Processing of Kanji and Kana characters within Japanese words

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Two experiments were conducted to examine the temporal relationship between whole-word and character processing in Japanese. Two kinds of Japanese script were used as stimuli: *Kanji*, an ideographic script, and *Kana*, a syllabic script. In Experiment 1, Kanji word processing and Kanji character processing were examined using a successive visual comparison task. The whole-word advantage (Marmurek, 1986) was not found. In Experiment 2, Kana words and characters were used. As in Experiment 1, no whole-word advantage was found. The absence of the whole-word advantage is attributed to the fact that Kanji and Kana characters represent higher level units of processing than alphabetic letters. The difference between word and nonword processing was shown by manipulations of the visual similarity and the homophony between stimuli presented successively. Visual similarity affected both words and nonwords, whereas homophony affected words only.

When two words were presented successively, decisions about the identity of the two words were made faster than decisions about the identity of a single alphabetic letter (hereafter, referred to as a *letter*) contained within a word (Johnson, 1975; Marmurek, 1986, 1987). This empirical phenomenon has been referred to as the *word-priority effect* (Sloboda, 1977) or the *whole-word advantage* (Marmurek, 1986). The implications of the whole-word advantage for hierarchical and race models, which are often referred to in the study of word perception, have been discussed. Both types of model assume that a word may be represented at various levels (i.e., at the feature level, the letter level, and the word level). Hierarchical models (e.g., McClelland & Rumelhart, 1981; Paap, Newsome, McDonald, & Schvaneveldt, 1981) assume that letter-level detectors provide output to higher level detectors, and that once the highest level detector is activated, it will control subsequent processing. For example, word-level units provide excitatory feedback to letter-level units (McClelland & Rumelhart, 1981), or word-level units control the verification and decision stages (Paap et al., 1981). This type of model implies that *same-different* comparisons for activated word-level units could be made directly, whereas letter-level comparisons would await further processing of the component detectors (Marmurek, 1986). The interpretation by race models (e.g., Allen &

Madden, 1990; Chambers & Forster, 1975) is that word-level processing and letter-level processing occur simultaneously, and that the word-level processing is completed earlier than the letter-level processing. Race models thus imply that the output of word-level processing is available before the output of letter-level processing.

Both types of model have interpreted the whole-word advantage as indicating that the availability of word level precedes that of letter level. However, it is not certain to be true in any "part-whole" relationship. The previous studies of the whole-word advantage have been restricted to the relationship between words and alphabetic letters. In other words, *whole* meant word-level processing and *part* meant letter-level processing. The main objective of the present study was to examine the robustness of the whole-word advantage. That is, we examined whether or not the effect is observed when part means a level other than the letter level; we did this by using Japanese, which has a linguistic structure different from English.

We conducted two experiments using *Kanji* and *Kana* characters, which are used for modern Japanese writing. Kanji words consisting of two Kanji characters play an important role in common Japanese writing: about 70% of Japanese dictionary entries are two-Kanji-character words. Moreover, because of the *word-superiority effect* (Reicher, 1969) found in a tachistoscopic forced-choice experiment (Yokosawa & Umeda, 1988), two-Kanji-character words are assumed to be perceptual units equivalent to English words.

Kanji characters are ideographic scripts and often multisyllabic. Thus, Kanji characters are considered to function midway between words and letters. Kana characters, on the other hand, are syllabic scripts with one Kana character representing one syllable, which usually requires several letters in English. Kana characters are thus assumed to function midway between Kanji characters and

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letters. Previous studies have been restricted to single-syllable words, such as *sleep*. English single-syllable words usually correspond to Japanese multisyllable words. For example, *sleep* corresponds to *suimin* in Japanese. *Su*, *i*, *mi*, and *n* each correspond to one Japanese syllable. Written in Kana, すいみん, and written in Kanji, 睡眠, 睡 (*sui*) is a higher unit than す (*su*). In previous studies, whole-word advantage referred to the fact that the identity of *sleep* was detected more quickly than that of *s* in *sleep*. In the present experiments, the robustness of this effect was tested by examining two types of part-whole relationship. In Experiment 1, Kanji words and Kanji characters were used. For example, the Kanji word 睡眠 was compared with the Kanji character 睡. In this case, *part* means the multisyllable and ideographic unit 睡. In Experiment 2, Kana words and Kana characters were used. For example, the Kana word すいみん was compared with the Kana character す. In this case, *part* means the single-syllable unit す. Moreover, the processing of Kanji nonwords and that of Kana nonwords were compared with the processing of words.

The visual similarity and the homophony between two successively presented Kanji stimuli were also manipulated in Experiment 1 because word processing is expected to differ from nonword processing, irrespective of the whole-word advantage. This is because words are assumed to comprise the visual and phonological units, but nonwords are not. Umansky and Chambers (1980) manipulated the visual similarity of items in *different* trials by using words differing only in their first letters (e.g., BLAME/FLAME) or differing completely (e.g., BOUND/FAME). Johnson, Turner-Lyga, and Pettegrew (1986) manipulated the similarity of items by dividing the letters into three classes. Although they found small effects of visual similarity, they avoided interpreting their data because appropriate control of similarity was impossible. Kanji characters, though, are visually more complex than letters, and some sets of Kanji characters are very similar. Thus, it is easier to control visual similarity. In the present study, the similarity of Kanji words was defined as the identity of a supraletter feature manipulated using a quantitative measure. There are also many homonyms in Japanese, so it is easy to examine the role of phonological information in the visual comparison task.

EXPERIMENT 1

Experiment 1 consisted of two parts. In Experiment 1A, Kanji words were used as stimuli; in Experiment 1B, Kanji nonwords were examined. To compare the processing of Japanese words with that of English words, we used experimental design, conditions, and methods similar to those of Marmurek (1987).

Experiment 1A

Method

Subjects. The subjects were 25 adults (12 men and 13 women). All reported having normal or corrected-to-normal vision and were

native Japanese readers. All subjects participated in Experiments 1A, 1B, 2A, and 2B. The order in which the subjects received the four experiments was counterbalanced among subjects.

Design. There were two types of comparison: whole and first character. The whole comparison required the decision about the identity of two entire words presented successively. The first-character comparison required the decision about the identity of the first characters of words. In *same* whole comparisons, there were 60 identical pairs. In *different* whole comparisons, there were two types of difference: (1) 30 pairs that differed in the first character (different-first-character pairs) and (2) 30 pairs that differed in the second character (different-second-character pairs). In *same* first-character comparisons, there were two types of identity: (1) 30 identical pairs and (2) 30 pairs that had only their first characters in common (common-first-character pairs). In *different* first-character comparisons, there were two types of difference: (1) 30 pairs that differed in the first character (different-first-character pairs) and (2) 30 pairs that differed in both characters (no-common-character pairs). Moreover, *same* trials in first-character comparisons and *different* trials in both types of comparison had three types of stimulus: control, similar shape, and homophony. Table 1 lists examples of stimuli.

In the present study, whole and first-character comparisons were compared using the same stimuli without repetition. The stimuli were assigned to identical pairs of both types of comparison from one stimulus set. This assignment was different for each subject. Each stimulus pair appeared in both types of comparison but was never given to the same subject twice. The same manipulations were conducted for the other two groups of stimuli: (1) different-first-character pairs in both types of comparison and (2) different-second-character pairs in whole comparisons and common-first-character pairs in first-character comparisons.

Materials. A total of 390 Kanji nouns, each consisting of two Kanji characters, was used. All Kanji characters used here are commonly used in modern Japanese writing.

In the similar-shape condition, stimuli were selected in the following way. First, 50 pairs of similar Kanji characters were selected. Next, 50 pairs of Kanji words were devised from those and other characters. The selected similar Kanji characters were included as either the first or the second character. The *peripheral direction contributivity feature* (Hagita, Naito, & Masuda, 1983; see Appendix) was used as a measure of visual similarity. In the homophony condition, paired words were homonyms. Moreover, the difference in the number of strokes between the first characters in the two stimuli and/or between the second characters in them was not more than three strokes, so the complexity of paired characters was approximately equal. In the control condition, neither the first nor the second characters in paired words were similar, but the difference in the number of strokes remained three or fewer. No paired words were homonyms.

Stimuli were presented to each subject, whose head was held fast with a chinrest at a viewing distance of 115 cm. A character was about 0.8° wide and 0.8° high. A word was about 1.8° wide and 0.8° high.

Apparatus. Stimuli were presented by a CRT tachistoscope controlled by a personal computer (NEC PC-9801). This tachistoscope draws a pattern using a random-scan method and features a fast-decay phosphor (p31) that decays to 10% intensity at 0.09 msec after display offset. The tachistoscope can present a stimulus and measure response latencies to an accuracy of 1 msec. The mean luminance of the blank display at a visual angle of 1.0° was 3.0 cd/m²; the average luminance of one character was 32 cd/m².

Procedure. Following instructions and 40 practice trials, each subject completed 240 trials. The instructions emphasized attending to both the first and the second stimuli and to both the first and the second characters. The subjects were required to respond as quickly and accurately as possible.

Table 1
Examples of Stimuli

Examples of Similarity					
Trial		Whole		First Character	
		Identical		Identical	Common-1st
Same	Control	哀愁-哀愁		压倒-压倒	音楽-音符
	Similar shape				在住-在任
	Homophony				公演-公園
		Diff-1st	Diff-2nd	Diff-1st	No-common
Different	Control	概要-需要	空席-空腹	遅刻-彫刻	審査-商社
	Similar shape	開店-閉店	小鳥-小島	著名-署名	徒勞-從事
	Homophony	証明-照明	体系-体型	強調-協調	帰省-規制

Note—Common-1st = Common-first-character pairs. Diff-1st = different-first-character pairs. Diff-2nd = different-second-character pairs. No-common = no-common-character pairs.

We employed the late-cue method (Marmurek, 1987); that is, the type of comparison (whole vs. first character) was specified by a cue given between the first and second stimuli. Both types of comparison were thus tested within a single session. We used an auditory cue (beep tones) instead of a visual cue (Marmurek, 1987). Each trial consisted of the following sequence of events. First, two fixation points were presented at the center of the display for 1 sec. Second, a Kanji character replaced each fixation point, and these two Kanji characters, presented for 1 sec, constituted the first Kanji word. Third, there was a blank delay of 1.5 sec, in the middle of which beep tones were presented to cue the type of comparison. One beep tone signaled a first-character comparison, and two beep tones signaled a whole comparison. The first beep tone was presented for 200 msec starting 800 msec after the first stimulus disappeared. To cue a whole comparison, after a delay of another 100 msec, the second beep tone was also presented for 200 msec. Finally, the second Kanji word was presented until the subject responded. Thirteen of the subjects were required to press the right button if the response was *same* and the left button if it was *different*; the rest of the subjects were given the inverse response mapping.

Results and Discussion

The mean correct latencies and the error rates are listed in Table 2 for *same* trials and in Table 3 for *different* trials. An overall analysis of the error rates revealed no significant difference between *same* and *different* trials [$F(1,24) < 1$]; however, an analysis of the mean latencies revealed that *same* was faster than *different* [$F(1,24) = 6.85$, $p < .05$]. These results are consistent with typical results in a *same-different* comparison task (Krueger, 1984).

Same trials. An analysis of the error rates revealed no significant differences [$F(4,96) = 1.61$, $p > .1$].

Concerning the whole-word advantage, identical pairs in *same* trials are critical. The mean latencies for identical pairs of both comparisons were analyzed. Whole comparisons were 27 msec slower than first-character comparisons, though not significantly so [$F(1,24) = 2.80$, $p > .1$]; that is, no whole-word advantage was found.

This indicates that there is no temporal priority in the processing of Kanji words over that of Kanji characters.

For first-character comparisons, the differences for type of stimulus in common-first-character pairs were not significant [$F(2,48) = 1.27$, $p > .1$]. Moreover, the difference between identical and common-first-character pairs was not significant [$F(1,24) = 1.61$, $p > .1$]. This result is inconsistent with the studies of Marmurek (1986, 1987), who found a significant difference between them.

Different trials. A 3 (type of stimulus) $\times$ 4 (type of difference) analysis of the error rates showed that the main effects of type of stimulus and type of difference were significant [$F(2,48) = 27.37$, $p < .001$, and $F(3,72) = 14.98$, $p < .001$, respectively], as was the interaction [$F(6,144) = 3.34$, $p < .01$]. The main effects were caused by the higher error rates in the similar-shape condition and with different-second-character pairs. The interaction was caused by the fact that, in the control and similar-shape conditions, different-second-character pairs showed significantly higher error rates [$F(3,72) = 8.85$, $p < .001$, and $F(3,72) = 8.35$, $p < .001$, respectively]; however, in the homophony condition, no significant difference was shown between type of difference [$F(3,72) = 2.61$, $p < .1$]. As can be seen in Table 3, however, the error rates tended to be positively correlated with the mean correct latencies ($r = .84$).

For the mean latencies, the main effects of type of stimulus and type of difference were significant [$F(2,48) = 54.45$, $p < .001$, and $F(3,72) = 14.34$, $p < .001$, respectively], as was the interaction [$F(6,144) = 2.51$, $p < .05$].

Concerning the type of difference, Tukey's studentized range test showed the significant differences ($p < .05$) between different-first-character and different-second-character pairs in whole comparisons. On the other hand, the difference between different-first-character and no-

Table 2
Mean Correct Latencies (in Milliseconds) and Percent Errors
for *Same* Trials in Experiment 1A (Kanji Words)

	Whole		First Character			
	Identical		Identical		Common-1st	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
Control	647	3.7	620	3.5	654	4.0
Similar shape					616	6.4
Homophony					639	6.8

Note—Common-1st = common-first-character pairs.

Table 3
Mean Correct Latencies (in Milliseconds) and Percent Errors
for *Different* Trials in Experiment 1A (Kanji Words)

	Whole				First Character			
	Diff-1st		Diff-2nd		Diff-1st		No-Common	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
Control	600	1.2	690	5.2	603	0.8	603	0
Similar shape	705	5.6	753	18.4	676	6.0	719	7.2
Homophony	636	0.8	715	4.4	631	2.4	602	1.2

Note—Diff-1st = different-first-character pairs. Diff-2nd = different-second-character pairs. No-Common = no-common-character pairs.

common-character pairs in first-character comparisons was not significant. These results replicate the results of the previous studies (Marmurek, 1986, 1987). In *different* trials, the analytical rechecking process (Krueger, 1978) based on character-level units occurred after word-level processing. The rechecking process was carried out in a left-to-right order; the subjects could make the *different* decision as soon as they perceived any difference (Krueger, 1984).

For type of stimulus, the homophony condition showed longer latencies than did the control condition and shorter latencies than did the similar-shape condition. Tukey's test showed that latencies of each type of stimulus were significantly different ($p < .05$). These results show that both visual similarity and homophony affected the *different* decision. These results contrast with the absence of the effects in *same* trials. This difference is attributed to the rechecking process. The rechecking process occurred in *different* trials when *same* visual and phonological information produced biasing effects.

The interaction was caused by the relatively short latencies for different-second-character pairs in the similar-shape condition for whole comparisons. Since a much higher error rate was shown in this condition, the short latency might have been caused by a speed-accuracy tradeoff. The interaction was also caused by the lack of difference between the control and homophony conditions in no-common-character pairs for first-character comparisons. Phonological information is not considered to af-

fect the comparisons when no character is common in the paired words.

Experiment 1B

Method

Subjects. The 25 adults who participated in Experiment 1A also participated as subjects in Experiment 1B.

Materials. A total of 390 two-character nonwords was constructed in the following way. In identical, different-first-character, and no-common-character pairs, only the second character was replaced with another character, so as not to constitute a word. In common-first-character and different-second-character pairs, only the first character was replaced. All nonwords were verified by consulting a Japanese dictionary. Furthermore, they were pronounceable, and "readings" (i.e., pronunciations) of stimuli were different from those of any words in the homophony condition.

Procedure. Procedural details were identical to those used in Experiment 1A. The subjects were informed in advance that all stimuli were nonwords.

Results and Discussion

An overall analysis of the error rates showed no difference between *same* and *different* trials [$F(1,24) < 1$]; however, the mean latencies showed that *same* decisions were faster than *different* decisions [$F(1,24) = 7.09$, $p < .05$].

Same trials. The mean correct latencies and the error rates are listed in Table 4. An analysis of the error rates showed significantly higher error rates for common-first-character pairs in first-character comparisons [$F(4,96) =$

Table 4
Mean Correct Latencies (in Milliseconds) and Percent Errors
for *Same* Trials in Experiment 1B (Kanji Nonwords)

	Whole		First Character			
	Identical		Identical		Common-1st	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
Control	691	2.9	616	0.9	677	7.2
Similar shape					661	10.4
Homophony					662	4.4

Note—Common-1st = common-first-character pairs.

6.67, $p < .001$). For the mean latencies, an analysis of identical pairs showed that first-character comparisons yielded latencies 75 msec shorter than whole comparisons [$F(1,24) = 16.73$, $p < .001$]. This result contrasts with the results found with Kanji words in Experiment 1A, which showed no difference between them.

For first-character comparisons, the differences between type of stimulus were not significant [$F(2,48) < 1$]. As for the type of identity, identical pairs yielded shorter latencies than did common-first-character pairs [$F(1,24) = 18.20$, $p < .001$]. This result is interpreted as indicating that information from the second characters affected the comparison of the first characters.

The result for identical pairs shows that nonwords were compared on a character-by-character basis because units that represent nonwords did not exist. In addition, the difference between identical and common-first-character pairs suggests that after the encoding of both characters was completed, the noise from the second characters interfered with the comparison of the first characters.

Different trials. The mean correct latencies and the error rates are listed in Table 5. A 3 (type of stimulus) $\times$ 4 (type of difference) analysis of the error rates showed that the main effects of type of stimulus and type of difference were significant [$F(2,48) = 44.00$, $p < .001$, and $F(3,72) = 6.50$, $p < .001$, respectively], as was the interaction [$F(6,144) = 2.98$, $p < .01$]. The main effects showed higher error rates for the similar-shape condition and with different-second-character pairs. In the control condition, no difference was shown between types of difference [$F(3,72) = 2.37$, $p < .1$]. In the similar-shape condition, different-second-character and no-common-

character pairs showed higher error rates [$F(3,72) = 5.11$, $p < .01$]. In the homophony condition, different-second-character pairs showed higher error rates [$F(3,72) = 3.58$, $p < .05$]. The error rates, however, tended to be positively correlated with mean latencies ($r = .82$).

For the mean latencies, the main effects of type of stimulus and type of difference were significant [$F(2,48) = 42.71$, $p < .001$, and $F(3,72) = 29.96$, $p < .001$, respectively]. The interaction was not significant [$F(6,144) = 1.21$, $p > .1$]. For type of difference, Tukey's studentized range test showed a significant difference ($p < .05$) between different-first-character and different-second-character pairs in whole comparisons; however, for first-character comparisons, there was no significant difference between different-first-character and no-common-character pairs. Comparing different-first-character pairs for whole comparisons with those for first-character comparisons, no significant difference was found. These results showed that the rechecking was carried out for *different* trials with nonwords as with words.

An analysis of type of stimulus showed significant differences ($p < .05$) between the control and similar-shape conditions and between the similar-shape and homophony conditions. The difference between the control and homophony conditions, however, was not significant. It is thus suggested that the phonological information did not affect the latencies, but the visual information affected them for *different* trials.

Words and nonwords. To compare word processing with nonword processing, analyses were carried out on the combined results of the mean latencies of Experiments 1A and 1B. For *same* trials, a 2 (lexicality) $\times$ 2 (type

Table 5
Mean Correct Latencies (in Milliseconds) and Percent Errors
for *Different* Trials in Experiment 1B (Kanji Nonwords)

	Whole				First Character			
	Diff-1st		Diff-2nd		Diff-1st		No-Common	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
Control	650	1.2	759	2.8	627	0.4	637	0.8
Similar shape	733	10.0	823	15.6	724	6.0	728	12.8
Homophony	669	2.0	745	5.6	640	2.4	616	0.8

Note—Diff-1st = different-first-character pairs. Diff-2nd = different-second-character pairs. No-Common = no-common-character pairs.

of comparison) analysis of identical pairs showed that the main effect of type of comparison was significant [$F(1,24) = 11.47, p < .01$], as was the interaction [$F(1,24) = 9.65, p < .01$]. The main effect of lexicality was not significant [$F(1,24) < 1$]. The interaction showed that words were processed faster than were nonwords for whole comparisons, though there was no difference for first-character comparisons. This effect for whole comparisons can be interpreted as a kind of word-superiority effect (Henderson & Chard, 1980).

For identical pairs, the difference between type of comparison was found with Kanji words and not with Kanji nonwords. These results indicate that words and nonwords are compared by different processes. For words, whole comparisons were based on word-level units, whereas first-character comparisons were based on character-level units. The comparison time for both types of comparison were almost equivalent. For nonwords, however, both whole and first-character comparisons were based on character-level units.

The difference found in type of identity for first-character comparisons was significant in nonwords, but nonsignificant in words. The significant difference in nonwords was attributed to the biasing effects of the second characters. It is difficult to explain why a significant difference was not found in Kanji words. One possible explanation is that even if the subjects received the biasing information of the second characters, their attention focused on the first characters, and rechecking was carried out very quickly with words.

For *different* trials, a 2 (lexicality) $\times$ 3 (type of stimulus) $\times$ 4 (type of difference) analysis showed that the main effects of type of stimulus and type of difference were significant [$F(2,48) = 95.98, p < .001$, and $F(3,72) = 27.60, p < .001$, respectively]. The type of stimulus $\times$ type of difference interaction was also significant [$F(6,144) = 3.14, p < .01$]. No other main effects or interactions reached significance. Decisions were usually made more slowly in the similar-shape condition and with second-character-different pairs. Concerning the type of stimulus, it became clear that the comparisons were affected by both visual and phonological information in words, but only by visual information in nonwords.

EXPERIMENT 2

In Experiment 2, we examined the relationship between Kana words and Kana characters. Kana characters are assumed to be units midway between Kanji characters and letters. Kana words were used in Experiment 2A, and Kana nonwords in Experiment 2B.

Experiment 2A

Method

Subjects. The 25 adults who participated in Experiment 1 also participated as subjects in Experiment 2.

Apparatus. The apparatus was identical to that used in Experiment 1. At a visual angle of 1.0° , the mean luminance of one character was 13.8 cd/m^2 . The mean luminance of one character was lower

in Experiment 2 than in Experiment 1 because the visual angle of one character was smaller and Kana characters are less complex than Kanji characters.

Materials, Design, and Procedure. A total of 130 Kana words, consisting of four Kana characters, were selected. In Japanese orthography, nouns are usually written in Kanji characters, whereas Kana characters are normally used only to write particles, as well as adjective and verb endings. All words in the present study were nouns, so the particular configurations as whole words were not familiar ones. Following instructions and 20 practice trials, each subject received 80 trials.

In *same* whole comparisons, there were 20 identical pairs. In *different* whole comparisons, there were (1) 10 pairs that differed in the first character (different-first-character pairs) and (2) 10 pairs that differed in the third character (different-third-character pairs). In *same* first-character comparisons, there were (1) 10 identical pairs and (2) 10 pairs that had only their first characters in common (common-first-character pairs). In *different* first-character comparisons, there were (1) 10 pairs that differed in the first character (different-first-character pairs) and (2) 10 pairs that differed in the first and third characters (different-first-and-third-character pairs). As in Experiment 1, the same stimuli appeared without repetition in both whole and first-character comparisons across the subjects. That is, identical pairs of whole and first-character comparisons were assigned from a stimulus set. Different-first-character pairs of both types of comparison were also assigned from a stimulus set. The procedure was the same as that used in Experiment 1, with one exception: a row of four, rather than two, fixation points was presented.

Stimuli were presented at a viewing distance of 172 cm. A character was about 0.5° wide and 0.5° high. A word was about 2.0° wide and 0.5° high.

Results and Discussion

The mean latencies and the error rates are listed in Table 6. An overall analysis of the error rates showed no significant difference between *same* and *different* trials [$F(1,24) < 1$]. On the means latencies, *same* decisions were faster than *different* decisions [$F(1,24) = 37.27, p < .001$]. This result is consistent with the results of Experiment 1 and with previous studies.

Same trials. There was no significant effect on error rate of type of identity [$F(2,48) = 2.13, p > .1$]. An analysis of the mean latencies for identical pairs showed that first-character comparisons were made 31 msec more quickly than were whole comparisons. This difference, however, was not significant [$F(1,24) = 1.21, p > .1$]; that is, for Kana words, no whole-word advantage was found. Examining the effect of type of identity in first-character comparisons, identical pairs were faster than common-first-character pairs. This difference was significant [$F(1,24) = 7.83, p < .01$], which indicates that the *different* information after the first character affected the *same* response.

Different trials. An analysis of the error rates showed significant differences [$F(3,72) = 6.39, p < .001$]. Different-third-character pairs showed a higher error rate. The mean latencies were significantly different between type of difference [$F(3,72) = 11.51, p < .001$]. Tukey's test revealed a significant difference ($p < .05$) between different-first-character and different-third-character pairs for whole comparisons. There was no difference, however, between different-first-character and different-first-

Table 6
Mean Correct Latencies (in Milliseconds) and Percent Errors in Experiment 2A (Kana Words)

Trial	Whole		First Character			
	Identical		Identical		Common-1st	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
<i>Same</i>	609	2.2	578	1.6	625	5.2
<i>Different</i>	Diff-1st		Diff-3rd		Diff-1st	
	Diff-1st-3rd		Diff-1st		Diff-1st-3rd	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
	633	0.8	750	6.8	640	0
	636	3.2				

Note—Common-1st = common-first-character pairs. Diff-1st = different-first-character pairs. Diff-3rd = different-third-character pairs. Diff-1st-3rd = different-first-and-third-character pairs.

and-third-character pairs for first-character comparisons. The present results cannot be readily compared with those of Kanji, because the visual similarity and homophony were not manipulated in Experiment 2. Nevertheless, the general tendencies of *different* results were similar to those of Kanji words.

Experiment 2B

Method

Subjects, Apparatus, and Procedure. The subjects, apparatus, and procedures were identical to those in Experiment 2A.

Materials. A total of 130 Kana nonwords was generated in the following way: Two nonsense syllables, each consisting of two Kana characters selected from Hayashi (1976, norm), were combined to make nonwords consisting of four characters. All Kana nonwords were pronounceable, but their orthographic regularity was low.

Results and Discussion

The mean latencies and the error rates are listed in Table 7. An overall analysis of the error rates showed no significant difference between *same* and *different* trials [$F(1,24) = 1.76, p > .1$]. For the mean latencies, there

was also no significant difference between *same* and *different* trials [$F(1,24) < 1$]. This result is different from the typical results in *same-different* judgments. As can be seen in Table 7, this is because the *same* identical decisions of whole comparisons were made much more slowly.

Same trials. The error rates were significantly different [$F(2,48) = 7.67, p < .01$], with common-first-character pairs showing a higher error rate. An analysis of the mean latencies for identical pairs showed that first-character comparisons were faster than whole comparisons. This difference was significant [$F(1,24) = 49.97, p < .001$]. No effect of type of identity was seen with first-character comparisons [$F(1,24) = 2.50, p > .1$]. These results are consistent with those of consonant strings reported by Marmurek (1986).

Different trials. An analysis of the error rates showed a significant effect of type of difference [$F(3,72) = 4.26, p < .01$]. This was due to the higher error rate of different-third-character pairs for whole comparisons. For the mean latencies, the effect of type of difference was also significant [$F(3,72) = 49.25, p < .001$]. Tukey's test showed that this effect was significant ($p < .05$) in

Table 7
Mean Correct Latencies (in Milliseconds) and Percent Errors in Experiment 2B (Kana Nonwords)

Trial	Whole		First Character			
	Identical		Identical		Common-1st	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
<i>Same</i>	769	3.6	611	2.0	636	10.0
<i>Different</i>	Diff-1st		Diff-3rd		Diff-1st	
	Diff-1st-3rd		Diff-1st		Diff-1st-3rd	
	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors	Mean Correct Latency	% Errors
	689	2.8	866	9.6	648	2.4
	613	2.0				

Note—Common-1st = common-first-character pairs. Diff-1st = different-first-character pairs. Diff-3rd = different-third-character pairs. Diff-1st-3rd = different-first-and-third-character pairs.

whole comparisons, but not in first-character comparisons, as seen in the previous experiments.

Words and nonwords. To compare words and nonwords, a 2 (lexicality) $\times$ 2 (type of comparison) analysis of the mean latencies was carried out separately for *same* and *different* trials. *Same* trials showed that the main effect of lexicality and type of comparison was significant [$F(1,24) = 4.86$, $p < .05$, and $F(1,24) = 23.24$, $p < .001$, respectively], as was the interaction [$F(1,24) = 23.44$, $p < .001$]. Comparing identical pairs with common-first-character pairs for first-character comparisons, words showed a significant difference and nonwords showed no effect. This suggests that *different* information from the second, third, and fourth characters affected *same* decisions with words. When nonwords were presented, however, the subjects made decisions based solely on the first character.

For *different* trials, the main effect of type of difference was significant [$F(3,72) = 47.91$, $p < .001$], as was the lexicality $\times$ type of difference interaction [$F(3,72) = 6.03$, $p < .001$]. The main effect of lexicality was not significant [$F(1,24) < 1$]. The interaction showed that for whole comparisons, nonwords were slower than words, whereas for first-character comparisons, words were not significantly different from nonwords. Although the rechecking process stops at the first position for first-character comparisons in both words and nonwords, it may take more time in nonwords than in words when the difference occurs at the third position on whole comparisons.

GENERAL DISCUSSION

The main objective of the present study was to examine the robustness of the whole-word advantage. No whole-word advantage was found for either Kanji or Kana, which are assumed to function midway between words and letters. The other results of this study, however, generally confirmed the previous studies in English (Marmurek, 1986, 1987). These results suggest that the whole-word advantage occurred only when word-level comparison preceded lower level comparison (i.e., letter-level comparison).

In Experiment 1, comparing Kanji words with Kanji nonwords, it is obvious that words and nonwords are processed in different ways. This difference was shown clearly in *same* trials. The analysis of identical pairs by type of comparison showed that the processing of Kanji words has no temporal priority over that of Kanji characters. On the other hand, the processing of Kanji nonwords required much more time than did that of Kanji characters. Moreover, a kind of word-superiority effect was shown: For whole comparisons of identical pairs, words were processed faster than were nonwords.

These results can be explained by both hierarchical models and race models, though they must be modified to apply to the processing of Japanese words. For example, the activation-verification model (Paap et al., 1981), a kind of hierarchical model, assumes that once the word-

level activity exceeds some criterion, the decision will be based on word-level units rather than letter-level units. In this model, only the lexicon (i.e., word-level units) has connections with the verification and decision stages. In Japanese, the character-level units are also assumed to be available for the decision stage, and the character-level decision can be made directly instead of after further processing, as in the case of letters.

The present results can also be explained by race models. In English, the word level wins the processing race and is available to provide the relevant information to perform a task, even if letter-level comparisons are required. In this case, the absence of a difference between whole and first-character comparisons can be interpreted as showing that the availability of word-level units and character-level units are equivalent. In other words, word-level units are available in whole comparisons and character-level units are available in first-character comparisons. Since the present study was not designed to evaluate these models, further discussion of the models would have no value. It is clear, however, that word-level and character-level units were functionally equivalent, and that word-level units had no priority or advantage.

In addition, it became clear that for *different* trials, visual similarity affected both words and nonwords, but homophony affected only words. It is, therefore, concluded that when the stimuli were words, visual and phonological information was available for *different* trials. When stimuli were nonwords, decisions were based only on the visual information.

For Kana words and Kana characters, the results of identical pairs were similar to those of Kanji—that is, no whole-word advantage was found. Thus, in the case of Kana also, the assumption that word-level and character-level information would be equivalent was supported. The tendencies were different, however, between words and nonwords in *same* first-character comparisons. Kanji words showed no difference in type of identity and Kanji nonwords showed a significant difference. Kana words and nonwords, however, showed reverse results. This may have something to do with the number of characters or the visual angles, which changed between Experiments 1 and 2. When Kana words were presented, the three characters after the first character strongly interfered with *same* decisions. For Kana nonwords, the information after the first characters might not be available for comparisons.

In the present study, word frequencies of Kana words were low because the Kana nouns used here are not normally used in writing. With regard to the whole-word advantage, the results with Kana words were the same as with Kanji words for which word frequencies were high. Johnson et al. (1986) noted that word frequency did not affect the part-whole relationship. Race models, though, assume that word frequency determines which unit level will win the processing race (e.g., Allen & Madden, 1990). More work is needed to investigate the nature of word-level units with Kana and the role of word frequency on the part-whole relationship.

REFERENCES

- ALLEN, P. A., & MADDEN, D. J. (1990). Evidence for a parallel input serial analysis model of word processing. *Journal of Experimental Psychology: Human Perception & Performance*, 16, 48-64.
- CHAMBERS, S. M., & FORSTER, K. I. (1975). Evidence for lexical access in a simultaneous matching task. *Memory & Cognition*, 3, 549-559.
- HAGITA, N., NAITO, S., & MASUDA, I. (1983). Handprinted Chinese character recognition by peripheral direction contributivity feature. *Transaction of the IECE, J66-D-10*, 10, 1185-1192. (In Japanese)
- HAYASHI, S. (1976). *Nonsense syllable shinkijunhyou (New norms of nonsense syllables)*. Toukaidagaku syuppan'kai (Toukai University Press). (In Japanese)
- HENDERSON, L., & CHARD, J. (1980). The reader's implicit knowledge of orthographic structure. In U. Frith (Ed.), *Cognitive process in spelling* (pp. 85-116). New York: Academic Press.
- JOHNSON, N. F. (1975). On the function of letters in word identification: Some data and a preliminary model. *Journal of Verbal Learning & Verbal Behavior*, 14, 17-29.
- JOHNSON, N. F., TURNER-LYGA, M., & PETTEGREW, B. S. (1986). Part-whole relationships in the processing of small visual patterns. *Memory & Cognition*, 14, 5-16.
- KRUEGER, L. E. (1978). A theory of perceptual matching. *Psychological Review*, 85, 278-304.
- KRUEGER, L. E. (1984). Self-termination in same-different judgments: Multiletter comparison with simultaneous and sequential presentation. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 10, 271-284.
- MARMUREK, H. H. C. (1986). Whole and part comparisons of words and nonwords. *Memory & Cognition*, 14, 113-123.
- MARMUREK, H. H. C. (1987). Attentional holism in visual word processing. *Psychological Research*, 49, 45-52.
- 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.
- PAAP, K. R., NEWSOME, S. L., McDONALD, J. E., & SCHVANEVELDT, R. W. (1981). An activation-verification model for letter and word recognition: The word-superiority effect. *Psychological Review*, 89, 573-594.
- REICHER, G. M. (1969). Perceptual recognition as a function of meaningfulness of stimulus material. *Journal of Experimental Psychology*, 81, 275-280.
- SLOBODA, J. A. (1977). The locus of the word-priority effect in a target-detection task. *Memory & Cognition*, 5, 371-376.
- UMANSKY, J. A., & CHAMBERS, S. M. (1980). Letters and words in word identification. *Memory & Cognition*, 8, 433-446.
- YOKOSAWA, K., & UMEDA, M. (1988). Processing in human Kanji-word recognition. *Proceedings of the 1988 IEEE International Conference on Systems, Man, & Cybernetics*, 377-380.

APPENDIX

Visual similarity of Kanji characters

When stimuli for the similar-shape condition were selected in Experiment 1, their visual similarity was defined by whether or not the contour of the characters was similar by using the peripheral direction contributivity (PDC) feature. This is a feature specific to each character and is known in Japan as a useful tool for machine recognition (Hagita et al., 1983). The PDC feature has 1,152 dimensions. A character is scanned from the outside and 288 points on the contour edges (e.g., point A, in Figure A1) are extracted. Four directional run lengths (horizontal, vertical, right diagonal, or left diagonal) of black pixels are then extracted for each point (e.g., length AB is the run length for point A in the vertical direction). The 1,152 dimensions represent these lengths ($288 \times 4 = 1,152$). Visual similarity is calculated on the basis of the absolute value of difference between all lengths for a character pair. A small difference in the PDC feature implies high visual similarity. The similarities were calculated for about 2 million pairs (i.e., all combinations of 2,020 commonly used characters); the 1,500 pairs with the highest mutual similarity were identified. These pairs satisfy what we call the *similar-shape condition*. We selected 50 of these pairs for use in Experiment 1.

Figure A1. Extraction of the peripheral direction contributivity feature.