Script Familiarity Effects on the Efficiency of Processing Numerals by Japanese University Students with High and Low English Proficiency

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Abstract Using the comparison task of two numerals presented in Arabic, kanji, hiragana or English alphabet, the study investigated the effects of script familiarity on numeral processing. 34 students at Matsuyama University were chosen for the experiment on the basis of an equal proportion of high/low English proficiency. The results indicated that the script was a major factor influencing efficiency (accuracy and speed) of the numeral processing ; Arabic and kanji numerals could be processed a greater degree of direct (visual) processing than those in hiragana and the alphabet. The length of numerals written in hiragana symbols or the alphabet did not affect numeral processing. The study illustrated only a slight, but consistent, difference in the numeral processing speed between the students of high and low English proficiency.

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INTRODUCTION

Arabic, kanji, hiragana and the English alphabet were used in the present experiment to measure the efficiency (speed as well as accuracy) of processing numerals. Kanji, which were adopted from the Chinese language, are often believed to be 'pictographic' or 'idiographic' characters. Kana symbols were developed to describe phonetic representations of the Japanese language. Due to the equal duration of the pronunciation in each kana symbols, they are technically called 'morae' (singular 'mora'), which are roughly equal to syllables. Kana symbols are divided into two types; one is hiragana and the other is katakana. Hiragana symbols are typically used to write grammatical inflections, while katakana symbols are used for loan-words from alphabetic languages such as Spanish, Dutch, English, German and French. Alphabetic scripts roughly represent phonemes, which are the smallest units of speech in the English language.

Although kanji numerals are often used, especially to print numerals vertically in Japanese publications, they are not employed as frequently as Arabic numerals. Thus, Arabic numerals should be processed faster than kanji numerals. Hiragana numerals are not as commonly used as Arabic or kanji numerals, so Arabic numerals and kanji numerals should be processed faster than hiragana numerals. English numerals are used almost exclusively in English classes, and not on a daily basis. Thus, the processing of alphabetical (English) numerals was expected to take longer than that of hiragana numerals.

Previous findings and reviews on kana and kanji processing (Kimura, 1984; Kimura & Bryant, 1983; Sasanuma, 1975, 1977, 1980; Saito, 1981 for experimental findings, and Bryant & Bradeley, 1983; Goryo, 1987;

McCusker, Hillinger & Bias, 1981 ; Morton & Sasanuma, 1984 ; Saito, 1982 for review) suggest that Arabic and kanji numerals are processed more like a pictorial image than are hiragana and alphabetic numerals. In other words, Arabic and kanji numerals can be processed as if they were a Gestalt image of a picture, with little reference to phonetic codes. On the other hand, hiragana or alphabetic numerals are perceived as an unfamiliar string of syllables or letters. Thus, phonetic recording could be required to a greater degree for processing hiragana and alphabetic numerals than for processing those in Arabic and kanji.

However, this argument should be refined because new research (Besner & Hildebrandt, 1987 ; Hirose, 1984 ; Sasanuma, Sakuma & Tatsumi, 1988) indicates that, as in the case of English scripts, familiar or high frequency katakana words can be processed directly as a total image without phonetic recording. These recent findings indicate that familiarity or frequency may be the major factors influencing the mechanism of numeral processing. Thus, using the task of comparing numerals presented in Arabic, kanji, hiragana or alphabetically, the study was designed to further refine the previous research findings on lexical access.

METHOD

Subjects

Using the English comprehension test produced by the authors, 17 subjects with high English proficiency, and 17 subjects with low English proficiency (overall, 6 males and 28 females) were selected from 49 volunteers of students at Matsuyama University. Since all the numerals used in the present study are not difficult for university students, who are expected to obtain an accuracy ratio of above 90 percent, it was assumed that the subjects' mental abilities and language skills in Japanese and English should be sufficient enough to cope with the tasks of numeric comparisons. The means and standard deviations of the subjects' ages, as adjusted for the month of experimentation, January, 1991 were 244.18 months with a standard deviation of 4.58 months, ($M=244.41$ with $SD=3.11$ for the students with high English proficiency, and $M=243.94$ months with $SD=3.26$ for the those with low English proficiency). The result of the English comprehension test was 28.06 with a standard deviation of 5.93 ; $M=32.94$ with $SD=2.73$ for the high-proficiency students and $M=23.18$ with $SD=3.40$ for the low-proficiency students. The means of the English comprehension test performed by the students with high and low English proficiency in the present study were acceptably far apart.

Stimuli

Stimuli for the present study were chosen from the numbers three to nine. 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 weakness in this experiment was the limited number of ways in which to combine two out of only seven numbers. There were only 21 combinations. The combinations were further extended to 42 by reversing right and left sides. These two numerals were presented randomly to the subject for judgment of their values.

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 scripts : (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 alphabetically (e. g., 6 and EIGHT). In no case did two numerals of equal value appear. Of the two numerals presented on the screen at any given time, one was always an Arabic numeral and it appeared randomly on either the right or the left side of the fixation point under every script condition. It was employed as a reference number so that students' reaction times to the four scripts could be compared so as to assess the relative difficulty of making lexical judgments about each script. The second number was presented in one of the four scripts : Arabic, kanji, hiragana or the alphabet. The 28 numerals (7 numerals × 4 script types) were compared in value with any Arabic numeral randomly selected from three to nine until all the stimuli were used.

Procedure

The 34 university students were tested individually in a quiet room on campus. Each student was seated in front of the computer screen, with the seat adjusted so that the student could view the screen at the appropriate height. A lap-top computer, the Toshiba J-3100GT was used for the experiment. The instructions, as described below in Instruction, were read orally to the student in Japanese. The session began with the presentation of 12 task familiarization trials using the practice stimuli of two numbers presented in each of the four scripts. The instructions stressed both speed and accuracy.

Instruction

You will see two numbers on the computer screen, one to the left, one to the right of the computer fixation point. One number is always an Arabic numeral ; the other is in Arabic, kanji,

> hiragana or the alphabet. As soon as the pair of numbers appear, you have to judge which number is larger in value. If the number on the left is larger, you press this key on the left (demonstration). If the number on the right is larger, you press this key on the right (demonstration). Remember, you have to judge which number is larger by pressing the left or the right key. Please work quickly and accurately.

The experimenter said "Ready" as a signal to the student just before pressing the operating key (the space key), so that the student could fixate visually on the central area of the computer screen and prepare for the presentation of the stimulus. The subjects were required to press either the right or the left key, depending on which number was larger. For example, if the hiragana representation of eight 'はち', was displayed on the left side of the screen and the Arabic numeral '7' on the right, the hiragana numeral was larger in value, so the subject had to press the left key. Two numerals, one in Arabic and the other in either the Arabic, kanji, hiragana or alphabetical form, were also randomized to display on either the left or the right side of the screen. The two numerals stayed on the screen until the subjdct pressed the right or the left key.

Feedback concerning correct or incorrect responses and reaction time was shown on the screen after each response to maintain the subjects' motivation. The feedback for an incorrect response was "It was a good try !", to avoid discouraging subjects from continuing the task, while the feedback for a correct response was "Your answer was correct." 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 (correct or incorrect) were recorded for every stimulus.

RESULTS

Analysis of Accuracy

The overall mean of accuracy (percentage of correct responses) in 28 trials each for 34 subjects (952 trials) was 93.07 percent with a standard deviation of 6.28 percent. The means and standard deviations of accuracy associated with high/low English proficiency are shown in Table 1 and graphically presented in Figure 1. A 2 (English proficiency) × 4 (script) ANOVA with repeated measures on script was performed on the accuracy data. There were no significant differences in any main factor of script and English proficiency. Therefore, as shown in Table 1 and Figure 1, subjects in the present study processed every numeral presented in any script type at a similar accuracy ratio; 95.38 percent for Arabic, 94.54 percent for kanji, 92.02 percent for hiragana, and 90.34 percent for the English alphabet.

The students' English proficiency had no effect on the accuracy of numeral processing. This result may indicate that the subjects, who were all university students were rather a homogenous group even though they

Table 1 Means and Standard Deviations (in Parentheses) for Accuracy (Percentage)

English	Script Type			
Proficiency	Arabic	Kanji	Hiragana	Alphabet
High	94.96 (8.66)	93.28 (11.43)	93.28 (10.25)	93.28 (7.35)
Low	95.80 (8.40)	95.80 (9.80)	90.76 (12.31)	87.39 (17.41)
Both	95.38 (8.41)	94.54 (10.56)	92.02 (11.23)	90.34 (13.49)

were chosen by the English comprehension test. Or the task of numeral processing may have been too simple for this highly educated group. However, as graphically indicated in Figure 1, processing of the numerals in the alphabet showed a slight, though not statistically significant, difference in accuracy between the students with the high and low English proficiency levels. High-proficiency students were 5.89 percent more accurate in their responses to the English alphabet than were those students who were less skilled in reading. This may reflect the slight difference in English numeral processing on the basis of the students' English proficiency, but this difference in accuracy is too small to discuss any further.

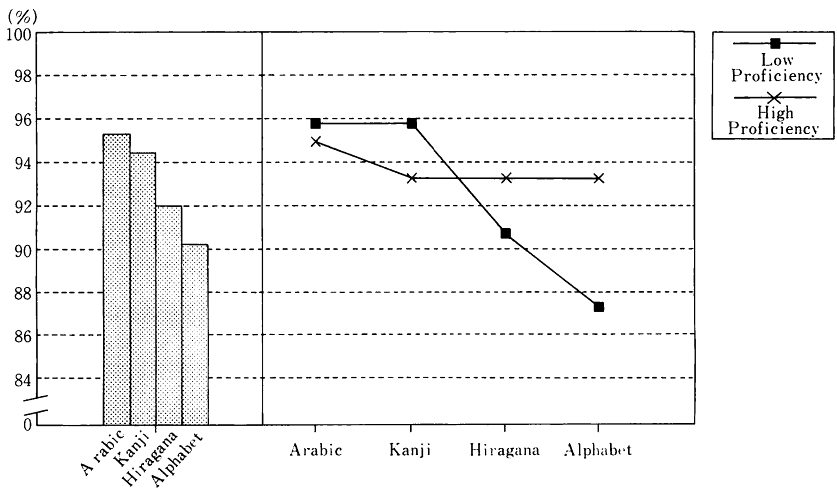

Figure 1 Accuracy of Numeric Processing in Arabic, Hiragana, Kanji and the Alphabet

Analysis of Reaction Time in Processing Numerals of Four Different Scripts

All incorrect responses were excluded from the analysis of reaction time, so that 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 individual subject 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).

Means and standard deviations resulting from the modified reaction time values are presented in Table 2. For the reaction time data, a 2 (English proficiency) × 4 (script) ANOVA with repeated measures on script was performed. The results of the two-way repeated measures ANOVA on reaction time are presented in Table 3. The means of reaction times in each script are graphically presented in Figure 2, and, further including the factor of low and high English proficiency, the means of reaction times are graphically presented in Figure 3.

Table 2 Means and Standard Deviations (in Parentheses) for Reaction Time (Rounded to the Nearest Millisecond) to Numerals in Four Scripts

English	Script Type			
Proficiency	Arabic	Kanji	Hiragana	Alphabet
High	521 (59)	621 (102)	691 (70)	828 (130)
Low	546 (91)	630 (118)	705 (84)	836 (130)
Both	534 (76)	626 (109)	698 (76)	832 (128)

There was a highly significant main effect of the script within-factor [$F(3, 96) = 158.04$, $p < .0001$]. This result is consistent with the assumption that efficiency in processing of numerals is influenced by script type. As graphically shown in Figure 2, each script was perceived at a different speed for the comparison tasks of two numerals; Arabic ($M = 534$) and kanji ($M = 626$) numerals were processed more efficiently (faster in reaction time) than hiragana ($M = 698$) and alphabetical ($M = 832$) numerals. There was no significant main effect of English proficiency level. In sum, the script type was the only factor affecting the processing speed of numerals.

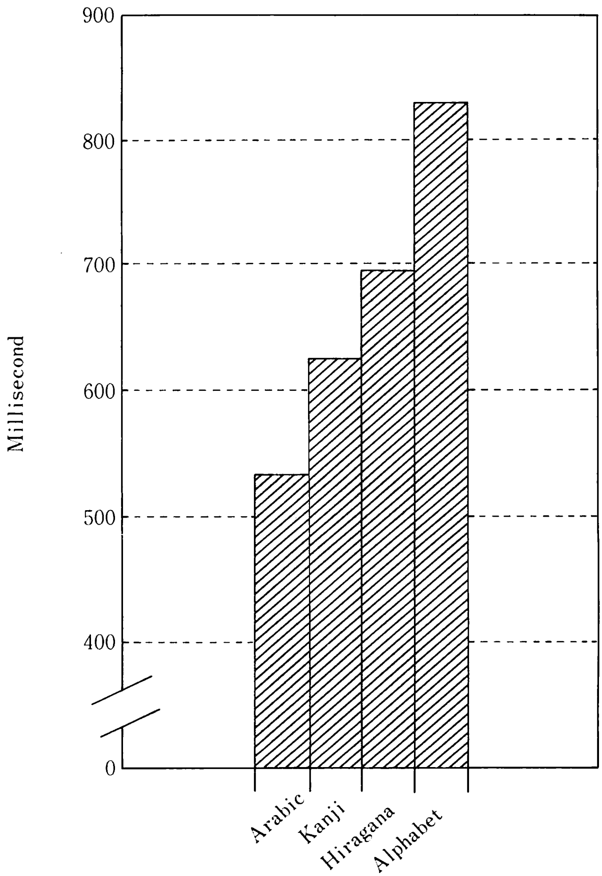

Figure 2 Means of Reaction Time for Processing Numerals in Four Script Conditions

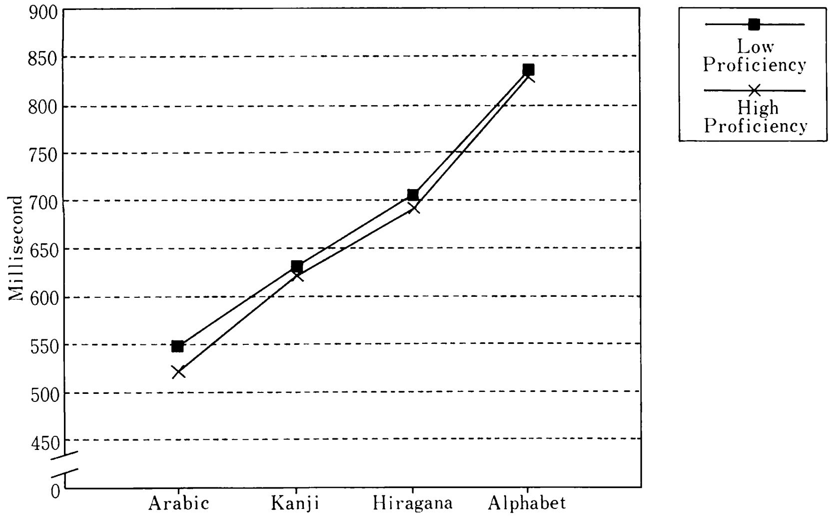

Figure 3 Means of Reaction Time for Processing Numerals in Four Scripts Across High and Low English Proficiency

Table 3 Analysis of Variance in Reaction Times to Numerals by English Proficiency

Source of Variation	SS	df	MS	F
Between Subjects				
E (Proficiency)	6689.19	1	6689.19	.22
Error-Between	987667.48	32	30864.61	
Within Subjects				
S (Script)	1611570.68	3	537190.23	158.04****
S×E	1586.41	3	528.80	.16
Error-Within	326319.79	96	3399.16	

**** $p < .0001$

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 hiragana and the alphabet are constructed by varying amounts of kana symbols or English letters. For example, in hiragana, 5 is described by one kana symbol, 3, 4, 6, 7 and 8 by two kana symbols, and 9 by three kana symbols. In the alphabet (English numerals), 6 is described by three phonemes, 4, 5 and 9 by four phonemes, and 7 and 8 by five phonemes. The number of kana symbols or

Table 4 Means and Standard Deviations in Each Numeral

	Arabic	Kanji	Hiragana	Alphabet
3	744(214)	903(467)	860(252)	931(332)
4	735(242)	846(279)	940(266)	1055(378)
5	805(251)	871(281)	909(280)	919(310)
6	809(261)	862(438)	930(340)	1024(325)
7	777(252)	851(259)	1012(350)	924(281)
8	767(249)	786(262)	886(276)	893(290)
9	754(297)	771(243)	876(282)	896(289)

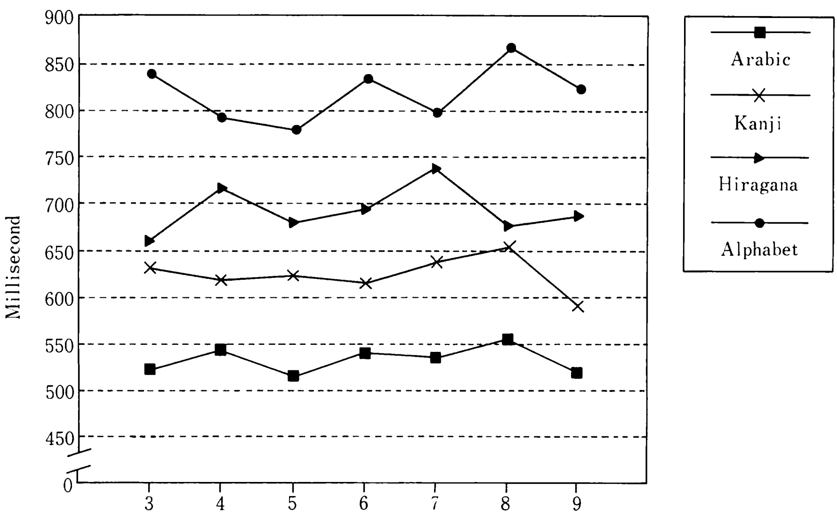

Figure 4 Means of Reaction Time for Processing Numerals from Three to Nine

letters (numeral length) may influence the processing speed for numerals. In order to examine the effects of numeral length, reaction times for each numeral were analyzed separately according to the script type. Statistically assuming to increase a level of difficulty in each numeral from 3 to 9 for numeral judgments, a series of a 2 (English proficiency) $\times$ 7 (numeral) ANOVA with repeated measures on numeral was performed in each script type. The means of reaction times are presented in Table 4 and graphically shown in Figure 4.

There were no significant main effects of the numeral within-factor (numerals 3 to 9) in any script type. These ANOVA results suggest that there were no differences in the processing speed of the numerals 3 to 9 presented in either Arabic, kanji, hiragana and the alphabet. As shown in Figure 4, it is concluded that the numeral length itself does not affect the processing speed of the numerals presented in any type of script.

DISCUSSION

As predicted in the hypothesis, each script was processed at a different speed with the descending order of Arabic, kanji, hiragana and the alphabet. This result reflects the degree of the students' familiarity with the four scripts employed to present numerals. Thus, imagining a continual scale of direct-to-indirect processing or visual-to-phonetic processing, it could be further interpreted based on the result of the present experiment, that numerals presented in the unfamiliar scripts of hiragana or the alphabet were, to a higher degree, processed phonetically while numerals presented in the familiar scripts of Arabic or kanji numerals were, to a higher degree, processed visually.

In the present experiment, the subjects were divided into two groups based on the level of their English language proficiency. The automaticity model of word recognition (LaBerge & Samuels, 1974; Perfetti, 1985; Stanovich, 1980, 1981) based on the level of English proficiency expects that the skilled reader can decode English letters more automatically (without much conscious cognitive effort) than a less skilled reader. Dijk and Kintsch (1983), for example, pointed out that what most separates good readers from poor readers is that the latter recognize isolated words inaccurately and too slowly. Thus, the present study assumed that a significant difference between the two English proficiency groups should also be obtained in the efficiency of decoding English numerals; the skilled readers may recognize alphabetic numerals more efficiently than their counterparts.

However, no significant differences between skilled and less skilled readers were found in the speed and accuracy of processing numerals in the present study. Yet, it should be noted that the skilled readers consistently processed every type of numeral slightly faster than the less skilled readers, although the difference was not statistically significant. In addition, the difference in accuracy in processing alphabetic numerals between the two groups was relatively large, but again of no statistical significance. The lack of a difference between the two groups may be partly due to the possibility that the task of comparing two numerals was too simple for university students, or may perhaps indicate that subjects in the study were too homogeneous to be divided into skilled and less skilled readers based on the English comprehension test.

In addition to the difference in scripts, the number of symbols or letters representing numerals (i. e., hiragana symbols or alphabetical letters) was a possible factor in influencing processing speed and accuracy. Since the length of alphabetically-written numerals differs in alphabet (e. g., 'eight' consists of 5 letters, while 'six' contains only three letters.), processing those numerals may require an extra reaction time in recording a string of kana symbols or alphabetic letters. However, the means of the numerals 3 to 9 in the four scripts did not indicate the effects of numeral length. Thus, numeral length was not relevant to processing speed.

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