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Exploring the Effects of Phonological Processing on Foreign-Language Reading: An Eye-Tracking Study for Chinese Learners of Japanese-as-a-Foreign-Language

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This study explored the effects of phonological processing on text comprehension and word processing in a group of advanced Chinese students learning Japanese-as-a-foreign-language (JFL). Participants' reading performance and global- and word-level eye-movement patterns were compared under five reading conditions: articulatory suppression, read-aloud, concurrent reading while listening to the text or to an irrelevant speech, and silent reading. In addition, the study examined whether text complexity moderates participants' phonological processing when reading Japanese text. Finally, how participants' Chinese knowledge affects their processing of Japanese words written in different script types was investigated through analysis of their word-level eye-movement behavior. The results indicated that participants could comprehend short Japanese texts without relying much on phonological recoding: Articulatory suppression and reading while listening to an irrelevant speech did not significantly impair reading comprehension nor did read-aloud and reading while listening to the text enhance text comprehension. Text complexity did not reliably moderate participants' phonological processing under the reading conditions. The word processing results showed that participants' Chinese knowledge facilitated their processing of Chinese-Japanese cognates (i.e., kanji existing both in Chinese and Japanese with the same meanings) but not the processing of Chinese-Japanese homographs or Japanese-coined kanji words. The fact that reading while listening to the text tended to only facilitate the processing of kana words but not the Chinese-Japanese cognates suggests that phonological recoding might not be necessary for accessing the Chinese–Japanese cognates' meanings but is essential for the processing of words written in kana.

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Teachers often ask students in foreign-language (FL) reading classes to read out loud the reading material to check students' accuracy in pronunciation and their fluency in reading, and hope to simultaneously enhance their concentration in reading. Sometimes, the teacher or some students may take turns to read aloud a text, while other students are reading it silently (i.e., reading while listening). Even when students read a FL text silently, they often can "hear" their inner voices articulating the text in their mind (Ridgway, 2009). These reading scenarios illustrate that FL reading is often involved with an internal and an external phonological processing. The former refers to a process called phonological recoding (PR; i.e., converting printed words into phonological codes), whereas the latter occurs when reading is accompanied by a spoken text in the background. However, a central question of this study is: how the different kinds of phonological processing may influence FL reading comprehension and word recognition?

Guan (2015) conducted an eye-tracking experiment with a group of advanced English learners in Taiwan to investigate the role of phonology in English as a foreign language (EFL) reading under five reading conditions: articulatory suppression (AS, i.e. loudly repeating a word while reading a text), read-aloud (RA), reading while listening to an irrelevant spoken text (IRS), reading while listening to the same text (RWL), and silent reading (SR). AS and IRS were supposed to interfere with the use of PR during reading, while RA and RWL were assumed to support the use of PR. The results showed that AS and IRS did not impair reading comprehension, and RA and RWL did not significantly improve reading comprehension. The eye- movement results indicated the possibility that the subjects could achieve text comprehension without relying much on PR.

This case study with a group of advanced Chinese learners of Japanese adopted the same experimental paradigm to explore the role of phonological processing in Japanese-as-a-foreign-language (JFL) reading comprehension. Since Japanese is a non-alphabetic language and has a mixed writing system including both a logographic (kanji) and a syllabic (kana) scripts, the effects of phonological processing in JFL reading should be more complex and worth investigation. By contrasting the reading performances and eye-movement behavior across experimental conditions, this study focused on examining the effects of phonological processing on Chinese JFL learners' reading comprehension and word recognition.

The Role of Phonological Recoding and Inner Speech in Reading

Many researchers concerned with the theories of lexical access have debated about whether meaning is necessarily accessed via PR. Reading researchers have examined the role of PR in L1 reading and believe that PR occurs rapidly and automatically, is an inherent part of word recognition, and is universally essential for developing reading ability (Jorm & Share, 1983; Liu, Tsao, Chang, Hsu, 2013; Luo, Johnson, & Gallo, 1998; Perfetti, 2003). Other researchers have suggested that the difficulty of the reading materials, readers' reading proficiency, and task demands can also affect the role of PR in reading (McCusker, Hillinger, & Bias, 1981; Perrone-Bertolotti et al., 2012). Recent studies indicated that low-proficient readers rely much more on PR in reading (Jobard, Vigneau, Simon, & Tzourio-Mazoyer, 2011), and as the complexity of the text increases, so does the readers' reliance on PR in reading (Alexander & Nygaard, 2008). However, PR might not be necessary for skilled readers reading high-frequency words or easy texts (Pollatsek, 2015; Rayner, Pollatsek, Ashby, & Clifton, 2012).

The functions of PR in reading have remained controversial over the last century. The major issues under debate focus on the nature of PR, and the timing (e.g., pre-lexical vs. post-lexical) and the timing-related functions of PR in reading. Leinenger (2014) pointed out that the pre-lexical phonological codes might be more abstract or impoverished, while the post-lexical ones are more complete and speech-like, which are perceived as the inner speech during silent reading. Baddeley's (1997) working memory model suggests that inner speech supports the processing of words, sentences or discourse in short-term memory via subvocalization. The phonological loop subsystem in working memory for processing verbal information has two components: a phonological store for keeping speech-based information and an articulatory control process. Since information in the phonological store fades very quickly, the articulatory control process helps store information longer by subvocal rehearsal and is responsible for converting visual words into phonological codes and holding them in the phonological store for further processing.

Many studies have examined the role of inner speech in reading by means of the articulatory suppression paradigm, in which participants must repeatedly say an irrelevant word (such as 'cola cola…'), or several numbers or letters while reading a text. The repeated articulation of words or digits is thought to disturb the articulatory control process during reading, and would "suppress" PR and subvocal rehearsal. Despite much evidence for subvocalization during silent reading, there is no consensus about whether PR is absolutely necessary for reading comprehension. Some studies found that AS significantly impairs reading comprehension and suggested that subvocalization is essential for integrating information across phrases or sentences, which particularly affects the understanding of complex materials (Coltheart, Avons, & Trollope, 1990; Daneman & Newson, 1992; Hardyck & Petrinovich, 1970; Slowiaczek & Clifton, 1980). Baddeley and others (Baddeley, 1979; Baddeley, Eldridge, & Lewis, 1981) found that AS did not affect processing speed but only the accuracy rate for judging sentence meaning and suggested that subvocalization might not be necessary for understanding the general meaning of a sentence but is necessary for more accurate processing of it. Rayner et al. (2012) argued that skilled adult readers rely less on phonological coding during word recognition, but inner speech (including both phonological coding and subvocalization) helps text comprehension by holding speech-like codes in short-term memory for syntactic and semantic processing of sentences or other larger units. It is worthwhile to note that recent studies on the neural correlates of inner speech in the human brains suggest that silent reading often can generate auditory verbal imagery (AVI) (cerebral activation observed during speech perception), but the generation of AVI is contingent on task demands and not always necessary (Perrone-Bertolotti, Rapin, Lachaux, Baciu, & Lœvenbruck, 2014). Perrone-Bertolotti et al. (2012) found that only proficient readers can automatically generate AVI during silent reading if they read texts attentively. They suggested that AVI could facilitate verbal working memory and its activation depends on readers' reading strategy and is sustained by their attention.

Although AS is a widely used experimental method, some researchers doubt if AS can really suppress PR and inner speech; as some people can still perceive their inner voice during AS and, AS could hinder comprehension simply because of the dual task effect (Leinenger, 2014; Pollatsek, 2015; Rayner et al., 2012). Norris, Butterfield, Hall, and Page (2018) found that AS did not completely suppress PR in the rhythm and homophone judgment tasks, but it did substantially degrade phonological representations and limit the use of PR. The current study has applied this method because many studies have provided evidence showing that AS can hinder PR and inner speech during reading (Baddeley, 1997; Coltheart et al., 1990; Eiter & Inhoff, 2010; Kato, 2009), and that AS is not simply equal to a dual task for distracting attention (Baddeley et al., 1981; Larsen & Baddeley, 2003).

Very few studies have examined the role of PR in L2 or FL reading. Kato (2009) investigated the performances on English sentence reading comprehension for college-level Japanese learners of English-as-a-second-language (ESL) under AS, tapping (i.e., tapping by foot on the floor at a rate about 700ms per tap throughout the experiment), and silent reading conditions. Kato found that in comparison to silent reading and tapping, AS substantially reduced reading rate and verification accuracy for both less proficient and proficient participants. Tapping only reduced the reading rate for less proficient participants but had no other effect, which suggests that suppression is different from an attention-consuming task like tapping. Kato further pointed out that participants with higher English proficiency cannot fully rely on their orthographic coding skill for ESL reading probably because they have been taught by reading-aloud techniques when learning English in Japan. However, it is unclear whether the use of PR is generally necessary for sentence comprehension of an alphabetic L2 or just because students were often trained to do so.

Guan (2015) found that AS did not significantly reduce their reading comprehension of short English passages, but their eye movements showed that in comparison to silent reading, their mean saccade length and mean number of regressive saccades in the texts were marginally significant larger under the suppression. For each word in the texts, their average gaze duration was considerably shorter and their mean re-reading time was significantly longer. The data indicated participants' attempt of skimming texts when PR was interfered, and re-reading was often needed to achieve comprehension. Since AS did not exert significant effects on reading comprehension scores, Guan argued that PR was not absolutely necessary for understanding the gist of passages, and those advanced Chinese EFL participants could read English texts without relying much on PR.

The two studies mentioned above demonstrate that AS can have different effects on the reading of EFL learners with different L1-backgrounds. The study by Guan (2015) demonstrated that even when readers' performances on comprehension test do not significantly differ from each other, their eye-movement behavior can still reveal how suppression affects learners' reading. Therefore, eye-tracking technique provides an insight into FL learners' online reading processes which cannot be observed by only measuring offline reading performances, such as reading rate and verification accuracy. Therefore, this study also collected eye-tracking data to better investigate the effects of phonological processing on FL reading.

The Effects of Irrelevant Background Speech on Reading

Many studies show that irrelevant sound in the background can interfere with the function of phonological store (Jones, 1995; Larsen, Baddeley, & Andrade, 2000). For word-level processing, Eiter and Inhoff (2010) examine how an irrelevant spoken word influenced word identification during reading and found that the irrelevant spoken word elicited longer viewing time on the target word. Martin, Wogalter, and Forlano (1988) found that unattended speech interfered with reading comprehension which was particularly impaired by meaningful background speech that competed with the current reading comprehension task. Oswald, Tremblay, and Jones (2000) found that both meaningful and meaningless speech impaired participants' memory of sentence contents with meaningful speech having a greater negative effect. Sörqvist, Halin, and Hygge (2010) found that irrelevant meaningful speech disrupted text comprehension, and this effect was greater for participants with poor ability in selecting relevant information in working memory for further processing. Overall, these findings suggest that an irrelevant spoken word in the background can affect target word processing and irrelevant meaningful speech impairs reading comprehension if the concurrent reading task strongly demands semantic processing.

Can RA and RWL Enhance Reading Comprehension?

While AS and IRS can impair reading comprehension, can RA and RWL support PR and enhance reading comprehension? The effects of RWL on reading comprehension are inconsistent. Some studies showed facilitating effect of RWL on reading comprehension (Chang & Millett, 2015; Chen, Lin, & Todd, 2018; Toh, Munassar, & Yahaya, 2010; Woodall, 2010), while other studies did not (Diao & Sweller, 2007; Holmes, 1985; Holmes & Allison, 1986; Gerbier, Bailly, & Bosse, 2018). It seems that the positive effect of RWL was only found for those participants who had poor reading skills or low FL proficiency, but was absent for their counterparts. Chang and Millett (2015), for example, found that both RWL and SR improved reading rates and comprehension for beginner learners in an EFL course, but the improvement by RWL was significantly larger than that by SR. However, Guan (2015) found that RWL did not exert significant effect on reading comprehension when advanced-level EFL students read English short passages, but it facilitated word recognition, which was indicated by shorter gaze duration, re-reading time, and total viewing time on individual words. In sum, RWL is beneficial for unskilled readers. However, whether it generally has no effect on advanced FL learners' reading comprehension is uncertain and need to be further examined.

Read-aloud is another widely used method for teaching reading. In practice, it can be executed as 'read-aloud by the teacher' or 'read-aloud by the students'. Since the former is actually 'reading-while-listening' from students' perspectives, only the latter is concerned in this study. Some studies suggest that read-aloud can enhance students' abilities in PR, vocabulary learning, reading comprehension, etc. (Holmes, 1985; Huff, 2012; Kailani, 1998; Takeuchi, 2003), but other studies indicate that read-aloud directs students' attention to pronunciation, reduces their reading rate or impairs their comprehension (Bernhart, 1983; Klapper, 2007; McCallum, Sharp, Bell, & George, 2004). Takeuchi, Ikeda, and Mizumoto (2012) demonstrated that reading a L2 text without comprehension revealed lower brain activation than that with comprehension, which suggests different qualities of processing involved in read-aloud-only and comprehension. Whether read-aloud impairs text comprehension depends on if enough attention is devoted to process meaning.

The studies reviewed indicated that the necessity of PR in word recognition and text comprehension is still controversial for FL reading. Whether PR is automatic or not appears to depend on the learners' proficiency. It is likely that PR becomes automatic for proficient learners, but it is unclear whether those learners must rely on PR to accomplish text comprehension, particularly when learners' L1 and the target FL are both non-alphabetic languages and have much vocabulary in common, such as Chinese and Japanese. Both learners' L1 knowledge and the writing system of their target FL may further affect their reliance on PR in FL reading (Matsumoto, 2013).

The Influence of L1 Orthography on FL Reading

Over the last 15 years, cross-language influences on reading has captured many researchers' attention. Some evidence indicates that a reader's L1 knowledge and reading behavior can affect his or her FL reading (Cook & Bassetti, 2005). Many investigations have demonstrated that learners transfer L1 reading strategies into L2 reading (Bhide, 2015; Sasaki, 2005). Hamada and Koda (2008) compared the decoding efficiency and semantic information retention of English pseudo-words among Chinese and Korean ESL learners. They found that the Korean ESL learners outperformed their Chinese counterparts, and the phonological regularity of the stimuli had a greater effect on Korean participants. This suggests that L1 orthographic experiences affects L2 word learning processes because Korean is an alpha-syllabic language, and the Korean ESL learners tend to rely on PR when learning new words, whereas Chinese ESL learners tend to rely less on PR because their L1 is a logographic language. Hamada and Koda (2011) found similar results and argued that PR is generally involved in word learning, but the contribution of phonology depends on learners' L1 background. Again, Chinese background learners rely less on PR (i.e., less affected by AS) and use visual information to learn new words. Several studies following this line of research yielded consistent results indicating that the alphabetic and non-alphabetic L1-backgrounds of ESL learners influence their performance on English word identification or text reading (Akamatsu, 2003; Wang, Koda, & Perfetti, 2003).

Chikamatsu (1996) found that when JFL learners read kana, Chinese participants relied more on the visual information while English participants relied more on the phonological information to recognize kana words. Machida (2001) compared Japanese learners' performance on kanji vocabulary comprehension (with vs. without context) and found that learners with a Chinese background performed significantly better than those with an alphabetic language background in kanji vocabulary comprehension. Matsumoto (2013) found that beginning level Chinese JFL learners processed Japanese kanji more efficiently than English JFL learners who had more exposure to Japanese kanji and suggested that L1 knowledge, rather than the amount of exposure, has a stronger influence on kanji recognition.

The Japanese writing system

The modern Japanese writing system mainly consists of two script types: one is kanji (i.e. logograms adopted from Chinese), and the other is kana (phonograms representing sounds in Japanese) which in turn has two kinds: hiragana (phonograms used for presenting grammatical morphemes and some content words) and katakana (phonograms used for presenting Western language loanwords, scientific terms, etc.). Japanese words may be written in kanji, kana or a mixed script of them (e.g., ご飯 gohan: rice, which is called MS-words later) (Tamaoka, 1991).

Kanji are mainly used to write content words (i.e. nouns, verbs, adverbs, adjectives) or Chinese loanwords. The fact that Chinese and Japanese share many kanji having the same/similar orthography and meaning (i.e., Chinese-Japanese cognates, which is called "Chinese kanji" later, such as 森林

shinrin means 'forest' in both languages) has explained the advantage of Chinese JFL learners in reading Japanese (Chikama-tsu,1996; Matsumoto, 2013). However, some Japanese kanji are Chinese-Japanese homographs (e.g., 念書 nensho means 'memorandum' in Japanese, but 'study' in Chinese), and still others have some shared and some unique meanings in each language. Some kanji characters or words are even developed in Japan whose orthography may look unfamiliar (i.e., shijitai: a simplified form of Chinese character, e.g., 塁 for 壘) or is totally unknown (i.e., wasei-kanji: Japanese-made kanji, e.g., 峠) to Chinese speakers (c.f. http://en.wiki-pediaorg/wiki /Kanji). Wasei-kango are Japanese-made Chinese words (e.g., 大根 daikon means radish) whose meanings are unrelated to the ones the characters have in Chinese. Tamaoka (2015) indicated that Chinese JFL learners tend to interpret the meanings of kanji based on their Chinese knowledge and may often misunderstand Japanese texts.

Furthermore, Japanese phonology is complex. A kanji character or compound word usually has multiple pronunciations (i.e., on-reading is the pronunciation adopted from Chinese, and kun-reading is the Japanese pronunciation), whose meanings and pronunciations can only be determined by the context (for more details, see Matsuo et al., 2010; Tamaoka, 1991). Due to the very opaque relationship between orthography and phonology of Japanese kanji, some studies suggested that for Chinese JFL learners, Chinese kanji are strongly connected to their phonology and meanings in Chinese, but are only weakly connected to those in Japanese, while Japanese kanji are only connected to their phonology and meanings in Japanese (details see Tamaoka, 2015). However, these studies only examined performances on naming single words or lexical decision tasks and did not examine whether Chinese JFL learners need PR for recognizing various types of kanji or comprehending a text when reading silently. By contrast, kana is fully phonologically-transparent (Tamaoka, 1991). Neuropsychological evidence indicated that kana words are processed in the phonological areas, while kanji words are processed in lexico-semantic areas in the brains of adult Japanese students (Sakurai et al., 2000). Nevertheless, how Chinese JFL learners process Japanese words in their brains is unclear, as the Japanese writing system simultaneously uses scripts that are phonologically very opaque (kanji) and very transparent (kana). Whether advanced Chinese JFL learners must rely on PR for Japanese word recognition and text comprehension should be meticulously examined by measuring learners' text comprehension and eye-movements in the reading conditions where the use of PR can be systematically manipulated and compared with each other.

Research Design

This experiment examined (1) whether advanced Chinese JFL learners who have passed at least the N2-level of Japanese Language Proficiency Test (JLPT: https://en. wikipedia.org/wiki/Japanese-Languag e_Proficiency_Test) would rely on PR for reading Japanese texts, (2) whether text complexity serves as a moderator for increasing the reliance on PR in JFL reading, and (3) how participants' L1 knowledge affects their processing of Japanese words written in different scripts. A 5×2 within-subject factorial design was used to investigate the effects of two main factors: *reading conditions* and *text complexity*. The reading conditions had five levels: AS, RA, IRS, RWL, and SR (the base-line condition). Text complexity had two levels: easy and difficult.

The dependent variables for general reading performances include the scores of immediate reading comprehension tests and participants' reading time. Additionally, both the global and word-level eye movements were analyzed to investigate the role of PR during the reading processes. Since the eye-movement measurements such as longer fixation (or gaze) durations, shorter saccade length, larger number of fixations and regressions have been proved to be reliable indicators of the difficulty in text comprehension when reading silently (Raney, Campbell, & Bovee, 2014; Rayner, Chace, Slattery, & Ashby, 2006), these measurements were considered for analyzing the global eye-movement behavior in this study, and the hypotheses were made specifically for each reading condition. For the word-level eye-movement measurements, gaze duration and total viewing time within a word region were analyzed. Gaze duration sums the time of the first fixation and other fixations of the first pass processing in the word that typically represents the early word recognition processing in text reading. The total viewing time sums all the fixations on a word and represents the last stage in word processing (Clifton, Staub, & Rayner, 2007; Rayner et al., 2012). Moreover, due to the diversity of Japanese writing system, the eye-movement measurements on words were analyzed based on the script types to simultaneously examine the effects of learners' L1 knowledge along with the other factors on Japanese word recognition.

Hypotheses

Hypotheses 1 to 3 are adopted from the study by Guan (2015) because this study used the same experimental paradigm to examine whether the previous findings can be replicated with a group of advanced Chinese JFL learners. Hypothesis 4 focuses on investigating the strategies used by Chinese JFL learners in word recognition.

> *H1: If participants must rely on PR for reading comprehension, their PR processes during reading should be hindered under AS- and IRS-condition, which should lead to poor comprehension and show eye-movement behavior indicating interferences resulting from AS and IRS.*

It is assumed that negative effects of AS and IRS should be found both for word recognition and text comprehension, with AS having stronger negative effect because it could strongly interfere with PR and inner speech. Specifically, it is predicted that AS reduces reading time, increases the saccade lengths and the ratio of regressive saccades because PR is impeded, and skimming text will be a compensation strategy that accelerates reading without much involvement of PR. IRS, on the other hand, does not suppress PR but rather distract participants' attention that could result in longer reading time and a larger ratio of regressions.

> *H2: If RA- and RWL-conditions facilitate reading comprehension, then higher comprehension scores and eye-movement behavior showing facilitated processing can be expected, i.e.: H2a: RA should result in longer reading time, but fewer regressions and better comprehension of complex texts. H2b: RWL should support word recognition and reading comprehension.*

RA involves overt articulation that consumes more time than covert PR, which should cause longer reading time than does SR. If PR is necessary for JFL reading comprehension, RA can presumably enhance the reading comprehension of complex texts through careful word reading and acoustic rehearsal of the text content, which should lead to higher comprehension scores, a smaller ratio of regressions in a text, and on average, longer gazes and total viewing time on each word. On the other hand, positive effects on word recognition (i.e., shorter total viewing time on words) and higher comprehension scores can be expected under RWL-condition if advanced Chinese JFL learners rely on PR for reading Japanese.

> *H3: All expected effects mentioned above should be more pronounced as text complexity increases. The reliance on PR for reading should be positively related to text complexity.*
> *H4: Participants should process kanji and kana words differently because of the nature of the scripts (logogram vs. phonogram). Additionally, participants' L1 knowledge in Chinese should only facilitate their processing of Chinese kanji because positive transfer only occurs for those words.*

It is assumed that participants' viewing times (i.e. gaze duration and total viewing time) on kanji should be shorter than those of kana words in SR-condition because of their L1 advantage in processing kanji. The viewing times on Chinese kanji words should be very similar in AS- and SR-condition if participants did not rely much on PR for processing kanji when reading silently, whereas the viewing times on kana words should become shorter in AS- and RWL-condition than those in SR-condition if the use of PR is reduced by AS but supported by RWL. Moreover, it is also assumed that L1 knowledge in

Chinese should not facilitate the processing of kanji words that only exist in Japanese or are the homographs of Chinese kanji because no positive lexical transfer could occur.

Method

Participants

Twenty-five volunteer Taiwanese JFL learners who are native Mandarin Chinese speakers, 18 females and 7 males, aged 20-28, were recruited and paid for participating in this study. On average, they started learning Japanese at 18 years of age (range = 10-26 years) and have learned Japanese for 6 years (range = 2-14 years). Twelve participants had passed the N1-level of JLPT and 13 had passed the N2-level of JLPT. They had either normal or corrected-to-normal vision, and none had a reading disability. Two participants were excluded from the final analyses due to their incomplete datasets.

Apparatus

An EyeLink 1000 eye-tracking system with a sampling rate of 1000 Hz. and 0.25º-0.5º average accuracy was used for this experiment (https://www.sr-research.com/products/eyelink-1000-plus/). The experimental materials were presented on a 22” LCD monitor with 1024×768 screen resolution. A speaker connected to the subject-PC was used to present the spoken texts in the background, and a chin-and-forehead rest was used to stabilize the head position.

Materials

Participants were asked to read ten texts, with five rated as easy and five as difficult. The easy texts were adapted from several N3- or N4-level sample reading tests of JLPT, while the difficult ones were adapted from N1-level sample reading tests[1]. On average, an easy text was 301-character long and non-redundantly contained 36.8 kanji-, 17.8 kana-, and 15.8 MS-words. A difficult text was on average 335.8 characters in length and non-redundant having 38.4 kanji-, 21.2 kana-, and 14.4 MS-words. Immediately after reading each text, the participants had to answer three multiple-choice comprehension questions; each question had four options. All the characters in the text were presented in the size of 32×32 pixels, and the line space was 80 pixels. Participants sat approximately 70 cm from the screen, so that a Japanese character corresponded roughly to 1º of visual angle on the computer screen.

Instrument

An extra Japanese reading comprehension test was administered after the eye-tracking experiment to estimate participants’ Japanese reading proficiency in general. The test-consisting of 5 texts and 20 associated questions-was adapted from five N1-level reading tests of JLPT dating back to 1997-2003 that were not accessible to the participants. The time limit for the test was 30 minutes.

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[1] Check two videos showing how a subject read an easy and a difficult text in RWL-condition at:
https://drive.google.com/file/d/1hZgs_WmaVMheTSP8HPXAc69sUIqtkdsg/view?usp=sharing
https://drive.google.com/file/d/1vhojQ5HWJeWCdU5SGqf9kEQ5wrdShmal/view?usp=sharing
The red dot in the videos indicates the subjects’ viewing positions in a real-time fashion.

Procedure

Participants were asked to read the purpose of this study and the task instructions carefully. The experimenter ensured that all participants fully understood the purpose and instructions. All participants signed a consent form before participating in this experiment. The experiment was divided into five blocks with each block corresponding to a reading condition. Participants' eye movements were recorded when they were reading the texts. A Latin-square design was used to counterbalance the sequence of reading conditions and the assignment of texts to reading conditions across participants.

The AS-condition required participants to loudly repeat a word (e.g., 天ぷら Tempura) at a rate of twice per second shortly before the text was presented and to keep doing so until they finished reading the text. The RA-condition required the participants to read aloud word-by-word. The concurrent reading and listening conditions presented irrelevant spoken texts (IRS-condition) or the same texts (RWL-condition) along with the reading materials. An exercise was performed before AS and RA blocks began, and only a forehead rest was used to fix participants' head position for the convenience of speaking under these two conditions. After reading a text, participants proceeded to answer three comprehension questions. Subsequently, they had to rate the text complexity by clicking on a number of a five-level rating scale: 1 = very easy, …, 5 = very difficult. The same procedure was repeated until participants finished reading and answering the questions for the ten texts.

Results

A Wilcoxon signed ranks test was used to analyze participants' subjective ratings on text complexity. A significant difference ($Z = -10.83$, $p < .001$) was found between the easy and difficult texts. The mean rating of easy texts ($M = 1.88$, $SD = 0.75$) was indeed significantly lower than that of the difficult ones ($M = 3.11$, $SD = 1.10$), which validates the experimenters' judgement on the text complexity. Additionally, the reliability of the extra Japanese reading comprehension test was adequate based on the Kuder–Richardson Formula 20 coefficient ($\alpha = .73$).

Five linear mixed or generalized linear mixed models[2] (LMM or GLMM) that followed a forward-selection method were computed for the dependent variable in the reading performances and global eye-movement measures. Starting with a null model in which no factor was considered, two random factors (i.e., subjects and texts) were first put into the model. Subsequently, two fixed factors (i.e., reading conditions and text complexity), the interaction between them and a co-variate for controlling participants' reading proficiency (the standardized scores of participants' extra reading comprehension test, later called Z_EXRT) were entered into the model step by step. The best fit model was the one with the smallest AIC (Akaike information criterion) value among the candidate models. Only the significant results of the best fit models were reported in this article.

General Reading Performances

Participants' reading performances were assessed by comprehension score and reading time. Table 1 shows the results of the best fit models. Since the interaction between reading conditions and text complexity was not significant for the two measurements, it was excluded from the best fit models:

Comprehension score. The best fit GLMM showed that only text complexity and the covariate Z_EXRT had significant effects, while reading conditions did not. Participants scored substantially higher

2 The superiority of LMM and GLMM over repeated measures ANOVA has been discussed in many papers (e.g., Kliegl, Hohenstein, Yan, & McDonald, 2013). Thus, this study adopted these approaches.

when reading easy texts than the difficult ones. Those who scored higher in the extra reading comprehension test also scored higher in the immediate posttests.

Reading time per text. A log transformation was conducted on the data based on the λ-coefficient of the Box-Cox power transformation (λ = 0.06) to meet the normality assumption of LMM. The results showed that the reading time for AS-condition was significantly shorter (*M* = 61.62 sec., *SD* = 4.03) while that for RA-condition (*M* = 102.62 sec., *SD* = 6.71) was significantly longer than the one for SR-condition (*M* = 69.97 sec., *SD* = 4.57). Participants also required more time to read difficult texts than the easy ones. With statistically insignificant differences in comprehension scores, the data indicated that SR saved 32.82% reading time compared to RA, and AS saved 11.93% reading time compared to SR.

Table 1

The Best Fit Models for the General Reading Performances

	Comprehension score				Reading time per text		
Fixed effects	*ß*	*SE*	*t*	*Odds ratio*	*ß*	*SE*	*t*
Intercept 1	-1.93	0.58	-3.40**		4.38	0.07	59.37***
Intercept 2	0.30	0.57	0.42				
Intercept 3	2.94	0.65	4.43**				
C(AS)	-0.52	0.41	0.63	0.6	-0.13	0.05	-2.72**
C(RA)	0.27	0.43	0.63	1.31	0.38	0.05	8.22***
C(IRS)	0.33	0.43	0.76	1.39	0.02	0.05	0.51
C(RWL)	0.21	0.43	0.49	1.23	-0.02	0.05	0.33
Comp(E)	2.33	0.70	3.33**	10.31	-0.28	0.07	-4.02**
Co-variate							
Z_EXRT	0.58	0.22	2.67**	1.79	-0.05	0.05	-1.02
Random effects			Wald Z				Wald Z
Subjects	0.33	0.24	1.37		0.05	0.02	2.95**
Passages	0.99	0.55	1.80*		0.01	0.01	1.63
Residuals	NA				0.05	0.01	9.85***

Note. Significance values are estimated as follows
***$p < .001$. **$p < .01$. *$p <= .05$.

Global Eye-movement Analyses

Participants' global eye-movement measurements-the overall mean fixation duration, number of fixations, mean saccade length, and regression ratio (i.e., proportion of regressive saccades) were compared across the whole text area.

Mean fixation duration (FD). The best fit model showed that the FD for RA-condition was significantly longer (ß = 50.47, $t = 9.47$, $p < .001$) compared with that for SR-condition. Furthermore, participants' reading proficiency had a significant effect on FD (ß = -13.43, $t = -2.15$, $p < .05$) in which participants with higher reading proficiency had much shorter FD than their counterparts.

Number of fixations per text (NF). The results indicated that the NF for AS-condition was significantly smaller (ß = -0.19, $t = -4.03$, $p < .001$) and that for RA-condition (ß = 0.17, $t = 3.69$, $p < .001$) was significantly larger than that for SR-condition, which is consistent with the result pattern of the reading time per text. The NF for easy texts (ß = -0.27, $t = -9.34$, $p < .001$) was significantly smaller than that for difficult texts.

Mean saccade length. The best fit model showed that the mean saccade length for AS-condition (ß = 21.1, $t = 4.58$, $p < .001$) was much longer and that for RA-condition (ß = -36.21, $t = -7.86$, $p < .001$) was substantially shorter than that for SR-condition.

Regression ratio. The regression ratio in a text was calculated by dividing the number of regressive saccades by the total number of saccades. The ratios were enlarged by 100 times for the convenience of statistical analysis. The result indicated that the regression ratio for AS-condition (ß = 3.43, t = 3.28, p < .001) was significantly larger and that for RA-condition (ß = -7.44, t = -7.11, p < .001) was significantly smaller than that for SR-condition.

Word-level Eye-movement Analyses

Two dependent variables (gaze duration and total viewing time on a word) were analyzed to explore the word-level processing. Except from reading conditions and text complexity, the effects of script types were also evaluated to examine the effect of participants' L1 knowledge on word recognition. The script types were classified into four categories: (1) *kana words* (including *hiragana* (e.g., かん kan: can), or *kata-kana* (e.g., バス basu: bus), (2) *Japanese kanji* (wasei-kango (e.g., 仕事 shigoto: work)) or Chinese-Japanese homographs (e.g., 勉強 benkyo means 'study' in Japanese but 'reluctantly' in Chinese), (3) *Chinese kanji* (i.e., Chinese-Japanese cognates (e.g., 日本 Nihon: Japan)), and (4) *MS-words* (mixed-script words, e.g., 休み yasu-mi: holiday, vacation or rest). The Japanese kanji are distinguished from the Chinese ones because they are different from their Chinese counterparts and should be processed differently. Since most of the Chinese and Japanese kanji words in the texts consisted of one or two characters while the length of kana words ranged from 1 to 8 characters, to avoid the confounding effect resulting from word length, only two-character words were included in the following analysis, which formed a corpus containing 177 Chinese kanji-, 97 Japanese kanji-, 66 kana-, and 90 MS-words.

Several LMM models that followed a backward-selection method were computed: The best fit model was found by using step-by-step removal of the insignificant factors from the full model which contained two random factors (i.e., subjects and words), three fixed factors (i.e., reading conditions, text complexity and script types), two interactions (reading conditions*text complexity, and reading conditions*script types) and two covariates (i.e., Z_EXRT and logwf (the logarithm to the base 10 of word frequency[3])). The following results reported only focus on the fixed and interaction effects.

Gaze duration (GD). The GDs shorter than 80ms were screened out because the durations were too short to be a meaningful processing in reading (cf. Rayner et al., 2012, pp. 53-54; White & Liversedge, 2004). This removed 2.49% of the data. A log transformation was performed on the data (λ = -0.38) to meet the normality assumption of LMM. The results indicated that reading conditions and their interaction with text complexity had significant effects. The GDs RA- and RWL-condition were both much longer than the one for SR-condition (ß = 0.60, t = 18.71, p < .001; ß = 0.12, t = 3.68, p < .001). The interaction between reading conditions and text complexity showed that the difference between the GDs in easy and difficult text was substantially larger for RA- than for SR-condition (ß = -0.09, t = -2.59, p < .05).

The factor script types (baseline condition - Chinese kanji) and their interaction with reading conditions were also significant. Figure 1 shows the estimated GDs for each script type by reading conditions. The effect of script types showed that the GDs on words with kana-element (i.e., MS-words and kana words) were significantly longer than those on kanji words (Chinese kanji and Japanese kanji) in SR-condition (ß = 0.13, t = 3.51, p < .001; ß = 0.11, t = 2.57, p < .05). However, RA- and RWL-condition had much longer GDs on Chinese-kanji than did SR-condition. Thus, the mean differences between Chinese-kanji and MS-words were largely reduced in those two conditions in comparison to that in SR-condition (ß = -0.12, t = -2.51, p < .05; ß = -0.11, t = -2.21, p < .05). Although read-aloud also prolonged the GD of kana words, it was much shorter than that of Chinese-kanji, which is

[3] The frequency of each word was found in the Balanced Corpus of Contemporary Written Japanese (BCCWJ 現代日本語書き言葉均衡コーパス). The corpus contains 104.3 million words.

opposed to the result found in SR-condition (ß = -0.23, t = -4.42, p < .001). Moreover, the mean difference between kana and Chinese-kanji words became much shorter in RWL-condition due to the increased GD of Chinese-kanji (ß = -0.13, t = -2.41, p < .05). Finally, the GD on MS-words became much shorter in IRS-condition, which made it close to that on Chinese-kanji (ß = -0.11, t = -2.28, p < .05).

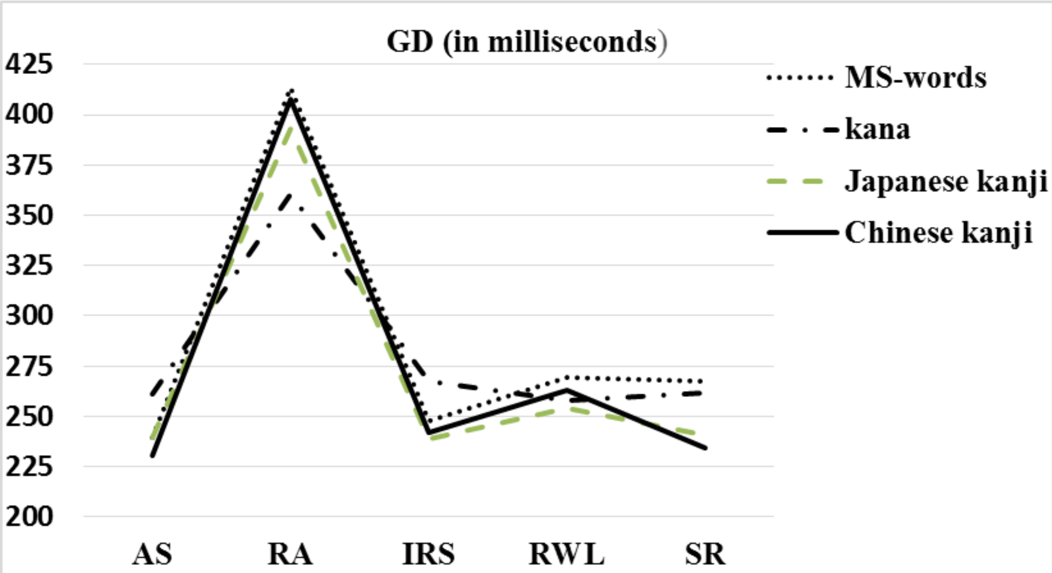

Figure 1 The estimated GDs for each script type by reading conditions

Total viewing time (TVT). TVT aggregates all the fixations on a word, which reflects the last stage in word processing. Again, the TVTs shorter than 80ms were excluded from the analysis, which resulted in 1.32% of the TVTs being removed. A log transformation was conducted on the data (λ = -0.01). The results showed that all factors had significant effects on TVT, except for the covariate Z_EXRT. The main effects of reading conditions and text complexity, and the interaction between them were significant (see Figure 2). The interaction effects indicated that the mean differences in the TVTs between easy and difficult texts were much larger in SR-condition but much smaller in AS- and IRS-condition (ß = 0.10, t = 2.21, p < .05; ß = 0.12, t = 2.68, p < .01). Furthermore, the effects of script types and its interaction with reading conditions were significant. Figure 2 shows the TVTs by reading conditions and script types. In the SR-condition, the mean TVT of Chinese-kanji was the shortest among the script types. Kana words had marginally significant longer TVT (ß = 0.12, t = 1.86, p = .06) while MS- and Japanese-kanji words had substantially longer TVTs (ß = 0.19, t = 3.54, p < .001; ß = 0.18, t = 3.31, p < .001). In AS-condition, the TVT of Chinese kanji was very close to that in SR-condition. Furthermore, the TVTs of the other three script types were all shorter, with the TVT of MS-words being significantly reduced (ß = -0.23, t = -4.42, p < .001), such that it was very close to the Chinese kanji value (ß = -0.22, t = -3.45, p < .001). By contrast, the TVTs of all script types became significantly longer in RA-condition, particularly the TVTs of words with kanji components. Therefore, the TVTs of MS-words, Japanese kanji and Chinese kanji were all close to each other (MS-words: ß = -0.22, t = -3.64, p < .001; Kana words: ß = -0.30, t = -4.40, p < .001; Japanese kanji: ß = -0.18, t = -3.07, p < .001). The increase in the TVT of kana words was much smaller than that of Chinese-kanji, which led to a larger difference in their TVTs in RA-condition ($M_{Chinese\text{-}kanji\ -\ kana}$: 97.81 ms) compared with that in SR-condition ($M_{Chinese\text{-}kanji\ -\ kana}$: -47.91 ms). In IRS-condition, the TVTs of words in all script types were very close to each other: Compared with SR-condition, the TVTs of MS-words and Japanese kanji decreased, whereas the TVT of Chinese kanji increased, which significantly reduced the differences among the three script types (MS-words: ß = -0.20, *t* = -3.26, *p* < .001; Japanese kanji: ß = -0.14, *t* = -2.48, *p* < .05). Similar result patterns for were also found for the three script types in RWL-condition. It should be noted that the TVT of kana words in RWL-condition significantly decreased and became even shorter than that of Chinese kanji (ß = -0.24, *t* = -3.51, *p* < .001), which is opposed to the result observed in SR-condition.

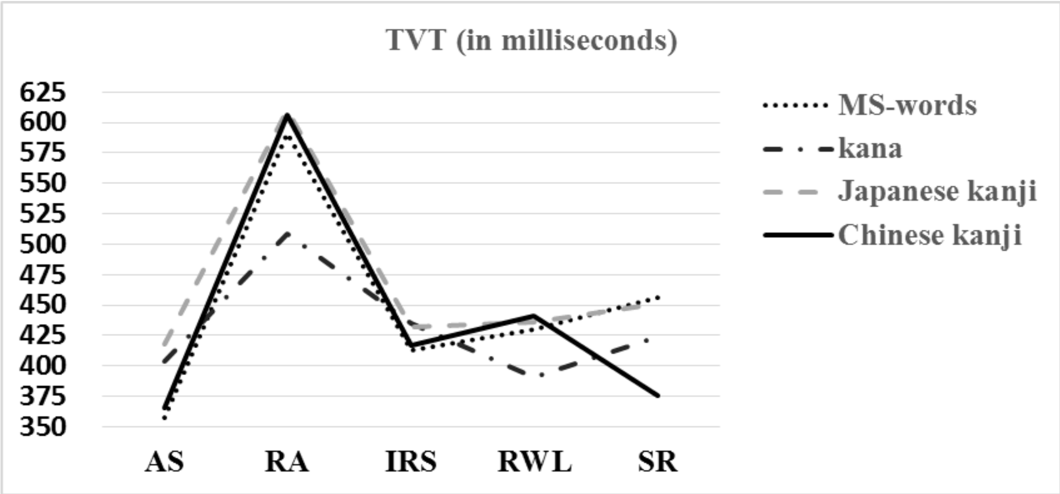

Figure 2 The estimated TVTs for each script type by reading conditions

Discussion

The current study used an eye-tracking experiment to examine whether advanced Chinese JFL learners would rely on PR for word recognition and reading comprehension, and whether text complexity would increase their reliance on PR for JFL reading comprehension. The result of comprehension performance did not support the assumption that the participants need to rely on PR for JFL reading comprehension (Hypothesis 1) because there was no statistically significant difference in comprehension scores among reading conditions. This finding is consistent with the one observed by Guan (2015). However, several new findings in this study are: (a) the reading time per text in AS-condition was significantly shorter than that in SR-condition, (b) longer saccades and higher regression ratio were found regardless of text complexity, which indicate that AS hindered PR and reduced the use of it. Consequently, participants skimmed texts when PR was less likely to be executed. The fact that speeding up reading was not at much cost of the overall text comprehension suggests that participants could comprehend Japanese texts without relying much on PR. Despite the null effect of AS on overall text comprehension, the result also suggests that skimming text resulted in a cost to local comprehension. Therefore, the participants had to adopt a compensatory re-reading strategy more often to achieve text comprehension. These results not only echo the findings showing how AS can hinder PR and affect word processing (Eiter & Inhoff, 2010; Norris et al., 2018), but also show that AS did not substantially influence overall reading comprehension.

IRS did not have significant effects on comprehension scores and reading time, but only had an effect on TVT indicating that text complexity did not have much effect on TVT when PR was interfered. Although IRS did cause certain interference, it had much weaker effect than AS and did not seem to distract much attention. Whether meaningful background speech in FL is generally easier to be ignored needs further investigation.

Hypothesis 2a is partially confirmed in that read-aloud did not significantly enhance reading comprehension but did substantially prolonged reading time, which was revealed by the longest fixation durations, largest number of fixations, shortest saccade lengths, and the highest values for all word-level eye-movement measures. Moreover, the results confirmed that read-aloud significantly reduced the regression ratio through the careful word reading. Overall, the results suggest that read-aloud can facilitate word recognition, but it causes longer reading time and does not enhance overall text comprehension for advanced JFL learners. These findings do not confirm the benefit of read-aloud suggested in other studies (Gibson, 2008; Holmes, 1985; Huff, 2012; Kailani, 1998; Takeuchi, 2003), nor do they confirm the negative findings suggested by others (Bernhart, 1983; McCallum et al., 2004). Participants' reading proficiency probably modifies the effect of read-aloud on reading comprehension. RA is not beneficial for advanced JFL learners presumably because they do not rely on PR to recognize each word and comprehend a text. Thus, articulating each word is extra work that prolongs reading time but do not further help word recognition and text comprehension.

Hypothesis 2b is not confirmed because RWL did not enhance comprehension, but only tended to facilitate the processing of kana, not kanji words (see the discussion of Hypothesis 4), which is partially consistent with the beneficial effect of RWL on word processing identified by Guan (2015) in EFL reading. Again, it could be that advanced Chinese JFL learners usually read texts without relying much on PR for processing kanji. Listening to their pronunciations does not accelerate kanji recognition, but rather slows down the reading speed and prolongs GD. Additionally, Japanese has a large amount of homophones which can only be distinguished by identifying their kanji characters. Thus, it is the orthography not the phonology of kanji that plays the crucial role in accessing word meanings (Tamaoka, 2015). Although the spoken text might be superfluous, RWL did not hamper comprehension either, which is inconsistent with the findings suggested by Diao and Sweller (2007) and Holmes (1985). It might be that the texts in this study were shorter than the ones used in those studies. Whether or not the participants followed the speed of the spoken text while reading did not significantly affect text comprehension. If the reading material is longer and comprehension tasks are more difficult, results could be different. Further research is required to clarify this issue.

Hypothesis 3 was supported when text complexity influenced participants' comprehension score and showed its effects on reading time and most eye-movement measures as predicted. However, the results of comprehension performance and global eye movements did not confirm that participants relied more on PR for comprehending complex texts because no significant interaction was found between reading conditions and text complexity. The only word-level eye-movement result supporting the notion that the use of PR was positively related to text complexity was found in RA-condition. This is not surprising because read-aloud guarantees the use of PR in FL-reading, while the other reading conditions do not.

Finally, in terms of Hypothesis 4, the results confirm that the participants used different strategies to read kanji and kana words, and different kanji types were processed differently, which is affected by participants' L1 knowledge. Additionally, words of different scripts were read differently in the early and the late stages of word processing. In the first pass reading (as revealed by GD) in SR-condition, the words with kana-elements (MS-words and kana words) were read substantially longer than kanji words (Chinese and Japanese kanji). Since kana words are visually and phonologically less complex than kanji words, the longer GD on kana words suggests that PR was probably involved when silently reading kana words but not for reading kanji words in the early stage of word processing. This result basically confirms that words written in kanji are processed faster than those in kana. Participants processed kanji words without paying much attention to PR, but PR was necessary for processing kana words, which is similar to the notions proposed by Tamaoka (2015).

In RA-condition, where the use of PR was guaranteed, the GDs of words with kanji elements (MS-words, Chinese and Japanese kanji) significantly increased, while the increase in the GD of kana words was much smaller. The differential increases of the GDs among words of different scripts in RA-condition suggest that it is more difficult to process the phonology of kanji than that of kana words. It is also intriguing that RWL (compared to the SR-condition) substantially increased the GDs of kanji words but not those of MS- or kana-words, which indicates an extra phonological activation of kanji words elicited by RWL. Moreover, the GDs of MS-words for AS- and IRS-condition were substantially shorter than those for the SR-condition, while the GDs of kanji and kana words were very similar to those for SR-condition. It could be that participants could bypass phonology and focus on the kanji part of the MS-words to access meaning when PR was strongly interfered, but they failed to do so for kana words. The similarity in GDs of kanji words for the SR-, AS-, and IRS-conditions indicate that PR of kanji words was not or only sparsely involved in all three conditions presumably because it was not essential for accessing word meanings and was abandoned under interference.

In regard to TVT, it may reveal the phonological, syntactic and semantic processing that occurs after the first pass of reading, because it represents the last stage of word processing. The results of GD and TVT have some similar patterns, but they also differ in several aspects. When reading silently, the TVT of Chinese kanji was the shortest among the words of different scripts indicating participants' advantage in processing Chinese kanji. MS- and Japanese kanji words had the longest TVTs during silent reading which are even longer than that of kana words. This suggests that not all words with kanji components were processed at the same rate. Obviously, participants' L1 knowledge in Chinese only facilitates their processing of Chinese kanji, but not that of Japanese kanji or MS-words. This difference becomes obvious after the first pass of reading.

The suppression effect elicited by AS was only evident for MS-words, but relatively weak for other words. In AS-condition, the TVTs of all words were shorter than those in SR-condition, but the decrease was only significant for MS-words (95.46 ms). The TVT of Chinese kanji was only slightly reduced (9 ms) compared to that in SR-condition. Again, the results could suggest that the PR of Chinese kanji was not much involved in JFL word processing. In RA-condition, the TVTs showed that words with kanji elements are phonologically much more complex than kana words. RWL tended to show a positive effect on kana word processing, and it particularly increased the TVT of Chinese kanji words, which suggests an extra phonological activation of Chinese kanji compared to those in SR-condition.

The current study provides an insight into JFL reading by documenting participants' reading performances and eye movements for processing words and texts of different complexities in different reading conditions. While reading conditions induce learners to flexibly adopt reading strategies to achieve text comprehension, readers' L1 knowledge also influences the way they process words written in different scripts in Japanese.

Limitations of this study are that both the participants and the experimental materials were limited in number. It is better to recruit participants of different proficiency levels in Japanese and use longer texts and different types of questions (i.e., gist, literal, and inferential questions) to test reading comprehension in future studies. Additionally, it is certainly worth including participants' interviews in which they can reflect their reading processes under different reading conditions to get more thorough insights into the processes of FL reading.

Conclusion

The results of the current study indicate that advanced Chinese JFL learners can comprehend Japanese texts in different complexities without relying much on phonological recoding. Concentrated silent reading is the most efficient reading mode. Read-aloud is not recommended because it consumes about 33% more of the reading time than silent reading does, but fails to promote text comprehension for advanced learners. Reading-while-listening should be used with caution, because it does not seem to be very beneficial for advanced JFL learners who have already mastered word recognition skills. If the speaking rate of the text does not match the learners' reading rate, it could result in unpleasant feeling during reading, which was actually observed in some studies (Holmes,1985; Gerbier et al., 2018). However, for less skilled readers, Reading-while-listening is useful because several studies have shown that it may help learners setting up connections between orthography and phonology.

Finally, this study found that Chinese JFL learners' L1 knowledge in Chinese facilitates their processing of Chinese kanji in Japanese texts, probably without much phonological recoding involved during silent reading. However, just as Tamaoka (2015) has pointed out, Chinese JFL learners might easily make erroneous interpretation of Japanese texts if they overly rely on their L1 knowledge to decipher different kinds of kanji words. Chinese JFL learners, therefore, should always pay attention to the different usages of Chinese morphemes in Japanese.

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探索語音處理對外語閱讀的影響：一個針對中文母語者閱讀日語為外語的眼動研究*

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本研究以中文母語的高階日語學習者為研究對象，探索語音處理對文章理解和字詞辨識的影響。透過實驗在 5 個閱讀條件下（語音抑制、逐字朗讀、聽不相干語音、聽文章語音以及安靜閱讀）比較了受試者的閱讀表現、整體性和詞層次的眼動模式。此外，研究也檢視文章難度是否影響受試者在閱讀日文文章時處理語音的傾向。藉由分析受試者在詞層次的眼動行為來檢視中文知識如何影響他們處理以不同字體書寫的日語詞彙。實驗結果顯示受試者不太需要依賴語音轉碼即可理解日文短文：語音抑制和聽不相干語音並未妨礙閱讀理解，而逐字朗讀以及聽文章語音並不能提升閱讀理解。除了在逐字朗讀的情況下，文章難度並不影響受試者在其他閱讀條件下語音處理的傾向。在字詞處理方面，受試者的中文知識僅促進他們處理中日同源詞，並無法促進他們處理中日文間的同形異義詞或僅在日語裡使用的漢字詞。聽文章語音傾向只有利於處理平假名或片假名的字詞，但會延長對中日同源詞的注視時間，此結果指向語音轉碼在提取中日同源詞的意義時，可能並非必要的過程，但對處理以平假名或片假名書寫的字詞較為重要。

關鍵詞：外語閱讀、眼動追蹤、語音處理、線性混合模型