experiments I, II, and III.

First, the proposed method improves the rates of correct answers of text comprehension questions (Figure 4). We observe that both the rate of correct answers "*without* re-reading" and the rate of correct answers "*with* re-reading" increased in the proposed method, as compared with the standard method (Table 2). In other words, rates of correct answers improve regardless of the occurrence or not in the re-reading in the proposed method.

Next, the analysis of reading speeds suggests that the entire text is read at a constant speed in the standard method (Figure 6), whereas sentences located at the beginning of paragraphs are read at a relatively slow speed in the proposed method (Figures 7 and 8). In addition, an analysis of re-reading movements indicates that re-reading concentrates mostly on sentences close to the beginning of the paragraph in the proposed method, as compared to the standard method (Figure 5). Moreover, the analysis of sentence memorization indicates that the proposed method tends to improve the recognition rates for sentences located at the beginning of paragraphs (Figure 9).

The experimental results suggest that the proposed method improves text comprehension. In fact, using the proposed method, texts located at the beginning of paragraphs that are displayed in a relatively thick mode tend to be read relatively slowly and the memorization scores related to these sentences tend to improve. Moreover, the re-reading subjects tend to concentrate on sentences located at the beginning of paragraphs, which are displayed in a thicker mode. From the above discussion, we hypothesize that, when the proposed text layout method is used, the reader is facilitated naturally to pay attention on the first sentence of each paragraph, even

when all sentences are being read, suggesting that this reading style could result in a more accurate comprehension of the text.

In this study, the quantitative evaluation method of text comprehension consists of "selecting the alternative that best suits the main idea conveyed in the main text, after reading texts." The difficulty level of the comprehension tests is high because the questions are extracted from Japanese civil service entrance examinations, considering subjects that are equivalent to an university education level. The main idea is not explicitly written in the main text, and thus, it is necessary to read the entire text for better understanding. In addition, for the questions used in this study, it is not possible to choose the right answer through a simple comparison between sentences assigned to the fading degree 0 (black) of the proposed method and the five alternative sentences. Therefore, to solve the text comprehension questions, the participants have to grasp the propositions contained in each sentence while reading the main text and understand the main idea conveyed in the main text by clarifying the relations among the propositions. In other words, to comprehend the main texts presented in this study, it is indispensable for the participants to at least build a propositional textbase related to the C-I model. The proposed method highlights the paragraph structure of the entire text and the relative positions of its sentences by fading out characters sequentially, sentence-by-sentence, from the beginning of each paragraph. It is suggested that partial fading could facilitate the formation of a propositional textbase and a situational model.

In addition, studies that examine the sentence reading times have shown that sentences that introduce a new discourse topic or a new narrative episode allocate more processing time than sentences that are in continuations of the same topic or episode [23, 27]. This phenomenon is called the "topic-shift effect." The processing of topic shifts involves a strategic component. It is reported that adults manifest a proportionately greater topic-shift effect in difficult expository texts as compared to fifth-grade children [26]. In this study, we find that in the proposed method, sentences located at the beginning of paragraphs are read at a relatively slower speed, which is not found in the standard method. These results indicate that, in the proposed method, the reader is naturally forced to allocate more processing time to the first sentence of each paragraph of a new discourse topic, suggesting that this artificial topic-shift effect could result in a more accurate comprehension of the text. Moreover, it is reported that an efficient suppression of irrelevant information is important for reading comprehension in working memory studies [17, 44, 45]. The partial fading may have contributed to the efficient suppression of irrelevant information, but this requires further investigation.

Limitation and future work

Application of the proposed method to web design and e-learning can enhance more accurate information grasp and effective learning. In addition, this proposed method is a static design method that can be applied not only to the design of electronic displays but also to paper design.

In this study, the stimuli were Japanese text. Further research is needed to investigate whether the proposed method is effective in other languages. However, in the proposed method, it seems to be promoting the topic-shift effect of fading out characters sequentially, sentence-by-sentence. That is, in the case of a language in which the topic-shift effect is observed, even if it is not Japanese, the proposed method might be effective.

In the proposed method, four types of conjunctions were selected for the *but*-sentences. These conjunctions were words used for resulting, paradox, comparing, or summarizing the contents of the previous sentence [28]. In this study, text comprehension was improved in the application of *but*-sentences based on these conjunctions. However, from the experimental results, no significant difference was found in the reading speed and memorization of *but*-sentences. Therefore, further research regarding the effect of *but*-sentences and how to select target types of conjunctions is necessary.

8 CONCLUSIONS

In this study, we proposed a new text layout that facilitates reading comprehension. The proposed method highlights the paragraph structure of the entire text and the relative positions of its sentences by fading out characters sequentially, sentence-by-sentence, from the beginning of each paragraph. According to experimental results, we found that the proposed method improves the rates of correct answers of text comprehension questions. Moreover, the proposed method leads to slower reading speeds and better recognition rates for the first sentences of paragraphs, which are displayed in a relatively thicker mode. With the paragraph-based faded text, the reader is naturally facilitated to pay attention to the first sentence of each paragraph, suggesting that this reading style could result in a more accurate text comprehension.

ACKNOWLEDGMENTS

The authors would like to thank Professor Hitoshi Matsubara for providing the apparatus. The authors would also like to thank the anonymous reviewers for their valuable comments and helpful suggestions.

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