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The Effects of Character Complexity on Recognizing Chinese Characters

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This study investigated the effects of varying the complexity of written Chinese characters in a lexical decision task. Forty adult Chinese students (20 from Mainland China and 20 from Taiwan) participated in the study. Subjects responded to individual characters presented by a tachistoscope and classified as simplified legal, complex legal, and illegal. Reaction times and correct responses by nationality were analyzed using analysis of variance and multiple regression. One result indicates that the number of strokes in a Chinese character affects reaction time when subjects identify characters they most often read. This result is consistent with well-documented findings that the number of letters in English words affect processing time. However, another result indicates that the fewer number of strokes in simplified characters did not lead to faster reaction times when compared to complex characters. The theoretical implications of the results are discussed in terms of how basic perceptual processes may interact with the characteristics of an orthography to maintain optimal processing speed during reading.

For competent readers of English the processing time for a word increases with its length. This conclusion is based on longstanding and robust findings across a variety of reading tasks such as recognizing a word presented briefly (McGinnies, Comer, & Lacey, 1952), responding to a lexical decision task (e.g., Whaley, 1978), reading a word aloud (Forster & Chambers, 1973), and reading texts (e.g., Carpenter & Just, 1983). Moreover, the relation between processing time and a word's length appears to be linear. For example, Carpenter and Just (1983) in their studies of college readers' eye movements while reading news articles reported that there is a linear relation between gaze duration and a word's length; each letter consistently increased the gaze duration approximately 30 ms for words categorized as high, medium, or low frequency. Referred to cumulatively as the word-length effect, this phenomenon has frequently been cited as support for the theoretical position that

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competent reading involves sequential encoding of individual letters or groups of letters in a word (see Just & Carpenter, 1987). In the present study we investigated whether an effect analogous to the word length effect in reading English words could be found in reading Chinese characters.

Written Chinese is a logographic orthography comprised of individual characters that are in turn comprised of strokes. Strokes are the constituents of Chinese characters much as letters are the constituents of English words. However, characters and words do not correspond perfectly. Chinese characters are more like morphemes than words, requiring in some instances more than one character to construct what would be equivalent to a word in English (see Cheng & Yang, 1989). English words and Chinese characters are also difficult to equate because of dissimilarities in the syntax of the respective languages. Despite these differences, both words and characters are distinct orthographic units, and it seems reasonable to consider whether the number of strokes in a Chinese character increases processing time as does the number of letters in an English word. In the present study we investigated this possibility by examining the relation between the number of strokes in a Chinese character and the processing time for that character in a lexical decision task. That is, would the reaction time for identifying whether a character was legal or illegal increase as the number of strokes increased under various conditions?

We were interested in clarifying whether the word-length effect in English reflects a fundamental encoding process that generalizes across orthographies; or, whether it may be only an artifact of an alphabetic orthography such as English. Unlike words in alphabetic orthographies such as English, Chinese characters do not encourage sequential analysis of a character's constituents. Thus, if an effect analogous to the word-length effect in English can be replicated in Chinese, it would suggest that the processing of constituent orthographic units during reading may be independent of the principles underlying an orthography, thus strengthening theories arguing for sequential processing of sub-word units in English. Indeed, much of the published research investigating aspects of reading Chinese has had a similar rationale as stated by Perfetti and Zhang (1991): "Interpretation of word-processing paradigms [in English] seems to be strengthened . . . when these paradigms are tested in orthographies that . . . are expected to work differently" (p. 642).

Studying the word-length effect in English has limitations that are inherent to English orthography. Confounded with the number of letters in an English word is the width of the word in the visual field. Longer words may require more than a single fixation, which increases reading time. Likewise, there is evidence that readers of English phonologically recode words prior to identifying them (cf. Jorm & Share, 1983; Perfetti, Bell, &

Delaney, 1988). This conclusion is consistent with the nature of an alphabetic orthography, but it raises the possibility that the increased reading time for longer words may be due in part to the greater number of speech sounds in longer words. There is no direct evidence that phonological recoding affects the results of studies investigating the word-length effect. However, the word-length effect has not been as robust when subjects read words in isolation as opposed to in discourse (cf. Henderson, 1982; Just & Carpenter, 1987; McGinnies, Comer, & Lacey, 1952). It is possible that speech recoding of whole words, which may occur more naturally in reading discourse than in reading isolated words, accounts for some of the processing time attributed to sequential processing of the letters in words.

The Chinese orthography negates these potential confounds. Each Chinese character occupies virtually the same portion of the visual field; that is, characters are distinguished on the basis of the number of strokes within the same space in the visual field. Likewise, although Chinese characters typically have a phonemic component in the form of a pronunciation clue, it is not equivalent to an alphabetic representation of a speech sound. There is no orthographic relation between the number of strokes in Chinese characters and the number of speech sounds that must be uttered to read aloud the text in which they occur. Although readers of Chinese apparently do access a phonological representation while reading (Tzeng, Hung, & Wang, 1977), they appear to do so only after recognizing a character and accessing its meaning (Ju, 1992; Perfetti & Zhang, 1991).

Two separate Chinese logographies are widely used. For historical reasons, a simplified logography has been widely used in the People's Republic of China (hereafter referred to as Mainland China), while a more complex logography is used in Taiwan. The simplified characters used widely in Mainland China since 1956 (see Cheng, 1978) require fewer strokes than the more complex characters used in Taiwan. Simplified and complex versions of a Chinese character are illustrated in Fig. 1. Again, for historical reasons, the Mainland Chinese are proficient at reading complex characters, which are used in older manuscripts, although the majority of their reading employs simplified characters. The Taiwan Chinese, on the other hand, are as a rule not able to read the official simpli-

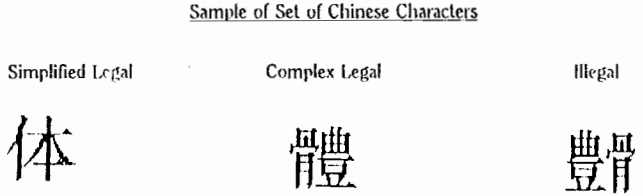

FIG. 1. The simplified and complex legal characters refer to the body. The illegal character is formed by switching the constituent radicals in the complex legal characters.

fied characters used in Mainland China because virtually all Chinese writing in Taiwan uses the complex characters.

The existence of a simplified and complex version of Chinese characters, and the availability of two distinct populations of Chinese readers who use the alternative versions create opportune conditions for testing the extent to which the number of strokes in a character might influence processing time. If individual strokes or groups of strokes in a character are being processed separately, one would expect characters with fewer strokes to be recognized more quickly. One would expect such a finding when comparing different characters in one version of Chinese (i.e., either simplified or complex). But, one might also expect that simplified characters, which are formed with fewer strokes, would be recognized more quickly than complex characters. Likewise, one might expect differences in recognition speed for complex characters between the Mainland Chinese and the Taiwan Chinese readers. The Mainland Chinese have less practice in reading complex characters, which may, therefore, require more attention to individual strokes in order to recognize a character. Such a result might be analogous to the finding that children exhibit stronger word-length effects than do adults who are more competent readers (Samuels, LaBerge, & Bremer, 1978). Or, it might indicate that the familiarity with the simplified characters interferes with recognizing complex characters.

In studying Chinese readers' eye movement while reading Chinese texts, Just, Carpenter, and Wu (as described in Just & Carpenter, 1987) reported results consistent with the word-length effect in English. That is, they reported that the gaze duration for Chinese words (composed of one, two, or three characters) increased as the number of characters increased and it also increased for characters as the number of strokes increased. However, in reading discourse, the gaze duration on individual characters may be influenced by phonological recoding, which must be accounted for somewhere in the time spent processing texts. Also, Chinese characters in isolation do not seem to be processed in the same fashion as characters in words (Cheng & Yang, 1989). Therefore, the present experiment was designed to extend current findings by using individual characters in a lexical decision task and by comparing results between two populations of Chinese readers (Mainland Chinese and Taiwan Chinese).

METHOD

Subjects

Subjects were 40 Chinese undergraduate and graduate students enrolled in a major U.S. university. Twenty of the subjects were citizens of Mainland China and 20 were citizens of Taiwan. Subjects were selected randomly from a pool of Mainland Chinese and Taiwanese students who responded to an invitation to participate in the experiment. All subjects were native Chinese who had completed high school and some undergraduate study in their home country. Thus, subjects were highly literate in Chinese, their first language, as well as in English, the language used in their university courses. Subjects' fields of study varied as did the time they had lived in the United States (1 to 6 years). The mean age of the subjects was 34 years at the time of the study, and all except one was born after 1950. Subjects' ages are important because before the early 1950s, an unofficial version of simplified characters was in use, and these characters differed from official simplified characters published in 1956. Given the age of the subjects in this experiment, it is unlikely that they would have had any significant exposure to the earlier unofficial version of simplified characters.

Stimuli and Apparatus

Stimuli consisted of 90 Chinese characters, 30 of which were simplified legal characters (mean number of strokes = 6.93, SD = 1.95), 30 of which were complex legal characters (mean number of strokes = 15.00, SD = 3.35), and 30 of which were illegal characters used as foils in the lexical decision task (mean number of strokes = 15.00, SD = 3.35). The number of strokes for each character was determined using criteria specified in the *Contemporary Chinese Dictionary* (1973).

The 90 characters formed 30 sets of three characters; each set was comprised of a simplified legal, a complex legal, and an illegal character (see Fig. 1). The simplified and complex legal characters in each set had identical meanings. The characters all occurred more than 187 times per million characters in Chinese texts according to figures compiled by Cheng (1982). Characters that appear relatively frequently in Chinese texts were selected because previous research does not clearly indicate whether the frequency of a word modifies the word-length effect (cf. Just & Carpenter, 1987; McGinnies, Comer, & Lacey, 1952). In addition, the use of high frequency characters, which are likely to be recognized automatically, was reasoned to be stronger test of the possibility that the number of strokes influences processing time. The illegal characters were generated by reversing the two constituent radicals of each complex legal character (see Fig. 1) and were meaningless and therefore unpronounceable.

The 90 characters were randomly ordered and presented one at a time to subjects using a Kodak Carousel Slide Projector with autofocus (Model 850H). To regulate the display of each character and to time subjects' responses, the slide projector was fitted with equipment manufactured by

Lafayette Instrument Company of Lafayette, Indiana, which included: (a) a visual reaction time apparatus (Model 63035), (b) a digital stop clock (Model 54030), (c) a tachistoscopic shutter and projection tachistoscope (Model 54030), (d) a tachistoscopic shutter and projection tachistoscope (Model 41010), and (e) three auxiliary relay boxes (Model 58026). When each slide was advanced to display a new character, the timing device began recording a running time. When a subject responded to the visual display by pressing a button to signal whether the character was legal or illegal, the timing device stopped indicating the elapsed time. The timing device recorded elapsed time in milliseconds. When a subject responded, the visual display was terminated, followed automatically by an 8-s interval prior to the display of the next character.

Procedure

Subjects carried out the experimental task individually in a room containing the experimental apparatus. Lighting was subdued to enhance the projected image of the characters on a small screen. Subjects were seated at a table directly in front of the screen where they had an unobstructed view. On the table were two keys labeled legal or illegal. Subjects were directed to press the appropriate key when each character was displayed in turn. As soon as subjects had made a decision by pressing a key, they were asked to say the character. An experimenter who sat behind the subject recorded subjects' times for each response and whether each response was correct or incorrect.

Subjects were told to respond as quickly as possible by pressing the appropriate key placed under the index finger of each hand. They were advised that because the presentation of characters was random, the most efficient strategy for the task was to fixate on the center of the screen. Subjects were given practice in using the apparatus for at least four trials or until the experimenter was convinced that they understood the procedure and were competent in using the apparatus.

Design and Analyses

Subjects served as their own controls in a mixed factorial design in which nationality was the between-subjects factor and type of character was the within-subjects factor. Means for response time and number of correct responses were compared separately using a 2 (Nationality) × 3 (Chapter Type) analysis of variance (ANOVA). Multiple regression procedures were used to determine if there was a statistically significant relation between two independent variables (character frequency and number of strokes) and the dependent measure (reaction time) for the legal characters (simplified and complex).

RESULTS

Analyses of variance (ANOVA) yielded significant interaction effects on correct responses and reaction times. Pairwise contrasts were employed to further investigate the interaction effects. Multiple regression analysis indicated that the number of strokes predicted reaction times for characters that subjects were most accustomed to reading. A pooled t test demonstrated that response times did not vary significantly when both Mainland and Taiwan Chinese read familiar characters. Except as noted, statistical tests were conducted with α set at $p < .05$ significance level.

Correct Responses

Means and standard deviations for the number of correct responses by nationality and type of character are shown in Table 1. The ANOVA comparing the means for correct responses resulted in a significant interaction effect, $F(2,76) = 166.39$, $MS_e = .007$. Pairwise comparisons using the Bonferonni procedure (adjusted $\alpha = .014$) revealed statistically significant differences for Mainland Chinese when comparing simplified legal and complex legal characters, $t(38) = 5.50$, $p < .001$, simplified legal and complex illegal characters, $t(38) = 3.21$, $p < .001$, and complex legal and complex illegal characters ($t(38) = 4.66$, $p < .001$. For the Taiwan Chinese, statistically significant differences were revealed between simplified legal and complex legal characters, $t(38) = 15.71$, $p < .001$, and between simplified legal and complex illegal characters, $t(38) = 12.84$, $p < .001$. Main effects for recognizing complex legal and illegal characters were not statistically significant.

Despite the statistically significant simple effects in this analysis, the mean number of correct responses indicated an accuracy rate of 93% or greater in each condition, except for the Taiwan Chinese reading simplified legal characters. Their mean accuracy rate of simplified legal characters was 55.7%. The poorer performance of the Taiwan Chinese in this

TABLE 1
MEANS (AND STANDARD DEVIATIONS) FOR CORRECT RESPONSES BY THE MAINLAND AND TAIWAN CHINESE

		Types of characters		
Group	N	Simplified legal	Complex legal	Complex illegal
Mainland	20	29.8 (.523)	29.0 (.562)	27.9 (1.496)
Taiwan	20	16.7 (3.499)	29.3 (.786)	28.3 (2.055)

Note. Maximum score for each type = 30.

condition reflects their unfamiliarity with simplified characters. The high rate of accuracy and relatively small standard deviations in the remaining conditions suggest that other simple effects reflect differences in familiarity rather than differences in underlying psychological processes. For example, Mainland Chinese subject's mean correct responses decreased in the same sequence as their familiarity with characters (simplified, complex legal, and illegal). Given the statistically significant differences in the accuracy rate across conditions, incorrect responses were not included in subsequent analyses.

Regression Analyses

A regression analysis was carried out to determine whether legal characters' relative frequency in written Chinese and their number of strokes were related to reaction time. The regression model included frequency and number of strokes as independent variables and reaction time as the dependent variable. For the present study, partial correlations are of interest because it is important to determine each independent variable's separate contribution to the variance in reaction times in each treatment condition. Partial correlations for frequency were not statistically significant except for the Taiwan Chinese reading simplified characters. Thus, character frequency did not account for a statistically significant portion of the variance in reaction times except when subjects were reading legal characters that were unfamiliar. Given Taiwan Chinese subjects' unfamiliarity with simplified characters (as indicated by their accuracy rate of 55.7%), it is difficult to draw conclusions about this finding. Perhaps Taiwan Chinese subjects recognized a few of the simplified legal characters just as English readers might recognize a few familiar words in a foreign language.

Partial correlations for the number of strokes were statistically significant for Mainland Chinese reading simplified characters, $r = .38$ and for Taiwan Chinese reading complex characters, $r = .45$. Thus, the number of strokes accounted for a statistically significant portion of the variance in reaction times for characters that subjects were most accustomed to reading.

Reaction Time

Means and standard deviations for reaction times by nationality and type of character are shown in Table 2. The ANOVA comparing means for reaction times resulted in a statistically significant interaction effect, $F(2, 11.6) = 13.40$, $MS_e = .08$. Contrasts consistent with the purpose of the study were tested for statistical significance using the main effects statistics from repeated measures and t tests. Of interest was whether

TABLE 2
MEANS (AND STANDARD DEVIATIONS) FOR REACTION TIME BY THE CHINESE FROM MAINLAND AND TAIWAN

	Types of characters		
Group	Simplified legal	Complex legal	Complex illegal
Mainland	855.3	875.3	1307.7
	(166.8)	(135.2)	(235.2)
Taiwan	1382.6	895.9	1275.6
	(297.6)	(183.3)	(204.2)

Note. The mean reaction time is in milliseconds. $n = 20$ for each cell.

Mainland Chinese would recognize simplified legal characters more quickly than complex legal characters (the simplified characters have fewer strokes), whether Taiwan Chinese would recognize complex legal characters more quickly than Mainland Chinese (the Mainland Chinese read complex characters less often), and whether the Mainland Chinese would recognize simplified legal characters more quickly than the Taiwan Chinese would recognize complex legal characters (the respective characters varied as to the number of strokes but were the most familiar to both groups of subjects). The latter contrast employed a pooled t test. None of these contrasts were statistically significant. Thus, although the regression analysis indicated that the number of strokes was related to reaction time for both Mainland and Taiwan Chinese reading familiar characters, response times did not vary significantly.

DISCUSSION

The results of the current experiment provide some support for the processing of individual strokes when Chinese readers are presented with Chinese characters in a lexical decision task. There was a statistically significant relation between the number of strokes and the reaction times of Mainland and Taiwan Chinese reading the characters they most often read and write. That is, the number of strokes accounted for a significant amount of the variance in reaction time when Mainland Chinese readers were reading simplified characters and when Taiwan Chinese were reading legal complex characters. This effect for the number of strokes was evident when the effect of word frequency was controlled by the use of high frequency characters and by statistically removing the effects of frequency on reaction time.

However, the data do not clearly support a simple explanatory model in which the fundamental constituents in an orthographic unit are processed individually as is often argued on the basis of the word-length effect in English. In the present study the difference in reaction times between

Mainland Chinese reading simplified characters (mean = 855.3 ms) and the Taiwan Chinese reading complex characters (mean = 895.9 ms) was not statistically significant. Because the number of strokes in simplified and complex characters varied considerably (mean = 6.93 and mean = 15.00, respectively), one might expect differences in reaction time if strokes were being processed individually. The lack of a statistically significant difference may indicate that although strokes are processed in reading a Chinese character, they may be processed more quickly or efficiently when the orthography employs more strokes, perhaps by chunking strokes into larger units. On the other hand, the difference, although not statistically significant, is in the predicted direction with an effect size of approximately .3. Further research is needed to address these possible explanations.

Further complicating an explanation of how strokes are related to reaction times in recognizing Chinese characters is the finding that there was no statistically significant relation between the number of strokes in complex legal characters and the reaction times of Mainland Chinese. Also, there was no significant difference in the mean reaction times for Mainland Chinese and Taiwan Chinese for complex legal characters, despite the fact that the Taiwan Chinese read exclusively complex characters and the Mainland Chinese read them only occasionally. These findings suggest that it is not necessary for competent readers to process individual strokes when recognizing complex legal characters. Presumably, the Mainland Chinese were processing complex characters as whole units rather than processing characters stroke by stroke. One possible explanation for this difference is that Mainland Chinese do not typically write complex characters as do the Taiwan Chinese. Writing individual strokes may reinforce attention to strokes during reading.

The results of this study also contribute to a consideration of broader theoretical and instructional issues. For example, global comparisons of factors such as eye fixations and reading time have long suggested that fluent reading is quite similar across languages and orthographies (see Gray, 1956). More recent theorists such as Just and Carpenter (1987) have argued that it is necessary to investigate specific lower-level processes in order to determine the effects of orthography on reading. In this regard the findings of the present study suggest that the processing of an orthography's constituent units may be adapted to accommodate more basic cognitive requirements. That is, an orthography alone may not dictate how basic perceptual processes occur.

Instead, basic perceptual processes may adapt to the demands of a particular orthography in order to meet more fundamental requirements of processing language such as maintaining optimal times for coordinating component processes such as lexical access, syntactic and semantic processing. The lack of statistically significant differences in reaction times for subjects reading simplified and complex characters with which they were familiar supports this explanation. We found additional support when we conducted a post hoc analysis of the quadratic function for strokes and reaction times resulting when Taiwan Chinese read complex legal characters. The quadratic function accounted for 28% of the variance compared to the 15% explained by the linear function. Thus, strokes apparently had less influence on processing as the number of strokes increased. Although a lexical decision task such as the one used in this experiment may not require adaptation to maintain an optimal speed for language processing, it is possible that typical modes of processing characters during the reading of connected texts may carry over to the task of identifying isolated words. Alternatively, radicals might exert an increasing effect on processing as the number of strokes increased. In Chinese, characters with many strokes have more radicals forming a more recognizable visual pattern. It may be that the increased number of radicals facilitated visual recognition of the characters with more strokes.

An instructional issue related to the findings of this study is whether it may be more efficient to teach Chinese children to read simplified or complex characters. It has been argued that simplified characters may be more efficient to read and easier to learn. Although this issue is a complex one having political, social, and pedagogical dimensions, the current study does not suggest an advantage for simplified characters in terms of processing speed or efficiency, at least for mature readers.

When compared to existing research on reading in English, the results of the present experiment suggest that there may be a disposition to process fundamental orthographic units such as letters and strokes. However, given the conditions of the present experiment, there seems to be a tendency to maintain a consistent speed of character identification leading to adaptations in how strokes are processed when comparing simplified and complex characters. These findings suggest that an optimal processing time may interact with the complexity of orthographic units to determine basic perceptual processes in reading different orthographies. This hypothesis awaits further testing through the study of how constituent units are processed in other orthographies.

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