PROCESSING NUMERALS IN ARABIC, KANJI, HIRAGANA AND KATAKANA BY SKILLED AND LESS SKILLED JAPANESE READERS IN GRADES 4-6

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Using the comparison task of two numerals presented in Arabic, kanji, hiragana and katakana, the study investigated the mechanism of kana and kanji processing. The 108 student sat Grade 4 to 6 were chosen for the experiment on the basis of an equal proportion of gender, grade and reading level. Numerals in the script mismatched conditions (*i. e.*, kanji vs. Arabic, hiragana vs. Arabic and katakana vs. Arabic) were processed less accurately in comparison to the script matched condition of Arabic vs. Arabic. Numerals in Arabic and kanji were processed faster than ones in hiragana and katakana. The numeral length of kana symbols did not show any effect in numeral processing. Therefore, the numerals presented in both hiragana and katakana would be processed in the higher degree of indirect (phonological) processing for numeric judgments with no effects of numeral kana-symbol length, while the same numerals presented in Arabic and kanji would be processed in the higher degree of direct (orthographic) processing. Furthermore, the study clearly illustrated strong influences from the subject's grade and reading level in the efficiency of numeral processing among the four different scripts.

The previous findings and reviews on kana and kanji processing (Kimura, 1984; Sasanuma, 1977, 1980; Saito, 1981 for experimental findings, and Bryant & Bradley, 1983; Goryo, 1987; McCusker, Hillinger & Bias, 1981; Morton & Sasanuma, 1984; Saito, 1982 for review) suggest that kanji characters are processed directly to access the lexicon, whereas kana symbols are processed indirectly. However, this argument should be refined since the new research findings (Besner & Hildebrandt, 1987; Hirose, 1984; Sasanuma, Sakuma & Tatsumi, 1988) indicated that, as in English, familiar high-frequency katakana words (alphabetic loan-words) can be processed directly without referring to phonetic recoding. Thus, using numerals presented in Arabic, kanji, hiragana and katakana, the present study was designed to confirm and refine the previous findings on kana and kanji processing.

In addition to the nature of Japanese scripts, the characteristics of readers also indicate a difference in processing time and accuracy. Haines and Leong (1983) found that less skilled readers required longer vocalization latencies, and had slower lexical access for the judgment of real and pseudo words in comparison with skilled readers. Haines and Leong interpreted their findings as suggesting that the difficulty which less skilled readers encounter in vocalizing stimulus words and accessing the

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lexicon is not necessary because of a poor lexicon, but because of a difficulty in recoding letter strings. Leong (1987) employed the automaticity model of word recoding proposed by LaBerge and Samuels (1974) to generalize the above results of longer vocalization latency and slower lexical access in less skilled readers; that is, skilled readers attain automaticity in reading that allows them to concentrate on the meanings, rather than on the mechanics of reading.

Leong, Cheng and Mulcahy (1987) further tested this automaticity hypothesis in morphemic orthography (Chinese characters). The study found that for vocalization latencies of Chinese characters, skilled readers were faster and had fewer errors than less skilled readers in both of two orthographic situations: (a) low and high printed-frequency, and (b) simple and complex structures. For the lexical decision of Chinese real or pseudo characters, the study also found that skilled readers were faster in real or pseudo judgment than less skilled readers under both orthographic conditions of real/pseudo and simple/complex structures. Parallel to the study of the English orthography (Haines & Leong, 1983), these two experiments supported the automaticity model that applies to the Chinese morphemic orthography.

Since Japanese kanji were adopted from the Chinese orthography, and have shown remarkable stability over the years across great distances (Leong, 1986), the automaticity model could be applicable to the lexical judgment of Japanese kana and kanji. Therefore, the sample in the present study was chosen according to reading level and grade ; not only the script differences of hiragana katakana, kanji and Arabic presenting numerals, but also the subjects' characteristics of reading level and grade were analyzed to examine automatic processing of numerals.

METHOD

Subjects: Subjects were chosen from a medium-size, public elementary school in the central area of Osaka city, Japan. The pool of potential subjects was developed by administering the TK Style Japanese Reading Ability Test (Kitao, 1984) to 200 students in Grades 4 to 6. After excluding a small number of children with severe learning disabilities and attention problems, the total converted scores of five subtests on the TK reading ability test were used for selecting 18 skilled readers (9 boys and 9 girls) and 18 less skilled readers (9 boys and 9 girls) in each of Grades 4 to 6. The means and standard deviations of the subject's ages were 124.25 months (SD=4.03) in Grade 4, 137.92 months (SD=3.11) in Grade 5, and 149.42 months (SD=3.26) in Grade 6. The means with standard deviations on the TK reading ability Test for the grades 4, 5 and 6 groups of 36 children each were respectively 84.58 (12.77), 106.50 (38.55), and 118.07 (39.17).

Stimuli: Since the numbers one, two and three in kanji are written by using horizontal bars, they could not be compared to each other for the experimental use of lexical judgments. Thus, the present experiment used only seven numbers, three to nine. The tasks of the present study required subjects to compare two numbers randomly presented on the computer screen and to decide which was larger in value by pressing the right or the left key. The two numerals were written in four different script conditions: (1) Arabic and Arabic (*e.g.*, 6 and 8); (2) Arabic and kanji (*e.g.*, 6 and 八); (3) Arabic and hiragana (*e.g.*, 6 and はち); (4) Arabic and katakana (*e.g.*, 6 and ハチ). There are no cases of two numerals of equal values appearing. An Arabic numeral was always presented randomly as a reference numeral on either the right or the left side of the fixation point under every script condition, so that reaction times of numerals in the four scripts can be compared to assess their relative difficulty for lexical judgments. A remaining number was presented in one of the four scripts: Arabic, kanji, hiragana and katakana.

Procedure: The 108 Grade 4 to 6 students were tested individually in a quiet room at school. The session

began with the presentation of eight familiarization trails using the practice stimuli of two numbers presented in each of the four script conditions. The subjects were required to press either the right or the left key, depending on which number was larger, as quickly and accurately as possible. For example, if the hiragana representation of eight, 'はち', was displayed on the left side of the screen and the Arabic numeral of '7' on the right as a reference number, the hiragana numeral was larger in value, so that the subject had to press the left key. Two numerals, one Arabic and the other in its Arabic, kanji, hiragana or katakana form, were also randomized for display on either the left or the right side of the screen. The two numerals stayed on the screen until the subject pressed the right or the left key. When the space key was pressed following each response, the next stimulus appeared after a 700-millisecond interval. During the interval, an asterisk was shown on the fixation point to indicate the centre of the screen. Accuracy and the length of time between the presentation of the two numerals and a subject's response were recorded for every stimulus.

RESULTS

Analysis of Reaction Time in Processing Numerals of Four Scripts

Only correct responses were used for the further data operation and analysis. To eliminate extremely deviant reaction time values, outliers with 2.5 standard deviation values of milliseconds above or below the mean in each grade were replaced by the corresponding lower or upper boundary reaction time values (the upper boundary value is the mean reaction time plus the 2.5 *SD* value, and the lower boundary value is the mean reaction time minus the 2.5 *SD* value) for the individuals. Means and standard deviations resulting from the modified reaction time values are presented in Table 1. For the reaction time data, a 3 (grade) × 2 (reading level) × 4 (script) ANOVA with repeated measures on script was performed. The means of reaction times are graphically presented in Fig. 1.

There was a highly significant main effect of the script within-factor [$F(3, 106) = 66.94, p < .0001$]. This result is consistent with the assumption that efficiency

Table 1.   Means and Standard Deviations (in Parentheses) for Reaction Time (Rounded to the Nearest Millisecond) of Numerals in Four Scripts

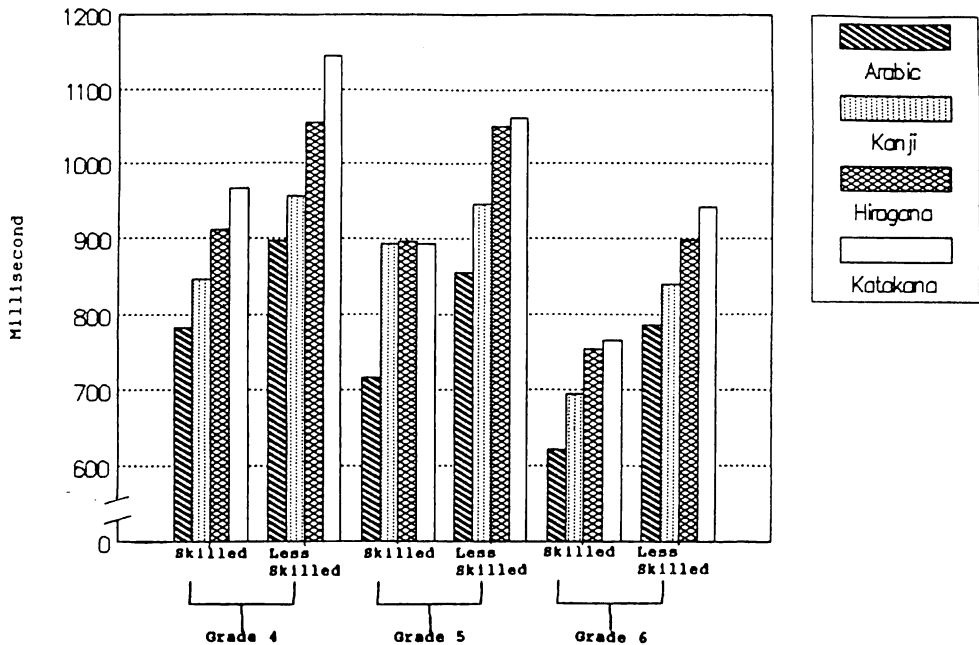| Grade	Reading Level	Script Type (mses.)			
		Arabic	Kanji	Hiragana	Katakana
4	Skilled	783	846	911	967
		(159)	(167)	(154)	(196)
	Less Skilled	898	956	1056	1145
		(175)	(229)	(244)	(247)
5	Skilled	716	893	897	893
		(187)	(405)	(224)	(185)
	Less Skilled	855	946	1050	1062
		(190)	(213)	(212)	(232)
6	Skilled	622	695	754	765
		(118)	(149)	(155)	(153)
	Less Skilled	786	840	898	941
		(168)	(193)	(207)	(198)

Fig. 1. Mean reaction times of numerals in four scripts across reading level by grade.

in processing of numerals is influenced by script type. As shown in Table 1 and Fig. 1, each script was perceived at a different speed for the comparison tasks; Arabic and kanji numerals were processed more efficiently (faster in reaction time) than kana (hiragana and katakana) numerals. This could be explained by the different processing mechanism that Arabic and kanji numerals are processed, to a higher degree, by the direct processing, whereas kana numerals, to a higher degree, by the indirect processing. In addition, there were highly significant main effects for grade [$F(2, 102) = 7.34$, $p < .001$] and reading level [$F(1, 102) = 15.71$, $p < .0001$] on reaction time. These results further add two influential factors on efficiency in the processing of numerals; subject's reading level and grade. The students' grade was a major influential factor on efficiency of processing numerals. This also supports the hypothesis that processing numerals could be related to a level of automaticity in lexical access.

A significant interaction was indicated between script and grade [$F(6, 306) = 2.21$, $p < .05$]. This interaction was created by the performance of the students in Grade 5; the students in Grade 4 ($M = 901$) performed faster in the numeric comparisons of kanji vs. Arabic than ones in Grade 5 ($M = 909$), although the students in Grade 4 were always slower in reaction time than ones in Grade 5 in other scripts. This interaction, however, does not present any crucial evidence to alter the explanation for processing of numerals presented in the four different scripts.

Analysis of Reaction Time in Processing the Numerals 3 to 9

Although the numerals (3 to 9) in Arabic and kanji are presented by a single

symbol, the same numerals in kana (hiragana and katakana are constructed by the different number of symbols (*e.g.*, 5 is described by one kana symbol, 3, 4, 6, 7 and 8 are described by two kana symbols, and 9 by three symbols). the number of kana symbols (numeral length) may influence processing speed of numerals. In order to examine effects of numeral length, reaction times of each numeral were analyzed separately according to the script type. Assuming increasing one number in each numeral from 3 to 9, a series of a 3 (grade) × 2 (reading level) × 7 (numeral) ANOVA with repeated measures on numeral was performed in each script type.

There were significant main effects of the numeral within-factor (numerals 3 to 9) in every script type: $F(6, 612) = 2.56$, $p < .05$ for Arabic vs. Arabic script condition, $F(6,612) = 3.27$, $p < .01$ for kanji vs. Arabic script condition, $F(6, 612) = 7.03$, $p < .0001$ for hiragana vs. Arabic script condition, and $F(6, 612) = 8.47$, $p < .0001$ for katakana vs. Arabic script condition. These results suggest that there were differences in processing speed of numerals 3 to 9. As it was revealed in the previous analysis in this study, the grade and reading level between-factors were significant in every script condition, and there were no significant interactions.

Although the factor of numeral difference (numerals from 3 to 9) was indicated as a significant factor in every script condition, the numeral of 9 ($M = 860$ for hiragana, and $M = 931$ for katakana) which is constructed by three hiragana or katakana symbols was processed faster than two kana symbol numerals of 6, 7 and 8 ($M = 930$, 1012, 886 for hiragana, and $M = 1024$, 924, 893 for katakana respectively). In addition, the one-kana symbol numeral of 5 ($M = 909$ for hiragana, and $M = 919$ for katakana) was not processed particularly faster than any other numerals. On the other hand, the numerals on 8 and 9 showed constantly and slightly faster processing speed in comparison to other numerals across the four script conditions. This tendency may be explained that the larger numerals of 8 and 9 were easily compared to other smaller numerals for the comparison task of two numerals. Therefore, it is concluded that the numeral length itself does not affect processing speed of the numerals, but rather the combinations of numerals to be asked to compare in the experiment could affect processing speed. Again, the script familiarity remained as the major factor affecting the numeral processing speed across all the numerals 3 to 9.

SUMMARY AND DISCUSSION

Because Arabic numerals are used in daily life, a comparison in value of two Arabic numerals was processed efficiently in comparison to the same numerals presented in the other scripts of kanji, hiragana and katakana. Since kanji numerals are occasionally used for a top-to-down style of Japanese writing, a comparison of an Arabic and a kanji numeral was also judged quickly. However, a numeral comparison of kanji vs. Arabic was slower than between Arabic numerals. There will be two reasons affecting the difference in processing speed between Arabic and kanji numeral processing: First, Arabic is more commonly used for representing numbers than kanji; and second, two numerals for kanji script were presented in the

mismatched script condition of kanji and Arabic numeral comparisons. However, since numbers in both scripts of Arabic and kanji are seen daily in a Japanese written materials, processing numerals in Arabic and kanji could be at the level of automaticity (LaBerge & Samuels, 1974; Perfetti & Lesgold, 1977; Stanovich, 1980) which no longer requires any attention for word processing and frees cognitive resources for higher level comprehension.

Although hiragana is commonly used in Japanese writing, mostly for grammatical inflections, it is unusual for it to be used for expressing numbers. Thus, hiragana numerals took longer to be recognized than Arabic and kanji ones. Katakana, which is used only for loan-words from alphabetic languages (*e.g.*, English, Spanish, Portuguese, French, German) is perhaps more difficult to decode than hiragana when it is used to present numbers. Compared to Arabic and kanji numerals, the longer reaction time in numeric comparisons of hiragana and katakana numerals could result from the involvement of the indirect (phonological) processing for digital decoding, since presenting numerals in hiragana and katakana is not familiar to the students. In other words, in order to overcome script unfamiliarity of numerals presented in hiragana and katakana, the students may have to process kana numerals indirectly through phonetic recoding, which is often called 'back-up mechanism' for special reading conditions (*e.g.*, unknown words, unfamiliar script). The difference in speed between two types of kana, hiragana and katakana may originate from the degree of script unfamiliarity when they are used for presenting numerals. This difference in reaction time could be further interpreted that processing the numerals in katakana could be more dependent on the indirect (phonological) processing than processing the same numerals in hiragana.

When analyzed separately in each script type of Arabic, kanji, hiragana and katakana, reaction time of processing the numerals 3 to 9 showed a significant differences. However, the means of the numerals 3 to 9 in the four scripts did not indicate the effects of numeral length. For example, the numeral of 9 constructed by three hiragana or katakana symbols was processed faster than two kana symbol numerals of 6, 7 and 8. Furthermore, the one-kana symbol numeral of 5 was not processed particularly faster than any other numerals. Therefore, the result suggests that the numeral length in kana symbols does not affect processing speed of numerals.

Furthermore, the present study investigated the subjects' characteristics of reading level and grade as well as the differences in script type. The analysis of the reaction time data indicated the highly significant main effects of grade and reading level. The differences in reaction time between the three grades suggest that, as they get older, students may develop proficiency in rapid, automatic recoding used in comparisons of numerals. Moreover, the different reaction times in the processing of numerals for the skilled and less skilled readers could derive from their differing abilities in speed for recoding numerals. The results of the study clearly illustrated differences in the efficiency of numeral processing among the four different scripts with strong influences from the subject's grade and reading level.

The model of automaticity hypothesis (LaBerge & Samuels, 1974; Stanovich,

1980) could be applicable to the numeral processing.   The numerals presented in Arabic and kanji could be processed more automatically by skilled readers in a higher grade.   The continuous decrease in reaction time for numeral processing based on the degree of the subjects' reading level and grade represent the development of automaticity level   The skilled readers in a higher degree also showed a faster speed in processing of kana numerals; they could develop better manipulation skills in phonetic script of kana for presenting numerals.   Therefore, as indicated in the English and Chinese orthography (Haines & Leong, 1983;   Leong, 1987;   Leong, Cheng & Mulcahy, 1987), the automaticity model could be applicable to the numerals presented in Arabic and kanji, and possibly ones in kana (hiragana and katakana).   In sum, not only the nature of scripts presenting numerals, but also the nature of subjects' reading level and grade influence efficiency in processing numerals.

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