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Phonological involvement in the processing of Japanese at the lexical and sentence levels

AIKO MORITA & KATSUO TAMAOKA
Hiroshima University, Japan

Abstract. The present study examined whether Japanese readers activate phonological information when reading kanji compound words and sentences and if so, how they do it. Experiment 1 used two-kanji compound words in a lexical decision task to study phonological processing at the lexical level. When nonwords were pseudo-homophones (朗費 /roR hi/ in place of the real word 浪費 /roR hi/), reaction times were longer and more errors occurred than with nonwords in the control group (削費 /saku hi/). Experiment 2 required participants to detect misspellings (i.e., incorrect kanji combinations) of two-kanji compound stimuli embedded in sentences. In the detection task of misspelled kanji, no homophonic effect was apparent. Experiment 3 used a semantic decision task. Included in this task were semantically similar but incorrect kanji compound words used as fillers in sentences (e.g., 向こうに見える大きな建物は、私の知人が設備したものだ meaning 'The building you can see over there was *facilitated* by my friend' instead of *designed*) as well as the sentences used in Experiment 2. Results from Experiment 3 indicated that participants could reject a sentence as incorrect more quickly when pseudo-homophones were embedded in the sentences rather than nonwords. These results suggest that readers activate phonological information of two-kanji compound words when reading for comprehension but not for simple proofreading.

Key words: Japanese kanji compound words, Lexical and sentence processing, Phonological processing, Pseudo-homophone

Introduction

It is a long-debated issue whether or not phonological information is essential during silent reading by skilled readers. Many studies have suggested that phonological information is essential for word recognition and for reading sentences in alphabetic scripts (e.g., Ferrand & Grainger 1992; Lesch & Pollastek 1993; Pollastek, Lesch, Moris & Rayner 1992; Rayner, Pollastek & Binder 1998). Coltheart, Avons, Masterson and Laxon (1991) suggested that both assembled and addressed phonology contribute to word recognition and the reading of sentences. It seems that the same phonological processing takes place during word recognition and sentence comprehension of alphabetic scripts. Furthermore, some studies done on the processing of Chinese characters have shown phonological involvement in visual recognition of kanji (Perfetti & Zhang 1995; Tan, Hoosain & Peng 1995; Tan, Hoosain & Siok 1996; Tan & Perfetti 1999). These studies suggest that phonological information is activated regardless of the writing system.

The Japanese writing system seems to differ from other writing systems. Modern Japanese consists of kanji and kana scripts (see details in Kess & Miyamoto 1999; Tamaoka 1991; Leong & Tamaoka 1995; Tamaoka & Hatsuzuka 1997, 1998; Tamaoka, Hatsuzuka, Kess & Bogdan 1998; Tamaoka & Miyaoka, in press). Kanji are so-called 'logographic' characters of Chinese origin used to represent morphemes of spoken Japanese. Each kanji has phonetic as well as semantic value. Kana consists of written characters used to represent phonological units of morae. In addition, sentences are written without spaces between words in Japanese. In this respect, Japanese has very unique characteristics in the way it is written.

Focusing solely on Japanese kanji can provide some very interesting research material. First, different from each letter in an alphabetical writing system, each single kanji character has semantic value. Second, according to the Database for the 1,945 Basic Japanese Kanji (Tamaoka, Kirsner, Yanase, Miyaoka & Kawakami 2001, 2002), approximately 60 percent of these kanji (i.e., *Joyo Kanji*), have two kinds of pronunciations, *Kun*-reading and *On*-reading. When Chinese characters were introduced in Japan, their pronunciations were adopted as *On*-readings into the Japanese written language. In addition, about 62 percent of commonly used kanji were assigned a Japanese way of pronunciation as well, known as *Kun*-reading. Thus, among Japanese two-kanji compound words, appropriate pronunciation is determined by the specific combinations of two or more kanji characters. Due to the these complex characteristics of kanji pronunciation, some researchers have claimed that phonological activation does not occur during reading of Japanese kanji (e.g., Goryo 1987; Nomura 1978, 1979; Saito 1981; Sasanuma 1974; Sasanuma & Fujimura 1972; Sasanuma & Monoi 1975). Therefore, it is a common belief that the Japanese kanji script differs from other writing systems in terms of its phonological processing.

Recently, some researchers have shown early phonological activation during Japanese kanji word recognition. Wydell, Patterson and Humphreys (1993) showed that phonological information contributes to the semantic activation of two-kanji compound words. Wydell et al. examined the role of phonological information by using a semantic categorization task with homophones. Participants were presented with a category name (e.g., 良い結果, meaning 'a good result') followed by a target word and were asked to make a decision whether or not the target word was a correct exemplar of the category. When the target words (e.g., 青果, /seika/, meaning 'fruit and vegetable') were homophones of a correct exemplar (e.g., 成果, /seika/, meaning 'an achievement'), reaction times were longer and more errors occurred than when the target words had no homophones. More recently, Sakuma, Sasanuma, Tatsumi and Ijuin (1998) showed that phonological information plays an important role in the comprehension of kanji words. Sakuma et al. used a semantic decision task that was similar to the semantic categorization task used by Wydell et al. Participants were presented with a definition (e.g., 建物などが焼けること, meaning 'burning of a building') followed by a target word. When target words (e.g., 家事, /kaji/, meaning 'house work') were phonologically and orthographically similar (i.e., sharing one common kanji) to the correct exemplar (e.g., 火事, /kaji/ meaning 'fire'), participants made more errors. These studies, therefore, support the notion that phonological information is activated during Japanese kanji word recognition.

Some researchers (e.g., Osaka 1989; Shimomura & Yokosawa 1995) have used sentences as test material to investigate the kanji reading process. Their findings focus on the length of eye fixation during reading, and reaction times and error rates for proofreading tasks. For example, Matsuda (1991) showed that pseudo-homophones in sentences were easily detected during proofreading tasks. Participants were given stimulus sentences that were typed out on paper and then asked to detect errors in spelling. There were incorrect words that were homophones of correct words (pseudo-homophones) and some that were not homophones (nonwords). For example, when the correct word was 食堂 (/syoku doR/, meaning 'dining room'), 食動 (possibly pronounced as /syoku doR/) was used as its pseudo-homophone and 食頻 (possibly pronounced as /syoku hiN/) was used as its nonword. Participants detected a greater number of pseudo-homophones as incorrect than nonwords. In addition, Matsuda (1993) further conducted a similar experiment and received the same results, suggesting that phonological information is activated in proofreading.

Shimomura and Yokosawa (1991) studied the processing of two-kanji constituents in Japanese using proofreading experiments. They used pseudo-homophones and nonwords as stimuli. For example, a two-kanji compound pseudo-homophone of 美熱 /bi netu/ was created from the real word 微熱 /bi netu/ meaning 'a slight fever'. Participants were asked to detect misspellings of words in sentences on a computer display. When the misspelling was a two-kanji compound pseudo-homophone (e.g., 美熱), detection time of participants was shorter than when the misspelling was a two-kanji compound nonword (e.g., 横熱, possibly pronounced as /oR netu/). This result suggested that participants used phonological information in proofreading. However, no significant difference was found between pseudo-homophones and nonwords with regards to accuracy rates (i.e., how well their misspellings were detected).

It still remains unclear whether the processing of kanji compound words during the reading of sentences is different from simple lexical recognition of these words. Although Yokosawa (1998) suggested that some contextual information affects the processing of two-kanji compounds embedded in Japanese sentences, it still remains an unanswered question as to how contextual information and phonological information affect reading. In addition, Yokosawa (1998) indicated that participants' performance of detecting misspellings did not change when they were required to answer questions (a comprehension test) after reading. Consequently Yokosawa (1998) drew the conclusion that the extent of understanding a sentence does not have any influence on misspelling detection.

In order to clarify phonological involvement in the processing of kanji compound words, the present study examined how skilled Japanese readers activate phonological information when reading kanji compound words at both the lexical and sentence levels. The main question to be asked is whether processing two kanji compound words presented individually differs from processing the same words embedded in sentences. To answer this question, three different experiments were used in the present study: (1) a lexical decision of two-kanji compound words (Experiment 1), (2) a proofreading task (detection of misspellings) of the same two-kanji compound words at the sentence level (Experiment 2), and (3) a semantic decision task of sentences with the same two kanji compound words (Experiment 3).

Experiment 1: Lexical decision of two-kanji compound words

This experiment examined the effects of pseudo-homophones during lexical decision of two-kanji compound words. Experiment 1 used pseudo-homophones constructed of two kanji. For example, a pseudo-homophonic word 基則 /ki soku/ was created from the real word, 規則 /ki soku/. A control nonword 想則 (possibly pronounced /soR soku/) was also created by the changing of one kanji where its sound did not correspond to any real word in Japanese. If phonological processing is involved in lexical decision of two-kanji compound words, it is expected that pseudo-homophonic nonwords should take longer to be rejected than nonwords with no lexical homophony.

Method

Participants. Twenty-four graduate and undergraduate students of Hiroshima University participated in the experiment. Average age of participants was 23 years and 10 months. All participants were native Japanese speakers.

Table 1. Mean values of possible influential factors on the processing two-kanji compound words for experiments 1–3

Influential factors	Pseudo-homophones	Nonwords
Grades	5.02	5.04
Number of strokes	9.83	9.69
Kanji frequency (1976)	0.50	0.51
Kanji frequency (1998)	7673	9284
CD-ROM Kanji frequency (1998)	10860	13226
Neighborhood size of left	26.60	30.92
Neighborhood size of right	37.85	25.73
Total neighborhood size	64.45	56.65
Accumulative neighborhood size of left	44.19	89.77
Accumulative neighborhood size of right	56.65	37.21
Total accumulative neighborhood size	100.83	126.98
Radical frequency	23.60	32.06
Number of constituents	2.16	2.13
Number of kanji homophones	17.79	17.29

Stimuli. Forty-eight sets of stimuli were constructed. Each set contained one 2-kanji compound word (core word) and two nonwords. The three stimuli in each set shared one commonly used kanji, for example, "浪費" (/roRhi/), "朗費" and "削費". One nonword was a pseudo-homophone ("朗費", /roRhi/), and the other was not ("削費", /sakuhi/). The two groups of nonwords were matched across 14 possible factors as shown in Table 1. A one-way ANOVA showed that there was no significant difference between the two groups of nonwords with regards to all these 14 factors. The first factor was the school grade in which the kanji is taught [$F(1, 94) = 0.00$]. The second factor was the number of strokes in each kanji [$F(1, 94) = 0.05$]. The frequency of occurrences of kanji in print was controlled by the third [$F(1, 94) = 0.01$], fourth [$F(1, 94) = 0.37$], and fifth factors [$F(1, 94) = 0.44$]. The sixth factor was the kanji neighborhood size of the left-hand side of the two-kanji compound words [$F(1, 94) = 0.47$]. The term 'kanji neighborhood size' refers to the number of possible characters one unit of kanji can combine with in order to create different compound words. The seventh factor was the kanji neighborhood size of the right-hand side of the compound word [$F(1, 94) = 3.49$]. The eighth factor was the total kanji neighborhood size for both the left-hand and right-hand sides of each compound word [$F(1, 94) = 0.56$]. A neighborhood size, however, counts the number of possible two-kanji combinations without considering word frequency. Thus the accumulative neighborhood size of the left-hand side as well as the right-hand side of the two-kanji compound words, and the total of these, were also controlled by the 9th, 10th, and 11th factors shown in Table 1 [$F(1, 94) = 1.61$, $F(1, 94) = 2.01$, $F(1, 94) = 0.44$, respectively]. Single kanji are often composed of two or more constituents: a radical and secondary elements. The twelfth factor was radical frequency that indicated how many of the 1,945 basic kanji in Japanese share the same radicals [$F(1, 94) = 2.58$]. The thirteenth factor was the number of kanji constituents, both radical and secondary elements [$F(1, 94) = 0.11$]. A single kanji's pronunciation is often shared by multiple kanji. Thus the fourteenth factor was the number of kanji homophones [$F(1, 94) = 0.04$].

In order to avoid repeating the same stimulus to participants, the experiment used the cross-counter design of assignment. According to this process, stimuli were divided into three counterbalanced groups with an equal number of core words, pseudo-homophonic nonwords and nonwords with no homophony. Each of the three stimuli in each set appeared separately either in List A, List B or List C. This method of assignment avoided the repetition of the same kanji (e.g., "費") and pronunciation (/roRhi/) on one list. Each participant viewed only one list so that no one saw a set in its entirety. Stimuli are listed in Appendix A. Sixteen two-kanji compound words were used as filler items for the lexical decision task. Filler items did not contain any kanji that was used in critical items.

Procedure. Existing words as well as nonwords were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of an asterisk '*' used as an eye fixation point. To one participant, 16 core words, 16 pseudo-homophones, 16 nonwords with no homophony, and 16 filler real words were presented. Participants were instructed to decide whether or not the item was a real compound word. The conductor of the experiment instructed participants, "If the item is a real word, please press the red key on the keyboard with your right hand as quickly and as accurately as possible. If the item is not a real word, please press the blue key with your left hand." Twenty-four practice trials were given to participants prior to commencement of the actual testing. The stimuli for practice consisted of 12 real two-kanji compound words, 6 pseudo-homophones, and 6 nonwords with no homophony.

Results

Only correct responses were used for the calculation of mean reaction times. Reaction times slower than 2,200 ms were recorded as incorrect responses. Six items fell into this category (about 0.39% of the total responses of the 24

Table 2. Mean reaction times and error rates in Experiment 1

Nonword type	Reaction time (ms)	Error rates (%)
Pseudo-homophones	842 (161)	9.4
Nonwords	802 (157)	6.2

Figures in parentheses represent the standard deviations.

participants). Before performing the analysis, reaction times more than 2.5 standard deviations (SD) above or below a participant's mean were replaced by the boundaries. The mean reaction times and error rates in the lexical decision task are presented in Table 2. Analyses of variance (ANOVAs) were conducted using both participant (*Fs*) and item (*Fi*) means.

A one-way ANOVA for repeated measures showed a significant difference for reaction times by participant means [$Fs(1, 23) = 5.86$, $MSE = 3245.3$, $p < 0.05$] and marginally significant by item means, [$Fi(1, 94) = 3.22$, $MSE = 8375.9$, $p < 0.10$]. These results suggested that participants responded to pseudo-homophonic nonwords more slowly than to those with no homophony. These results were further examined by way of error rates. A one-way ANOVA showed no significant difference in error rates by participant means. By item means, however, the difference was significant [$Fi(1, 94) = 4.16$, $MSE = 0.811$, $p < 0.05$]. The result of error rates showed a tendency that participants are likely to miss pseudo-homophonic nonwords slightly more than nonwords with no homophony.

Discussion

Experiment 1 indicated effects of lexical homophony from the 'No' responses in the lexical decision task. Nonwords with lexical homophony took longer and were more difficult to reject than those with no lexical homophony. The previous study by Tamaoka (submitted) also indicated inhibitory effects of lexical homophony during lexical decision and naming of two-kanji compound words with multiple lexical homophones. Therefore, involvement of lexical phonology is supported from both the 'Yes' responses of real words (Tamaoka, submitted) and the 'No' responses of nonwords (Experiment 1) from these lexical decision tasks. The findings of Experiment 1 further lead to Experiment 2 which investigated the effects of lexical homophony at the sentence level.

Experiment 2: Misspelled-word detection at the sentence level

The findings of Experiment 1 indicated effects of lexical homophony during the task of lexical decision. Therefore, in order to examine homophonic effects at the sentence level, the next experiment was conducted using the same nonwords from Experiment 1, however this time embedded in sentences. For example, we took a sentence with all its words correct like バイオリンが上達し、今度は独奏することになった /baioriN ga joRtatu si, koNdo wa *dokusoR* suru koto ni naQta/ meaning 'His/her skill of violin improved, so she/he will play *solo* this time'. We then created another sentence where one of the two kanji of the underlined word was altered to form 独総 /dokusoR/ and thus created another sentence with a pseudo-homophonic nonword of the word 独奏. A control condition was created by using yet another sentence where the nonword 独公 (possibly read /doku koR/) with no homophony was used as a second substitute. If lexical homophonies affect the processing of two-kanji compound words, it would be expected that pseudo-homophonic nonwords would take longer and be harder to detect than nonwords with no homophony at the sentence level as well.

Method

Participants. Twenty-four graduate and undergraduate students of Hiroshima University, who had not participated in Experiment 1, participated in the experiment. The average age of the participants was 23 years and 5 months. All participants were native Japanese speakers.

Stimuli. Forty-eight sets of sentences were created. Each set contained a sentence under the correct condition, the pseudo-homophonic condition and the non-homophonic condition. The same stimuli from Experiment 1 were used as core words in each sentence. Sixteen filler sentences were also created containing the filler items from Experiment 1.

Procedure. The 64 sentences were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of a series of asterisks '*********' representing an eye fixation point. Participants were instructed to decide whether or not the two-kanji compound in the sentences was a real compound word. The conductor of the experiment instructed participants, "If you find no nonword in the sentence, please press the red key on the keyboard with your right hand as quickly and as accurately as possible. If you find a nonword, please press the blue key with your left hand." Twenty-four practice trials were given to participants

Table 3. Mean reaction times and error rates in Experiment 2

Nonword type	Reaction time (ms)	Error rates (%)
Pseudo-homophones	2066 (699)	8.3
Nonwords	2130 (664)	12.0

Figures in parentheses represent standard deviations.

prior to commencement of the actual testing. The practice trial consisted of 12 sentences with no nonword, 6 sentences with a pseudo-homophone, and 6 sentences containing a nonword with no homophony.

Results

Only correct responses were used for the calculation of mean reaction times. Reaction times slower than 10,000 ms were recorded as incorrect responses. Eight items fell into this category (about 0.52% of the total responses of the 24 participants). Before performing the analysis, reaction times more than 2.5 SD above or below a participant's mean were replaced by the boundaries. The mean reaction times and error rates for this task are presented in Table 3. ANOVAs were conducted using both participant (*Fs*) and item (*Fi*) means.

A one-way ANOVA for repeated measures showed no significant difference for detection times of incorrect words in both participant and item means [$Fs(1, 23) = 1.32$, $MSE = 37349.1$, $Fi(1, 94) = 0.02$, $MSE = 144398.9$]. A one-way ANOVA was also conducted for error rates. The result also showed no significant difference for error rates both in participant and item means [$Fs(1, 23) = 0.96$, $MSE = 167.7$, $Fi(1, 94) = 2.07$, $MSE = 0.98$]. Thus, the effects of lexical homophony seem to disappear at the sentence level.

Discussion

Unlike the results from Experiment 1, those from Experiment 2 did not show any homophonic effects on incorrect two-kanji compound words at the sentence level. It was not hard to reject pseudo-homophones compared with nonwords. In addition, the error rate was rather high in the control condition. In this task, participants seemed to take the strategy of only searching for the incorrect kanji pair. Phonological processing might not be required when checking for incorrect words in a sentence. Participants were likely to make errors in incorrect two-kanji compounds because one of the two-kanji was taken from a correct two-kanji compound word. This suggests that participants' judgements depended on orthography. There is the question, however, of whether or not participants were just simply verifying that the combinations of two kanji were correct. In this case, the following experiment was performed in order to see whether the same pseudo-homophones at the sentence level would be as easily detected as nonwords with no homophony when participants are required to semantically process sentences.

Experiment 3: Semantic decision at the sentence level

In Experiment 1, participants found lexical decision of pseudo-homophones more difficult than of nonwords that were not homophones of any real words. However, once the pseudo-homophonic words were embedded in sentences, the effects of pseudo-homophony disappeared as shown in Experiment 2. To ascertain whether or not there actually is phonological involvement in the processing of two-kanji compound words at the sentence level, one further experiment was carried out using the same nonwords. In Experiment 3, real two-kanji compound words were included as part of the stimulus sentences. For example, a stimulus sentence like 向こうに見える大きな建物は、私の知人が<u>設備</u>したものだ /mukoR ni mieru oRkina tatemono wa, watasi no tyijin ga *setubi* shita mono da/ meaning 'The building you can see over there is *facilitated* by my friend' was used including the real two-kanji compound word 設備 /setubi/. It is a real word but in the context of this sentence, it is incorrect. The correct word is 設計 /seQkei/ 'to design'. Including this type of sentences as fillers, participants were required to judge whether each sentence made sense (i.e., a semantic decision task of sentences). This would provide an actual reading situation where comprehension of semantic context would be an essential condition for correct performance on the task. Under this reading condition, phonological involvement was examined.

Method

Participants. Twenty-four graduate and undergraduate students at Hiroshima University participated in the experiment. Average age of participants was 23 years and 4 months. All participants were native Japanese speakers.

Stimuli. The 48 sets of sentences and 16 filler sentences that were used in Experiment 2 were also used in Experiment 3. However, in order to make participants read sentences carefully, nine dummy sentences were added. Although the dummy sentences did not contain nonwords, they did contained two-kanji compound words that did not suit the sentence (see Appendix B). Nine new filler sentences were also added.

Table 4. Mean reaction times and error rates in Experiment 3

Nonword type	Reaction time (ms)	Error rates (%)
Pseudo-homophones	1955 (509)	7.7
Nonwords	2167 (856)	3.6

Figures in parentheses represent standard deviations.

Procedure. All 82 sentences were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of a series of asterisks '∗ ∗ ∗ ∗ ∗ ∗ ∗ ∗ ∗' representing an eye fixation point. Participants were instructed to read the sentences in order to understand their meaning and to respond as quickly and as accurately as possible in deciding whether there was a misspelling in the sentence. If they find a misspelling, they were to press a key on the keyboard with their left hand as quickly and as accurately as possible. If they did not find any misspellings, they were to respond with their right hand. Twenty-four practice trials were given to participants prior to commencement of the actual testing. The twenty-four sentences included 12 correct sentences, 4 sentences that contained a pseudo-homophone, 4 sentences that contained a nonword with no homophony, and 4 dummy sentences that contained a contextually incorrect word. After the practice, the experimenter emphasized that there were dummy sentences, and that participants should read sentences with the purpose to understand.

Results

Only correct responses were used for the calculation of mean reaction times. Reaction times slower than 10,000 ms were recorded as incorrect responses. No items fell into this category. Before performing the analysis, reaction times of more than 2.5 SD above or below a participant's mean reaction time were replaced by the boundaries. The mean reaction times and error rates for the proofreading task are presented in Table 4. ANOVAs were conducted using both participant (Fs) and item (Fi) means.

A one-way ANOVA for repeated measures on semantic decision times indicated a significant difference in both participant and item means [$Fs(1, 23) = 5.99$, $MSE = 89720.9$, $p < 0.05$] and [$Fi(1, 94) = 7.77$, $MSE = 142264.0$, $p < 0.01$]. As shown in the means of semantic decision times, the result was rather unique in that sentences with pseudo-homophones were judged much more quickly than those sentences with embedded nonwords having no lexical homophony. A one-way ANOVA for repeated measures on error rates was also performed. The results showed a significant difference for error rates between sentences with pseudo-homophones and those with nonwords in both participant and item means [$Fs(1, 23) = 6.51$, $MSE = 31.06$, $p < 0.05$, and $Fi(1, 94) = 4.38$, $MSE = 0.608$, $p < 0.05$]. This time, the results were the reverse of those from the semantic decision times. Therefore, sentences with pseudo-homophones were semantically judged more quickly but not as accurately as sentences with nonwords.

Discussion

Experiment 3 indicated very different results from both Experiments 1 and 2. Effects of pseudo-homophones were apparent in semantic decision of sentences. However, results differed in direction of speed versus accuracy. Indeed, pseudo-homophones were likely to help participants use semantic decision more quickly than nonwords with no homophony, however they caused a greater number of mistakes in comparison to sentences with nonwords having no homophony. This result suggests the involvement of phonological processing when reading a sentence for its semantic context, however, it is important to note that participants' strategy in Experiment 3 was different from that of Experiment 2.

General discussion

The purpose of the present study was to examine whether skilled Japanese readers activate phonological information when they read words and sentences and if so, how they do this. In order to answer this question, a lexical decision task of kanji words in Experiment 1, a proofreading task of misspelled words at the sentence level in Experiment 2, and a semantic decision task of sentences in Experiment 3 were conducted. Results were compared in terms of the effects of lexical homophony and are summarized in Table 5.

A homophonic effect of incorrect two-kanji compound words was significant on lexical decision in Experiment 1 and on semantic decision in Experiment 3, but not significant on misspelling detection in Experiment 2. Phonological processing seems to differ depending on whether the type of task is at the lexical or sentence level.

In lexical decision at the word level, participants took longer to reject pseudo-homophones than to reject nonwords. The reason for this is because a pseudo-homophone activates the same phonological information as the

Table 5. Summary of the results in Experiments 1, 2 and 3

	Reaction times	
	Participant analysis	Item analysis
Experiment 1		
Lexical decision	pseudo-homophone > nonword	pseudo-homophone > nonword (marginally)
Experiment 2		
Incorrect-word detection at the sentence level	pseudo-homophone = nonword	pseudo-homophone = nonword
Experiment 3		
Semantic decision of sentences	pseudo-homophone < nonword	pseudo-homophone < nonword
	Error rates	
	Participant analysis	Item analysis
Experiment 1		
Lexical decision	pseudo-homophone = nonword	pseudo-homophone > nonword
Experiment 2		
Incorrect-word detection at the sentence level	pseudo-homophone = nonword	pseudo-homophone = nonword
Experiment 3		
Semantic decision of sentences	pseudo-homophone > nonword	pseudo-homophone > nonword

correct word, and thus causes participants to respond to it as being 'correct'. In order to avoid responding incorrectly, participants have to judge whether this phonological information corresponds to the correct orthography, which results in longer reaction times for pseudo-homophones than for nonwords. In other words, participants who engaged in lexical decision task used phonological information in the verification process at least when the stimuli were unfamiliar. This result supports the suggestion by Wydell, Patterson and Humphreys (1993), and Sakuma et al. (1998) that phonological information is involved in the processing of orthographically similar two-kanji compound words; therefore, dismissing the claim that phonological activation does not occur during reading of Japanese kanji (e.g., Goryo 1987; Nomura 1978, 1979; Saito 1981; Sasanuma 1974; Sasanuma & Fujimura 1972; Sasanuma & Monoi 1975).

Experiment 2 and Experiment 3 included the same sentences to examine the phonological involvement in reading sentences. The results of Experiment 2 suggest that phonological processing of two-kanji compound words is not required in the task of proofreading. Semantic decision at the sentence level in Experiment 3, however, indicates phonological involvement. The difference between these two tasks at the sentence level was whether or not participants were required to understand the meaning of the sentences. Unlike the task in Experiment 3, in Experiment 2, participants only had to decide whether there was an incorrect word in the sentence. In this case, participants seemed to pay attention only to orthography. In fact, it was more efficient to concentrate on mismatched kanji combinations in order to accomplish the proofreading task. Thus, Experiment 2 did not indicate any effects of homophony. It means that participants use an efficient strategy depending on the task types.

In Experiment 3, however, participants were required to understand the meaning of sentences. They seemed to use phonological information to access semantic information. It was the most interesting result in Experiment 3 that responses to pseudo-homophones were faster than to nonwords. Different from Experiment 1, participants could use both phonological information and context information. This context information would help participants to verify the orthographic information with the visual information of the present stimuli. Thus, the verification process might be much faster in the pseudo-homophone condition than that in the control condition.

In addition, the results in Experiment 3 are very interesting in terms of the difference in direction between reaction times and error rates. Concerning reaction time for semantic decision, sentences including pseudo-homophones were rejected faster than sentences with nonwords of simple two kanji combinations, although sentences with pseudo-homophones caused higher error rates than sentences with nonwords. A high error rate means that the response used phonological information and could not be suppressed by orthographic information. In some cases, participants might depend on phonological information strongly, and this led to making errors. It may be the case that context information led to the prediction of the phonological information of the correct word. In this case, verification did not occur using orthographic information but using only phonological information. Thus, the more predictable the contexts are, the more errors were likely to make to pseudo-homophones. Predictability could have influenced the verification process. In summary, pseudo-homophones were likely to help in the understanding of the meaning of the sentences, but they also created difficulties for participants in detecting incorrect kanji combinations embedded in the sentences. The results of reaction times in Experiment 3 are consistent with those of Shimomura and Yokosawa (1991), which also showed that pseudo-homophones are rejected faster than nonwords at the sentence level. However, their study did not display higher error rates as the present study does.

The difference between Experiment 3 and the study by Shimomura and Yokosawa (1991) was the method used to make participants comprehend sentential meaning. The proofreading task used by Shimomura and Yokosawa was followed by a comprehension test, while Experiment 3 in the present study included filler sentences containing real words used incorrectly according to context. The procedure of Experiment 3 would make participants more likely to respond incorrectly to pseudo-homophones. Pseudo-homophones in the sentences activated phonological information and furthermore, brought about activation of orthographic information of correct words. When participants concentrated on semantic decision of the sentences, they were likely to overlook pseudo-words.

In summary, phonological information of two-kanji compound words is activated at the sentence level as well as the lexical level at least when the two-kanji is unfamiliar to the reader. The present study supports the notion that phonological information is activated regardless of script types used as claimed by several studies on the processing of Chinese characters (Perfetti & Zhang 1995; Tan et al. 1995, 1996; Tan & Perfetti 1999). Furthermore, although simple proofreading did not activate phonological information of pseudo-homophones, once semantic decision was required, phonological information of pseudo-homophones was used for semantic understanding which speeded up completion of the semantic decision task, but created greater errors by causing participants to overlook pseudo-homophones of two-kanji compound words.

However, this study used only On-On reading compound words, and required participants to find an incorrect word. This situation is not exactly the same as a natural reading situation. When a Japanese reader encounters an unfamiliar kanji compound, they process the two characters separately. In this case, Japanese readers would activate the On-reading in favor to the Kun-reading. The Kun-reading might be activated only when the On-reading is not appropriate. In normal reading, however, readers process whole two-kanji compound as a unit when they meet a familiar word. In this case, readers would activate the appropriate pronunciation, even if that is Kun-Kun reading. In the future, investigation should be made into more natural reading styles.

Appendix A. Materials in Experiments 1–3

	Correct Word	Experimental	Control
貯金が少ないのは、学生のときに□□したせいだ。	浪費	朗費	削費
後で迷惑がかかるので、人名を□□しない方がよい。	例示	例字	例休
本を読んでいて結末が予測できると、興味が□□する。	半減	犯減	批減
両親は考え方が□□で、よく私と意見が対立する。	古風	古封	古案
成功するためには、□□な意志を持つ必要がある。	強固	教固	戦固
昨日は天気が悪かったが、演奏は□□で行われた。	野外	野害	野福
児童たちを□□しているのは、その学校の先生だ。	引率	因率	血率
道路を渡ろうとしたとたん、信号が□□し始めた。	点滅	典滅	執滅
その事実から、彼は潔白だということが□□できる。	推察	推撮	推粉
若者の服装はよく似ていて、個性が□□している。	埋没	枚没	君没
彼女が礼儀正しいのは、厳格な□□の中で育ったからだ。	家風	華風	均風
彼女は□□ある家の出で、立居ふるまいが上品だ。	由緒	唯緒	亜緒
暖かいので□□して薄着をしたら、風邪をひいた。	油断	油段	油昨
いるかは、言葉を解するほど□□が高いといわれる。	知能	知悩	知借
結婚する友人から、□□を述べるように頼まれた。	祝辞	祝磁	祝胎
彼女は料理は下手だけれども、鋭い□□の持ち主だ。	味覚	味格	味席
列車に乗っていて□□の事故にあったが、軽傷だ。	不慮	府慮	以慮
日本は犯罪が少なく、他の国より□□がいいそうだ。	治安	致安	柄安
幼い頃に別れた□□との再会を求めて、日本に来た。	肉親	肉振	肉装
何年も厳しい修行を積み、ついに悟りの□□に達した。	境地	境遅	境獣
その行為は法律では罰せられないが、□□に反する。	倫理	倫離	倫幅
機械が故障するとは思わず、□□に気づくのが遅かった。	異変	異返	異殺
善悪の□□もつかないような人に、仕事は任せない。	区別	句別	妹別
部長に昇進させるのに、□□な人材が見当たらない。	適当	的当	自当
生徒が決められた□□を守らないと、校風が悪化する。	規則	基則	想則
医者の話には専門の用語が多く、□□できなかった。	理解	理階	理朝
近所に、深夜でも営業している店があって□□だ。	便利	勉利	絡利
彼は有名な先生と□□の関係にある、と自慢した。	師弟	師呈	師僕
多くの食品に、身体に悪いものが□□されている。	添加	展加	首加
子どもの名前をつけるとき、□□の画数を気にした。	姓名	征名	浸名
困難があっても、絶対に逃げないことを□□とする。	信条	信乗	信沈
希望に満ちて留学したのだが、□□の帰国となった。	傷心	傷臣	傷恐
人との接触の回数と好意には、□□があるらしい。	相関	草関	険関
彼は戦場で目ざましい活躍をし、□□と称えられた。	勇士	勇止	勇討
冷静に対応しようとしたが、□□されてかっとなった。	挑発	挑髪	挑誉
幽霊を見た、などの□□な現象を信じている人も多い。	怪奇	悔奇	肪奇
翌日は六時に起きる予定だったので、早めに□□した。	就寝	習寝	暴寝
権力を持つと、それを他人に□□したがる人が多い。	誇示	鼓示	疫示
バイオリンが上達し、今度は□□することになった。	独奏	独総	独公
鉄の製品を放置しておくと、□□してさびてくる。	酸化	酸火	酸私
夜道では、□□するものを身につけておくと安全だ。	発光	発交	発氏
私の故郷ではカキの□□が盛んで、冬に多く出荷される。	養殖	様殖	飛殖
色を識別する□□のしくみは、他の動物にもある。	視覚	詞覚	喪覚
初めてあったときの印象には、□□の影響が大きい。	容姿	要姿	送姿
この計画を成功させる、という重大な□□がある。	使命	使迷	使探
最近の気候が□□なのは、地球が暖かくなったせいだ。	異常	異剰	異肥
その法案は□□を重ねた結果、実施を見送ることになった。	協議	協戯	協覇
政治に関心がなく、□□する政党もない人が多い。	支持	支慈	支扶

Appendix B. Dummy materials in Experiments 3

Sentences involving incorrect word	Correct words
棚を整理し始めたので、部屋じゅうに書類が散歩している。	散乱
彼女の話は非常に聞きやすいが、話し方に独身の癖がある	独特
この飲料は果汁を濃霧しているので、水を加えて飲む。	濃縮
最近の子供は、昔に比べて体質が低下しているらしい。	体力
有名な作品が展示されているが、なかでもこれは絶望だ。	絶品
植物は、日光と水と簡素がないところでは育たない。	酸素
少年の犯罪が増え、家庭での飼育のあり方が問われている	教育
その友人からの連絡がとだえており、休息は不明だ。	消息
この商品を買うと、厳選で豪華な賞品が当たるそうだ。	抽選

Note: In dummy sentences, one incorrect word was involved. The incorrect word was made from "Correct word."

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Address for correspondence: Katsuo Tamaoka, Ph.D., Institute for International Education, Hiroshima University, 1-2, 1-chome, Kagamiyama, Higashi-Hiroshima, 739-8523 Japan
Tel/Fax: +81-824-246288; E-mail: ktamaoka@hiroshima-u.ac.jp