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Role of Fourth Graders' Vocabulary Ability in Modulating Their Multiple-Text Comprehension: An Eye Tracking Study

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Studies have demonstrated that young readers can integrate information across texts. However, the literature on the online processes of young readers during multiple-text reading is limited. The present study uses children's vocabulary ability as a covariable to investigate how they process information across texts and to determine how multiple-text reading differs from single-text reading in terms of eye-movement control, lexical access, subsequent integration, and macro-integration. For this study, we ensured that the texts used in the single-text and multiple-text reading scenarios were equivalent; for the multiple-text reading scenario, participants read a first text followed by a second text. Five sets of Traditional Chinese texts were used in this study, with each set comprising two expository texts centered on a common topic. The two texts in each set did not present conflicting information. Instead, the information in the second text expanded on the information in the first text. To create texts suitable for elementary school students, the text structures of all 10 experimental texts in addition to their word-level characteristics and article length were standardized. The results of this study indicate that the tested fourth-grade children could adjust their reading strategies spontaneously, depending on whether they were engaged in single-text reading or multiple-text reading. Regarding the role of vocabulary during multiple-text reading, we discovered that the fourth graders with higher vocabulary proficiency exhibited increased engagement in lexical processing and macro-integration when they were reading the first and second texts, respectively. By contrast, the fourth graders with lower vocabulary proficiency exhibited less engagement in lexical processing while reading the first text and were less likely to reread the second text. The fourth graders with higher vocabulary proficiency were more inclined to adjust their reading strategies depending on the text they were reading, whereas those with lower vocabulary proficiency were more inclined to adopt a minimalist strategy. We discussed these findings in relation to current models of multiple-text comprehension and explored their educational implications.

Keywords: eye movement, multiple-text reading, vocabulary ability, individual difference, adjustment of reading processes

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Reading is an important competence in contemporary society (Ko, 2020). For a long time, models of reading comprehension focused on single-text comprehension (STC). The cognitive process underlying STC was outlined in the Construction-Integration Model (C-I Model) by Kintsch (1988, 1998). As accessible information on the Internet has grown, digital texts have witnessed an expansion in their accessibility, coverage, and topicality (Chang & Ko, 2019). Researchers have paid more and more attention to multiple-text comprehension (MTC). Nevertheless, learning from multiple-text reading (MTR) may be difficult for primary-school students since their reading experience, which is in its earliest stages, depends almost completely on single-text reading (STR). Undoubtedly, if we can better understand the processes that underlie children's engagement in MTR, we can develop evidence-based instruction methods that improve children's MTC (Beker et al., 2019). However, little is known about the online reading processes involved in children's reading of multiple texts. In the present study, we aim to extend knowledge about the MTC of 4^{th} graders by tracking their eye movement when they read two texts about a given topic. We specifically address the role of vocabulary in text comprehension by investigating whether or not–and if so, in what ways–the vocabulary abilities of 4^{th} graders can influence MTC in the context of online processing.

Multiple texts Comprehension

Text comprehension is important not only for readers' immediate grasp of specific content, but also for broader learning, educational success, and employment (Oakhill et al., 2014). In the digital era, when readers want to learn about or comprehend a particular topic, a wealth of information is readily available for them. As texts shift from paper to digital screens (Kroehne et al., 2019), readers must be increasingly able to integrate information from disparate texts–a process discussed below in detail.

Conceptually, all the abilities required for STC are required for MTC. This is because, for MTR, readers must be able to understand each text individually. From the perspective of search after meaning, STC and MTC share two core prosesses: Construction and integration. But, MTC is different from STC in two aspects. One major difference is the responsibility of constructing coherence among sources (Barzilai & Strømsø, 2018; Stadtler et al., 2013). In STC, the conjunction words and phrases provided in the text can guide the reader to comprehend and make sense of the relation among the ideas (Goldman & Rakestraw Jr, 2000; Kamalski et al., 2008; Sanders & Noordman, 2000). In MTC, there are no conjunction words and phrases among the information from different texts for readers to figure out the relation among information of different sources. The second major difference between STC and MTC is the skill of source evaluation. In MTC, the readers usually evaluate and compare the trustworthiness of each text to help them decide which to believe and how each text can contribute to the comprehension of the issue.

Mahlow et al. (2020) found that STC and MTC are highly correlated yet separable. In their analysis of college students' STC and MTC, the researchers found that some college students performed better in STR than in MTR but that, for other college students, the opposite was the case. These research findings suggest that STC and MTC differ from each other regarding their respective cognitive requirements for readers. Nevertheless, the findings are consistent with the assertion that MTC requires cognitive abilities above and beyond those required for STC.

The documents model framework (DMF) is an extension of STC model, which describes how readers comprehend and represent multiple texts (Perfetti et al., 1999). According to DMF, readers who encounter multiple texts must first efficiently process each text and must then construct a model of the relationships among the texts. Readers do so on the basis of strategic integrative processes whereby, for example, readers compare information from several texts in order to identify unique pieces of information and overlapping pieces of information. By linking the ideas of one text with those of another text, readers can organize the various ideas into a coherent representation encompassing multiple texts. Thus, readers' ability to integrate multiple texts requires skills that transcend mere comprehension of lexical cues (Primor & Katzir, 2018). In particular, MTC involves two additional mental representations derived from the DMF: integrated model and the intertext model (Britt & Rouet, 2012; Perfetti et al., 1999). The integrated model refers to the reader's overall understanding of a topic as described across the texts. It includes separate situation model for each text and the interconnections between those texts. In this model, some idea may exist uniquely, while other ideas of different texts are linked together according to certain relationship. The ideas from different texts may be connected together because they agree upon, supplement, or conflict with one another to form an integrated representation of the texts read. The intertext model involves the source information of multiple texts. In the intertext model, the reader constructs the representation of information about the author, the style, the rhetorical goals, and some pieces of important information in the content of each text.

In line with DMF, to create a coherent intertext model, readers undertake mental activity that includes bottom-up and top-down inferencing. In a think-aloud study focusing on the reading behavior of historians, Wineburg (1991) found evidence that, in general, skilled readers try to coherently interpret, through comparisons and evaluations, a historical event as described in various primary and secondary textual sources. In another think-aloud study, Anmarkrud et al. (2013) found that the more relevant a text is to university students, the more likely they are to build connections between that text and other texts. However, for elementary school students, when they learn to read from multiple texts, the primary purpose is to acquire and build knowledge. As such, much greater emphasis is placed on the development of integrated model compared to the intertext model.

The Role of Vocabulary in MTC

In the line of single text comprehension research, ample literature shows that vocabulary knowledge contributes to reading comprehension through semantic meaning identification and played a collaborator role with inference on sentence meaning comprehension (Lawrence et al., 2019; Lervåg et al., 2018; Silva & Cain, 2015). Furthermore, high-quality of word semantic meaning identification establishes word-and-word unit for sentence proposition coherence (Braze et al., 2016; Cain et al., 2004; Perfetti & Hart, 2002). In other words, vocabulary knowledge provides the possibility of necessary cognitive capacity or plays a collaborator role with inference for higher-level reading processes (Wang et al., 2012).

In contrast, fewer studies have examined the role of vocabulary knowledge in MTC. Two studies have examined the relationship between vocabulary and MTC (Bråten et al., 2014; Strømsø et al., 2008), both of them found that readers' vocabulary knowledge did not affect the performance of MTC. As so far, most emerging MTC models have focused on high-level cognitive and metacognitive processes related to relevance judgments, source evaluations, and intertextual integration (Braasch & Bråten, 2017; Goldman, 2011; Richter & Maier, 2017; Rouet et al., 2017). The reason for this may be that most MTC research has included undergraduate or upper-level secondary-education students as participants; under the assumption that these students have large and rich vocabularies, researchers have the tendency to neglect the role of vocabulary in MTC.

A study conducted by Bråten et al. (2013) provided evidence for the role of vocabulary knowledge in reading to learn from multiple texts. They found that 10th graders' word identification ability significantly predicts their performance of multiple texts comprehension, once prior knowledge is controlled. This finding suggest that vocabulary knowledge can help junior high school students construct a coherent, integrated model by reading multiple texts. Florit et al. (2020) also found that 4th graders with better vocabulary knowledge, their performance of STC and MTC are better than those students with poor vocabulary knowledge. This result showed that fourth graders' vocabulary ability play common and similar roles in STC and MTC. This finding is in line with STC models and extends the research base showing that, at least with younger students, vocabulary ability affects MTC.

Reading to learn from multiple texts is a primary goal of promoting content area knowledge development for elementary students. It can be difficult for elementary students to understand how concept and ideas are interrelated as they read an unfamiliar content. Considering the surface-form level as it applies to two similarly themed texts: They are likely to have a set of words that appear repeatedly. For words that appear in both the previous text and the current text, current information will rapidly be activated through a process of resonance for skilled readers (i.e., through a remembrance of prior related information). The mechanism of resonance is very specific circumstance in MTC, as the cognitive load of word decoding in a current text will be less than the cognitive load in the prior text. In addition, the overlapping of time, space, causation, and other dimensions can trigger resonance (Magliano et al., 1999; McKoon et al., 1989). However, it is unclear whether young students' vocabulary knowledge can help them to use the word information of a prior text to enhance their construction of a text-based representation for a current text. Similarly, it is also unclear whether young students' vocabulary knowledge can facilitate the formation of between-text links during the integration processes for a prior text combined with a current text. These explain why it is worth investigating how children process multiple similarly themed texts. We have designed our current study to gain insights into this very matter.

Moment by moment processing

There are different methods to measure moment-by-moment cognitive processes during reading. Think-aloud protocols can provide insights into readers' cognitive processes. Wolfe and Goldman (2005) used a think-aloud protocol during students' reading of conflicting historical texts. In their study, they found that the students could connect information in the current text not only with prior knowledge but also with information the students had just gleaned from the previous text. Beker et al. (2019) used the paradigm of multiple-text integration to assess the online MTC processing of 4th and 6th graders. The researchers found that the time spent on reading "inconsistent-without-explanation" sentences was significantly longer than the time spent on reading "inconsistent-with-explanation" sentences. These results demonstrate that, when reading multiple texts, primary-school students use integrative processing insofar as they (1) activate information from an earlier text when reading a later text and (2) integrate the co-activated information into a coherent representation of all the texts.

In recent decades, eye-tracking methods have been considered a sensitive way to reflect readers' online processing of texts (Hessel et al., 2021; Hyönä & Kaakinen, 2019; Wang & Jian, 2022). Indeed, for primary-school students, measures of eye fixation and eye movement may have some advantages over the traditional verbal thinking-aloud method. A limitation of the thinking-aloud method is that it involves only information that can be verbalized, which means that researchers cannot investigate a reader's processing that is either unconscious or not verbally reportable by the reader. For primary-school students, text comprehension involves higher-level cognitive processes; therefore, the task of thinking aloud not only consumes valuable available cognitive resources, but also fails to support a reasonably complete assessment of online comprehension processes. In other words, an eye-tracking method can provide a more ecologically valid reflection of how a text representation takes shape in the minds of primary-school students who are reading texts (van der Schoot et al., 2008).

The Present Study

In the present study, we aim to extend knowledge about the MTC of 4th graders by tracking their eye movements when they read two texts about a given topic. We adopted a within-subject block-design paradigm consisting of two blocks: STR conditions and MTR conditions. In the STR block, 4th graders were encouraged to read a text for the purpose of understanding it alone. In the MTR block, 4th graders were told that they would be reading two texts sequentially with the same topic. These readers were encouraged not only to understand each text individually, but also to recognize the common concepts between the two texts. Because the STR and MTR blocks present one text at a time, they constitute comparable environments for text-reading comprehension.

We propose the following two research questions, which serve to guide the present study. The first research question investigates whether there is any difference between STR and first-text MTR, and if yes, whether vocabulary ability of individual readers moderates the difference. According to the hypothesis of DMF (Britt & Rouet, 2012), readers construct coherent mental model for each text in multiple texts set. Therefore, in the MTR context, the eye movement pattern of the first MTR text should be relatively similar to the eye movement pattern of the STR text. And, regarding the association between vocabulary knowledge and text comprehension, we predict the higher the student's vocabulary ability, the more efficient the moment-by-moment cognitive process in STR text and first text MTR. However, according to the task model hypothesis (Rouet et al., 2017), the cognitive processing differs between first-text MTR and STR due to their different tasks. Because of the different purposes, readers will not treat the first-text MTR as a single text like the STR. Furthermore, it is also legitimate to expect that the more vocabulary-knowledgeable a reader is, the better able the reader will be to grasp the quality of content. So, it is hypothesized that differences in online processing between first-text MTR and STR are more likely to be observed on students with higher vocabulary knowledge.

The second research question is do readers adjust their online reading processing differently between the first MTR and second MTR text, and what is the role of reader's vocabulary ability? According to the hypothesis of DMF, students still need to construct individual coherent reading representation for the second text, so, it is legitimate to expect readers will have relatively similar eye movements pattern between first and second text in MTR condition, and the role of vocabulary knowledge in both texts are also similar. However, if we consider students have obtained the information from the first text as they read the second text (Beker et al., 2016; Britt & Sommer, 2004), the online reading processes of the second text may be different from the processes of the first text based on two reasons. The first reason is the resonance mechanism in the second-text reading. Readers' word decoding process could be benefited by reduced cognitive load. The second reason is that readers need to construct integrated mental model of the two texts in second-text MTR, so they will make more efforts on the integration processing than in first-text MTR. Furthermore, as vocabulary knowledge facilitating the processes of word decoding and integration, it is expected that the higher the students' vocabulary knowledge, the greater the difference in cognitive processing between first and second text.

Method

Participants

Participating in this study were 44 fourth graders (27 girls and 17 boys) from four classrooms at two primary schools. Participation was voluntary, and parental consent was obtained. Each participant received a small gift as a reward for participation. At the time at which we collected the eye-tracking data, the students had received approximately 3 years and 7 months of formal reading instruction. All participants were native Chinese speakers and were between 9 years, 4 months old and 10 years, 8 months old (M = 10.23 years, SD = 1.57 years). Their vocabulary abilities were assessed by using the Progress Monitoring Test of Vocabulary (PMTV; Hung et al., 2014). PMTV is a standardized ability test based on the norm for 4th to 6th graders. Participants' PMTV ability scores were between -0.60 and 3.54 (M = 1.07, SD = 0.87)[1]. The data-collection and data-handling procedures that we followed in this study were approved by our university's research-ethics committee.

Apparatus

We recorded eye movements monocularly by using an SR Research Eyelink 1000 system with a sampling frequency of 500 Hz in a remote mode. Stimuli were presented on a 24-inch Viewsonic XG2402 monitor with a 144-Hz refresh rate, a 1,024 × 768 screen resolution (in pixels), and a 4:3 aspect ratio. Each text screen consisted of a maximum of 10 lines (30-pixel spacing) and 25 characters (4-pixel spacing) per line. The characters were presented in 32-point DFKai-SB font. The distance between participants and their screen was 68 cm; at this distance, each character had a visual angle of approximately 1°. The text area was centered in the screen, with 100-pixel margins on the top and bottom of the screen and 60-pixel margins on the left and right sides. Although the children read with both eyes, only the right eye was monitored. We used a chin and forehead rest to minimize head movements. The eye tracker was calibrated with a 13-point calibration routine until the calibration error was less than a maximum visual angle of 0.5°.

Materials

In this study, we used five sets of Traditional Chinese texts, with each set containing two expository texts on the same topic: ‘Communication,’ ‘Tea,’ ‘The Development of Theory,’ ‘Tourism,’ and ‘Message Retention’. The two texts in each set did not present conflicting information; rather, the information in the second text expanded on the information in the first text. Take ‘Communication’ set as an example. The content of its first text concerned communication in ancient times, and the content of the second text concerned communication in modern times. Thus, we expanded the topic of communication in the time dimension. The text structure of all ten experimental texts is controlled: There are two paragraphs per text; the first paragraph contains the topic sentence, followed by three information sentences; and the second paragraph gives an overall perspective of the main idea and sums up the whole text. There are 7 propositions in each text (e.g., Appendix D).

In writing the experimental reading materials, we carefully selected topics that would be familiar to primary-school students. To ensure that our texts would be suitable for the students, we invited two expert primary-school teachers and one reading-research professor to conduct a reading-level evaluation of the main ideas and contents of the five sets of ten texts. On a five-point scale, ‘1’ is referred as very unsuitable for a 4^{th} grader and ‘5’ as very suitable. The three experts gave scores that averaged 4.60 for main-idea reading-level and 4.37 for content reading-level. The three assessors identified no significant differences between the five sets regarding either the main-idea reading-levels or the content reading-levels (main idea: $p = .65$; content: $p = .07$).

In the present study, we controlled for word-level characteristics and article lengths to ensure that they were suitable for primary-school students. We also controlled for the length of each set’s two texts. Every pair of texts had the same number of Chinese characters, but the five sets differed slightly from one another regarding their total number of characters, which ranged from 199 to 214. The mean text length was 142.20 characters; at the word level, the mean word frequency (log10 transformed) was 2.58 per million words, and the mean word length[2] was 1.63 characters. We conducted statistical tests on the word frequency and word length of the material, and we found no significant differences either (1) between the two texts in each of the five sets or (2) among the five sets (all $ps > .15$).

Design

Our experiment used a within-subject block design in which two blocks corresponded to the two experimental conditions, MTR and STR. MTR refers to what readers understand after reading two texts in sequence, and the expected reading focus is on the integration between the texts. STR, on the other hand, refers to readers reading one text at a time, and the expected reading focus is single-text reading comprehension. The sequence of MTR and STR were counterbalanced. In the MTR block, we randomly selected two sets from the five material sets. Then, we randomly chose one text from each of the remaining three sets as reading texts for the STR block. Thus, each reader read a total of seven texts. Appendix A shows a counterbalanced example for the text sequence. According to the experimental design of our study, each text of the 10 experimental texts could be the first or the second text in the MTR condition or the sole text in the STR condition (e.g., Text 1 in Appendix A, Table A1). In this way, we sought to make fair comparisons of the text-reading process under the three experimental manipulations (STR text, first MTR text, second MTR text).

Procedure

The eye-tracking experiment was held in a quiet room on school grounds during school hours. The children were instructed to read and comprehend each text at their own pace and to indicate when they had finished and understood the text by clicking a mouse button. They were encouraged to read silently and were instructed to tell their instructor what they understood. They were informed that the computer would also record their oral report. As mentioned above, we calibrated the eye tracker by using a 13-point calibration routine until the calibration error was less than a maximum visual angle of 0.5°. When a participant did not complete the calibration after seven attempts with instrument adjustment, no follow-up eye-movement experiment was performed.

All children completed two practice trials before the experimental trials (see Appendix A, Table A1). The purpose of the practice phase was two-fold: we sought to familiarize the children with quiet text reading for comprehension, and then we wanted the children to orally report their post-reading comprehension of the given text's ideas. Before the start of each experimental block, the examiner announced the reading goal and the number of reading texts of the experimental block. In the STR condition, participants were asked to present an oral summary of what they understood about the given text in each trial. In the MTR condition, participants were informed that they were to read two texts and that, after reading the second text, they were to verbally report what they understood from the two texts and what concepts were common between them. The purpose of the oral-report requirement was to engage the children in their reading comprehension of the texts and to check whether or not the children could comply with the experimental requirements of both the MTR condition, and the STR condition.

Before viewing each text screen, each child fixated on a cross point at the location of the first character of each text. This step ensured that the child was ready and the calibration was accurate. Afterward, each screen presented a text for the children to read quietly. The children completed the experiment (text reading and oral report) in approximately 30 minutes.

After the eye movement experiment, we assessed the participant's vocabulary ability by using PMTV. This test is compiled based on the frequency distribution of commonly used words in elementary school children in Taiwan. The PMTV test consists of 36 multiple-choice questions that required students to choose the correct synonym for a given word. One point is awarded to each correct answer, with a full score of 36 points. It took about 20 minutes for the children to complete the test.

Data Analysis

Oral Report Data

Participants' oral reports of each trial were collected as their offline mental representation measurements. These collected responses were transcribed verbatim and parsed into idea units, which consisted of a verb and a noun (Anderson et al., 2001; Ericsson & Kintsch, 1995; McKoon & Ratcliff, 2008) and were divided into three levels of representations: Text-based representations, situation model representations, and integrated model representations.

The idea units were scored by following criteria: (1) When the idea unit contains identical words from specific propositions in our experimental text, it was scored as 1 count for "text-based representation." Because there were 7 propositions in each text, the maximum count for any given text-based representation was 7 counts for an STR scenario and 14 counts for an MTR scenario; (2) when the idea units could identify to the specific text proposition, but participants did not use identical words from the experimental texts, it was scored as 1 count for "situation model representation," because the situation model representation is a construction that integrates the text-based and relevant aspects of comprehender's knowledge (Kintsch, 1998); (3) when the idea unit is not specific to each single text in an MTR set, and are generated from the two texts in an MTR set, it was scored as 1 count for "integrated model." Appendix E is the examples for idea unit coding of the three representation types.

Three participants were randomly selected and scored independently by two raters (the first and second authors). Difference in scoring were settled by consensus. The remaining protocols were split between the two raters (the first author and research assistant) and scored independently. Then, if there are differences in scoring, they will be settled by consensus among three raters.

Eye-movement Measures

Before measuring the eye movement of participants, we cleaned their eye-fixation data in two steps: First, fixation durations of < 70 ms or > 1,000 ms were discarded (4.02%); subsequently, participants' first and last fixations for each text were removed (1.04%).

In the present study, we use the C-I model (Kintsch, 1988, 1998) to divide the eye-movement measures of previous reading-oriented research into three categories corresponding to the stages of readers' comprehension: The lexical-access stage, the subsequent-integration stage, and the macro-integration stage. Below are detailed descriptions of the three stages as they apply to the current study.

In the lexical-access stage, we used two temporal eye-movement measures and one saccadic eye-movement measure[3] to reflect the initial phase of lexical processing, which, in general, involves word recognition and lexical access (Clifton et al., 2007). These three measures are (1) first-fixation duration (FFD), representing the time spent of readers' initial perception of a word, (2) gaze duration (GD), representing the amount of time of readers' first pass of a word, and (3) refixation probability, representing whether or not readers fixated more than once during the first-pass on a word, usually occurs for the purpose of information acquisition following initially incomplete lexical-access after the first fixation.

In the subsequent-integration stage, we used one saccadic eye-movement measure and one temporal eye-movement measure to reflect readers' ongoing processing of their subsequent integration of a word with the surrounding sentence or passage (Cook & Wei, 2019). These two measures are (1) the go-past probability, representing whether or not readers, after an instance of GD, engage in regression behavior (a return to a previous area in a text) in order to obtain information from the area before proceeding to the next unread area, and (2) go-past duration (GPD), representing the amount of time fixating a word and refixating the words preceding it before moving on the right (Hessel et al., 2021). In some cases, higher-level comprehension occurs in the first-pass process and can involve word recognition or lexical access. Therefore, eye-movement measures during the go-past stage can reflect how much effort readers are devoting to the formation of local successive-word coherent representation.

In the macro-integration stage, we used one temporal eye-movement measure and two saccadic eye-movement measures to reflect the macro-integration phase during reading, a phase that involves further word processing and backward information processing (Hyönä et al., 2003). These three measures are (1) rereading time (RRT), representing the amount of all fixation durations in which readers re-fixate on a word after their first pass of the word, (2) the reread probability, representing whether or not readers engage in second-pass fixations, which means the given word has RRT, and (3) the reread fixation number (RRFN), representing the total number of fixations in an RRT. In principle, longer RRTs can be a result of either more fixations or longer durations on the words. Therefore, the RRFN can capture considerable details regarding RRT. In general, the measures regarding to reread a word are known to reflect the post-lexical integration of meaning at the sentence level or text level (Hessel et al., 2021; Radach & Kennedy, 2004, 2013). For example, a greater RRT for words suggests that the reader is attempting to resolve inconsistency or to regulate comprehension (e.g., by using repair strategies), and these attempts go beyond just a simple detection of the needs of resolving or regulating processes (Connor et al., 2015).

In this study, we expressed all temporal eye-movement measures in milliseconds and recorded all saccadic measures as binominal (1 = happened; 0 = did not happen), with the exception of the RRFN, which we recorded as counts.

Mixed-effects Analysis

This study features a linear mixed model (LMM, with an afex package) (Singmann et al., 2022) for data analysis in an R environment (R Core Team, 2022).

In all LMM models of the participants' oral report data, the random effects are participants and texts. Regarding the text-based representations and the situation model representations, the fixed effects are the conditions of text reading, children's PMTV ability, and the interaction between the condition and PMTV. For the integrated model representations, the only fixed effect is the children's PMTV ability.

In all LMM models of eye movement measures, the random effects are participants, texts, and words. Conditions of text reading, children's PMTV ability (the PMTV-norm ability score), and the interaction between the condition and PMTV are the fixed effects in LMMs. Word length and word frequency usually affect readers' eye movements during reading. Long words generally receive longer and more fixations than short words and infrequent words are fixated longer than frequent words (Reichle et al., 2013; Tiffin-Richards & Schroeder, 2015). Therefore, in this study, word length and word frequency serve as statistical controls in LMMs. Regarding the research questions, we focus on two conditional comparisons in eye movement data: (1) we compared the eye-movement measures of the STR condition with those of the first MTR-text condition (STR–fstMTR), and (2) we compared the eye-movement measures of the first MTR-text condition with those of the second MTR-text condition (fstMTR–secMTR). The intercept of LMM is the grand mean, and the two condition effects are specified by the custom contrasts.

The LMM models are reported in Appendixes B and C. For each LMM, we used the emmeans package to calculate the estimated marginal means of different text-reading conditions (Lenth, 2022).

Results

The Oral Report Data

This result suggests that the participants could follow the instructions regarding the comparison and integration of the two texts.

In the oral report data of this study's 4th-grade participants, we first focused on the interaction effects related to how the vocabulary-ability differences among the 4th graders affected their idea-unit counts of the three representation levels in the STR and MTR reading conditions. Then, if no interaction effect was observable, we set out to determine whether or not there was a significant main effect between the two text-reading conditions. Table 1 presents the oral report data for the STR and MTR conditions.

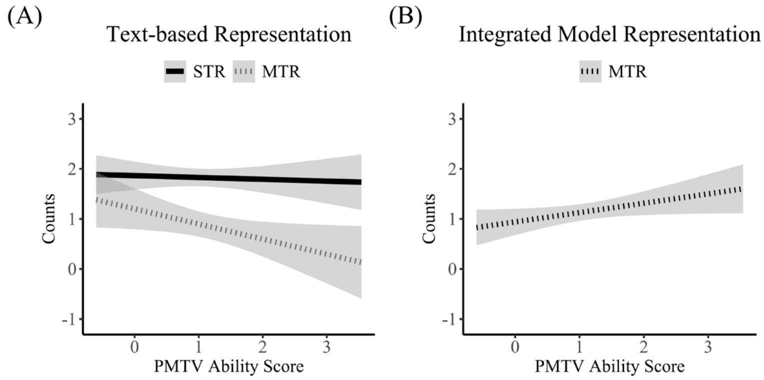
Table 1
Means and standard errors for the oral-report data in each of the two conditions

Measures	STR		MTR	
	M	*SE*	*M*	*SE*
Text-based Representation (counts)	2.27	0.18	1.10	0.19
Situation Model Representation (counts)	0.22	0.05	0.15	0.06
Integrated Model Representation (counts)	–	–	1.14	0.08

For the text-based representation, the differences between the STR and the MTR conditions were interacted with PMTV ability ($b = 0.70$, $SE = 0.19$, $t = 3.78$, $p < .05$). The significance of these associations can be seen in Figure 1A: The PMTV ability on the x-axis is a continuum, the readers with lower ability are on the left side and the readers with higher ability are on the right side. The envelopes denote 95% confidence intervals (CI). The difference between STR and MTR text-based representations tends to expand with the increase of students' vocabulary ability. From Figure 1A, it can be found that the idea units of text-based representation reported by students after STR does not vary with their vocabulary abilities. However, after MTR, as students' vocabulary ability increased, they reported fewer idea units of text-based representation.

Figure 1

The text-based representations and integrated model representations as a function of children's PMTV ability in the text reading conditions



We uncovered no evidence of either significant interactions or main effects relative to the counts of situation models representation (all $ps > .16$), and in most cases, regardless of whether it was the STR condition or the MTR condition, most of the counts for the situation model added up to 0. These results imply that the formation of the situation model is difficult for children in the 4^{th} grade of primary school. In addition, under the MTR condition, the mean of the integrated model representation counts was 1.14. This means that, on average, the 4^{th} grade participants reported more than one integrated model representation under the MTR requirements. Furthermore, there was a marginal significant main effect of PMTV abilities ($b = 0.20$, $SE = 0.11$, $t = 1.84$, $p = .07$), which suggested a trend that the higher the 4^{th} graders' vocabulary ability was, the more integrated model units were reported (See Figure 1B).

Taking the findings in Figure 1 together, as students' vocabulary ability getting better, students report fewer text-based representations and more integrated model representations during MTR. Does this result imply that students with higher vocabulary knowledge are able to adjust their online cognitive processing to match the reading needs of the MTR? Results from online reading processing may provide further clarification.

Online Reading

Table 2 presents the eye-movement measures as a function of the three text-reading conditions.

Table 2

Means, standard errors, and number of eye-movement observations in each condition

Measures	STR			fstMTR			secMTR		
	M	*SE*	*N*	*M*	*SE*	*N*	*M*	*SE*	*N*
Lexical-access Stage									
FFD (ms)	252.23	5.48	6,442	252.54	5.60	4,215	243.13	5.43	3,643
GD (ms)	286.83	8.42	6,442	287.41	8.55	4,215	269.34	8.07	3,643
Refixation Probability	0.15	0.01	6,442	0.15	0.01	4,215	0.12	0.01	3,643
Subsequent-integration Stage									
GPD (ms)	857.71	43.27	1,733	810.48	43.77	1,137	819.90	44.94	1,068
Go-past Probability	0.29	0.02	6,442	0.30	0.02	4,215	0.33	0.02	3,643
Macro-integration Stage									
RRT (ms)	426.28	14.04	7,882	381.79	12.81	4,671	384.83	12.92	4,610
Reread Probability	0.53	0.02	15,235	0.47	0.02	10,128	0.47	0.02	10,117
RRFN	2.06	0.09	7,882	1.67	0.09	4,671	1.72	0.09	4,610

Note. N is the amount of data in each condition for the corresponding LMM analysis.

The Differences between Reading the STR Texts and Reading the First MTR Texts

In the experimental design of this study, we ensured that the reading conditions for STR and fstMTR would be similar to each other; specifically, neither the STR text nor the fstMTR text would involve prior information. This design enabled us to examine whether or not the 4^{th} graders would read the only STR text and the first MTR text identically.

In the lexical-access stage, for all the three measures (FFD, GD, and refixation), the differences between the STR and the fstMTR interacted with PMTV ability (FFD: $b = -0.03$, $SE = 0.01$, $t = -3.30$, $p < .05$; GD: $b = -0.06$, $SE = 0.01$, $t = -5.19$, $p < .05$; Refixation: $b = -0.25$, $SE = 0.06$, $z = -4.28$, $p < .05$). The nature of the significant interactions can be seen in Figure 2. From Figures 2A, 2B, and 2C, it can be observed that the slope of fstMTR is gentler than the slope of STR. This indicates that the student's vocabulary ability has a different influence in the lexical-access processing of the fstMTR compared to the STR. Taking a closer look at the overlap of CI in the figures, we can observe that this phenomenon is caused by two tendencies: (1) children with higher vocabulary had longer FFDs, longer GDs, and higher refixation proportions in the fstMTR condition than in the STR condition; and contrarily, (2) children with lower vocabulary had shorter GDs and lower refixation proportions in the fstMTR condition than in the STR condition.

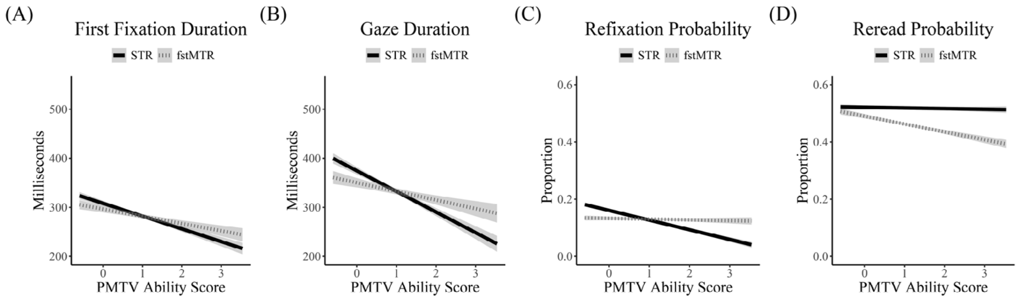
In the subsequent-integration stage, neither a significant interaction nor a significant main effect was observable for either the GPD measure (all *ps* > .08) or the go-past measure (all *ps* > .31).

In the macro-integration stage, for the reread measure, the differences between STR and fstMTR interacted with PMTV ability ($b = 0.09$, $SE = 0.03$, $z = 3.18$, $p < .05$). The nature of the significant interaction can be seen in Figure 2D. The reread probability does not vary with students' vocabulary abilities during STR. However, as students' vocabulary ability increased, the reread probability during fstMTR decreased. For RRT and RRFN, the interactions were not significant (all *ps* > .80), but the main effects between the STR and fstMTR conditions were significant. Children tended to have shorter RRTs ($b = 0.11$, $SE = 0.01$, $t = 8.62$, $p < .05$) and less reread fixation numbers ($b = 0.39$, $SE = 0.03$, $z = 12.08$, $p < .05$) in the fstMTR condition than in the STR condition.

From Figure 2, it can be clearly observed that students with different vocabulary abilities take different reading strategies in fstMTR than in STR. We further explore the differences in online processing of secMTR and fstMTR among students with different vocabulary abilities in the next section.

Figure 2

The eye-movement measures as a function of children's PMTV ability in the STR and fstMTR conditions



The Differences between Reading the First MTR Texts and Reading the Second MTR Texts

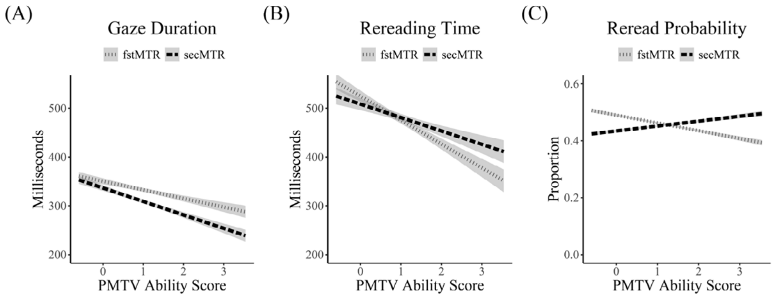
In the lexical-access stage, we found that, for the GD measure, the differences between the fstMTR and the secMTR interacted with PMTV ability (b = 0.03, SE = 0.01, t = 2.31, p < .05). Figure 3A presents the interaction data. From Figure 3A, it was found that as students' vocabulary ability increased, their GDs in secMTR was shorter than those in fstMTR. Conversely, if students' vocabulary ability was lower, then their GDs in fstMTR and secMTR showed no difference. It could be inferred from these results that vocabulary ability determined whether lexical-access processing was speeded up at secMTR as compared to fstMTR. For FFD and refixation, there were main effects between the fstMTR and the secMTR. Children tended to have shorter FFDs (b = 0.04, SE = 0.01, t = 3.59, p < .05) and lower refixation proportions (b = 0.25, SE = 0.07, z = 3.71, p < .05) during the secMTR than during the fstMTR.

Regarding the GPD and go-past probability variables in the subsequent-integration stage, the interaction between Condition (fstMTR – secMTR) and children's PMTV ability was not significant (all ps > .36). However, we observed a significant condition main effect on the go-past probability measure (b = -0.18, SE = 0.05, z = -3.31, p < .05). Children tended to engage in more go-past behavior during the secMTR than during the fstMTR.

In the macro-integration stage, the differences between RRT in the fstMTR and the secMTR significantly interacted with PMTV ability (b = -0.04, SE = 0.01, t = -2.65, p < .05), as did the differences between the Reread measures in the fstMTR and the secMTR (b = -0.17, SE = 0.03, z = -5.39, p < .05). Figures 3B and 3C present these interaction results. The RRT trends are just the opposite of the GD trends. Students with higher vocabulary tended to have longer RRTs in the secMTR than in the fstMTR (Figure 3B). Likewise, students with higher vocabulary tended to have higher reread proportions in the secMTR than in the fstMTR, whereas students with lower vocabulary tended to have lower reread proportions in the secMTR than in the fstMTR. (Figure 3C).

From Figure 3, students with different vocabulary ability showed different patterns of online reading process in secMTR as compared to in fstMTR; when these children are engaged in MTR, they do not read multiple texts as individual texts and perform integration sequentially; rather, adjustments were made according to their vocabulary abilities during the reading process for integration of information across texts.

Figure 3
Eye-movement measures as a function of children's PMTV ability in the fstMTR and secMTR conditions



Discussion

The ability to read multiple texts is a core competence for students because the knowledge needed to understand domain topics even at the most basic levels cannot be acquired by reading a single text. Therefore, it is vital that we improve our understanding of the offline production and the online processes when students read multiple texts.

The Role of Vocabulary Ability for MTC Offline Representation

The purpose of the oral report requirement is to engage the children in the reading comprehension of the texts, and to check whether the children can comply with the experimental requirements of MTR and STR. In the case of MTR, we additionally inquired into the participants' understanding of the concepts common to a given pair of texts. Our results show that the trade-off phenomenon of the idea units between text-based representations and integrated model representations was more pronounced when the students had higher vocabulary abilities. Children with higher vocabulary ability had fewer text-based representations in MTR than in STR, not so much that they processed fewer text-based representations, but rather that they were able to adjust to retain more MTC content (integrated model representations) in their reading comprehension. This finding, which suggests that efficient word reading may be particularly important for MTC, is in line with both Beker et al. (2019) and Florit et al. (2020), as students need to assimilate and integrate information across several sources within time constraints. As for children with lower vocabulary ability, there was no significant difference between their STR and MTR text-based representation. This finding suggests that poor word-reading ability may leave these children struggling in the representational processing of the text-surface meaning at the time of MTR, limiting their cognitive resources to integrated model processing.

The Moderating Role of Vocabulary Ability in the Online Processing of MTC

Readers' comprehension of multiple texts may involve processes similar to those involved in single-text comprehension. However, reading multiple texts on the same topic may be more beneficial than reading a single text because this approach provides broader conceptual coverage, resulting in deeper, more integrated understanding (Bråten et al., 2013; Florit et al., 2020).

When looking for possible differences between how children read the STR text and how they read the first MTR text, three findings were discovered in our study. First, we found that students with higher vocabulary exhibited longer FFDs and GDs when reading the first MTR text than reading the only STR text.

By contrast, students with lower vocabulary ability presented shorter FFDs and GDs in the first MTR text than in the only STR text. These results imply that even at the early lexical-access processing of fstMTR, students have begun to adapt to MTR reading requirements based on their vocabulary abilities. Students with higher vocabulary knowledge pay more efforts to the lexical processing, allowing them to keep good lexical quality for subsequent processes to perform multiple texts comprehension. This pattern is in line with the lexical quality hypothesis (Perfetti & Stafura, 2014). However, students with lower vocabulary knowledge might show the opposite coping strategy, they are aware that the MTR task is more difficult than the STR task, so, they saved cognitive effort at the lexical access stage. This pattern is in line with the minimalist hypothesis (McKoon & Ratcliff, 1992). According to this hypothesis, readers only encode explicit statements in the text or information readily available in general knowledge to maintain locally coherent inferences.

Second, regarding the pattern of macro-integration stage, we found that no matter higher or lower children's vocabulary abilities are, their (1) RRT were apparently short while less RRFN, and (2) reread proportion were relatively small when reading the first MTR text. This result shows that regardless of the vocabulary ability, students do not pay too much effort to construct rich situation model when reading the first MTR text. These findings imply that fourth graders are aware they did not construct similar situation model as STR when they read the fstMTR.

Third, from our experiment, we found that regardless of the students' vocabulary ability, the GPD and go-past probability results showed no difference between the fstMTR and the STR condition. This finding implies that obtaining local coherent mental representation does not cause students to adjust differently because of the fstMTR or the STR.

Then, when we compare the differences between how children read the second MTR text and how they read the first MTR text, there are three findings worth discussing. First of all, we found that, as students' vocabulary ability increased, their GDs became shorter as they move on from the fstMTR to the secMTR. This result can be explained by the reason that the second text contain similar concept with the first text, so, students can rapidly activate the lexical access process through a process of resonance (i.e., through a remembrance of prior related information). In general, children with higher vocabulary ability have better comprehension performance on the text (Florit et al., 2020). Previous studies have also demonstrated that shorter gaze duration is associated with better comprehension (Everatt & Underwood, 1994; Southwell et al., 2020; Underwood et al., 1990). Therefore, due to the design of the materials – the two texts sharing the same topic, a better comprehension of the first text may benefit the understanding of the second text, as suggested by the shorter GD in secMTR.

Second of all, we found that regardless of the students' vocabulary ability, the go-past duration in the secMTR condition was slightly longer in the fstMTR condition, and participants performed more go-past behavior in the secMTR condition than in the fstMTR condition. Usually, go-past related measures are sensitive with the early stage of comprehension monitoring (Cook & Wei, 2019; Hessel et al., 2021). When students, regardless of their vocabulary ability, have more go-past probability in the secMTR condition, this pattern implies that 4th graders adopt more monitoring strategies of subsequent-integration during secMTR since they were already having the reading comprehension representations of the fstMTR.

Third of all, as students' vocabulary ability grew, their RRT became longer and the reread proportion became higher when they read the second MTR text than in the first MTR text. This result implies that the better a participant's vocabulary ability was, the more likely the participant could be constructing a coherent mental model within the text, and possibly across the two texts in the MTR condition. Conversely, students with poor vocabulary ability may had difficulty constructing coherent mental models across two texts–a finding that is consistent with the pattern that we observed in the offline data.

Taken together, our results show that the eye movements pattern during MTR in fourth graders are quite different from those in STR. Fourth graders are sensitive to the requirement of MTR in two aspects. First, they were able to adjust their cognitive processing during the lexical access stage in MTR according to their vocabulary abilities. Second, they spent less RRT and fewer reread in MTR than those in STR. This result revealed that subsequent-integration was likely to be different during MTR as compared with STR. However, students with higher vocabulary ability gradually showed a tendency of longer RRT and more reread in the integrated processing on the subsequent text.

Conclusion

The present study makes two major contributions to research on multiple-text comprehension. First, the study extends our understanding of primary-school children's MTR processes. In this regard, our findings go beyond the children's corresponding STR processes and constitute fine-grained evidence of vocabulary's role in children's online processing of MTC. As we know, MTC requires that children harness subtle information-integration processes when reading second (and subsequent) MTR texts. The second major contribution of the present study is related to previous studies' demonstration that vocabulary ability plays an important role in the MTC of elementary school students (Beker et al., 2019; Florit et al., 2020). Our results show that the moderating effect of vocabulary in MTC appears not only in the later integration stage, but also in the lexical-access stage. Thus, the current study suggests that students in and around the 4th graders can adjust their reading strategy according to their vocabulary ability. Those with higher vocabulary ability are more inclined to adjust the reading strategies of the two texts respectively, while those with lower ability are more inclined to adopt a minimalist strategy. Furthermore, it is interesting to note that students with higher vocabulary knowledge produce less text-based representation in MTR condition. Intuitively, it seems to mean that they pay less efforts on text-based processing in MTR than those in STR. But combined eye movement data findings, these higher-ability students spent more efforts on lexical access in first-text MTR than in STR. During second-text MTR, they directed more efforts to the integration process than in first-text MTR. It implies that they pay more attention to integrate information from two texts. Therefore, they have reported less text-based representation and tended to have more integrated model representations.

In addition, our study also provides an important educational contribution. It has been argued that learning from multiple texts is difficult for elementary students. However, the results of the current study suggest that elementary students are capable of distinguishing the difference between STR and MTR. Therefore, teachers could confidently provide more MTR opportunities for students and adopt differentiated instruction based on the interaction pattern revealed from the present study. Taking the results of Figure 2B and 3A as an example, teachers can encourage lower vocabulary students pay more attention to the words in the texts of MTR, e.g., the repeated or topic-related words, this reading strategy could help them generate higher lexical quality as well as reduce them using minimalist reading strategy. For higher vocabulary students, taking the result of Figure 1B as an example, teachers can encourage them using taking note strategies for constructing more integrated mental models.

It is important that we point out several limitations to the current study. First, our study's participants were not allowed, during the MTR phase, to read the two texts back and forth–the participants had to read the texts sequentially, the second one after the first one. This design for the MTR portion of our study can support a detailed and rigorous comparison between online MTR reading processes and online STR reading processes. However, a possible confounding factor related to our experimental design is the role of short-term memory in our participants' performance. In the current study, we found that participants with different PMTV abilities had adopted different MTR reading strategies, a fact that may be related to the young participants' short-term memory capacity. Because our study design required the 4th grade participants to read two MTR texts sequentially rather than back and forth, the participants had to undertake more short-term memory loading than would have been the case in a more flexible study design. Previous studies have pointed out that short-term memory plays an important role in comprehension monitoring and inference integration. However, because of the experimental paradigm proposed in this study, we perhaps can observe more clearly the different reading strategies adopted by children who differ from one another regarding their respective abilities. This hypothesis may be confirmable from a side-by-side presentation of the two MTR texts.

A second potential limitation of the current study is that the number of reading tasks for students varied between the MTR and STR phases. In this study, the participants were asked not only to comprehend two MTR texts but also to orally report the texts' common concepts. This pair of task requirements might explain why the young participants adjusted their reading processes during the MTR phase, because, in the STR phase, in which no such adjustments took place, the participants faced only one requirement: Comprehend the text. The additional requirement in the MTR condition was designed to guide readers to pay attention to their integration of information from multiple texts. The requirement led our participants to report, on average, more than one integrated model representation in their oral data. Perhaps future research can explore whether students spontaneously engage in integrated model processing when they are simply required to comprehend texts: The results of this study can serve as a basis for such a comparison. In addition, future studies should consider the possibility that the reading instructions for an MTR assignment affect students' comprehension monitoring, cognitive adjustment, and other reading processes. These studies will likely uncover evidence supportive of educational practices.

Annotation

[1] For the 4th graders, the Cronbach's alpha scores for the PMTV were between .749 and .880, the split-half PMTV reliability scores were between .728 and .889.

[2] Similar to the 'text length', the 'word length' refers to the length of a Chinese word, that is, the number of characters it contains.

[3] Temporal eye movement measures correspond to fixations, while saccadic eye movement measures correspond to saccades. And these two are two consecutive main eye movement events during reading. In general, temporal eye movement measures reflect readers' cognitive processing efforts (when), and saccadic eye movement measures reflect readers' strategies for the processing (where), as the reader's initiative is usually involved. For example, deciding to go back and not continue reading, or to fixate once more in order to stay in an area for deeper processing, or to reread more areas.

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Appendix A An Example of the Experimental Design

Link: https://bit.ly/BEP_2023_A

Appendix B Linear Mixed Models of the Oral-Report Data

Link: https://bit.ly/BEP_2023_B

Appendix C Linear Mixed Models of Eye-Movement Data

Link: https://bit.ly/BEP_2023_C

Appendix D Translation of the Topic of the "Communication" Set

Link: https://bit.ly/BEP_2023_D

Appendix E Examples of Idea Unit Coding

Link: https://bit.ly/BEP_2023_E

國立臺灣師範大學教育心理與輔導學系
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詞彙能力在國小學童多文本閱讀理解歷程之角色：來自眼動研究的證據

陳家興[1]、陳明蕾[1]

多文本閱讀是現代讀者學習新知的有效路徑之一（Britt & Rouet, 2012）。探討兒童多文本閱讀認知歷程有助於開發證據本位的多文本閱讀教學模式，以提升學童多文本閱讀理解之表現（Beker et al., 2019）。本研究以眼動技術探究詞彙能力對四年級學生多文本閱讀理解歷程之影響。結果發現，隨著學生詞彙能力越佳，多文本閱讀後所形成的文本表徵的概念數，較單文本閱讀時來得少；但是會形成更多的跨文本整合概念數。此外，由單文本閱讀與閱讀文本組合中的第一篇文章眼動資料發現，詞彙能力愈佳的學生，閱讀文本組合中的第一篇文本時，詞彙處理時間（FFD 與 GD）較長，但重新回視的時間較短（RRT）。反之，詞彙能力較弱的學生，詞彙處理時間與重新回視的時間，都比單文本閱讀時來得短。進一步比較多文本閱讀的第一篇與第二篇文本眼動型態，則發現詞彙能力愈佳的學生，閱讀文本組合中的第二篇文本時，詞彙重新回視的時間比第一篇文本來得長，且發生重新回視的詞彙比率（Reread）也較高。反之，詞彙能力較弱的學生則在第二篇文本發生重新回視的詞彙比率較第一篇文本低。綜合上述研究發現，本研究進一步討論詞彙能力在學生多文本閱讀歷程的角色及其在教育應用上的方向。

關鍵詞：眼動追蹤、多文本閱讀、詞彙能力、個別差異、閱讀歷程調節

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