Reading and Writing (2007) 20:413–439
DOI 10.1007/s11145-006-9036-8

Rebounding activation caused by lexical homophony in the processing of Japanese two-kanji compound words

KATSUO TAMAOKA[1]
International Student Center, Hiroshima University, 1-1, 1-chome, Kagamiyama, Higashihiroshima, 739-8523, Japan

Abstract. The present study investigated the effects of lexical homophony on the processing of Japanese two-kanji compound words. Experiment 1 showed that participants took longer to perform lexical decisions for words with a high degree of lexical homophony than those with no homophony. Interestingly, the same inhibitory trend was found in the naming task of Experiment 2. Participants took longer to name words with a high degree of lexical homophony than those with no homophony. The consistency of an inhibitory effect through the two experiments suggests that during naming and lexical decisions for Japanese two-kanji compound words, an orthographic representation activates the phonological representation, which then leads to a *rebounding activation* of orthographic representations of homophonic forms.

Key words: Inhibitory effects, Lexical decision, Lexical homophony, Naming, Rebounding activation

Introduction

Many homophones are found in the Japanese language among two-kanji compound words. The sound /koRka/ (/R/ refers to a moraic long vowel), for example, can be written several ways, such as 硬 貨 ('a coin'), 高 価 ('valuable'), 校 歌 ('a school song'), 効 果 ('effect'), 降 下 ('falling'), 工 科 ('technology'), 高 架 ('a high bridge'), and 硬 化 ('solidification'). These compound words, all having the same sound /koRka/, are often seen in written Japanese and yet have very different meanings. Simultaneous activations of these homophonic words seem not to have any benefits for the performance of lexical decision and naming. Thus, if lexical homophony has an inhibitory effect on cognitive processing, this may suggest that when one of these words is processed, all other orthographic representations of its homophones are activated by its phonological representation without any specific benefit to the task. Consequently, the present study investigated the effects of lexical homophony on the processing of Japanese two-kanji compound words using simple tasks of both lexical decision and naming.

Contradictory Claims on Homophonic Effects

Early studies on homophonic effects were conducted in the English language. Rubenstein, Lewis and Rubenstein (1971) found that the lexical decision times for homophonic words (e.g., 'weak' and 'week') were longer than for nonhomophonic words with the same word frequency (e.g., 'clay,' which has the same word frequency as 'weak'). The study explained that this delay was caused by the process of comparing homophonic words to identify the orthographically appropriate lexical entry. After activating the phonological representation of [wi:k] from the orthographic representation of 'weak,' homophonic words such as 'week' must be activated by the sound [wi:k] in order for an interference effect from the visually-presented homophonic word to occur. This process requires extra orthographic checking time.

Later, multiple studies of word recognition within alphabetic languages indicated phonological involvement during cognitive processing of words (e.g., Coltheart, Patterson, & Leahy, 1994; Lukatela, Lukatela, & Turvey, 1993; Perfetti, Bell, & Delaney, 1988; Pollatsek, Lesch, Morris, & Rayner, 1992; Van Orden, Johnston, & Hale, 1988) and sentence comprehension (e.g., Bosman & de Groot, 1996; Coltheart & Laxon, 1990; Coltheart, Avons, Masterson, & Laxon, 1991). However, findings of these studies done on the processing of the nonalphabetic script of Chinese characters provided fodder for debate on this issue. One group of studies suggested that Chinese native speakers process characters from orthography to meaning without any activation of phonological representations (e.g., Chen, d'Arcais, & Cheung, 1995; Chen, Yung, & Ng, 1988; Hoosain & Osgood, 1983; Peng, Guo, & Zhang, 1985; Tzeng, Hung, & Wang, 1977). On the contrary, another group of studies argued that phonological representations are indeed activated during the processing of Chinese characters without any specific benefit to the task (e.g., Cheng & Shih, 1988; Leck, Weeks, & Chen, 1995; Perfetti & Zhang, 1991, 1995; Perfetti, Zhang, & Berent, 1992; Pollatsek, Tan, & Rayner, 2000; Tan, Hoosain, & Peng, 1995; Tan, Hoosain, & Siok, 1996; Xu, Pollatsek, & Potter, 1999; Zhang & Perfetti, 1993; Zhang, Perfetti & Yang, 1999; Zhou & Marslen-Wilson, 1999a, b). Despite the extensive focus given to phonological involvement in the recognition of Chinese characters and words, only few attempts have been made concerning phonological activity during the processing of Japanese kanji compound words.

Feedback Phonology and Rebounding Activation

In order to discuss the phonological processing of Japanese words, it is essential to look closely at the interaction between phonology and orthography in general. The two-way street model of *feedforward* and *feedback phonology* proposed by Stone, Vanhoy and Van Orden (1997) provides the framework for mapping out such interaction. Their model is unique in that there are no closed loops during lexical processing. According to this concept, a series of activations occurs between orthography and phonology. The visual input of a word activates an orthographic representation, which further serves to activate its phonological representation. This phonological representation, in turn, rebounds to activate additional orthographic representations of lexical homophones. Within the framework of this two-way street phonological processing model, Stone et al. (1997) found that words with a high degree of lexical homophony, which are considered *feedback inconsistent* in mappings from phonology to orthography, display an inhibitory effect. They explained that this effect was produced by the suppression of activated lexical homophonic forms.

The study by Stone et al. (1997) provides an interesting perspective and a processing model for homophonic effects for interpreting the context of the Japanese language. If lexical homophony affects the cognitive processing of words, the following series of activations are hypothesized to take place when applied to Japanese homophones as shown in Figure 1. Since homophonic effects seem to show no benefit for performance of the lexical decision and naming tasks, activations must be generated to be simultaneously distributed within and across the orthographic and phonological lexica, and to some degree, the semantic lexicon. Thus, to describe a series of possible activations for Japanese homophonic words, Figure 1 adapted the parallel distributed processing (PDP) model, depicted for Japanese kanji processing in Ijuin, Fushimi, Patterson and Tatsumi (1999), Ijuin, Fushimi and Tatsumi (2002), and Tamaoka (2005).

The details of homophonic activations are as follows. When 硬貨 meaning 'coin' (one of the orthographic representations for /koRka/) is visually presented to a native Japanese speaker, this visual input activates its orthographic representation, which further raises the activation level of the phonological representation of /koRka/. In turn, this lexical phonology further rebounds to activate lexical orthographic homophones sharing the same sound /koRka/ such as the original input word 硬貨 and other homophones of 高価 ('valuable'), 効果 ('effect'), 硬化 ('solidification') and so on. Since this series of activations starts from orthography to phonology and rebounds back to orthography, this could

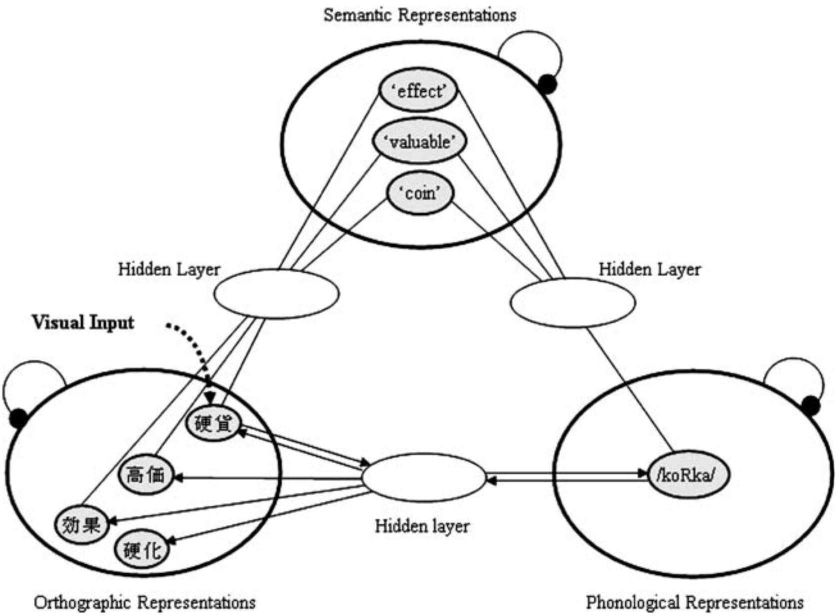

Figure 1. Rebounding activation for Japanese homophonic words.

be hypothetically considered as *rebounding activations*. As such, it is assumed that many lexical homophonic cases displaying the cognitive inclination of *rebounding activations* would be found among Japanese words.

Previous Studies on Homophonic Effects in the Japanese Language

A series of experiments on homophonic effects with Japanese words (Wydell, Patterson, & Humphreys, 1993) was conducted using a semantic categorization task with lexical homophones. In one such experiment, the category name of 'good results' in Japanese was shown to a participant. Following this category, a target homophonic word of either 成 果 ('an achievement,' /seRka/) as a correctly categorized word or the same sound of homophonic word 青 果 ('fruits and vegetables,' /seRka/) as an incorrectly categorized word was presented. Compared to counter stimuli of nonhomophonic words (e.g., 大 臣 'a minister' /daiziN/ or 大 根 'white radish' /daikoN/ for the semantic category of 'a member of the Government'), Wydell et al. (1993) found a significant homophonic effect. The homophonic words showed longer reaction times and higher error rates than the nonhomophonic words. Likewise, they found a significant effect of visual similarity in kanji orthography. Drawing upon both the effects of homophony and orthographic similarity, Wydell et al. suggested that semantic representations of kanji were activated from parallel activations of both orthographic and phonological representations.

The proposal by Wydell et al. (1993) supports homophonic effects at the semantic level. The orthographic representation, 成果 not only raises the activation level of the semantic representation of 'an achievement' but also activates its phonological representation /seRka/. Again, the phonological representation, /seRka/ serves to increase the activation level of semantic representation. At the same time, the phonological representation /seRka/ must rebound to activate a series of orthographic representations that share the same sound, possibly 青 果 ('fruit and vegetables'), 聖 歌 ('a hymn') and 盛 夏 ('high summer'), which in turn activates their semantic representations although their activation levels could be weak. A replication study conducted by Sakuma, Sasanuma, Tatsumi and Masaki (1998) revealed congruent findings.

The studies of Wydell et al. (1993) and Sakuma et al. (1998) found homophonic effects of Japanese two-kanji compound words using a semantic categorization task. In this task, intense activations occur between the orthographic and semantic lexica. A visual input of a word activates its orthographic representation, which further causes its phonological activation and rebounds back to activate multiple orthographic representations of homophonic words sharing the same sound. Since the semantic task requires semantic activations, these homophonic words may also raise activation levels of semantic representations of multiple homophones, which in turn create further intensive inter-activations between the orthographic and semantic lexica, which results in slowing down the processing of lexical items with multiple homophones. It could be also possible that the phonological representation directly raised some activation levels of homophonic words in the semantic lexicon without rebounding back to orthographic representations. However, the semantic categorization task (Sakuma et al., 1998; Wydell et al., 1993) involves an activation process too complex to clearly elucidate exactly what lexical homophony is affecting in word processing. As Stone et al. (1997) explained, homophonic effects display an inhibitory effect mostly during inter-activations between phonology to orthography, with little involvement of semantics. Therefore, the present study utilized a much simpler approach of lexical decision and naming to focus only on this aspect.

Outline of the Present Experiments and their Purpose

The present study required participants to perform a lexical decision task in Experiment 1 and a naming task in Experiment 2, focusing on two-kanji compound words of varying degrees of lexical homophony. In both experiments, it was assumed that *rebounding activation* between orthography and phonology would be in play, with a visual input of a single word activating its orthographic representation, which would further activate its phonological representation and then rebound back to raise the activation levels of orthographic representations of its homophonic words. This series of rebounding activation was expected to have little benefit for performing the tasks of lexical decision and naming. The two experiments together would thus further examine the effects of lexical homophony described above.

Experiment 1: Lexical Decision

Experiment 1 examined whether or not the degree of lexical homophones affects the visual recognition of Japanese two-kanji compound words using the lexical decision task. All words presented to participants had varying degrees of lexical homophony from high to none at all. If the hypothetical concept of *rebounding activation* takes place, the results of this experiment should display an inhibitory effect on the processing of words with a high degree of lexical homophony in comparison to words with no lexical homophony.

Method

Participants

Eighteen graduate and undergraduate students (13 females and 5 males), all native speakers of Japanese, participated in this experiment. Ages ranged from 19 years and 1 month to 27 years and 1 month. The average age was 21 years and 3 months on the day of testing.

Stimulus Items

For the lexical decision task, two types of stimuli (54 real words in total) were selected for the correct 'Yes' responses while three types of stimuli (54 pseudo-words and nonwords in total) were chosen for the correct 'No' responses. A complete description of all types of stimuli is listed in the Appendix. Since there were many influential factors that could have affected the cognitive processing of the stimulus items, careful selection was crucial for Experiments 1 and 2. A detailed list of these factors is provided in Table 1.

Stimulus Items for Correct 'Yes' Responses—Real Words

Stimulus items for correct 'Yes' responses were selected from two-kanji compound words with varying degrees of lexical homophony. The degree of lexical homophony was identified by the number of two-kanji compound words sharing the same pronunciation. Only words constructed of two kanji from *Jooyoo Kanji* (the 1945 basic Japanese kanji) were used in this experiment and evaluated for lexical homophony. Rare words written in kanji beyond the 1945 basic kanji were excluded from the experiment. More than four commonly used words sharing the same sound were regarded as having a high degree of lexical homophony. A counter group, two-kanji compound words with no lexical homophony, was also selected.

As shown in Table 1, the two groups of correct 'Yes' responses were matched across 18 possible factors, which could affect cognitive processing. There were no significant differences in these 18 factors when examined by *t*-tests between nonhomophones and multiple homophones. None of the 18 possible influential factors differed significantly between words with high and no lexical homophones (see *t*-values in Table 1). Thus, none of these factors would affect the findings of the present study. The 18 influential factors are explained in detail below.

(1) *Word frequency* (Amano & Kondo, 2000; National Institute for Japanese Language, 1973) in the influential factors #1 and #2 described in Table 1 (hereafter, factors refer to an item number in Table 1). The word frequency index in 1973 provided an index of word frequency from a total of 1,967,575 words printed in three major Japanese newspapers (*Asahi, Mainichi* and *Yomiuri*) during 1966. According to this index, the two stimulus groups had very similar averages (8.56 occurrences for words with a high degree of lexical homophony and 8.37 occurrences for words with no lexical homophony). Likewise, the word frequency index provided by Amano and Kondo (2000, or CD-ROM version, 2003b) provided no difference between the two groups.

(2) *Familiarity* in the influential factor #3: The database of Amano and Kondo (1999, or CD-ROM version, 2003a) provides a subjective index of word familiarity, measured by asking native speakers to check 1-to-7-point scales. According to Amano and Kondo (1999, 2003a), the mean familiarity for stimulus words with no homophony was 5.52 while the mean of words with multiple homophony was 5.28.

Table 1. Possible influential factors on the processing of two-kanji compound words for Experiments 1 and 2.

Response type	Correct 'Yes' responses		t value of t-test $n = 54$	Correct 'No' responses			Values of t-test or F value of one-way ANOVA $n = 54$
Degree of lexical homophony	Real words			Nonwords		Nonsense-words	
Number of stimuli and examples	None $n = 27$	More than $n = 27$		only one $n = 18$	More than $n = 18$	Random $n = 18$	
# Influential factors	治安/tiaN/	視覚 /sikaku/		写回 /sjakai/	歌 定/katei/	面残	
1. Word frequency (1973)	8.37	8.56	$t = -0.05$	–	–	–	–
2. Word frequency (2000, 2003b)	3028	5894	$t = 0.44$	10855	13730		$t = -0.81$
3. Familiarity (1999, 2003a)	5.52	5.28	$t = 1.79$	–	–	–	–
4. Polysemy	1.52	1.26	$t = 1.72$	–	–	–	–
5. Abstractness versus concreteness	4.32	4.33	$t = -0.03$	4.46	4.61	–	$t = -0.84$
6. Number of morae in stimuli	3.22	3.37	$t = -0.95$	3.50	3.50	3.56	$F = 0.06$
7. Number of strokes to write stimuli	18.59	18.04	$t = 0.51$	19.89	20.17	20.00	$F = 0.02$
8. Single kanji frequency (1976)	1.80	1.88	$t = -0.22$	1.22	1.23	1.24	$F = 0.00$
9. Single kanji frequency (1998)	32469	33327	$t = -0.14$	22457	21522	21470	$F = 0.02$

10.	CD-ROM kanji frequency (1998)	47267	47937	$t = -0.08$	33203	30680	29800	$F = 0.09$
11.	Number of kanji constituents	4.07	4.04	$t = 0.18$	4.33	4.28	4.33	$F = 0.02$
12.	Radical frequency	60.11	50.59	$t = 0.84$	46.22	72.00	55.72	$F = 1.26$
13.	On-reading kanji frequency	1405	1439	$t = -0.11$	916	1041	1069	$F = 0.15$
14.	Kun-reading kanji frequency	1664	1764	$t = -0.32$	1167	1152	1191	$F = 0.01$
15.	On-reading ratio	156.64	165.26	$t = 0.82$	160.71	174.25	170.30	$F = 0.66$
16.	Number of pronunciations	5.15	5.19	$t = 0.89$	4.56	4.50	5.50	$F = 1.82$
17.	Type frequency of kanji lexical productivity	232.44	200.48	$t = 0.56$	132.61	167.44	163	$F = 0.65$
18.	Token frequency of kanji lexical productivity	486.30	436.74	$t = -0.06$	288.11	322.61	351.89	$F = 0.25$

Note 1: Figures from the 7th to 18th factors were calculated for two kanji together.
Note 2: Years of influential factors in the table refer to the sources of lexical and kanji databases. The details are provided in the text and references.
Note 3: Nonwords were not used for the naming task in Experiment 2.
Note 4: None of the *t*-tests indicated significant differences, and none of the ANOVAs showed main effects.

(3) *Polysemy* in the influential factor #4: Some words have multiple meanings which are also known to affect word processing (Hino, Lupker, & Pexman, 2002; Hino, Lupker, Sears, & Ogawa, 1998). Thus, using a Japanese dictionary (Kabashima, Uegaki, Sonoda, & Satake, 1999), a number of meanings were checked for each stimulus. The mean number of meanings for stimulus words with no homophony was 1.52 while the mean of words with multiple homophones was 1.26.

(4) *Abstractness versus concreteness* in the influential factor #5: When presented without context, words representing concrete ideas or concepts are processed faster and more accurately in naming and lexical decision tasks than words representing abstract ideas or concepts (e.g., Bleasdale, 1987; Kroll & Merves, 1986; Schwanenflugel & Shoben, 1983). Because of this, the degree of concreteness and abstractness of each word was controlled in the present study. Words were placed on a 7-point continuum with '7' being labeled as 'very abstract' and '1' as being 'very concrete.' The purpose of this was to test the concreteness (or abstractness) of word meaning. The averages of the abstractness–concreteness scale were 4.33 for the words which had a high degree of lexical homophony and 4.32 for the words which had no homophony.

(5) *Number of morae* in the influential factor #6: The average number of morae contained in the words in each stimulus group was 3.37 morae for words with a high degree of lexical homophony and 3.22 for words with no homophony.

(6) Number of strokes in the influential factor #7: Orthographic complexity has an effect on the processing of Chinese characters (e.g., Leong, Cheng, & Mulcahy, 1987) and Japanese kanji (e.g., Tamaoka & Takahashi, 1999). Thus, the number of strokes needed to write each word was also controlled to within a half-stroke between the two groups, ranging from 18.04 strokes for words with a high degree of lexical homophony to 18.59 strokes for words with no homophony.

(7) *Kanji frequencies* in 1978 and 1998 indicated in influential factors #8 to #10: The frequency of occurrence of kanji in written materials also affects the processing of two-kanji compound words (Tamaoka & Hatsuzuka, 1995). The National Institute for Japanese Language (1976) calculated the frequency of kanji occurrences from the words printed in the *Asahi*, *Yomiuri* and *Mainichi* newspapers during the year 1966. According to this index, the frequency average of two-kanji making up compound words in the present study was kept to a narrow range of 1.88 (per thousand printed kanji) for words with a high degree of lexical homophony and 1.80 (per thousand printed kanji) for words with no homophony. A newer index of kanji frequency was provided by Yokoyama, Sasahara, Nozaki and Long (1998) based on kanji in the

Tokyo edition of the *Asahi* newspaper printed in 1993. Tamaoka, Kirsner, Yanase, Miyaoka and Kawakami (2002) calculated Pearson product-moment correlations to find the relationship between frequency of occurrence of the 1945 basic kanji (n = 1945) for 1966 and 1993. The correlation was r = .969, a figure, which indicates that the frequency of occurrence for printed kanji was stable over the 27-year period from 1966 to 1993. The index for the 1993 version provides actual numbers of kanji occurrence. Yokoyama et al. (1998) also provided kanji frequency calculated from a much larger pool of words taken from 110,000 *Asahi* newspaper articles published in 1993 and stored on CD-ROM. This index showed averages of 47,937 occurrences for words with a high degree of lexical homophony and 47,267 for words with no homophony.

(8) *Number of kanji constituents* in the influential factor #11: A single kanji is often composed of two or more constituents. Tamaoka et al. (2002) provided an actual number of kanji constituents for the 1945 basic Japanese basic kanji. Words with a high degree of lexical homophony showed an average of 4.04 constituents (for both kanji together) while words with no lexical homophony had an average of 4.07.

(9) *Radical frequency* in the influential factor #12: Another particular constituent, known as the radical, has been argued to have an effect on the processing of Japanese kanji (e.g., Leong & Tamaoka, 1995; Saito, 1997; Saito, Masuda, & Kawakami, 1998; Tamai & Abe, 1999) and Chinese characters (e.g., Ho & Bryant, 1997; Ho, Wong, & Chan, 1999; Li & Chen, 1997, 1999; Taft & Zhu, 1997). The index of radical frequency was calculated by counting the number of 1945 basic Japanese kanji, which share the same radical. It was found that approximately 1057 kanji (54.34%) of the 1945 basic kanji are constructed using only 24 radicals out of 214 (Tamaoka et al., 2002; Tamaoka & Makioka, 2004). Radical frequency average was 50.59 for words with a high degree of lexical homophony and 60.11 for words with no lexical homophony.

(10) *On-reading and Kun-reading kanji frequency* in the influential factors #13 to #14: Japanese kanji pronunciation can be divided into two types: On-reading and Kun-reading (see details, Tamaoka, 1991, 2003). Multiple readings of Japanese kanji could affect the processing of two-kanji compound words used in this study (e.g., Kayamoto, Yamada, & Takashima, 1998). Thus, the factors to be controlled were concerned with the phonological effects of kanji reading. The accumulative frequency for kanji with On-readings was calculated by summing the frequency of occurrence as it appeared in the 1966 editions of the *Asahi*, *Mainichi* and *Yomiuri* newspapers (Tamaoka et al., 2002; Tamaoka & Makioka, 2004). Kanji used for proper nouns were excluded from the calculation. The average On-reading frequency was 1439 times for words with a high

degree of lexical homophony and 1405 times for words with no lexical homophony. In the same way as for On-reading frequency, the accumulative frequency of occurrence for kanji with Kun-reading was calculated using the 1976 index of kanji frequency (Tamaoka et al., 2002; Tamaoka & Makioka, 2004). The average Kun-reading frequency was 1764 occurrences for words with a high density of lexical homophony and 1664 for words with no lexical homophony.

(11) *On-reading ratio* in the influential factor #15: The On-reading ratio was calculated by dividing the accumulative On-reading frequency by the accumulative frequency of both On- and Kun-readings added together. The average On-reading ratio was 165.26 for words with a high degree of lexical homophony and 156.64 for words with no lexical homophony.

(12) *Number of pronunciations* in the influential factor #16: A single Japanese kanji usually has more than one pronunciation. Since stimuli in Experiment 1 were all two-kanji compound words, the average number of different pronunciations for each word was calculated using the Database for the 1945 Basic Japanese Kanji (Tamaoka et al., 2002; Tamaoka & Makioka, 2004). The average number of pronunciations was 5.19 for words with a high degree of lexical homophony and 5.15 for words with no lexical homophony.

(13) *Type and token frequencies of kanji lexical productivity* in the influential factors #17 and #18: An index of kanji productivity was provided by Kawakami (1997) and is included in the *Database for the 1945 Basic Japanese Kanji* (Tamaoka et al., 2002; Tamaoka & Makioka, 2004). Kanji lexical productivity refers to the unit of one kanji combined with another to create two-kanji compound words. The average type frequency of kanji lexical productivity was 200.48 for words with a high degree of lexical homophony and 232.44 for words with no lexical homophony. The token frequency of kanji lexical productivity was calculated by summing all word frequencies provided by the National Language Research Institute (1973). The totals of both sides are added together. The average of token frequency was 436.74 for words with a high degree of lexical homophony and 486.30 for words with no lexical homophony.

(14) *Light verb –suru attachment* (not included in Table 1): Many two-kanji compound nouns can be used as a verb by simply adding the light verb *–suru*. However, the light verb cannot be attached to all Japanese nouns. It is assumed that some specific meanings possessed by nouns must determine whether or not the light verb can be attached to them (Iida, 1987; Ito & Sugioka, 2002; Kageyama, 1996; Matsuoka, 2004; Shibatani & Kageyama, 1988; Tamaoka, Matsuoka, Sakai, & Makioka, 2005). Word

with a high degree of homophony had 10 out of 27 items attached a light verb while words with no homophony had 15 out of 27 items. A χ^2-test of independence showed no relation between light verb attachment and homophony [$\chi^2(1) = 1.86, p = .17$].

Stimulus Items for Correct 'No' Responses—Nonwords

For the correct 'No' responses, three types of stimulus items were selected. First, two-kanji nonwords with a high degree of lexical homophony were created. For example, the sound /kateR/ can be written by two kanji morphemes as 課 程 ('a course of study'), 仮 定 ('hypothesis'), 家 庭 ('home') and 過 程 ('process'). To make a nonword with multiple homophones, kanji such as 歌 /ka/ and 定 /teR/ were combined to form 歌 定 /kateR/, which does not orthographically exist in Japanese. Second, nonwords with a single homophone were created by altering real words with no lexical homophony. Changing the individual morphemes of the real word 社 会 /sjakai/ to 写 /sja/ and 回 /kai/ created a new kanji compound, 写 回 /sjakai/. The third category of nonwords was formed by combining two kanji morphemes together which had no orthographic or phonological form similar to real words. Eighteen words in each of these three groups were used as stimuli for the 'No' responses of the lexical decision task. Possible influential factors noted in Table 1 were controlled for the two or the three stimulus conditions of the correct 'No' responses. A series of *t*-tests and ANOVAs on the influential factors conducted to examine their effects for correct 'No' responses found no significant effects. Therefore, all these factors in Table 1 were controlled, meaning that none would interfere with or alter the findings of the present study.

Procedure

Stimuli with both 'Yes' and 'No' correct responses were presented to participants in random order in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 milliseconds after the appearance of an asterisk '*' indicating an eye fixation point. Participants were instructed to respond as quickly and as accurately as possible in deciding whether or not they considered the item to be a word. Response was made by pressing a 'Yes' or 'No' button. Twenty practice trials were given to the participants prior to the commencement of the actual testing.

Analyses and Results

The means of correct 'Yes' and 'No' reaction times and error rates for the lexical decision task are presented in Table 2. Before performing the analysis, reaction times outside of 2.5 standard deviations in both the high and low ranges were replaced by the boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. Only stimulus items of correct responses were used in the analyses of reaction times. The statistical tests which follow analyze both participant (F_1) and item (F_2) variability.

A one-way ANOVA for repeated measures (words with a high degree of lexical homophony versus words with no lexical homophony) was performed on reaction times for the correct 'Yes' responses. Participants made lexical decisions for words with a high degree of lexical homophony 36 milliseconds slower than for words with no lexical homophony. This difference was significant in both participant variability [$F_1(1,17) = 20.25$, $p < .001$] and item variability [$F_2(1,26) = 4.39$, $p < .05$]. An inhibitory effect related to the degree of lexical homophony was observed in performance of the lexical decision task for the correct 'Yes' responses. The same one-way ANOVA for repeated measures was carried out on error rates of the same two stimulus groups. A significant main effect on error rates was also observed in participant variability [$F_1(1,17) = 5.28$, $p < .05$] but not in item variability [$F_2(1,26) = 2.39$, $p = .13$].

A one-way ANOVA for repeated measures of the three different stimulus types (three types of nonwords) was performed on reaction times for lexical decision of the correct 'No' responses. The result indicated no significant main effect on reaction times either in participant variability

Table 2. Means of Reaction times and error rates for lexical decision of two-kanji compound words.

Stimulus type	Degree of lexical homophony	Reaction time (ms)		Error rate (%)
		M	SD	M
Real words	No lexical homophony	676	109	6.4
	A high degree of lexical homophony	712	123	10.1
Nonwords	A single lexical homophone	852	215	11.1
	A high degree of lexical homophony	834	208	14.5
	Random combinations of two kanji	873	234	15.1

Note: A high degree of lexical homophony refers to stimuli with more than 4 lexical homophonies.

[$F_1(2,34) = 3.09$, $p = .08$] or in item variability [$F_2(2,34) = 0.68$, $p = .49$]. The same one-way ANOVA analysis was carried out on error rates. Again, no significant main effect was observed on the error rates either in participant variability [$F_1(2,34) = 1.58$, $p = .22$] or in item variability [$F_2(2,34) = 1.91$, $p = .16$]. The degree of lexical homophony, therefore, had no effect on lexical decision of the correct 'No' responses.

Discussion

The lexical decision task in Experiment 1 indicated an effect of lexical homophony on the processing of real words with 'Yes' responses. A high degree of lexical homophony caused an inhibitory effect on performance of the lexical decision task for Japanese words: real words with a high degree of lexical homophony took longer to process than real words with no lexical homophony. An inhibitory effect of lexical homophony was not observed in the lexical decision of nonwords with a high degree of lexical homophony for the correct 'No' responses. In sum, these findings suggest that during the processing of the two-kanji compound words with a high degree of lexical homophony, orthographic forms sharing the same sound are activated by *rebounding activation* as shown in Figure 1. Activations of orthographic representations of multiple homophones seem to occur without any benefit to performance when deciding upon correct 'Yes' responses. A further investigation on lexical homophony was conducted using the naming task in Experiment 2.

Experiment 2: Naming

Experiment 1 indicated an inhibitory effect of lexical homophony on the processing of real words with 'Yes' responses. Unlike lexical decision, performance of the naming task requires the activation of a phonological representation when pronouncing a visually presented stimulus, but does not necessarily require activating orthographic representations of multiple homophonic words. Thus, the presence of an inhibitory effect related to the degree of lexical homophony is further investigated using the naming task in Experiment 2.

Participants

Eighteen graduate and undergraduate students, all native speakers of Japanese (10 females and 8 males) participated in Experiment 2.

Participants who took part in Experiment 1 were not included in Experiment 2. Ages ranged from 19 years and 8 months to 32 years and 0 months; the average age was 21 years and 7 months on the day of testing.

Stimulus Items

The same stimulus items of Experiment 1 were used for Experiment 2 except for nonwords created by randomly combining two kanji morphemes (see details in Appendix). Two types of nonwords, ones with a high degree of lexical homophony and ones with a single word sound were included in this experiment. Each kanji of these nonwords often has more than one pronunciation, so these two-kanji compound nonwords could be pronounced in multiple ways, which were recorded as correct responses.

Procedure

Stimulus items were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 milliseconds after the appearance of an asterisk '*' indicating an eye fixation point. Specially designed voice key equipment, which makes all inputs electrically high-pitched flat sounds, was used to avoid timing differences of initial sounds, to turn off a reaction time measurement. Participants were instructed to pronounce the items as quickly and as accurately as possible. Twenty practice trials were given to the participants prior to the commencement of the actual testing.

Analyses and Results

The means of latencies for correctly named stimuli and error rates are presented in Table 3. Before performing the analysis, naming latencies outside of 2.5 standard deviations in both the high and low ranges were replaced by the boundaries indicated by 2.5 standard deviations from the individual means of participants in each category. Only stimulus items of correct responses were used in the analyses of naming latencies. The statistical tests which follow analyze both participant (F_1) and item (F_2) variability.

A one-way ANOVA for repeated measures (real words with a high degree of lexical homophony versus real words with no homophony) was conducted on naming latencies. The result of the analysis showed that real

Table 3. Means of naming latencies and error rates for naming two-kanji compound words.

Stimulus type	Degree of lexical homophony	Naming latency (ms)		Error rate (%)
		M	SD	M
Real words	No lexical homophony	670	123	5.1
	A high degree of lexical homophony	706	156	6.0
Nonwords	A single lexical homophony	987	244	27.5
	A high degree of lexical homophony	996	232	25.6

Note: A high degree of lexical homophony refers to stimuli with more than 4 lexical homophonies.

words with a high degree of lexical homophony took a significantly longer time to be named than those with no homophony in both participant variability [$F_1(1,17) = 6.20$, $p < .05$] and item variability [$F_2(1,26) = 4.51$, $p < .05$]. The error ratios indicated no significant difference between the two homophonic conditions in both participant analysis [$F_1(1,17) = 0.43$, $p = .50$] and item analysis [F_2 $(1,26) = 0.14$, $p = .70$]. Taking the results of naming latencies into consideration, one might reasonably deduce that there is an inhibitory effect of lexical homophony on the processing of real words during naming tasks.

It should be noted that the voice key equipment used for Experiment 2 cannot completely guarantee that all initial sounds will be treated equally (e.g., Sakuma, Fushimi, & Tatsumi, 1997; Tamaoka & Hatsuzuka, 1997; Yamada & Tamaoka, 2003). Thus, a post hoc analysis using multiple regression was conducted to predict naming latencies involving three different major initial consonants /k/, /s/ and /t/, because these consonants were used for initial sounds of multiple target lexical items. The results confirmed null effects of these initial consonants. Each of three consonants was treated as a separate variable, recorded ‘1’ if it was an initial sound and recorded ‘0’ if it was not. The results showed that none of these consonants was a significant predictor [$R^2 = .046$; $\beta = .227$, $p = .145$ for /k/; $\beta = .065$, $p = .673$ for /s/; $\beta = -.001$, $p = .995$ for /t/; β refers to a standardized regression coefficient and p refers to probability]. Due to the absence of a significant result, this post hoc analysis was not applied to error rates.

The naming task in Experiment 2 also included nonwords. Nonwords were created by exchanging the two kanji within a real compound word for other kanji, which had the same sounds. The means of naming latencies and error rates are shown in Table 3. A one-way ANOVA for repeated measures was conducted on naming latencies. Unlike the case of real word naming, the results indicated that nonwords with a high degree of lexical homophony were named as fast as those with single homophonic words, as indicated by the analyses of both participant variability [$F_1(1,17) = 0.09$, $p = .76$] and item variability [$F_2(1,26) = 0.64$, $p = .43$]. Again, the same ANOVA was conducted on the error rates of naming nonwords. The error rates indicated no significant difference between the two conditions of lexical homophony in either participant variability [$F_1(1,17) = 0.44$, $p = .52$] or item variability [$F_2(1,26) = 0.06$, $p = .81$]. Consequently, the degree of lexical homophony had no effect on the naming of nonwords. Since no significant results were found, a post hoc analysis of a multiple regression was not conducted for naming of nonwords.

Discussion

As predicted by the results from the lexical decision task in Experiment 1, the naming task indicated an inhibitory effect on the cognitive processing of real words. Real words with a high degree of lexical homophony took longer to name than real words with no lexical homophony. Therefore, the results of the naming task in Experiment 2 as well as those of Experiment 1 support the processing model of *rebounding activation* between orthography and phonology, as depicted in Figure 1.

General Discussion—Evaluating the Concept of Rebounding Activation

As described in Figure 1, the present study investigated *rebounding activation* between orthography and phonology at the lexical level created by the lexical homophony of two-kanji compound words.

The lexical decision task in Experiment 1 showed that lexical homophony displays an inhibitory effect on the cognitive processing of real words. Real words with a high degree of lexical homophony take longer to be processed for lexical decision than real words with no lexical homophony. Furthermore, Experiment 2 used the naming task to investigate the homophonic effect since this task only requires an activation of a phonological representation to create phonological output. Again, an inhibitory effect of lexical homophony was observed in the naming performance. Thus, Experiments 1 and 2 clearly demonstrated an inhibitory effect of lexical homophony through both lexical decision and naming tasks for real words. As depicted in Figure 1, a visually presented word (i.e., visual input) generates an activation of an orthographic representation, which further activates its phonological representation. In turn, the phonological representation rebounds to generate a series of orthographic representations of lexical homophones. As such, the consistent results of both Experiments 1 and 2 supported the proposed model of *rebounding activation*.

The present experiments controlled for semantic aspects of target two-kanji compound words as shown in Table 1, and especially for possible major factors of polysemy and abstract–concreteness. However, this stimulus control of semantic aspect does not eliminate the possibility of activations of semantic representations in the processing of two-kanji compound words in Experiments 1 and 2. As previous studies in the Chinese language suggested (e.g., Perfetti, Liu, & Tan, 2005; Perfetti & Tan, 1998, 1999; Tan, Spinks, Eden, Perfetti, & Siok, 2005), three inter-linked constituents among orthography, phonology and semantics take place in Chinese word identification. In addition, using functional magnetic resonance imaging (fMRI), Siok, Perfetti, Jin and Tan (2004) found that reading impairment in the Chinese language is related to two aspects of orthography-to-syllable conversion and orthography-to-semantics mapping. Although these studies were conducted in recognition of Chinese words, this finding is readily applicable to Japanese word processing. The present study also assumes that semantic representations are initiated by rebounding activation. As shown in Figure 1, a visual input of 硬 貨 activates both phonological and semantic representations. The phonological representation of /koRka/ rebounds back to activate multiple orthographic representations sharing the same sound, which further activates the semantic representations of 'effect,' 'valuable,' 'coin' and so on. As with Chinese two-character compound words, the present study also predicts rich activations of semantic representations in Japanese two-kanji compound words sharing the same sound /koRka/. However, since the present study focused on the phonological perspective of Japanese homophonic words by controlling semantic characteristics of target stimuli, semantic activation was not considered in the present study.

The present study demonstrated an inhibitory effect similar to that shown in previous studies by Wydell et al. (1993) and Sakuma et al. (1998). Homophonic effects, however, were expected to interfere with the task performance when orthographic representations of multiple homophonic words were simultaneously activated via the original stimuli of phonological activation. Since these studies used the semantic categorization task to produce intense activations between the orthographic and semantic lexica, the inhibitory effect can be seen to involve a complex process, which renders it difficult to clarify the actual mechanism through which lexical homophony affects word processing. The present study utilized a much simpler but more informative approach of lexical decision and naming to determine the extent and nature of homophonic effects. The major contribution of the present study is the clear demonstration of a *rebounding activation* phenomenon between orthography and phonology in the processing of homophonic words.

While focusing on the processing of Chinese two-character words, Perfetti and Tan (1999) discovered that phonological activation was involved in a meaning-judgment task in their first experiment, and a lexical decision task with manipulation of phonological consistency in their second experiment. The lexical decision task, which was also utilized in Experiment 1 of the present study, revealed that phonologically inconsistent words required more time to make lexical decisions than consistent words. Therefore, as these authors noted, phonology seems to be 'an obligatory constituent' of word identification in both Chinese and Japanese.

In contrast to the processing of real words, a closer inspection of the processing of nonwords in the lexical decision task in Experiment 1 and the naming task in Experiment 2 indicated no inhibitory effect of lexical homophony. Nonwords with a single lexical homophony were rejected or named as quickly and accurately as nonwords with a high degree of lexical homophony. Likely explanations for this result may be as follows. For the lexical decision task, the combining of two kanji did not result in any real word so that participants simply made a 'No' lexical decision. Likewise, for the naming task, participants simply sounded nonwords by choosing the most common pronunciations of each of two kanji without much reference to lexical unit. As indicated by 26.55% overall error rates, naming for nonwords was quite difficult since each kanji has multiple pronunciations which cannot be identified without making such reference. As such, it is quite possible that lexical orthographic representations might be accessed as a whole word, and not a separate kanji morpheme.

Error rates seem to display a discrepancy between lexical decision and naming even though stimulus words were identical for both tasks. Error rates for real words with no lexical homophony were similar at 6.4% for lexical decision and 5.1% for naming to those for real words with a higher degree of lexical homophony, at 10.1% for lexical decision and 6.0% of naming. Since participants have to perform using activation of orthographic representations for lexical decision, multiple activations of orthographic representations caused by *rebounding activation* of homophonic words interfered with the performance of lexical decision. On the contrary, as naming only required the use of phonology for actual output, the homophonic interference on naming was not as strong as it was on lexical decision.

While Experiments 1 and 2 of the present study appear to offer clear evidence to support the concept of *rebounding activation*, there are three additional—yet not unrelated—explanations for the inhibitory effects of homophones. The first explanation is *fan effects*. Since multiple activations of orthographic representations regarding lexical homophony took place simultaneously, a total activation also extends to multiple homophonic items, becoming diffuse in the process. As a result, each lexical item including the target word cannot receive a strong activation, prolonging the task performance. However, even allowing for *fan effects*, orthographic representations of homophonic words should be activated, most probably via phonological activation of the visual input, which bounces back to activate multiple orthographic representations of homophonic items. Thus, the observation of *fan effects* actually depends upon *rebounding activation*.

The second possible explanation is *strategy effects of post lexical access*. As an explanation for homophonic words used by Rubenstein, Lewis and Rubenstein (1971), activation of the pronunciation of the target word ‘weak’ [wi:k] further rebounded to activate a homophonic word ‘week.’ Thus, participants are required to have extra orthographic checking time, to avoid confusing ‘weak’ with ‘week.’ Again, this orthographic checking strategy after lexical access would be necessary because multiple orthographic representations were activated by the *rebounding activation* of lexical homophony. While the present study cannot clearly identify when homophonic effects take place, this explanation of post lexical access strategy does not deny the occurrence of *rebounding activation*.

The third possible explanation is *direct semantic activation*. The phonological representation of a target word having a high degree of lexical homophony further activates a series of semantic representations sharing the same sound. In other words, a single sound like /koRka/ in Figure 1, activates homophonic items with meanings such as ‘valuable,’ ‘effect’ and ‘solidification,’ in addition to the meaning of the initially inputted word ‘coin.’ Multiple semantic activations slow down the task performance for words with many homophones. This process is quite likely to occur, especially when the semantic categorization task is used for experiments such as those conducted by Wydell et al. (1993) and Sakuma et al. (1998). For this reason, Figure 1 of the present study included the possibility of semantic activations in homophonic effects. However, rather than focusing upon the involvement of semantic activations, the present study used simple lexical decision and naming tasks to determine that *rebounding activation* does in fact occur between orthography and phonology in the processing of homophonic words.

Acknowledgement

The present study is supported by the Research Institute of Science and Technology for Society (RISTEX) at the Japan Science and Technology Agency (JST), Kawaguchi, Japan. The principle recipient of this grant is Dr. Hiroko Hagiwara at the Tokyo Metropolitan University, Japan.

Appendix

Stimuli Used in Experiments 1 and 2

1. Correct 'Yes' responses

1.1 Real words with no lexical homophony

浪 費 /roR hi/	例 示 /rei zi/	半 減 /haN geN/	古 風 /ko huR/
強 固 /kjoR ko/	野 外 /ja gai/	引 率 /iN sotu/	点 滅 /teN metu/
家 風 /ka huR/	埋 没 /mai botu/	推 察 /sui satu/	由 緒 /jui sjo/
油 断 /ju daN/	知 能 /ti noR/	祝 辞 /sjuku zi/	異 変 /i heN/
不 慮 /hu rjo/	治 安 /ti aN/	肉 親 /niku siN/	境 地 /kjoR ti/
倫 理 /riN ri/	味 覚 /mi kaku/	区 別 /ku betu/	適 当 /teki toR/
規 則 /ki soku/	理 解 /ri kai/	便 利 /beN ri/	

1.2 Real words with a high degree of lexical homophony

師 弟 /si tei/	添 加 /teN ka/	姓 名 /sei mei/	信 条 /siN zjoR/
傷 心 /sjoR siN/	相 関 /soR kaN/	勇 士 /juR si/	好 感 /koR kaN/
挑 発 /tjoR hatu/	怪 奇 /ki kai/	就 寝 /sjuR siN/	誇 示 /ko zi/
独 奏 /doku soR/	再 考 /sai koR/	養 殖 /joR sjoku/	視 覚 /si kaku/
酸 化 /saN ka/	下 降 /ka koR/	起 床 /ki sjoR/	発 光 /haQ koR/
容 姿 /joR si/	計 器 /kei ki/	刊 行 /kaN koR/	使 命 /si mei/
異 常 /i zjoR/	協 議 /kjoR gi/	支 持 /si zi/	

2. Correct 'No' responses

2.1 Nonwords prounced as a real word with no homophony

結 違 /ketu i/	準 頂 /zjuN tjoR/	准 除 /zjuN zjo/	写 回 /sja kai/
洗 殖 /seN sjoku/	銅 得 /doR toku/	雲 名 /uN mei/	約 真 /jaku siN/
危 販 /ki haN/	預 優 /jo juR/	私 近 /si kiN/	改 酪 /kai raku/
封 系 /huR kei/	半 邸 /haN tei/	呼 締 /ko tei/	務 更 /mu koR/
憶 街 /oku gai/	句 身 /ku siN/		

2.2 Nonwords with a high degree of lexical homophony

委 紙 /i si/	影 聖 /ei sei/	懐 宝 /kai hoR/	歌 定 /ka tei/
拡 浸 /kaku siN/	汗 商 /kaN soR/	貴 正 /ki sei/	記 感 /ki kaN/
抗 停 /koR tei/	臣 張 /siN tjoR/	資 要 /si joR/	士 坑 /si koR/
宗 幹 /sjuR kaN/	次 耐 /zi tai/	退 招 /tai sjoR/	道 陽 /doR joR/
偏 震 /heN siN/	舗 消 /ho sjoR/		

2.3 Nonwords with random kanji combinations

面 残	満 蓄	疎 版	独 対
背 弦	班 値	眼 外	産 増
老 勤	威 劇	案 表	必 媒
砂 痛	利 刷	差 絶	経 借
滋 温	貧 転		

Note: The naming task in Experiment 2 used real words in 1.1 and 1.2, and nonwords in 2.1 and 2.2. Nonsense-words with random kanjicombinations were excluded from Experiment 2.

References

Amano, N., & Kondo, K. (1999). *Nihongo-no goi tokusei Vol. 1-6 [Lexical properties of Japanese—Vol. 1–6]*. Tokyo: Sanseido (In Japanese).

Amano, N., & Kondo, K. (2000). *Nihongo-no goi tokusei Vol. 7 [Lexical properties of Japanese—Vol. 7]*. Tokyo: Sanseido (In Japanese).

Amano, N., & Kondo, K. (2003a). *Nihongo-no goi tokusei—Dai-1-ki CD-ROM-ban [Lexical properties of Japanese—The first volume of CD-ROM verson]*. Tokyo: Sanseido (In Japanese).

Amano, N., & Kondo, K. (2003b). *Nihongo-no goi tokusei—Dai-2-ki CD-ROM-ban [Lexical properties of Japanese—The second volume of CD-ROM verison]*. Tokyo: Sanseido (In Japanese).

Bleasdale, F.A. (1987). Concreteness-dependent associative priming: Separate lexical organization for concrete and abstract words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *13*, 582–594.

Bosman, A.M.T., & de Groot, A.M.B. (1996). Phonological mediation is fundamental to reading: Evidence from beginning readers. *Quarterly Journal of Experimental Psychology*, *49A*, 715–744.

Chen, H.-C., d'Arcais, G.B., & Cheung, S.-L. (1995). Orthographic and phonological activation in recognizing Chinese characters. *Psychological Research*, *58*, 144–153.

Chen, M.-J., Yung, Y.-F., & Ng, T.-W. (1988). The effect of context on the perception of Chinese characters. In I.M. Liu, H.-C. Chen & M.-J. Chen (Eds.), *Cognitive aspects of the Chinese language* (pp. 27–39). Vol. 1 Hong Kong: Asian Research Service.

Cheng, C.-M., & Shih, S.-I. (1988). The nature of lexical access in Chinese: Evidence from experiments on visual and phonological priming in lexical judgment. In I.M. Liu, H.-C. Chen & M.-J. Chen (Eds.), *Cognitive aspects of the Chinese language* (pp. 1–14). Vol. 1 Hong Kong: Asian Research Service.

Coltheart, V., Avons, S.E., Masterson, J., & Laxon, V.J. (1991). The role of assembled phonology in reading comprehension. *Memory & Cognition*, *19*, 387–400.

Coltheart, V., & Laxon, V.J. (1990). The development of phonological mediation in reading comprehension. *Language and Cognitive Processes*, *5*, 81–104.

Coltheart, V., Patterson, K., & Leahy, J. (1994). When a rows is a rose: Phonological effects in written word comprehension. *Quarterly Journal of Experimental Psychology*, *47A*, 917–955.

Hino, Y., Lupker, S.L., & Pexman, P.M. (2002). Ambiguity and synonymy effects in lexical decision, naming, and semantic categorization tasks: Interactions between orthography, phonology, and semantics. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *28*, 686–713.

Hino, Y., Lupker, S.L., Sears, C.R., & Ogawa, T. (1998). The effects of polysemy for Japanese katakana words. *Reading and Writing*, *10*, 395–424.

Ho, C.S.-H., & Bryant, P. (1997). Learning to read Chinese beyond the logographic phase. *Reading Research Quarterly*, *32*, 276–289.

Ho, C.S.-H., Wong, W.-L., & Chan, W.-S. (1999). The use of orthographic analogies in learning to read Chinese. *Journal of Child Psychology and Psychiatry*, *40*, 393–403.

Hoosain, R., & Osgood, C.E. (1983). Information processing times for English and Chinese words. *Perception and Psychophysics*, *34*, 573–577.

Iida, M. (1987). Case-assignment by nominals in Japanese. In M. Iida, S. Wechsler & D. Zec (Eds.), *Working papers in grammatical theory and discourse structure: Interactions of morphology, syntax, and discourse* (pp. 93–138). Stanford, CA: CSLI.

Ijuin, M., Fushimi, T., Patterson, K., & Tatsumi, I. (1999). A connectionist approach to Japanese kanji word naming. *Psychologia*, *42*, 267–280.

Ijuin, M., Fushimi, T., & Tatsumi, I. (2002). Neural network-ni okeru kanji-go ondoku-no model [A simulation study for naming Japanese kanji words using an attractor network. *Cognitive Studies*, *9*, 187–199 (In Japanese).

Ito, T., & Sugioka, Y. (2002). *Go no shikumi to go keisei [Functions of words and their formation]*. Tokyo: Kenkyuusha.

Kabashima, T., Uegaki, S., Sonoda, F., & Satake, H. (Eds.) (1999). *Fukutake Kokugo Jiten [Fukutake Japanese Dictionary]*. Toppan Insatsu, Tokyo.

Kageyama, T. (1996). *Dooshi imi ron [Theory of verb semantics]*. Tokyo: Kuroshio Shuppan.

Kawakami, M. (1997). JIS 1-shu kanji 2,965-ji o mochiite sakusei sareru kanji niji jukugoshu-hyo [Tables of the numbers of two-kanji compound words constructed with 2,965 JIS 1st kanji characters]. *Bulletin of the School of Education at Nagoya University*, *44*, 243–299. (In Japanese).

Kayamoto, Y., Yamada, J., & Takashima, H. (1998). The consistency of multiple-pronunciation effects in reading: The case of Japanese logographs. *Journal of Psycholinguistic Research*, *27*, 19–637.

Kroll, J.F., & Merves, J.S. (1986). Lexical access for concrete and abstract words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *12*, 2–107.

Leck, K.J., Weeks, B.S., & Chen, M.-J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese reading. *Memory & Cognition*, *23*, 68–476.

Leong, C.K., Cheng, P.-W., & Mulcahy, R. (1987). Automatic processing of morphemic orthography. *Language and Speech*, *30*, 81–196.

Leong, C.K., & Tamaoka, K. (1995). Use of phonological information in processing kanji and katakana by skilled and less skilled Japanese readers. *Reading and Writing*, *7*, 77–393.

Li, H., & Chen, H.-C. (1997). Processing of radicals in Chinese character recognition. In H.-C. Chen (Ed.), *Cognitive processing of Chinese and related Asian languages* (pp. 141–160). Hong Kong: Chinese University Press.

Li, H., & Chen, H.-C. (1999). Radical processing in Chinese character recognition: Evidence from lexical decision. *Psychologia*, *42*, 199–208.

Lukatela, G., Lukatela, K., & Turvey, M.T. (1993). Further evidence for phonological constraints on visual lexical access: TOWED primes FROG. *Perception and Psychophysics*, *53*, 461–466.

Matsuoka, C. (2004). Fukugoodooshi –suru o keiseisuru kango meishi ni tsuite [Sino-Japanese nouns used in –suru compounds]. *Nihongo Kyooiku [Journal of Japanese Language Teaching]*, *120*, 13–22. In Japanese.

National Institute for Japanese Language [Kokuritsu Kokugo Kenkyuujo] (1973). *Shinbun no goi choosa (IV) [A study of Japanese word usage in newspapers]*. Tokyo: National Language Research Institute In Japanese.

National Institute for Japanese Language [Kokuritsu Kokugo Kenkyuujo] (1976). *Gendai shinbun no kanji [A study of the usage of Japanese kanji characters in modern newspapers]*. Tokyo: National Language Research Institute In Japanese.

Peng, D.-L., Guo, D.J., & Zhang, S.L. (1985). The retrieval of information of Chinese characters in making similarity judgments under recognition condition. *Acta Psychologica Sinica*, *3*, 277–324.

Perfetti, C.A., Bell, L., & Delaney, S. (1988). Automatic phonetic activation in silent word reading: Evidence for backward masking. *Journal of Memory and Language*, *27*, 59–70.

Perfetti, C.A., Liu, Y., & Tan, L.-H. (2005). The lexical constituency model: Some implications of research on Chinese for general theories of reading. *Psychological Review*, *112*, 43–59.

Perfetti, C.A., & Tan, L.-H. (1998). Phonological codes as early sources of constraint in Chinese word identification: A review of current discoveries and theoretical accounts. *Reading and Writing*, *10*, 165–200.

Perfetti, C.A., & Tan, L.-H. (1999). Phonological activation in visual identification of Chinese two-character words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 382–393.

Perfetti, C.A., & Zhang, S.-L. (1991). Phonological processes in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 633–643.

Perfetti, C.A., & Zhang, S.-L. (1995). Very early phonological activation in Chinese reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 24–33.

Perfetti, C.A., Zhang, S.-L., & Berent, I. (1992). Reading in English and Chinese: Evidence for a 'Universal' phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology and meaning* (pp. 227–248). Amsterdam: Elsevier.

Pollatsek, A., Lesch, M., Morris, R.K., & Rayner, K. (1992). Phonological codes are used in integrating information across saccades in word recognition and reading. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 148–162.

Pollatsek, A., Tan, L.H., & Rayner, K. (2000). The role of phonological codes in integrating information across saccadic eye movements in Chinese character identification. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 607–633.

Rubenstein, H., Lewis, S.S., & Rubenstein, M.A. (1971). Evidence for phonemic reading in visual word recognition. *Journal of Verbal Learning and Verbal Behavior*, *10*, 647–657.

Saito, H. (1997). Shinteki jisho [Mental lexicon]. In Y. Ohtsu & T. Gunji (Eds.), *Linguistic Sciences* (pp. 93–153). Vol. 3 Tokyo: Iwanami Shoten (in Japanese).

Saito, H., Masuda, H., & Kawakami, M. (1998). Form and sound similarity effects in kanji recognition. In C.K. Leong & K. Tamaoka (Eds.), *Cognitive processing of the Chinese and the Japanese languages* (pp. 169–203). London: Kluwer Academic Publishers.

Sakuma, N., Fushimi, T., & Tatsumi, I. (1997). Onseiha no shisatsu-ni yoru kana no ondokusenji no sokutei—Ondokusenji-wa gotooon no choo'onhoo niyori ookiku kotonaru-ka [Naming latency measurement by visual inspection of sound wave forms]. *Shinkei Shinrigaku [Neuropsycholgy]*, *13*, 126–136.

Sakuma, N., Sasanuma, S., Tatsumi, I., & Masaki, S. (1998). Orthography and phonology in reading Japanese kanji words: Evidence from the semantic decision task with homophones. *Memory & Cognition*, *26*, 75–87.

Schwanenflugel, P.J., & Shoben, E.J. (1983). Differential context effects in the comprehension of abstract and concrete verbal materials. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *9*, 82–102.

Shibatani, M., & Kageyama, T. (1988). Word formation in a modular theory of grammar: Postsyntactic compounds in Japanese. *Language*, *63*, 451–484.

Siok, W.T., Perfetti, C.A., Jin, Z., & Tan, L.H. (2004). Biological abnormality of impaired reading is constrained by culture. *Nature*, *431*, 71–76.

Stone, G.O., Vanhoy, M., & Van Orden, G.C. (1997). Perception is a two-way street: Feedforward and feedback phonology in visual word recognition. *Journal of Memory and Language*, *36*, 337–359.

Taft, M., & Zhu, X.P. (1997). Sub-morphemic processing in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *23*, 761–775.

Tamai, M., & Abe, J. (1999). Michi no kanji no 'yomi' ni taisuru bushu to sono ichi no kooka [The effect of radicals and their spatial locations when reading pseudo-kanji]. *Proceedings of the 63rd Japanese Conference of Psychology*, 459 (In Japanese).

Tamaoka, K. (1991). Psycholinguistic nature of the Japanese orthography. *Studies in Language and Literature (Matsuyama University)*, *11*, 49–82.

Tamaoka, K. (2003). Where do statistically-driven indicators and human strategies meet when identifying On- and Kun-readings of Japanese kanji?. *Cognitive Studies*, *10*, 1–28.

Tamaoka, K. (2005). Meimei kadai-ni oite kanji 1-ji no shoji to on'in no tan'i wa itti suruka [Is an orthographic unit of a single Japanese kanji equivalent to a kanji phonological unit in the naming task?. *Cognitive Studies*, *12*, 47–73 (In Japanese).

Tamaoka, K., & Hatsuzuka, M. (1995). Kanji niji jyukugo no shori ni okeru kanji shiyoo hindo no eikyoo [The effects of Kanji printed-frequency on processing Japanese two-morpheme compound words]. *The Science of Reading*, *39*, 121–137 (In Japanese).

Tamaoka, K., & Hatsuzuka, M. (1997). Hiranaga to katakana no shori-ni okeru kankaku benbetsu oyobi kankaku shikibetu kinoo [Sense-discriminative and sense-determinative functions in the processing of Japanese hiragana and katakana]. *The Science of Reading*, *41*, 15–28 (In Japanese).

Tamaoka, K., Kirsner, K., Yanase, Y., Miyaoka, Y., & Kawakami, M. (2002). A web-accessible database of characteristics of the 1,945 Japanese basic kanji. *Behavior Research Methods, Instruments and Computers*, *34*, 260–275.

Tamaoka, K., & Makioka, S. (2004). New figures for a Web-accessible database of the 1,945 basic Japanese kanji, fourth edition. *Behavior Research Methods, Instruments & Computers*, *36*, 548–558.

Tamaoka, K., Matsuoka, C., Sakai, H., & Makioka, S. (2005). Predicting attachment of the light verb –suru to Japanese two-kanji compound words using four aspects. *Glottometrics*, *10*, 73–81.

Tamaoka, K., & Takahashi, N. (1999). Kanji niji jukugo no shoji koodoo ni okeru goi shiyoo hindo oyobi shoji-teki fukuzatu-sei no eikyoo [The effects of word frequency and orthographic complexity on the writing process of Japanese two-morpheme compound words]. *Japanese Journal of Psychology*, *70*, 45–50 (In Japanese).

Tan, L.-H., Spinks, J.A., Eden, G.F., Perfetti, C.A., & Siok, W.T. (2005). Reading depends on writing, in Chinese. *Proceedings of the National Academy of Sciences of the United States of America (PNAS)*, *102*, 8781–8785.

Tan, L.-H., Hoosain, R., & Peng, D.-L. (1995). Role of pre-semantic code in Chinese character recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 43–54.

Tan, L.-H., Hoosain, R., & Siok, W.W.T. (1996). The activation of phonological codes before access to character meaning in written Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 865–883.

Tzeng, O.J.L., Hung, D.L., & Wang, W.S.-Y. (1977). Speech recording in reading Chinese characters. *Journal of Experimental Psychology: Human Memory & Learning*, *3*, 621–630.

Van Orden, G.C., Johnston, J.C., & Hale, B.L. (1988). Word recognition in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*, 371–385.

Wydell, T.N., Patterson, K.E., & Humphreys, G.W. (1993). Phonologically mediated ccess to meaning for kanji: Is a rows still a rose in Japanese Kanji?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 491–514.

Xu, Y., Pollatsek, A., & Potter, M.C. (1999). The activation of phonology during silent Chinese word reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 838–857.

Yamada, J., & Tamaoka, K. (2003). Measurement errors in voice-key naming latency for hiragana. *Perceptual and Motor Skills*, *97*, 1100–1106.

Yokoyama, S., Sasahara, H., Nozaki, H., & Long, E. (1998). *Shinbun denshi media no kanji—Asahi shinbun CD-ROM niyoru kanji hindo hyoo [Japanese kanji characters in the newspaper media—Kanji printed-frequency index of Asahi newspaper on CD-ROM]*. Tokyo: Sanseidoo (In Japanese).

Zhang, S., & Perfetti, C.A. (1993). The tongue twister effect in reading Chinese. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1082–1093.

Zhang, S., Perfetti, C.A., & Yang, H. (1999). Whole word, frequency-general phonology in semantic processing of Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 858–875.

Zhou, X., & Marslen-Wilson, W. (1999a). Phonology, orthography, and semantic activation in reading Chinese. *Journal of Memory and Language*, *41*, 579–606.

Zhou, X., & Marslen-Wilson, W. (1999b). The nature of sublexical processing in reading Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 819–837.

Address for correspondence: Katsuo Tamaoka, International Student Center, Hiroshima University, 1-1, 1-chome, Kagamiyama, Higashihiroshima, 739-8523, Japan
Phone: +82-424-6288; Fax: +82-424-6288; E-Mail: ktamaoka@hiroshima-u.ac.jp