Reading and Writing: An Interdisciplinary Journal **10:** 293–322, 1998.
C.K. Leong & K. Tamaoka (eds.), Cognitive Processing of the Chinese and the Japanese Languages, pp. [139–168]

The effects of morphological semantics on the processing of Japanese two-kanji compound words

KATSUO TAMAOKA[1] & MAKIKO HATSUZUKA[2]
[1]*Hiroshima University, Japan;* [2]*Nagoya Ryujo College, Japan*

Abstract. The present study investigated the way in which the activation of semantic representations at the morpheme level affects the processing of two-kanji (morpheme) compound words. Three types of Japanese two-kanji compound words were used as stimulus items: (1) words consisting of two kanji representing opposite concepts (e.g., 長 long + 短 short = length), (2) words consisting of two kanji representing similar concepts (e.g., 柔 soft + 軟 flexible = pliable), and (3) control words consisting of two closely bound kanji (e.g., 荒 wild + 野 field = wilderness). Words consisting of kanji of opposite concepts (M = 768 ms for LD and M = 645 ms for naming) were processed more slowly for lexical decision, but not for naming, than words with kanji of similar concepts (M = 743 ms for LD and M = 636 ms for naming), both of which were, furthermore, processed more slowly for lexical decision and naming than the control compound words (M = 716 ms for LD and M = 590 ms for naming). These results were explained in the framework of the multiple-level interactive-activation model as follows. Because kanji morphemes of opposite and similar concepts are semantically activated both as morpheme units and compound word units, semantic representations of the two morphemes and the compound word which they create compete with each other at the concept level, which slows down lexical decision and naming of the compound word.

Key words: Morphological semantics, Multiple-level interactive activation, Processing of Japanese two-kanji compound words, Semantic representations

Introduction

Because relatively few Japanese kanji morphemes are used to produce the various compound words in the Japanese language, it is not particularly difficult to guess the overall meanings of these compound words from one's basic knowledge of kanji. For example, the word 'euthanasia' which, in English, is derived from Greek ('eu' easy, and 'thanatos' death) is presented by three kanji as 安楽死. In Japanese schools, these characters are taught during the early years: the first kanji, 安 meaning 'peaceful' is taught in Grade 3, the second kanji, 楽 meaning 'comfort' in Grade 2, and the third kanji, 死 meaning 'death' in Grade 3. Thus, although they may not be familiar with the word euthanasia, Grade 3 students can gain some idea of its meaning by semantically combining three kanji morphemes, 'peaceful comfort death'. If this process is used, morphological semantics, as well as the meaning of the whole word, must be activated during the processing of compound words. The present study investigated the involvement of morphological semantics in the processing of morphologically compound words in the Japanese language.

Statistical figures on Japanese kanji support the likelihood of morphological activations while a whole compound word is processed. First, approximately 70 percent of the 51,962 words listed in a Japanese dictionary are compound words constructed by two kanji morphemes (Yokosawa & Umeda 1988). Second, a total of 3000 kanji encompasses 99.9 percent of the printed kanji in Japanese written materials (Kaiho & Nomura 1983). Combining these two figures, one can estimate that roughly 3000 kanji morphemic units are used to create approximately 70 percent of the words found in a Japanese dictionary.

Evidence for morphological activation during the processing of compound words was shown in the effect of morphemic frequency by studies of English (e.g., Andrews 1996; Taft & Forster 1975, 1976), Chinese (e.g., Taft, Huang & Zhu 1994; Wu, Chou & Liu 1994; Zhang & Peng 1992, Zhou & Marslen-Wilson 1994), French (e.g., Beauvillain 1994) and Japanese (e.g., Hirose 1992; Tamaoka & Hatsuzuka 1995). In a study on the effect of Japanese kanji frequency, Tamaoka and Hatsuzuka (1995) revealed that kanji frequency affected the processing of compound words differently for naming and lexical decision when the whole word frequency and stroke numbers of those words were controlled. In the naming task for left-hand kanji (kanji characters which are positioned on the left side of a two-kanji compound word), high kanji frequency led to faster whole-word naming responses compared with low kanji frequency. For right-hand kanji (kanji characters which are positioned on the right side of a two-kanji compound word), no difference in kanji frequency was obtained. The pattern was reversed for lexical decision. For the left-hand kanji, no effect of kanji frequency was obtained. However, for the right-hand kanji, subjects reacted faster to kanji morphemes of high frequency than to those of low frequency.

The following explanation was given by Tamaoka and Hatsuzuka (1995) for these results. If the processing of two-morpheme compound words proceeds from left to right as the words are written, the activation of the morpheme unit presented on the left will commence before the activation of that on the right. Since naming can be initiated by the phonological activation of the left-hand kanji, the frequency of that kanji affects whole-word naming. For lexical decision, subjects have to wait until they process the right-hand kanji, and therefore the frequency of the right-hand kanji shows its effect. Although the left-hand kanji frequency also influences the processing speed of the whole word, its effect is hidden by the time spent processing the right-hand kanji. The effect of left-hand kanji frequency on lexical decision regarding two-kanji compound words was also consistent with the findings of Zhang and Peng (1992) in a study of Chinese character frequency. Consequently, the frequency of the morphemes in a two-kanji compound word would independently affect the processing of the whole word for either naming or lexical decision, regardless of the frequency of the whole-word itself.

A study using the priming paradigm also supports morphological activation. Comparing high and low word 'construction size' (i.e., how many two-kanji compound words can be constructed by each kanji), Hirose (1992) found that priming affected lexical decisions regarding two-kanji compound words when the left-hand kanji was primed, but not when the right-hand kanji was primed. The study explained that the left-hand kanji play a key role in cueing subjects regarding the appropriate second kanji needed to create a two-kanji compound word. Consequently, a morphemic unit of kanji must be activated during the performance of the lexical decision task for a two-kanji compound word.

Taking a kanji morpheme as a single unit, the concept of 'construction size' proposed originally by Kaiho and Nomura (1983) and implemented by Hirose (1992) can be equated with the concept of 'neighborhood size'. Neighborhood size was operationally defined by Coltheart, Davelaar, Jonasson and Besner (1977) as the number of words which can be generated by replacing a single letter from the base string. For example, *trick*, *truck* and *crack* are all neighbors of the word *track*, so that the neighborhood size for *track* becomes 3. In the same way, once one considers that Japanese kanji compound words are orthographically constructed by multiple kanji units, a single kanji can be regarded as a unit among neighbors. Then, because a word's construction size is determined by changing a single kanji, construction size could be perceived as to 'neighborhood size', except that the orthographic unit in play is a single kanji morpheme, not a letter of the alphabet. Thus, the study by Hirose (1992) provided an 'inhibitory effect' of the kanji neighborhood size (namely, the larger the neighborhood size is, the slower the lexical decision time becomes), especially when a kanji with a large neighborhood size is placed on the left size of kanji compound words.

This result of Hirose (1992) is congruent with the studies which showed an 'inhibitory effect' on lexical decision for Dutch and French words (Grainger 1990; Grainger, O'Regan, Jacobs & Segui 1989; Grainger & Segui 1990; Peereman & Content 1995). This was the result of the 'neighborhood frequency effect'. However, the opposite result, a 'facilitatory effect', for naming English words was reported by Andrews (1989, 1992). It was produced by the 'neighborhood size effect'. By manipulating neighborhood frequency and neighborhood size, the facilitatory effect of neighborhood size was supported by Sears, Hino and Lupker (1995) in a series of experiments on the processing of English words (lexical decision and naming).

The alternative explanation, however, could be advanced that the subjects of Hirose's (1992) study may have developed the strategy of predicting what kanji might be coming next, particularly in cases of kanji which would normally combine with only a few others, but also in cases where the kanji could combine with a wide variety of other kanji. It is likely that the study of Hirose (1992) actually showed the ease of predictability for the following compound word based upon a primed kanji, not the actual mechanism subjects used to process two-kanji compound words. Subjects were able to make these predictions because Hirose used an unusually long SOA (Stimulus Onset Asynchrony) of 3000 milliseconds (i.e., the interval time between the onset display of a primed kanji and of a target two-kanji compound word).

In fact, Posner and Snyder (1975) suggested that SOA over 500 milliseconds produced 'conscious control' or 'attentional processing' for target stimuli. Cheesman and Merikle (1985), whose study compared three SOA conditions of 50, 550 and 1050 milliseconds, found that attentional processing began with the priming of SOA with 550 milliseconds. They further suggested that the priming effect should properly refer only to the condition where a subject did not remember the primed stimulus. Given this, recent studies using a priming technique are likely to employ SOA which range from 60 to 90 milliseconds (e.g., Forster, Davis, Schoknecht & Carter 1987; Forster & Taft 1994; Perfetti & Zhang 1995, Experiment 2).

Nonetheless, Hirose's study (1992) did show that kanji morphemes are used by subjects to find another kanji to identify the proper two-kanji compound word. Because Hirose's study used such a long SOA, it is still undetermined whether his inhibitory effect was created by the subjects' task-specific strategy or by the kanji neighborhood size. Consequently, the direction of the kanji neighborhood size effect (i.e., inhibitory or facilitative) remains under-investigated (Saito 1997). Because the kanji neighborhood size is confounded with other factors such as kanji printed-frequency which acts to speed up the processing of kanji compound words for naming and lexical decision (Tamaoka & Hatsuzuka 1995), these factors should be separately examined. In addition, if a unit of neighborhood calculation in Japanese words is regarded as a kana (or an equivalent phonological unit of a mora), not as a kanji, neighborhood size alters. As a result, the effect of neighbors may not be the same as when the neighborhood condition is perceived in terms of kanji units.

Most studies on phonological involvement in the processing of kanji morphemes have been conducted for the Chinese language. As the orthographic nature of Chinese and Japanese characters is remarkably similar (Tamaoka 1991) and traditional Chinese orthography has shown great stability across a large geographical area (Leong 1986), some findings concerning the processing of Chinese characters should be applicable to the processing of Japanese kanji characters.

The effect of morphological semantics was found in the task of Chinese character identification. Using a backward-masking procedure, Tan, Hoosain and Peng (1995) observed a significant phonological mask facilitation effect for high-frequency targets. They also found that there was no semantic mask effect. However, as Chen (1996) pointed out, a single Chinese character can stand for numerous different words. Chen claimed that these multiple meanings make a character semantically ambiguous. A post-experimental analysis by Tan et al. (1995) indicated that when high-frequency targets had a well-defined meaning, the semantic masks facilitated target identification whereas when the high-frequency targets had a 'fuzzy' meaning, there was no significant semantic mask effect. Based upon this, Tan et al. (1995) suggested that 'the semantic fuzziness of Chinese characters affects the time course of activating phonological and semantic codes' (p. 50). If this is so, morphological semantics would be involved much more frequently in simple tasks such as character identification, lexical decision and naming than we previously thought. Consequently, morphological semantics seem to have some affect on the processing of Chinese characters, and probably on Japanese kanji processing as well.

The topic of semantic involvement in naming and lexical decision for Japanese kanji compound words is not new. For example, a series of experiments was carried out on semantic processing for kanji. Saito (1981) showed that words presented in kanji were named more slowly than when they appeared in the Japanese syllabic (precisely, a unit of mora) symbols of kana. This trend was reversed when subjects performed the task of semantic decision: words in kanji were processed more quickly to make sentence acceptance judgments than those in hiragana. Feldman and Turvey (1980) also reported that two Japanese adults named colors written in kana faster than ones in kanji, even though kanji are more frequently used to describe colors. In addition, using concurrent articulation in which subjects constantly repeated the numbers from 1 to 5, Kimura (1984) found that vocal interference had no effect on kanji processing, but that it interrupted hiragana processing. These findings led to the generally-held belief (e.g., Feldman & Turvey 1980; Goryo 1987; Kaiho & Nomura 1983; Kimura 1984; Kimura & Bryant 1983; Morton & Sasanuma 1984; Saito 1981) that, for naming, kanji are processed from orthography via the semantic level to phonology whereas kana are processed from orthography to phonology.

However, a study using concurrent articulation questioned this explanation for kana and kanji processing. Using Kimura's (1984) method, Tamaoka, Leong and Hatta (1992) studied Japanese children in Grades 4–6, and found that the processing of both kanji and kana for lexical decision for words presented as part of a sentence was adversely affected by concurrent articulation. The study further reported the interesting result that younger children and less-skilled readers were more impeded by concurrent articulation than the older children and skilled readers. In fact, skilled readers in Grade 6 did not experience strong interference from concurrent articulation. Therefore, distraction by concurrent articulation appeared to occur not for the type of script but for the characteristics of readers (i.e., age, grade and reading skill). Concurrent articulation may not disturb the actual phonological processing of kana and kanji, but it may affect other cognitive functions, possibly acting to impair the function of working memory (Baddeley 1986; Baddeley, Lewis & Vallar 1984; Gathercole & Baddeley 1993).

Further detailed experiments using concurrent articulation were conducted by Kinoshita and Saito (1992). Their results differed from those discussed above in that concurrent articulation disrupted rhyme decisions and homophone decisions for the kanji condition more than it did for the kana-transcribed condition (Experiments 1 and 2), and it did not disrupt lexical decision in either kanji or kana (Experiment 3). The study suggested that concurrent articulation does not prevent the generation of assembled phonology, but instead it disrupts the maintenance of phonological codes involved in working memory. The argument of Kinoshita and Saito (1992) can be used to explain the findings of Tamaoka, Leong and Hatta (1992) as regards the characteristics of subjects because it seems very likely that less-skilled and lower-grade readers will be more impaired in semantic decisions regarding target words presented in both kana and kanji than are skilled and higher grade readers due to disturbance of the phonological loop in working memory.

Recent discussions have focused mostly on orthographic and phonological activations during the reading of Chinese characters and Japanese kanji (e.g., Chen, Flores d'Arcais & Cheung 1995; Leck, Weekes & Chen 1995; Leong & Tamaoka 1995; Perfetti & Zhang 1991, 1995; Tamaoka, Leong & Hatta 1992; Wydell, Butterworth & Patterson 1995; Wydell, Patterson & Humphreys 1993; Zhang & Perfetti 1993; Zhou & Marslen-Wilson 1994, and many others). Some researchers who have examined phonology and orthography are now building on those results by including arguments regarding semantics, and there is a great possibility of interactive activation among representations of orthography, phonology and semantics, and even of interplay at both the word and morpheme levels which may lead to a model of multiple-level interactive activation for morphologically compound words. Thus, the present study focused upon the semantic processing of kanji in order to examine the involvement of morphological semantics for the processing of kanji compound words.

Various studies on semantic variables at the word level have been conducted using the tasks of lexical decision and naming. When a word has multiple meanings (i.e., is a polysemous word) lexical decisions regarding it are normally faster than for words with few meanings (e.g., Balota, Ferraro & Connor 1991; Hino & Lupker 1996; Jastrzembski 1981; Kellas, Ferraro & Simpson 1988; Strain, Patterson & Seidenberg 1995). Recently, Azuma and Van Orden (1997) suggested that the relatedness among a word's meanings as well as the polysemous factor can influence the performance of lexical decision. For example, the word 'bank' is polysemous in that it can mean 'a financial institution' or 'the land alongside a river'; its two meanings are not related. Azuma and Van Orden measured meaning relatedness by asking a subject to rate it on a seven-point scale where 1 meant not related and 7 meant very related. Using this scale, they found that words with few and unrelated meanings produced slower response times for lexical decision than all other words which themselves produced equivalent response times. The factor pertaining to the number of a word's meanings is often confounded with the factor of relatedness: a word with many meanings is likely to have highly related meanings. Yet, both effects are facilitative.

Pronunciation of a polysemous word occurred even more quickly than of a word with a single meaning (Hino & Lupker 1996). Hino and Lupker argued that semantic variables at the word level affect the performance of lexical decision, and probably naming performance as well, by speeding up their processing. Again, the effect of polysemy is facilitative.

Employing the framework of the interactive-activation model, Balota et al. (1991) provided an explanation for the results of these studies as follows. Polysemous words activated multiple semantic representations which generated feedback to the orthographic representation. The process of feedback activations from the semantic level resulted in raising the activation level of polysemous orthography. In contrast, nonpolysemous words received only a single feedback activation from the semantic level. These differences in feedback activation from the semantic level created the faster orthographic activation of polysemous words in comparison with nonpolysemous words.

Assuming that semantic effects exist in naming and lexical decisions for a single word, do morphological semantics affect the processing of morphemic compound words? If so, how do semantic variables at the morpheme level interact with semantics at the word level?

The interplay of orthographic and semantic representations at the morpheme and word levels could be investigated by altering the morphological semantics of two-kanji compound words. If feedback activation at the morpheme level occurs in the semantics at the word level, as suggested by Balota et al. (1991), we expected that the orthographic representation of the compound word should receive feedback activation from morphological semantics for opposite- and similar-concept kanji. This should facilitate the performance of lexical decision, and possibly naming. However, if each kanji unit in a two-kanji compound word is processed separately from the whole word, the semantic representation of the compound word may interfere with semantic representations of the two kanji morphemes. If this is the case, it is still an open question as to whether the effect of morphological semantics is facilitative or inhibitory.

Experiment 1

In Experiment 1, a lexical decision task for two-kanji compound words was conducted to examine the effect of morphological semantics. To make their lexical decision, subjects had to distinguish a real compound word from a non-word. This task was especially difficult since the non-words were created by combining two real kanji: each kanji used for both a real word and a non-word actually exists as a Japanese kanji morpheme. Thus, the process of lexical decision involved judging whether or not the two kanji were combined into proper words. In the process of identifying the proper combination, semantic representations of the two kanji morphemes could be activated as well as the semantic representation of the compound word in its entirety. If morphological semantics create the feedback activation to morphological and lexical orthography, it was expected to speed up the task performance (i.e., to have a facilitative effect), even though the task requires activation of the orthographic representation at the word level. In contrast, if morphological semantics interfere with lexical semantics, the speed of performing the lexical decision task will decrease (i.e., will experience an inhibitory effect). If there is no difference across the three types of compound words, this suggests that morphological semantics must receive little or no activation during the task performance (i.e., null effect).

Subjects. Twenty-four graduate and undergraduate students (12 female and 12 male) who were native speakers of Japanese participated in the experiment. Their ages ranged from 19 to 25: on the day of testing, the average age was 21 years and 4 months for females, and exactly 23 years for males.

Table 1. Characteristics of stimulus items used for the experiments with two-kanji compound words

Type of kanji compound	Examples	Word frequency	Familiarity rating	Stroke numbers	Concrete-abstract	Number of morae
Opposite	長 短	8.62	3.60	19.42	3.43	3.58
concepts	善 悪	(9.74)	(0.44)	(4.37)	(0.54)	(0.58)
Similar	柔 軟	8.62	3.77	20.88	3.62	3.69
concepts	悲 哀	(9.60)	(0.44)	(4.10)	(0.49)	(0.47)
Closely-	荒 野	8.62	3.76	20.85	3.61	3.50
bound	運 河	(9.73)	(0.49)	(3.48)	(0.55)	(0.58)

The stroke numbers are averages for the strokes used to create two kanji. Figures in parentheses are the standard deviations.

Materials and design. All kanji used for the experiment were selected from the basic 1945 characters taught before the completion of Grade 9, so that all the subjects would be well-acquainted with them. Three types of two-kanji compound words were used as stimulus items: (1) words consisting of two kanji representing opposite concepts (e.g., 長 long + 短 short = length), (2) words consisting of two kanji representing similar concepts (e.g., 柔 soft + 軟 flexible = pliable), and (3) control words consisting of two closely-bound kanji (e.g., 荒 wild + 野 field = wilderness). All the compound words used in this experiment are listed in the Appendix.

Five factors which might affect the processing of two-kanji compound words (i.e., word frequency, orthographic complexity as measured by kanji stroke numbers, the number of morae, the degree of concreteness or abstractness, and the degree of familiarity) were controlled throughout the three stimulus conditions. The averages of each factor across the three conditions of the two-kanji compound words are shown in Table 1.

For the word frequency, the three stimulus conditions had exactly the same average of 8.62 occurrences in the total of 1,967,575 printed words calculated according to the index provided by the National Language Research Institute (1973). A one-way analysis of variance (ANOVA) on the word frequency across the three types of two-kanji compound words indicated no significant main effect [$F(2,75) = 0.00$, $p < 0.999$]. Thus, there was no difference in the means of word frequencies among the three conditions of the compound words.

The effect of familiarity on lexical decision has been reported by other researchers (e.g., Gernsbacher 1984). It also was controlled throughout the three conditions of compound words. Using a seven-point scale from 1 as 'seldom seen' to 7 as 'very often seen', all the items used in this experiment were measured for their degrees of familiarity. A one-way ANOVA on the degree of familiarity was conducted across the three conditions of compound words. The result showed no main effect [$F(2,75) = 1.15$, $p < 0.325$].

Because orthographic complexity has been observed to affect the processing of Chinese characters (Leong, Cheng & Mulcahy 1987; Tamaoka 1992), we controlled the average number of strokes (figures from Kamata 1991) for our compound words to within a single stroke. The compound words with two opposite concepts were drawn with an average of 19.42 strokes (10.04 for left-hand kanji and 9.38 for right-hand kanji); those with two similar concepts had 20.88 strokes (10.42 for left-hand kanji and 10.46 for right-hand kanji); and those which functioned as our control words had 20.85 strokes (10.81 for left-hand kanji and 10.04 for right-hand kanji). A one-way ANOVA on stroke numbers across the three types of compound words did not show any significant main effect; left-hand kanji [$F(2,75) = 0.37$, $p < 0.695$], right-hand kanji [$F(2,75) = 0.82$, $p < 0.446$] and both kanji [$F(2,75) = 1.13$, $p < 0.330$].

When presented without a context, concrete words are processed for the tasks of both naming and lexical decision faster and more accurately than abstract words (e.g., Bleasdale 1987; Kroll & Merves 1986; Schwanenflugel & Shoben 1983). Because of this, the degree of concreteness or abstractness was controlled in the present study across the three conditions of the compound words. The stimulus items used in the present study were measured on a seven-point scale of semantic differentiation where 1 point stood for 'very abstract' and 7 for 'very concrete'. As indicated in Table 1, the degree of concreteness or abstractness produced only small differences among the three conditions of compound words. As predicted from the small range of the means, a one-way ANOVA did not show a main effect of the degree on the concreteness-abstractness continuum [$F(2,75) = 1.53$, $p < 0.228$].

Word length is also reported to be an influential factor for the processing of English words (Weekes 1997), and of Japanese katakana loan-words (Tamaoka, Hatsuzuka, Kess & Bogdan 1998). Given this, the average number of morae in each type of compound word which we used varied only within the small range of 3.50 to 3.69 morae, as indicated in Table 1. Again, a one-way ANOVA on the number of morae across the three types of compound words did not have any main effect [$F(2,75) = 0.82$, $p < 0.446$].

Each kanji often has a multiple reading as described in various studies (e.g., Leong & Tamaoka 1995; Tamaoka 1991; Wydell, Butterworth & Patterson 1995). In addition to the above five factors, to avoid the possible effect of these multiple readings which are known as On- and Kun-readings, all the compound words used in the present study were pronounced only

Table 2. Lexical decision times and errors for the three types of two-kanji compound words

Type of kanji compound	Reaction times (ms)	Error rates (%)	RT differences (ms)
Opposite concepts	768 (97)	5.29	+52
Similar concepts	743 (94)	7.85	+27
Closely-bound	716 (90)	7.05	—

The differences in reaction times were calculated by subtracting the mean reaction time of the word conditions of opposite concept and similar concept from the control condition of closely-bound. Figures in parentheses are the standard deviations of reaction times.

as On-readings. Consequently, this fundamental phonological feature of the compound words should not affect their processing.

To solicit the correct 'no' response in the lexical decision task, we created 78 non-words by simply combining two characters from the list of the 1945 basic characters. These non-words do not exist orthographically or phonologically in the Japanese language.

Procedure. The compound words and non-words were randomly presented to subjects in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 milliseconds after the appearance of an eye fixation point marked by an asterisk '*'. The subjects were instructed to respond as quickly but as accurately as possible in deciding whether the item was a word or not. The response was made by pressing a 'yes' or a 'no' button. Twenty-four practice trials were given to the subjects prior to commencement of the actual testing.

Results

The mean reaction times and error rates for the lexical decision task in the three types of compound words are presented in Table 2. The statistical tests which follow analyze both subject (Fs) and item (Fi) variability. A one-way ANOVA for the three types of compound words was conducted on reaction times of correct responses and accuracy ratio. Before performing the analysis, reaction times outside of 2.5 standard deviations in both the high and low range were replaced by the boundaries indicated by 2.5 standard deviations from the individual means of subjects.

The one-way ANOVA on reaction times for lexical decision indicated that the type of two-kanji compound word showed a significant main effect on subject analysis [$Fs(2,46) = 17.06$, $p < 0.0001$] and item analysis [$Fi(2,50) = 3.20$, $p < 0.05$].

Further analysis using an orthogonal polymetric comparison was carried out to isolate the main effect over the three types of compound words. The compound words with two opposite-concept kanji were processed significantly slower than words with two similar-concept kanji [Fs(1,23) = 6.61, $p < 0.05$] and the control group of the closely-bound two-kanji compound words [Fs(1,23) = 31.13, $p < 0.0001$]. The similar-concept kanji compound words also showed significantly slower reaction times than did the control group [Fs(1,23) = 13.56, $p < 0.001$].

The same analysis was conducted using the item means. The result differed in the condition of words with two similar-concept kanji. These did not show slower reaction times than words of two opposite-concept kanji [Fi(1,25) = 1.46, $p < 0.238$] or the control group of closely-bound two-kanji compound words [Fi(1,25) = 1.71, $p < 0.203$]. Thus, despite the significant main effect indicated by both the subject and item means, some specific items may create the significant results of pair-matched comparisons for the condition of two similar kanji compounds. In contrast, the words with two opposite kanji hold the same result as shown by the subject means – they differed significantly from the control group [Fi(1,25) = 6.44, $p < 0.05$].

Although the analysis of the item means for pair-matched orthogonal polymetric comparisons did not show a clear trend as the result of the subjects' means indicated, the overall results pointed to how the compound words constructed by morphemic units affected the processing speed for lexical decision, especially for the words with opposite-concept kanji.

The accuracy ratio was also analyzed by a one-way ANOVA for the type of compound word. The result showed that there was no significant main effect by either subject analysis [Fs(2,46) = 2.65, $p < 0.08$] or by item analysis [Fi(2,50) = 0.99, $p < 0.38$]. Therefore, the type of kanji combination did not affect the processing accuracy of the words.

Discussion

The results of Experiment 1 indicated that two-kanji compound words were processed differently for lexical decisions, depending upon the way in which they were constructed by kanji morphological semantics. The words consisting of two kanji with opposite concepts were processed more slowly than those of two kanji with similar concepts, both of which were even slower than the controlled group of closely-bound kanji compound words. This finding suggests that kanji morphemes of opposite and similar concepts are semantically activated as a morpheme unit, as well as a word unit at the semantic level. However, since the effect of the activation was inhibitory, semantic representations of the two morphemes and the compound word must compete with each other at the semantic level. This interference is particularly strong when morphemic representations of opposite meanings are activated. The degree of semantic competition must be reduced when compound words consisting of two kanji with similar concepts are processed. Therefore, the present study suggests that semantic activations will occur at both the morpheme and word level when two-kanji compound words are processed for lexical decision, and that their activations at the semantic level will compete with each other.

Experiment 2

Further investigation was carried out using the naming task with the same stimulus items employed in Experiment 1. When subjects name two-kanji compound words, they are obliged to activate a phonological representation of the whole word to produce its phonological output. If the semantic activation at the morpheme level does not interfere with phonological activation, naming latency will not differ across the three conditions of the compound words (i.e., null effect). If the null effect does not occur, it is also interesting to examine, as we did for the lexical decision task, whether naming slows down when two kanji have opposite meanings (i.e., inhibitory effect). If naming of compound words with opposite- and/or similar-concept kanji is faster than naming of the control group, it could be assumed that morphological semantics create extra activation to morphological and lexical phonology (i.e., facilitative effect).

Subjects. Twenty-four graduate and undergraduate students (12 female and 12 male) who were native speakers of Japanese participated in the experiment. Their ages ranged from 19 to 32: on the day of testing, the average age was 22 years and 6 months for females, and 24 years and 3 months for males. Subjects who had participated in Experiment 1 were not included in Experiment 2.

Materials. The 78 compound words (26 of each type of compound word) from Experiment 1 were also used in Experiment 2 for the naming task. Because the kanji used to create the non-words in Experiment 1 could be pronounced in multiple ways, non-words were not included in the naming task of Experiment 2.

Procedure. The items of compound words were randomly presented to subjects in the center of a computer screen 600 milliseconds after the appearance of an eye fixation point marked by '∗'. The subjects were required to pronounce the compound word shown on the screen as quickly but as accurately

Table 3. Naming latencies and errors for the three types of two-kanji compound words

Type of kanji compound	Naming latencies (ms)	Error rates (%)	RT differences (ms)
Opposite concepts	645 (98)	3.53	+55
Similar concepts	636 (91)	2.40	+46
Closely-bound	590 (76)	1.28	—

The differences in naming latencies were calculated by subtracting the mean reaction time of the word conditions of opposite concept and similar concept from the control condition of closely-bound. The figures in parentheses are standard deviation of naming latencies.

as they could. A voice-activated key turned off a timer to measure the naming latency. The correctness of pronunciation was entered into the computer by the examiner. The next fixation point was presented 600 ms after the examiner pressed the key. Eight practice trials were given to the subjects prior to the commencement of the actual testing.

Results

The mean reaction times and error rates for the naming task in the three types of compound words are presented in Table 3. As conducted in Experiment 1, the statistical tests which follow analyze both subject (Fs) and item (Fi) variability. Using the methods employed in Experiment 1, we discarded outliers and performed a one-way ANOVA on the type of words for the reaction times of correct responses and for the accuracy ratio.

The one-way ANOVA indicated that the type of two-kanji compound word showed a significant main effect on both subject analysis [$Fs(2,46) = 32.43$, $p < 0.0001$] and item analysis [$Fi(2,50) = 4.31$, $p < 0.02$]. Further analysis with an orthogonal polymetric comparison was carried out to isolate the main effect of the word type. Naming latency for words consisting of two opposite concepts did not differ significantly from that for similar concepts [$Fs(1,23) = 1.43$, $p < 0.245$, and $Fi(1,25) = 0.67$, $p < 0.421$]. Interestingly, naming latency for words of opposite concepts differed significantly from that for the closely-bound words [$Fs(1,23) = 46.36$, $p < 0.0001$, and $Fi(1,25) = 8.00$, $p < 0.01$], as well as for similar concepts and closely-bound words [$Fs(1,23) = 55.24$, $p < 0.0001$, and $Fi(1,25) = 9.21$, $p < 0.01$]. Thus, our results of analysis using both the subject and item means showed a strong trend that kanji semantic concepts constructing compound words have an inhibitory effect upon the speed of naming two-kanji compound words.

The accuracy ratio was also analyzed by a one-way ANOVA for the type of compound word. The result showed that there was no significant main effect by subject analysis ($Fs(2,46) = 2.94$, $p < 0.06$] or by item analysis [$Fi(2,50) = 1.66$, $p < 0.21$]. Therefore, as shown in Experiment 1 for lexical decision, the type of kanji combination did not affect processing accuracy for naming two-kanji compound words.

Discussion

Similar to the results regarding lexical decision in Experiment 1, naming latency differed among the three types of compound words. The words consisting of two kanji with opposite concepts and with similar concepts were named more slowly than the controlled words of closely-bound kanji. Because, as was the case in lexical decision, the effect was inhibitory, semantic representations of two morphemes and their compound word must compete with each other at the semantic level, which results in slowing down their whole-word naming. This tendency was transparent when subjects processed compound words with opposite kanji concepts. Semantic competition seemingly interfered to a lesser degree in the processing of compound words with similar kanji concepts.

General discussion

The present study indicated that morphological semantics affected the processing of compound words for both tasks of lexical decision and naming. The effect was inhibitory.

According to Seidenberg and his colleagues (Seidenberg 1985, 1989; Seidenberg & McClelland 1989; Waters & Seidenberg 1985), the major difference between the tasks of lexical decision and naming is in the type of activation used for performing each task. Both types operate at the word level, but naming requires the activation of phonological representations whereas lexical decision requires the activation of orthographic representations. However, the results of the present study cannot be explained solely by the activations of phonological and orthographic representations since semantic variables also affected the processing of compound words.

A recent study by Strain, Patterson and Seidenberg (1995) revealed that reading aloud is affected not only by spelling-sound typicality but also by the semantic variable of imageability for lower-frequency words. Likewise, although the present study focused on morphological semantics, its results also indicated that semantics has an affect on word processing. Therefore, when we apply the framework of the interactive activation model described by Seidenberg and McClelland (1989) to the results of the present study, the representations of orthography, phonology and semantics should interact with each other based upon the subject's need for a strategy which is developed for the task performance.

Previous studies (e.g., Balota, Ferraro & Connor 1991: Hino & Lupker 1996; Jastrzembski 1981; Strain, Patterson & Seidenberg 1995) concerning the semantic aspect of word processing suggested that, due to feedback activation from the semantic level, words with multiple meanings (i.e., polysemous words) were processed faster than nonpolysemous words in lexical decision and possibly in naming. Again, within the framework of the interactive activation model, an explanation was applied to the task of lexical decision (Balota, Ferraro & Connor 1991) as follows. The orthographic representation of polysemous words receives support from the multiple feedbacks generated at the semantic level and this results in increasing activation. By contrast, nonpolysemous words receive only a single feedback. Naming is affected in a similar manner in that the phonological representations of the polysemous words receive multiple feedback activations from the semantic level. Because the feedback activation from the semantic level helps to raise the activation level of orthographic representation for lexical decision, and phonological representation for naming, the speed of processing is accelerated for both tasks, unlike in the processing of nonpolysemous words. Consequently, this effect is facilitative.

The spreading-activation theory in the lexical network (e.g., Collins & Loftus 1975; Dell 1986; Stemberger 1985) predicts the facilitative results of the present study, as far as two-kanji compound words of two similar concepts are concerned. An equivalent in English is that the activation of the word *doctor* will automatically raise the activation level of other related words such as *nurse, surgeon* and *hospital*. Correspondingly, the Japanese compound word *sorrow* (悲哀 /hi ai/) used in the present experiments is constructed by the two kanji morphemes of *sad* (悲 /hi/) and *pity* (哀 /ai/). If an activation of a single semantic code spreads to various similar concepts which are closely linked to each other, the semantic activation of *sad* or *pity* should result in raising the activation level of *sorrow*. This tendency should occur in other compound words used in the present study (e.g., the words, *darkness* (暗黒 /aN koku/) which consists of *dark* (暗 /aN/) and *black* (黒 /koku/), *joy* (歓喜 /kaN ki/) which consists of *joy* (歓 /kaN/) and *rejoice* (喜 /ki/), and *extinct* (断絶 /daN zetu/) which consists of *cut* (断 /daN/) and *die out* (絶 /zetu/). Accordingly, this semantic effect should be facilitative for the compound words of two similar concepts. Simply, the tasks of lexical decision and naming should be performed more quickly for compound words of similar kanji concepts than for the control words.

The result of the present study, however, contradicts the hypotheses of feedback activation (e.g., Balota, Ferraro & Connor 1991; Hino & Lupker 1996; Jastrzembski 1981; Strain, Patterson & Seidenberg 1995) and spreading-activation (e.g., Collins & Loftus 1975; Dell 1986; Stemberger 1985). By contrast, our results showed an inhibitory rather than a facilitative effect upon the processing of two-kanji compound words in both tasks of lexical decision and naming. In the explanatory framework provided by the feedback activation and spreading-activation models, it should be noted that they allow only for the facilitative effect, or, if this does not occur, for null effect. Thus, they cannot explain the results of the inhibitory effect in the present study.

Morphological semantics in the present study were inhibitory because two morphemes seem to have been independently activated at the semantic level, unlike in the control condition of closely-bound compound words. In contrast, multiple meanings in polysemous words are all activated from one source which produces feedback activation from multiple lexical semantics. Similarly, the spreading-activation theory also developed within a network at the word level. However, since the activation from morphological semantics originates in two different orthographic representations at the morpheme level, semantic activation cannot easily play a major role in raising the activation level of the target orthographic representation (i.e., a compound word) by feedback from the semantic system. Thus, morphological semantics cannot provide as strong a feedback to activate the orthographic representation of the compound word.

Our study differs from other studies of polysemous words (e.g., Balota, Ferraro & Connor 1991; Hino & Lupker 1996; Jastrzembski 1981; Strain, Patterson & Seidenberg 1995), spreading-activation (e.g., Collins & Loftus 1975; Dell 1986; Stemberger 1985) and imageability (e.g., Strain, Patterson & Seidenberg 1995) in two ways.

First, these studies concentrated on words of polysemousness, spreading-activation and imageability as they operated at the word level. Although our study also examined this area of semantic effects, we analyzed semantic variables presented at the morpheme level. As previous studies in various languages (e.g., for English: Andrews 1989; Taft & Forster 1975, 1976; for Chinese: Taft, Huang & Zhu 1994; Wu, Chou & Liu 1994; Zhou & Marslen-Wilson 1994; Zhu & Taft 1994; Zhang & Peng 1992; for French: Beauvillain 1994; for Japanese: Hirose 1992; Tamaoka & Hatsuzuka 1995) suggest that morphemic units also play an important role in the processing of compound words, the present study should deal with the two different levels of word and morpheme together. The interplay between the different levels may create the different effects. Second, when we examined semantics, we investigated the semantic effect of opposite and similar concepts at the morpheme level, particularly in connection with the processing of compound words. Therefore, the explanation regarding the result of the inhibitory effect in the present study should take these two differences into consideration.

The model of interactive activation (e.g., McClelland & Rumelhart 1981; Seidenberg 1985, 1989; Seidenberg & McClelland 1989; Waters & Seidenberg 1985) holds that all compound words or polymorphemic words are represented as whole words. Although we employed their theoretical framework, the results of the present study cannot be fully explained by the activation of whole-word representations. Because morphological semantics affected the processing of compound words created by semantically-independent morphemes such as two kanji for similar and opposite concepts, we assumed that representation at the morpheme level did exist separately from representations at the word level.

Previous studies support the role of morphological units in the processing of compound words (e.g., Andrews 1989; Beauvillain 1994; Taft 1991; Taft, Huang & Zhu 1994; Taft & Zhu 1995; Tamaoka & Hatsuzuka 1995; Wu, Chou & Liu 1994; Zhang & Peng 1992; Zhou & Marslen-Wilson 1994; Zhu & Taft 1994). It is, however, important to distinguish between two views regarding the processing model which differ over how morphological units are represented in the lexicon. Taking the English compound word of *flowerpot* as an example, one view holds that the representation of this compound word could be independently stored as the whole word of *flowerpot* as well as separately, as the free morphemes of *flower* and *pot*. The representation of the whole word plays the major role in processing, and the morphemic representations are used as a back-up mechanism if the whole word access fails (Butterworth 1983). The second view states that the two morphological units of *flower* and *pot* are separately stored, and that they create their compound word of *flowerpot* which is not independently stored. The former view could be called 'whole-word representation' while the latter view is known as 'morphological decomposition' or 'morphological listing'.

To explain the results of the present study, morphological representations should be included as a part of the overall processing model. To produce competition between two kanji morphemes of opposite concepts (e.g., 'long' and 'short'), and, at the same time, to disrupt the activation of lexical semantics (e.g., 'length'), all these semantic representations should be listed in the lexicon to interact with each other in the semantic system.

This is also true when we consider the result of the present study that compound words with two kanji of similar concepts displayed a lesser degree of morphological semantic effect than those with kanji of opposite concepts. Therefore, it is logical to suggest that the whole word, as well as the morphemes, are represented together in the lexicon. Including all these elements and processes in the structure of the processing model, the model for Japanese two-morpheme (kanji) compound words is developed within the framework of interactive activation but the morphological structure is added to it.

Japanese kanji are fundamentally used for representing content vocabulary, that is, words originally borrowed from Chinese, compounds of these words created by the Japanese themselves, and native Japanese vocabulary. Because the compound words with kanji of two opposite concepts displayed a clear tendency to be affected by the inhibitory effect, we will focus on an opposite-concept compound word to clarify its cognitive processing. As shown in Figure 1, the word *length* in Japanese is created by two kanji morphemes having opposite concepts, namely, *long* and *short*. A visually-presented word is orthographically processed as the two orthographic morphemes of *long* (**長**) and *short* (**短**) which further orthographically combine to create the two-kanji compound word, *length* (**長短**). Morphological semantics are included within the compound word in the condition where the meaning of the two morphemes conflicts with each other.

Semantic representations of these two opposite concepts are almost simultaneously activated at the morpheme level, at the same time that the semantic representation of the compound word of 'length' (**長短**) is being activated. Then, not only do the kanji morphemes of 'long' (**長**) and 'short' (**短**) compete with each other, they also interfere with the activation of the whole-word lexical representation of 'length'. As a result of this competition, the performance of lexical decision and naming slows down. Therefore, our study suggests that morphological semantics, particularly for compound words of two kanji of opposite concepts and to a lesser degree for those with similar concepts, create semantic competition between the two kanji morphemes and interfere with the activation of the whole word in the semantic system.

Despite the prediction of the facilitate effect by the spreading-activation theory (e.g., Collins & Loftus 1975; Dell 1986; Stemberger 1985), our compound words with two kanji morphemes of similar concepts also indicated the inhibitory effect in naming although the effect was not clearly apparent in lexical decision. A single two-kanji compound word actually raises, through similar concepts, three similar semantic representations, one for a whole word and two for the kanji morphemes. The activation from orthographic representations, then, may be distributed into three semantic representations. As a result, the levels of activation in each semantic representation are weakened, and further compete with each other as increasing the activation level of the semantic representation of the target meaning. For instance, *sorrow* (**悲哀**) receives a semantic activation as do the kanji morphemes of *sad* (**悲**) and *pity* (**哀**). These three semantic representations compete with each other to

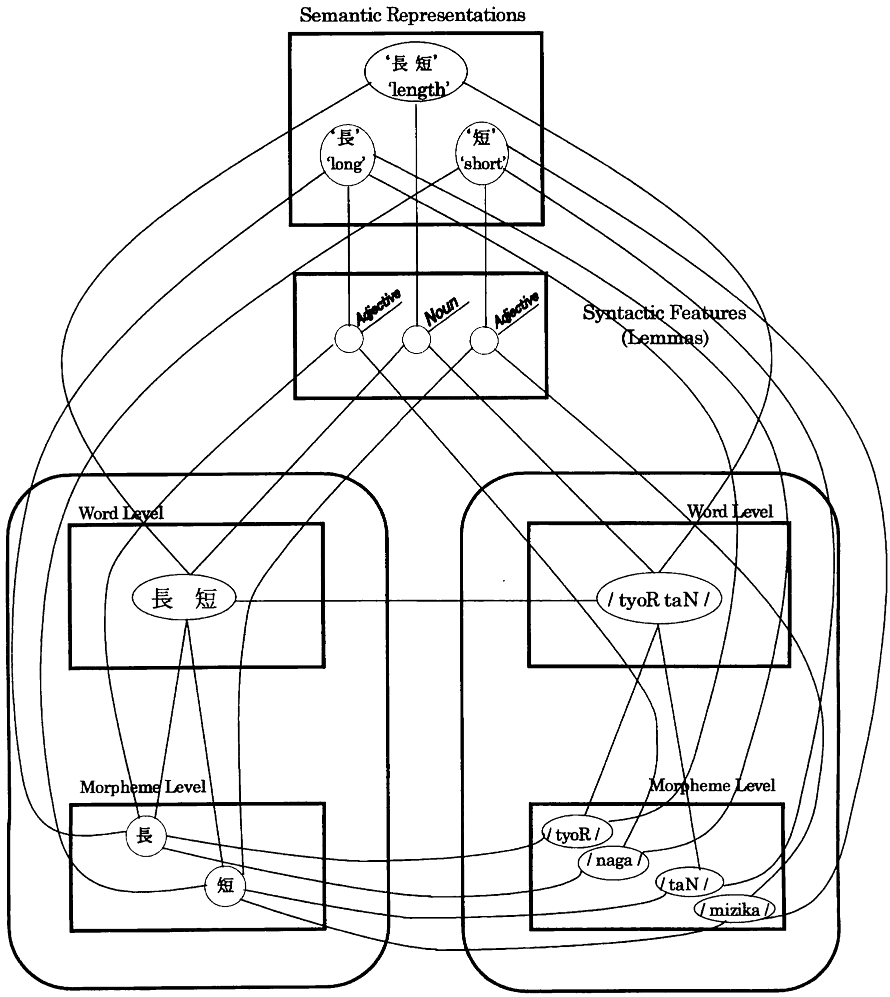

Figure 1. The processing model of the word for 'length' consisting of two kanji for 'long' and 'short'.

gain more activation. For this process, the compound words of two-kanji morphemes, even those with similar concepts, but particularly those with opposite concepts, require extra time for performing the tasks of naming and, to some degree, lexical decision than the control compound words.

Syntactic features did not play a major role in the present study. Nonetheless, the involvement of syntactic features in the processing of two-kanji words is to be expected because the morphemic kanji units are often accompanied by an adjective or a verb inflectional suffix. Taking the compound word *length* (長短) used in the present experiments, the kanji morpheme of *long* (長) on the left side of the compound word always appears as 長い (infinitive form) in the written Japanese text. It is formed by combining the kanji morpheme of 長 with an adjective suffix of い and together they are read as /naga-i/. Likewise, the kanji morpheme of *short* (短) on the right side of the compound word is combined with the same adjective suffix of い /i/ and is pronounced as /mijika-i/. Nevertheless, the compound word of 長短 is pronounced /tyoR taN/ with a combination of the two morphemic sounds of /tyoR/ and /taN/. Given this, the pronunciation of the two kanji morphemes of 長 and 短 changes depending upon grammatical category, in this example, upon whether they are to be interpreted as part of a noun or as adjectives.

As mentioned previously, there are two types of kanji readings, namely On-reading and Kun-reading. On-reading pronunciations were adapted from the Chinese language when kanji were implanted in Japanese, whereas Kun-readings were created by the native Japanese themselves (for the details of On- and Kun-readings, see Leong & Tamaoka 1995; Tamaoka 1991; Wydell, Patterson & Humphreys 1993). The compound words used in the present study were all of the On-reading type (e.g., 長短 /tyoR/ and /taN/). Kanji morphemes with an adjective or a verb suffix are frequently read as Kun-readings (e.g., 長い /naga-i/ and 短い /mizika-i/). Although not all the compound words used in the present experiment follow this rule, most of the kanji morphemes in the present study can be separately used as verbs, adverbs and adjectives with inflectional suffixes and, then, these kanji morphemes are most normally read as Kun-readings.

Since Kun-reading originated from the Japanese language, there is even a claim that Kun-readings of kanji are closely linked to their meanings (Kaiho & Nomura 1983; Nomura 1979). The claim by Nomura (1979), however, seems too extreme. It is sometimes observed that some Japanese native speakers misidentify On-readings of kanji morphemes as Kun-readings when the On-readings are firmly tied to their meanings, as in the case of 菊 /kiku/ meaning 'chrysanthemum' and 茶 /tya/ meaning 'tea'. Consequently, the cognitive boundary between On- and Kun-readings held among Japanese native speakers may not be as clearly-defined as in a dictionary. It is very possible that On- and Kun-readings might exist only for the purpose of 'convenience' in order to help speakers choose the proper pronunciation from among multiple kanji readings, depending on the type of words in different grammatical categories.

As the phonological choice of On- and Kun-reading is closely related to grammatical category, the processing model of two-kanji compound words as depicted in Figure 1 included the syntactic features associated with On- and Kun-readings. The phonological representations of On-readings, /typoR/ and /taN/ at the morpheme level are combined at the word level to form the phonological representation of /tyoR taN/. The orthographic representations of 長 and 短 at the morpheme level are connected not only to the On-readings of /tyoR/ and /taN/, but also to the Kun-readings of /naga/ and /mizika/ at the same morpheme level. Both On- and Kun-readings are further linked to their semantic representations of 'long' and 'short' which also have their connections to the orthographic representations at the morpheme level.

In the phonological aspect, the two kanji morphemes with the Kun-readings of /naga/ and /mizika/, however, have their connections to the syntactic features of adjectives. The syntactic features are frequently referred to as 'lemmas', a term coined by Kempen and Huijbers (1983). Lemmas represent the various syntactic properties of a word. Taking the compound word *length* (長短) as an example depicted in Figure 1, the meaning of 'long' which is represented by the single kanji morpheme of 長 (an orthographic representation at the morpheme level) or the Kun-reading of /naga/ (a phonological representation at the morpheme level) is indicated to be an adjective by combining it with an adjective suffix, い /i/ at the level of the syntactic features (i.e., the lemmas). Its actual syntactic uses are specified in the lemmas to create a phrasal structure such as 'a long nose' (長い鼻 /naga-i hana/), or 'a long bridge' (長い橋 /naga-i hasi/). In the same way, 'short' is syntactically specified by its lemma. Kempen and Huijbers (1983) also refer to the mental representation of word-form information as the 'lexeme', but we chose to use orthographic and phonological representations because they have the advantage of describing mental representations in greater detail.

Recent neuropsychological studies have provided evidence to prove the independent existence of the lemmas. Studies of brain-damaged patients have shown selective deficits in the processing of a single grammatical category such as dissociation between nouns and verbs (Caramazza & Hills 1991; Daniele, Giustolisi, Silveri, Colosimo & Gainotti 1994; Hills & Caramazza 1995; Miceli, Silveri, Nocentini & Caramazza 1988; Rapp & Caramazza 1997). These studies suggest that information concerning grammatical categories is an important organizational tool for the cognitive processing of languages. In a study of grammatical gender, Caramazza (1997) further proposed that access to a word's lexical-semantic representation does not automatically guarantee access to its syntactic features, and likewise, that access to the word's phonological features can occur independently of access to its syntactic features. This claim seems very reasonable for Japanese as well because the kanji morpheme unit of 長 (/tyoR/ for On-reading or /naga/ for Kun-reading) seemingly allowed direct access to its meaning of 'long' even when the syntactic feature of the adjective suffix い /i/ was not present. Thus, in the model in Figure 1, a direct connection to semantic representations is allowed from orthographic and phonological representations at the morpheme and word level. We assumed that the syntactic features or the lemmas could be independently located to specify grammatical categories and their uses to comprehend and produce words, phrases, clauses and sentences.

In sum, the present study suggests four major theoretical parameters. First, the variable of semantics at the morpheme level affected the processing of compound words as did other semantic factors such as fuzziness (e.g., Tan et al., 1995) abstract versus concrete (e.g., Bleasdale 1987; Kroll & Merves 1986; Schwanenflugel & Shoben 1983), imageability (e.g., Strain, Patterson & Seidenberg 1995), and polysemy (e.g., Azuma & Van Orden 1997; Balota, Ferraro & Connor 1991; Hino & Lupker 1996; Jastrzembski 1981; Strain, Patterson & Seidenberg 1995). Second, the morphological activation in orthographic representations leads to the raising of the activation level of morphemic semantics. Japanese two-kanji compound words are probably processed as a decomposed form as shown in previous studies (e.g., for English: Andrews 1989; Taft & Forster 1975, 1976; for Chinese: Taft, Huang & Zhu 1994; Wu, Chou & Liu 1994; Zhang & Peng 1992; Zhou & Marslen-Wilson 1994; Zhu & Taft 1994; for French: Beauvillain 1994; and for Japanese: Hirose 1992; Tamaoka & Hatsuzuka 1995). Third, contrary to the prediction of the facilitative effect by the previous theories of feedback activation (e.g., Balota, Ferraro & Connor 1991; Hino & Lupker 1996; Jastrzembski 1981; Strain, Patterson & Seidenberg 1995), neighborhood size effect (e.g., Andrews 1989, 1992; Sears, Hino & Lupker 1995) and spreading-activation (e.g., Collins & Loftus 1975; Dell 1986; Stemberger 1985), the effect of morphemic semantics in the present study was inhibitory. This effect was explained as competition between the morphemic semantics and the semantic representation of a whole word when the compound words of two kanji morphemes are processed. It was particularly strong with words of opposite concepts and less so with those of similar concepts. Fourth, syntactic features may be involved in the processing of two-kanji compound words, especially when each kanji morpheme is used with an adjective or verb suffix, although this was not a major concern in the present study. Then, as proposed by neuropsychological studies (e.g., Caramazza 1997; Caramazza & Hills 1991; Daniele, Giustolisi, Silveri, Colosimo & Gainotti 1994; Hills & Caramazza 1995; Miceli, Silveri, Nocentini & Caramazza 1988; Rapp & Caramazza 1997), it is possible that the syntactic features (or the lemmas) may independently exist and play an equally important part in the cognitive system as related to language processing.

Appendix

Word	Kanji meaning	Word meaning
(1) Compound words with two kanji of opposite concepts		
善悪	good + evil	= good and evil
因果	cause + effect	= cause and effect, misfortune
軽重	light + heavy	= the importance of the matter
難易	difficult + easy	= the importance of the matter
濃淡	dark + faint	= shade
高低	high + low	= uneven
強弱	strong + weak	= strength
貧富	poor + rich	= the degree of wealth or poverty
長短	long + short	= length
遠近	far + near	= distance
真偽	true + lie	= truth
表裏	front + back	= two sides
進退	advance + retreat	= movement, course of action
貸借	credit + debt	= loan
送迎	send + receive	= welcome and farewell
生死	life + death	= safety
増減	increase + decrease	= vary
新旧	new + old	= old and new
利害	advantage + damage	= interests
往復	go + return	= a return trip
攻守	attack + protect	= offense and defense
売買	sell + buy	= trade
有無	exist + nothing	= existence
勝敗	win + lose	= victory or defeat
終始	end + beginning	= throughout
内外	inside + outside	= around, inside and outside
(2) Compound words with two kanji of similar concepts		
断絶	cut + die out	= extinct
滅亡	perish + dead	= downfall, destruction
悲哀	sad + pity	= sorrow
柔軟	flexible + soft	= flexibility
束縛	bundle + bind	= constraint
喪失	dead + lose	= loss
適宜	suitable + alright	= suitable

Word	Kanji meaning	Word meaning
遭遇	meet + encounter	= encounter
形態	form + condition	= shape, configuration
模倣	copy + imitate	= imitation
歓喜	joy + rejoice	= joy, delight
睡眠	sleep + sleep	= sleep
暗黒	dark + black	= darkness
帰還	return + return	= return
妨害	obstruct + damage	= disturbance
下降	lower + go down	= falling
温暖	warm + warm	= warm
同等	same + equal	= equal
根源	root + source	= origin
船舶	ship + ship	= ship
奉仕	dedicate + serve	= service
単独	single + alone	= independent
満足	full + suffice	= satisfaction
功績	merit + achievement	= meritorious service
犠牲	sacrifice + sacrifice	= sacrifice
身体	body + body	= body
	(3) Closely-related compound words	
発酵	beginning + fermentation	= fermentation
関与	border + give	= participation
遺伝	leave behind + transmit	= heredity
荒野	wild + field	= wilderness
接続	join + continue	= connection
移住	move + residence	= migration
間食	interval + eat	= eating between meals
愛着	love + attached	= attachment, affection
運河	carry + river	= canal
校歌	school + song	= a school song
溶解	melt + solution	= dissolve
点線	dot + line	= perforated line
監査	keep watch over + investigate	= inspection
義理	righteousness + reason	= sense of duty
任意	appoint + will	= optional
欠席	lack + seat	= absence
鉛筆	lead + writing brush	= pencil
紅茶	red + tea	= black tea

Word	Kanji meaning	Word meaning
慣行	get used to + proceed	= custom
自慢	self + lazy	= be proud of
活用	active + errand	= practical use
集合	gather + meeting	= gathering
彫刻	carve + engrave	= sculpture
経過	longitude + pass	= lapse, passage of time
感覚	feeling + aware	= sense
別荘	separate + villa	= villa

The English translations of kanji morphemes and their compound words are mostly taken from *The Kanji Dictionary* by Spahn and Hadamitzky (1996).

Acknowledgements

We would like to thank anonymous reviewers and Deborah Kerr for comments on our earlier version of this article.

References

Andrews, S. (1986). Morphological influences on lexical access: Lexical or nonlexical effects? *Journal of Memory and Language* 25: 726–740.

Andrews, S. (1989). Frequency and neighborhood effects on lexical access: Activation or search? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 15: 802–814.

Andrews, S. (1992). Frequency and neighborhood effects on lexical access: Lexical similarity or orthographic redundancy? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 18: 234–254.

Azuma, T. & Van Orden, G. C. (1997). Why SAFE is better than FAST: The relatedness of a word's meanings affects lexical decision times, *Journal of Memory and Language* 36: 484–504.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D., Lewis, V. J. & Vallar, G. (1984). Exploring the articulatory loop, *Quarterly Journal of Experimental Psychology* 36A: 233–252.

Balota, D. A., Ferraro, F. R. & Connor, L. T. (1991). On the early influence of meaning in word recognition: A review of the literature. In: P. J. Schwanenflugel (ed.), *The psychology of word meanings* (pp. 187–221). Hillsdale, NJ: Erlbaum.

Beauvillain, C. (1994). Morphological structure in visual word recognition: Evidence from prefixed and suffixed words, *Language and Cognitive Processess* 9: 317–339.

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.

Butterworth, B. (1983). Lexical representation. In: B. Butterworth (ed.), *Language production, Vol. 2: Development, writing and other language processes* (pp. 257–294). London: Academic Press.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology* 14: 177–208.

Caramazza, A. & Hills, A. E. (1991). Lexical organization of nouns and verbs in the brain, *Nature (London)* 349: 788–790.

Cheesman, J. & Merikle, P. M. (1985). Word recognition and consciousness. In: D. Besner, T. G. Waller & G. E. MacKinnon (eds.), *Reading research: Advances in theory and practice, Vol. 5* (pp. 311–352). Orlando, FL: Academic Press.

Chen, H.-C. (1996). Chinese reading and comprehension: A cognitive psychology perspective. In: M. H. Bond (ed.), *The handbook of Chinese psychology* (pp. 43–62). Hong Kong: Oxford University Press.

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

Collins, A. M. & Loftus, E. F. (1975). A spreading-activation theory of semantic processing, *Psychological Review* 82: 407–428.

Coltheart, M., Davelaar, E., Jonasson, J. T. & Besner, D. (1977). Access to the internal lexicon. In: S. Dornic (ed.), *Attention and performance, Vol. 4* (pp. 535–555). Hillsdale, NJ: Erlbaum.

Daniele, A., Giustolisi, L., Silveri, M. C., Colosimo, C. & Gainotti, G. (1994). Evidence for a possible neuroanatomical basis for lexical processing of nouns and verbs, *Neuropsycholgia* 32: 1325–1341.

Dell, G. S. (1986). A spreading-activation theory of retrieval in sentence production, *Psychological Review* 93: 283–321.

Feldman, L. & Turvey, M. T. (1980). Words written in kana are named faster than the same words written in kanji, *Language and Speech* 23: 141–147.

Forster, K. I., Davis, C., Schoknecht, C. & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *Quarterly Journal of Experimental Psychology* 39A: 211–251.

Forster, K. I. & Taft, M. (1994). Bodies, antibodies, and neighborhood-density effects in masked form priming, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 20: 844–863.

Gathercole, S. E. & Baddeley, A. D. (1993). *Working memory and language*. Hillsdale, NJ: Erlbaum.

Gernsbacher, M. A. (1984). Resolving 20 years of inconsistent interactions between lexical familiarity and orthography, concreteness, and polysemy, *Journal of Experimental Psychology: General* 2: 256–281.

Goryo, K. (1987). *Yomu to yukoto* [*Concerning Reading*]. Tokyo: Tokyo University Press (in Japanese).

Grainger, J. (1990). Word frequency and neighborhood frequency effects in lexical decision and naming, *Journal of Memory and Language* 29: 228–244.

Grainger, J. & Segui, J. (1990). Neighborhood frequency effects in visual word recognition: A comparison of lexical decision and masked identification latencies, *Perception and Psychophysics* 47: 191–198.

Grainger, J., O'Regan, J. K., Jacobs, A. M. & Segui, J. (1989). Neighborhood frequency effects and letter visibility in visual word recognition, *Perception and Psychophysics* 51: 49–56.

Hills, A. E. & Caramazza, A. (1995). Representation of grammatical categories of words in the brain, *Journal of Cognitive Neuroscience* 7: 396–407.

Hino, Y. & Lupker, S. J. (1996). Effects of polysemy in lexical decision and naming: An alternative to lexical access accounts, *Journal of Experimental Psychology: Human Perception and Performance* 22: 1331–1356.

Hirose, H. (1992). Jukugo no ninchi katei ni kansuru kenkyu: Priming-hou ni yoru kentou [An investigation of the recognition process for jukugo by use of priming paradigm], *Japanese Journal of Psychology* 63: 303–309 (in Japanese).

Jastrzembski, J. E. (1981). Multiple meanings, number of related meanings, frequency of occurrence, and the lexicon, *Cognitive Psychology* 13: 278–305.

Kaiho, H. & Nomura, Y. (1983). *Kanji jouhou shori no shinrigaku [Psychology of kanji information processing*]. Tokyo: Kyouiku Shuppan (in Japanese).

Kamata (1991). *Kuwashii shougaku kanji jiten [A detailed Japanese Kanji dictionary in an elementary school*]. Tokyo: Buneido (in Japanese).

Kellas, G., Ferraro, F. R. & Simpson, G. B. (1988). Lexical ambiguity and the timecourse of attentional allocation in word recognition, *Journal of Experimental Psychology: Human Perception and Performance* 14: 601–609.

Kempen, G. & Huijbers, P. (1983). The lexicalization process in sentence production and naming: Indirect election of words, *Cognition* 14: 185–209.

Kimura, Y. (1984). Concurrent vocal interference: Its effects on kana and kanji, *Quarterly Journal of Experimental Psychology* 36A: 117–131.

Kimura, Y. & Bryant, P. (1983). Reading and writing in English and Japanese: A cross-cultural study of young children, *British Journal of Developmental Psychology* 1: 143–154.

Kinoshita, S. & Saito, H. (1992). Effects of concurrent articulation on reading Japanese kanji and kana words, *Quarterly Journal of Experimental Psychology* 44A: 455–474.

Kroll, J. F. & Merves, J. S. (1986). Lexical access for concrete and abstract words, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 12: 92–107.

Leck, K. J., Weekes, B. S. & Chen, M. J. (1995). Visual and phonological pathways to the lexicon: Evidence from Chinese readers, *Memory and Cognition* 23: 468–476.

Leong, C. K. (1986). What does accessing a morpheme script tell us about reading and reading disorders in an alphabetic script? *Annals of Dyslexia* 36: 82–102.

Leong, C. K., Cheng, P.-W. & Mulcahy, R. (1987). Automatic processing of morpheme orthography, *Language and Speech* 30: 181–196.

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: An Interdisciplinary Journal* 7: 377–393.

McClelland, J. L. & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings, *Psychological Review* 88: 375–407.

Miceli, G., Silveri, M. C., Nocentini, U. & Caramazza, A. (1988). Patterns of dissociation in comprehension and production of nouns and verbs, *Aphasiology* 2: 351–358.

Morton, J. & Sasanuma, S. (1984). Lexical access in Japanese. In: Henderson (ed.), *Orthograhies and reading* (pp. 25–42). Hillsdale, NJ: Erlbaum.

National Language Research Institute [Kokuritsu Kokugo Kenjyujo] (1973). *Shinbun no goi chosa (IV) [A study of uses of Japanese words in newspapers]*. Tokyo: National Language Research Institute (in Japanese).

Nomura, Y. (1979). Kanji no joho shori: On-doku kun-doku no densa katei [Information processing of Chinese characters (kanji): Retrieval processes in Chinese-style reading (On) and Japanese-style reading (Kun)], *The Japanese Journal of Psychology* 50: 101–105 (in Japanese).

Peereman, R. & Content, A. (1995). Neighborhood size effect in naming: Lexical activation or sublexical correspondences? *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 409–421.

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

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

Posner, M. I. & Snyder, C. R. R. (1975). Attention and cognitive control. In: R. L. Solso (ed.), *Information processing and cognition: The Loyola symposium* (pp. 55–85). Hillsdale: NJ: Erlbaum.

Rapp, B. & Caramazza, A. (1997). The modality-specific organization of grammatical categories: Evidence from impaired spoken and written sentence production, *Brain and Language* 56: 248–286.

Saito, H. (1981). Kanji to kana no yomi ni okeru keitaiteki fugouka oyobi oninteki fukouka no kentou [Use of graphemic and phonemic encoding in reading kanji and kana], *Japanese Journal of Psychology* 52: 266–273 (in Japanese).

Saito, H. (1997). Gengo no kagaku 3 – Shinteki jisho [Linguistic sciences 3 – Mental lexicon]. In: Y. Matsumoto (ed.), *Tango to jisho [Words and dictionary]* (pp. 93–153). Tokyo: Iwanami (in Japanese).

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.

Sears, C. R., Hino, Y. & Lupker, S. J. (1995). Neighborhood size and neighborhood frequency effects in word recognition, *Journal of Experimental Psychology: Human Perception and Performance* 21: 876–900.

Seidenberg, M. S. (1985). The time course of phonological code activation in two writing systems, *Cognition* 19: 1–30.

Seidenberg, M. S. (1989). Visual word recognition and performance: A computational model and its implications. In: W. Marslen-Wilson (ed.), *Lexical representation and process* (pp. 25–74). Cambridge, MA: MIT Press.

Seidenberg, M. S. & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming, *Psychological Review* 96: 523–568.

Spahn, M. & Hadamitzky, W. (1996). *The kanji dictionary*. Tokyo: Charles E. Tuttle Company.

Stemberger, J. P. (1985). An interactive activation model of language production. In: A. W. Ellis (ed.), *Progress in the psychology of language, Vol. 1* (pp. 143–186). Hillsdale, NJ: Erlbaum.

Strain, E., Patterson, K. & Seidenberg, M. S. (1995). Semantic effects in single-word naming, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 1140–1154.

Taft, M. (1991). *Reading and the medical lexicon*. Hillsdale, NJ: Erlbaum.

Taft, M. & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words, *Journal of Verbal Learning and Verbal Behavior* 14: 638–647.

Taft, M. & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words, *Journal of Verbal Learning and Verbal Behavior* 15: 607–620.

Taft, M., Huang, J. & Zhu, X. P. (1994). The influence of character frequency on word recognition responses in Chinese. In: H.-W. Chang, J.-T. Huang, C.-W. Hue & O. J. L. Tzeng (eds.), *Advances in the study of Chinese language processing, Vol. 1* (pp. 59–73). Taipei, Taiwan: Department of Psychology, National Taiwan University.

Taft, M. & Zhu X. P. (1995). The representation of bound morphemes in the lexicon: A Chinese study. In: L. B. Feldman (ed.), *Morphological aspects of language processing* (pp. 293–316). Hillsdale, NJ: Erlbaum.

Tamaoka, K. (1992). Processing efficiency of the Japanese words by Japanese learners of English speakers, *International/Transcultural Education* 6: 99–113 (in Japanese).

Tamaoka, K. (1991). Psycholinguistic nature of the Japanese orthography, *Studies in Language and Literature* (Matsuyama University) 11(1): 49–82.

Tamaoka, K. & Hatsuzuka, M. (1995). Kanji niji jukuo no shori ni okeru kanji shiyou hindo no eikyou [The effects of kanji printed-frequency on processing Japanese two-morpheme compound words], *The Science of Reading* 39: 121–137 (in Japanese with a substantial English summary).

Tamaoka, K., Hatsuzuka, M., Kess, J. F. & Bogdan, D. R. (1998). Hiragana vs Katakana: The script familiarity effect on the processing of Japanese words and non-words, *The Science of Reading* (in Japanese with a substantial English summary) (in press).

Tamaoka, K., Leong, C. K. & Hatta, T. (1992). Effects of vocal interference on identifying kanji, hiragana and katakana words by skilled and less-skilled Japanese readers in Grades 4–6, *Psychologia* 35: 33–41.

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

Waters, G. S. & Seidenberg, M. S. (1985). Spelling-sound effects in reading: Time course and decision criteria, *Memory and Cognition* 13: 557–572.

Weekes, B. (1997). Differential effects of number of letters on word and nonword naming latency, *Quarterly Journal of Experimental Psychology* 50A: 439–456.

Wu, J.-T., Chou, T.-L. & Liu, I.-M. (1994). The locus of the character/word frequency effect. In: H.-W. Chang, J.-T. Huang, C.-W. Hue & O. J. L. Tzeng (eds.), *Advances in the study of Chinese language processing, Vol. 1* (pp. 31–58). Taipei, Taiwan: Department of Psychology, National Taiwan University.

Wydell, T. N., Butterworth, B. & Patterson, K. E. (1995). The inconsistency of consistency effects in reading: The case of Japanese kanji, *Journal of Experimental Psychology: Learning, Memory, and Cognition* 21: 1155–1168.

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

Yokosawa, K. & Umeda, M. (1988). Processes in human kanji-word recognition. *Proceedings of the 1988 IEEE International Conference on Systems, Man, and Cybernetics* (pp. 377–380). Beijing and Shenyang, China.

Zhang, B. & Peng, D. (1992). Decomposed storage in the Chinese lexicon. In: H.-C. Chen & O. J. L. Tzeng (eds.), *Language processing in Chinese* (pp. 131–149). Amsterdam: North-Holland.

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

Zhou, X. & Marslen-Wilson, W. (1994). Words, morphemes and syllables in the Chinese mental lexicon, *Language and Cognitive Processes* 9: 393–422.

Zhu, X. P. & Taft, M. (1994). The influence of perceptual experience on Chinese character processing. In H.-W. Chang, J.-T. Huang, C.-W. Hue & O. J. L. Tzeng (eds.), *Advances in the study of Chinese language processing Vol. 1* (pp. 85–99). Taipei, Taiwan: Department of Psychology, National Taiwan University.

Address for correspondence: Katsuo Tamaoka, Ph.D., Institute for International Education, Hiroshima University, 1-2, 1-chome, Kagamiyama, Higashi-Hiroshima, 739-8523, Japan
Phone & Fax: +81-824-24-6288; E-mail: ktamaoka@ipc.hiroshima-u.ac.jp