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Identifying Context-dependent Modes of Reading

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Abstract. Past literature has suggested that reading text as a whole cannot be reduced to merely an aggregation of sentence processing, but instead there are expected to be some context-dependent stylistic differences in the reading process. It has been, however, difficult to capture such context-dependent reading styles or modes. In this study, under the hypothesis that the statistics of reading time reflects such reading modes, we introduce a new statistical approach to capture them. Our analysis of the distributions of reading times identified two distinct modes of reading. In further analysis, we found that the temporal profiles of the two reading modes were correlated to the reader's degree of engagement. We discuss how the context dependency of the reading modes is related to dynamic construction of the reader's knowledge of narratives.

Keywords: Literary · Reading · Reading-time analysis

1 Introduction

Reading literature is not merely information processing of prose; it also evokes various feelings. Many past studies have discussed intrinsic features of readers' responses to literary works [9, 7, and see also Miall [11] for a discussion about literariness]. In addition to these theoretical studies, there are also empirical studies about reading literary works [10, 8]. For example, Miall & Kuiken [12] conducted four experiments to study reader response to aspects of literature known as *foregrounding* and *defamiliarization*, which are concepts in Russian formalism. They analyzed readers' emotional ratings to each word or sentence with the stylistic details of the literary text, such as alliteration, inversion, and metaphor. This study concluded that a number of these stylistic features in words or sentences were associated with an increase in reading time, higher strikingness ratings, and higher affect ratings.

* Please note that the LNCS Editorial assumes that all authors have used the western naming convention, with given names preceding surnames. This determines the structure of the names in the running heads and the author index.

Although there is no doubt about the effects of stylistic details in reading literature, reading experience would also be affected by the contextual structure of the story. Therefore, to approach a reader's cognitive process, which can be associated with a reader's experience *in* the story, we need to analyze the context-dependent changes in reading processing over the entire text.

In past studies, hypothetical constructs such as *story grammar* or *script*, which the reader is supposed to process in reading, were used to capture the contextual structures of stories [14, 2]. Introducing the concepts of story grammar and script, Thorndyke [14] and Beaugrande [2] claimed that narratives have their own internal structure like a grammar, but at the discourse level, and these structures can be expressed by several kinds of elements (such as setting, theme, characters, goal, and so on) and associated combinatorial rules. However, using these, we can analyze only limited classes of stereotypical stories such as folk tales [11, 2]. This limitation is likely to be due to their inflexibility, as literary works need to be updated to give the reader fresh interpretation. There have been other approaches to capture the context of stories, but, as far as we know, none of them have ever offered a satisfactory way to capture the context access to it .

In the present study, rather than assuming a specific story grammar, we focus on temporal changes in the reading process across different contextual structures of stories. Miall [10] analyzed the relationship between readers' affect ratings and reading times of introductory sections of novels. He analyzed readers' responses by assuming two stages of reading processes. One was called the registration stage, in which readers formed anticipations about the likely meaning of the narrative, and the other was called the interpretation stage, in which readers used the formed anticipations to comprehend the narrative. Miall assumed that the two stages could be separated according to the contextual structure of a story, and how much new information the story has. Thus, the shift across two stages would depend on both context of the story and the reader's background knowledge. From his analysis, he concluded that the reading process forms a cycle and repeatedly shifts between the two stages in the reading of a narrative.

With the working hypothesis that there are separable stages in reading processes correlated to the contextual structure, as suggested by Miall, we investigate the stage-like changes in reading process across the entire story, not only in an introductory part as analyzed by the previous study.

In this study, we investigate the "modes" of reading processes, which are supposed to be correlated to the context of the story or reader's background knowledge. The modes are operationally defined by statistical properties of reading times of each unit of text. We will further discuss modes in Section 1.1. Specifically, we run two experiments, in which we analyze reading time of each pair of pages for a collection of readers. A pair of pages approximately corresponds to twenty phrases, which is the unit of text analyzed for readers' responses in the previous study by Miall.

1.1 Statistical analysis of reading time

We assume the reading processes are composed of several qualitatively distinct subprocesses, and we call such a subprocess a *reading mode*. The question is, given reading data, how can we infer the number of reading modes reflected in the data? In previous studies about short texts and more rapid processes, differences in reading time alone have been interpreted as a reflection of two qualitatively distinct processes [10, 4]. However, reading time may vary depending on multiple factors, such as frequency, familiarity, and the lengths of words [6, 15]. We cannot, therefore, naively interpret reading time alone as an indicator of multiple reading modes.

This observation motivates the development of a new analysis technique for reading time. The analysis we present as an alternative is based on a statistical theory of processing time [5]. In this theory, the presence of multiple different modes of processing can be detected by the statistical distribution of the processing time.

If the reading process consists of n subprocesses with the same constant processing rate over time, in other words, the process finishes only when all these subprocesses have finished, then the reading time would follow a gamma distribution with shape parameter n (Figure 1(a)). If, on the other hand, the reading process consists of one subprocess with process rate t^k as a function of the process time t, in other words, the process finishes when at least one subprocess has finished, then the reading time would follow a Weibull distribution with shape parameter k (Figure 1(b)).

Setting $n = 1$ in a gamma distribution or $k = 1$ in a Weibull distribution yields an exponential distribution. There is, therefore, a statistical relationship between the types of distributions of the processing time and the numbers of subprocesses.

This statistical analysis allows us to distinguish processes that have the same average speed of processes, but have different numbers of subprocesses (Figure 2 Mode A and Mode B), and to distinguish processes that have the same number of subprocesses but have different average speeds of processes. This subprocess estimation gives an advantage over previous studies that analyzed differences in the reading time alone.

We adopt this statistical account of processing time for evaluating the number of reading modes based on reading time. If each observation in a reading time dataset follows essentially the same distribution as the others, we treat this as an indicator of a single reading mode. If, on the other hand, the data set appears to have been generated by sampling from a mixture of distributions, we treat it as an indicator of multiple reading modes (Figure 3). Each dataset in question is composed of observations about a single subject. This technique, therefore, removes overall reading speed as a factor in the analysis.

1.2 Approach

When reading, one is generally also engaged in many other processes , such as eye movements, posture management, and so on. If one were only lightly engaged

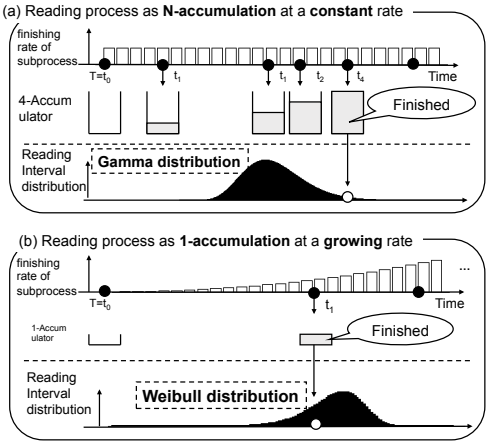

Fig. 1. Schematic illustrations of the different types of reading processes and corresponding statistical distributions.

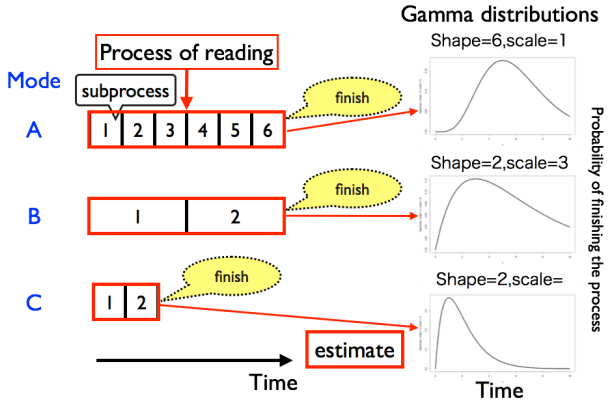

Fig. 2. Three hypothetical processing modes, A, B, and C, which have different numbers of subprocesses with different average rates. In each mode, all the subprocesses run in serial order, and the reading time follows a gamma distribution. Mode A: 6 subprocesses, each takes a short time on average; Mode B: 2 subprocesses, each takes a long time; and Mode C: 2 subprocesses, each takes a short time. The overall average of both Mode A and Mode B is the same, but their distributions (on the right-hand side of the figure) are different.

in reading and more heavily preoccupied with a number of these other activities, it is entirely possible that their preoccupation could appear as distinct reading modes in our statistical analysis. To prevent the detection of such false modes, it would be valuable to have a measure of reading engagement independent from

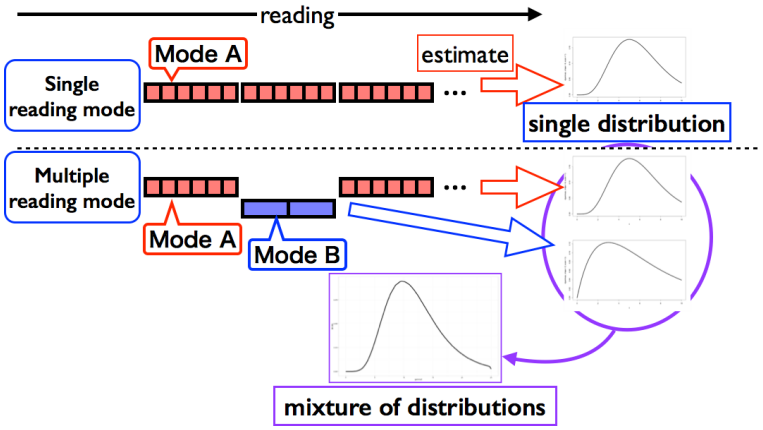

Fig. 3. (top) If one type of reading mode is repeated across multiple pages, it would result in a gamma distribution.
(bottom) If both types of reading modes, A and B, take place across different pages, it would result in a mixture of two gamma distributions.

reading time. We could then test the results of our statistical analysis based on their correlation with that measure.

Since the analytic technique we will use is statistical in nature, it requires relatively large datasets to produce meaningful results. To this end, and although this is not typical of existing studies of reading, we use entire prose narratives as the texts in our experiments.

Given the burden that reading such long texts places on the subjects of our experiments, our first experiment consisted of only one subject : Miho Fuyama, the first author of this paper. She is an avid reader, which suggests that she is generally easily engaged in reading as an activity. In Experiment 1, we studied her reading time and the degree of engagement in reading across two books in order to empirically establish the validity of our analysis. We then analyzed data generated during her readings of 18 additional novels in order to test whether her reading process had a single or multiple reading modes.

Having validated our statistical analysis, we adopted it in our second experiment to a cross-sectional study of multiple subjects. In Experiment 2, we asked ten subjects to read a short story and introductory part of a longer story. The subjects were also asked to evaluate their degrees of reading engagement each two pages after the reading session. This experiment was designed to evaluate whether our findings from Experiment 1 hold in general. We also evaluated whether changes in reading modes could be related to the semantic structure of the text itself. To do so, we analyzed the consistency of the dynamics governing the change of reading modes across subjects and treated consistent dynamics as text-specific semantic effects in reading.

2 Experiment 1

The first author was the sole subject of several high-load reading tasks. We asked her to read 20 Japanese novels. Each session took one day, including breaks. The set of samples from these 20 sessions of 20 novels was submitted to statistical analysis using the scheme described in the previous section, and we estimated the statistical distribution of her reading time for each two pages for which the reader needs to turn over a page. For two of the novels (novels 17 and 18 in Table 1), she evaluated her degrees of absorption each two pages as an indicator of her engagement in reading. Specifically, we asked her how absorbed she was in reading every pair of pages in these novels. These absorption ratings were used to validate the statistical analysis.

2.1 Participant

The subject was the first author, Miho Fuyama, who was 30 years old when the experiment was conducted. She is a native Japanese speaker, is a regular reader, and has normal vision.

2.2 Material

We used 20 Japanese novels, which the first author read for the first time in this experiment. The titles, authors, and page lengths of the books are listed in Table 1. We selected as texts books written by authors who have won Japan's prestigious literature prizes, such as the Naoki Prize or Akutagawa Prize.

2.3 Procedure

In each session of the experiment, the subject was asked to read a novel. Each session lasted several hours (including breaks), but was completed in one day. The subject reported her degrees of absorption for every two pages read in novels number 17 and 18. These reports were made approximately 100 days after the reading sessions. This delay in the absorption rating is due to experimenter's procedural mistake. Her degree of absorption was measured on a five-level scale – "extremely bored", "bored", "normal", "absorbed", and "deeply absorbed". This scale was coded using the numbers $-2, -1, 0, 1$, and 2, respectively, for each of the states. As the experiment required her to focus on and become absorbed in such long texts, the subject was allowed to perform her readings at her home in order to minimize her tension. She was also allowed to have breaks whenever she wanted. The breaks were typically 5 to 15 minutes long, but there were also several hour-long lunch breaks. While reading, she sat at her desk and was videotaped with two small web cameras.

2.4 Analysis

From the videos, we transcribed the reading time for each pair of pages. These reading times were measured as the lengths of time between page turns, excluding time spent on breaks. Statistical analysis was performed on these transcribed

Table 1. The novels read in Experiment 1.

No.	Title (Abbreviated)	Author	Page length
1	*Shikisai*	H. Murakami	370
2	*Kamisama*	H. Mori	314
3	*Nameraka*	H. Kawakami	189
4	*Tenchi*	T. Ubukata	474
5	*Chinmoku*	Y. Ogawa	308
6	*Hikari*	S. Miura	297
7	*Kuchi*	M. Banto	309
8	*Mizuumi*	B. Yashimoto	206
9	*Kogoeru*	A. Shino	401
10	*Self-Reference*	T. Enjo	308
11	*Shi no izumi*	H, Minagawa	427
12	*Kisetsu no kioku*	K. Hosaka	316
13	*Eien no deguchi*	E. Mori	313
14	*Hokanaranu hito he*	K. Shiraishi	295
15	*Shorou tomurai dou*	N. Kyogoku	498
16	*Kodoku no utagoe*	A, Tendo	312
17	*Neko*	Y. Ogawa	359
18	*Ruto 225*	C. Fujino	282
19	*Yasashii uttae*	Y. Ogawa	260
20	*Burahuman*	Y. Ogawa	146

reading times. We analyzed the aggregate of the data gathered across all the sessions of the experiment in order to increase the statistical power of our analysis.

In our analysis, we fitted mixtures of exponential distributions, those of Weibull distributions and those of gamma distributions, to the aggregate data based on the Expectation–Maximization algorithm [3]. For each mixture distribution, ranging from 1 to 5 components, we estimated the parameters by maximizing likelihood. As these statistical models have different numbers of parameters, we chose the model with the smallest Bayesian Information Criterion (BIC) statistic [13] as the one that best explains the data. The choice of the BIC is not exclusive. As a result, we found that other criteria, such as Akaike information criterion (AIC) [1] chooses the same model in our analysis.

2.5 Results and discussion

We found that a mixture of two gamma distributions provided the best fit to the aggregate data amongst all the distributions considered. Figure 4 illustrates the differences between these various classes of distributions in explaining our data. It shows the hazard function $H(t)$ of the page-turn interval t. The hazard function $H(t)$ is the probability (density) to finish reading on condition of the reading being unfinished until t. Exponential distributions in general exhibit a constant $H(t)$, which means this random process has “no memory” , that

is, a constant rate of reading interval regardless of time. Weibull and gamma distributions, in contrast, have increasing hazard functions. This means that the reading becomes more and more likely to be finished as time goes on. The two classes of distributions, however, exhibit differences in the shapes of their hazard functions.

The exponential distribution, with a constant hazard function, did not fit the data well, as shown in Figure 4 (BIC = 29421.71). Likewise, the Weibull distribution has large deviation from the data at the tails of distribution ($t < 30$ and $140 < t$) (BIC = 26146.06). The single gamma distribution fits better than the exponential and Weibull distributions (BIC = 25722.64), but the mixture of two gamma distributions provides the best fit (BIC = 25655.29). Further, mixtures of three gamma distributions (BIC = 25677.24) or more did not provide better fits than the two-component gamma distribution.

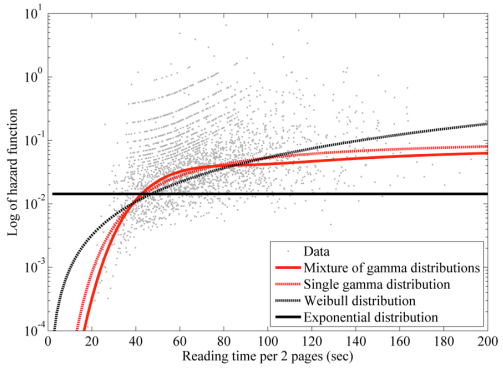

Fig. 4. The hazard functions for the sample (dots) and for the estimated probability distributions (lines) of reading time per two pages.

Figure 5 shows the probability density function of empirical reading intervals and the estimated probability density function, which is a mixture of two gamma distributions. One subcomponent, Distribution 1, has shape 13.80 and scale 4.24. The other subcomponent, Distribution 2, has shape 7.58 and scale 10.67. This result suggests that the subject shows two distinct modes in her reading, with each mode involving different reading subprocesses. It is worth noting that, at this point, we have not established the relationship between the two statistically estimated modes and the putative cognitive processes for reading.

Correlation to reading engagement We now address the question of whether the two distinct modes identified in our analysis are actually reflective of the text being read. In order to test this, we analyzed the correlation between the temporal change in mode and the degree of absorption reported by the reader.

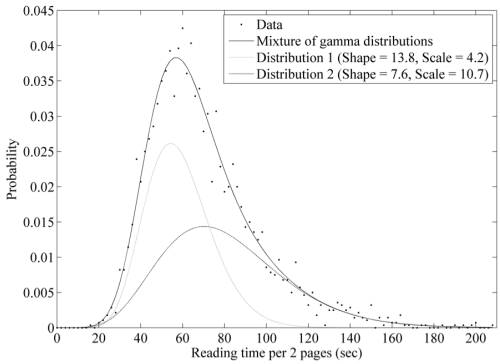

Fig. 5. Sample (dots) and estimated (solid) probability distributions of reading time per two pages. The two curves under the fitting curve show subcomponents of the gamma mixture distribution.

We obtained the reader's post-hoc report on engagement for each two pages of books 17 and 18.

Taking book 17 as a representative case, Figure 6 shows the temporal profile of the weighted-average of shape parameters (black dots) and the reader's degrees of absorption (red dots). The weights were given by the mixture of the two gamma distributions for each reading time of two pages. The corresponding moving averages of the two over five data points are shown as the black and red lines, respectively.

We performed correlation analysis for a pair of the estimated shape parameters and the degrees of absorption. For book 17 across 141 pairs of pages, we had correlation -0.284 (Pearson product-moment correlation coefficient, $p < 0.001$). For book 18 across 118 pairs of pages, we had correlation -0.283 ($p < 0.01$). This indicates that the temporal changes in the modes identified from our reading time analysis (Figure 6) do indeed reflect changes in reading engagement.

Recall that the shape parameter can be interpreted as the number of subprocesses involved in processing a given text, and that the scale parameter can be interpreted simply as the inverse of reading speed (Figure 1). Taking this theory into account, we conclude that the two modes estimated in this analysis are likely to represent a fast reading mode (Distribution 1) with a larger number of subprocesses, and a slow reading mode (Distribution 2) with a smaller number of subprocesses.

3 Experiment 2

In Experiment 1, our statistical analysis detected two different modes of behavior in the reading data generated by the experiment. We further showed that the change in mode over time had a statistically significant correlation to the levels of engagement with the text reported by the subject. Our goal for Experiment

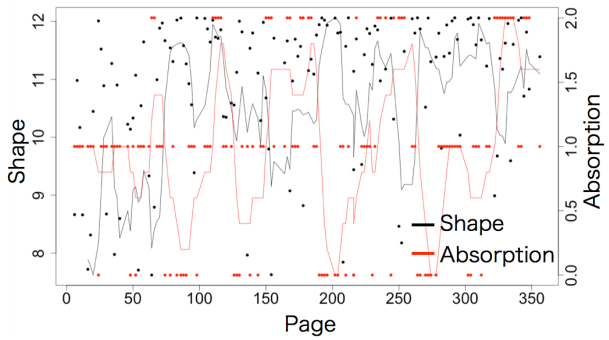

Fig. 6. Page-based temporal profile of the statistical property (shape parameter) of reading time and the absorption ratings of book 17.

2 was to establish whether or not these findings are consistent across multiple subjects and, if so, to identify the various factors governing the reading modes detected in Experiment 1. In order to answer these questions, we designed a short experiment for the other subjects. In our second experiment, we asked different subjects to read a short prose narrative but kept the rest of the procedure the same as it was in case 17 and 18 of Experiment 1. Namely, subjects were asked to read a short story or a part of a novel, and then they were asked to report their degrees of absorption for each two pages. The story itself took less than an hour to read.

We expected two possible cases:

1. We may observe individual variance in reading time across subjects, which would reflect that different subjects exhibit very different ways of processing the text.
2. The reading time may depend on the contextual structure of the text, and different subjects may exhibit similar mode changes in reading the same text.

The major factor dictating reading modes would be a subject's reading strategy in the first case. In the second case, it would be the contextual structure of the text itself.

3.1 Participants

In Experiment 2, we employed ten participants. Each participated in two reading sessions. In one session they read one short but complete story, and in the other session, they read an introductory part of a different, longer story. The order of sessions was counterbalanced across participants, and all of them participated in their second session two weeks or longer after the first session. The subjects were five male and five female undergraduate and graduate students at Keio University. Most of these subjects were not regular readers.

3.2 Procedure

The procedure was the same except for the length of the text and the environment in which the reading took place. During each session, one participant read a 49-page short story or a 39-page introductory part of a long story in a room reserved specifically for the experiment. Right after the reading session, the participant was asked to report their degrees of absorption in the same scale as Experiment 1 for each two pages. Five participants read the short story first, and the other five participants read the introductory part first. The participants took part again at a greater than two week interval, and read another text. The short story was "Kino", which is included in *Onna no inai otoko tachi*, a commercially available part of an omnibus authored by Haruki Murakami. The other text is the introductory part of *Chinmoku Hakubutukan* written by Yoko Ogawa. For the chosen introductory part, from pages 3 to 40, this particular text does not include any major change in context. After their reading session, each subject was asked to report his/her degrees of absorption for each two pages using the same five-point scale used in Experiment 1.

3.3 Analysis

For consistent comparison, we analyzed the aggregate of the reading time data across subjects by fitting to it a two-component mixture of gamma distributions. We fixed the class of distributions instead of identifying it from data. This was largely due to the small sample size of our data at this point. Each participant provided reading time data for only 23 or 18 pairs of pages, which did not provide sufficient statistical power to be conclusive even for aggregation across subjects. Thus, we employed the statistical distribution estimated in Experiment 1.

3.4 Results

The data of two readers were excluded from the analysis for their irregular method of reading back and forth many times, giving a completed dataset of 18 readers in total.

Each panel of Figure 7 shows the page-based temporal profile of the modes estimated from reading time. In each panel, a dot shows the estimated shape parameter for each reading time data point, and the line indicates its moving average. As in Experiment 1, we found that the temporal changes in modes were significantly correlated to the reported degree of reading engagement. The trend correlations were, however, opposite to each other: the readers of "Kino" showed positive correlation ($R = 0.3, p < 0.01$), while those of *Chinmoku Hakubutukan* showed negative correlation ($R = -0.16, p < 0.04$). We have multiple possible explanations for this seemingly conflicting finding, which we will discuss later.

Further, the results shown in Figure 7 exhibit inter-subject consistency in temporal changes in reading modes. Each panel in Figure 7 shows the estimated shape parameter for each reader. The top panels show those of "Kino", and the bottom ones show those of *Chinmoku Hakubutukan*. We found within-story

similarity in the shape parameter profiles across pages; the readers of "Kino" showed similar U-shape profiles, and those of *Chinmoku Hakubutukan* had similar flat profiles.

We performed correlation analyses on all the pairs of subjects in order to test whether readers of the same story showed correlated temporal profiles of the shape parameters. The average correlation across all the reader pairs of "Kino" was 0.67 (from 0.46 to 0.87, $p < 0.02$ for every pair of readers), and that of *Chinmoku Hakubutukan* was 0.51 (from 0.05 to 0.86, $p < 0.05$ for 23 out of 36 pairs of readers). Thus, this result suggests that each story had an effect on the reading-mode profiles, for which the readers exhibited similar profiles, while individual readers exhibited little effects on their own profiles.

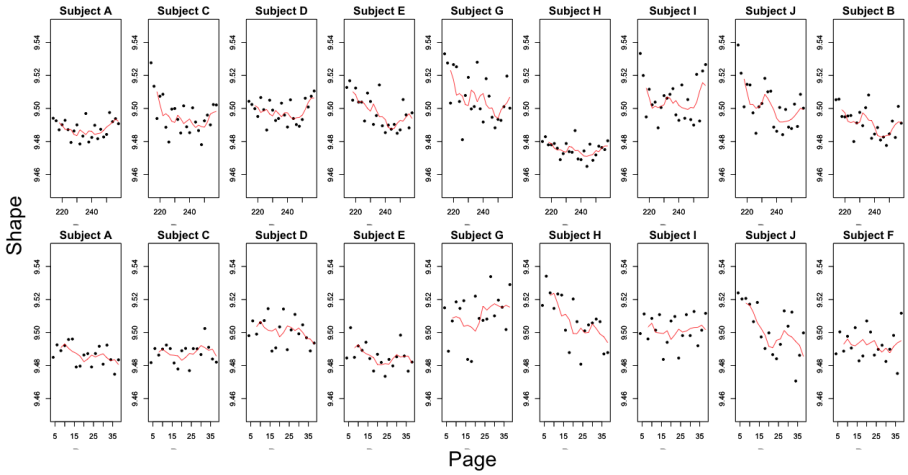

Fig. 7. The page-based temporal profiles of the estimated shape parameters for each subject. The top row shows the results of reading "Kino", and the bottom row shows the results of reading *Chinmoku Hakubutukan*.

3.5 Discussion

The results above suggest that there is a story-specific effect on the statistical properties of reading time, which we can interpret as mode-switching profiles of the reading process. As the page-based temporal profiles within the same story were similar, this suggests that the contextual structure of each story had a major impact on the switching of reading modes. In addition, the temporal profiles could be interpreted as a reflection of the semantic structure of each story. "Kino" is a short but complete story, while the selected text of *Chinmoku Hakubutukan* was an introductory part of the novel. According to Miall's theory, a full novel is expected to involve both formation and exploitation of anticipation. Consistent with this theory, we found U-shaped patterns in reading mode

switching for "Kino" with its complete story, but we found flat patterns for the introductory part of *Chinmoku Hakubutukan*, which indicated no clear distinct modes. The finding of no clear modes in reading an introductory part is not well-consistent with Miall's theory, but we interpret that an introductory part of a full novel is likely to include only the formation of anticipation. In summary, these findings could be treated as supportive evidence that temporal profiles in reading distributions reflect context-dependent reading modes.

4 General Discussion

Reading is an essentially mental and subjective experience. Its cognitive underpinnings have been difficult to characterize directly, and reading time is a major tool for drawing inferences about the underlying cognitive mechanism behind reading. This study offers a new approach to the analysis of reading time, an approach capable of identifying different modes of reading behavior from reading time data.

In Experiment 1, we collected and analyzed reading time data generated by a single subject reading several full novels in a natural situation. We observed significant correlation between the subject's report of her engagement in reading, and her reading modes as inferred from the estimated reading time distribution. This experiment has three major implications:

1. In contrast to conventional studies on controlled, short readings, this is perhaps the first study involving reading entire books in a more natural situation.
2. It establishes a new analytical technique for reading time data by associating the estimated modes with the subject's engagement in reading.
3. It provides supporting evidence that there are at least two distinct reading modes in the reading of whole novels.

A clear limitation of Experiment 1 was that we could not employ many subjects, owing to the intensely time-consuming nature of the experiment. In Experiment 2, each session was designed to be as minimally demanding as possible. This allowed us to perform the experiment using a number of different subjects. We once again observed two distinct reading modes, and found that the mode switches across different subjects reading the same story were consistent with each other. This suggests that, to a large extent, the reading modes are dictated by the contextual structure of the text being read.

What is the contextual structure? We hypothesize that it is deeply related to the predictability of the story. Perhaps, we can consider the two discovered reading modes as low- and high- predictability modes. With reading of "Kino", the major shifts between two modes took place at the beginning and end of the story. At the beginning, a reader has little knowledge of the story, as discussed by Miall [10], and they need to build knowledge of the characters and the stage where they play their roles. When approaching the end, this story has a twist, which is unexpected for most readers. This is another place where the reader

needs to rebuild their knowledge of the story. Therefore, the U-shape temporal profile is supposed to reflect lower predictability at the beginning and end of the story, and higher predictability in the middle of the story.

Our interpretation of the estimated reading modes is consistent, at least on a conceptual level, with Miall's; he hypothesized that reading can be separated in two different stages, the registration stage and the interpretation stage, and they may be repeated more than once across a narrative [10].

This hypothesis and theoretical understanding of the reading modes clearly requires further research to in order to be answered. For the questions raised by the present study, we are preparing for extensions of the current experimental paradigms.

5 Acknowledgements

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