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Role of Phonology in Reading: A Stroop Effect Case Report With Japanese Scripts

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Abstract

An experiment investigated the role of phonological activation in Japanese adults' reading of ideograms (Kanji) and syllabic characters (Kana), using the Stroop effect. A group of 21 native speakers of Japanese completed color-naming (Stroop) and word-reading (reverse-Stroop) tasks with Kanji and Kana scripts. A series of analyses contrasted the reaction time required for different script types; including Kanji color words, Kanji homophones, and Kana. On the hypothesis that a word's pronunciation plays an important role in its semantic activation process, it was predicted that color-naming/word-reading interference and facilitation would be demonstrated for both the Kanji color words and Kanji homophones, with Kanji homophones showing somewhat reduced effects. The results showed robust color-naming (Stroop) patterns for the Kanji color words, significant effects for Kana, and no significant Stroop effects for the Kanji homophones. A word-reading (reverse-Stroop) task revealed uniform effects of interference with incongruent stimuli across the three script types. Taken together, the data suggest different processing routes may be accessed in color-naming and word-reading tasks.

Key words: Stroop effect; reverse-Stroop effect; Japanese; Kanji; Kana; Phonology

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INTRODUCTION

One of the key factors in language processing is the extent to which phonetic and semantic codes contribute to word processing. One theory, the Universal Phonology Principle (UPP), explains that a word's pronunciation must be involved in order for its semantic representation to be accessed (Perfetti, Zhang, & Berent, 1992; Perfetti, 2003). Perfetti explains that we first activate our sound units unconsciously, and the processing of the word meaning units follows in reading, as evidenced by the considerably faster rate of oral reading than general conversation (Perfetti, Zhang, & Berent, 1992; Perfetti, 2003). In contrast, the Dual Route Model maintains that a semantic representation may be accessed via faster, direct orthographic or visual codes (Coltheart, 2000; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seidenberg, 1985). The goal of the present study was to investigate the way phonological and semantic routes were processed in Japanese for different orthographic systems by using the Stroop effect paradigm.

John Stroop (1935) first demonstrated the effects of the conflicts between the word processing and visual information with the Stroop effect. He presented a list of color name words printed in congruent or incongruent colors to his experimental participants, and asked them to name the color as accurately and quickly as they could. He found that color names written with incongruent colors interfered with the color-naming tasks, as demonstrated by the longer reaction times than those written in congruent colors. For example, participants could name the color "green" quicker when the word was "green" (congruent stimulus) than when the word was "red" (incongruent). Stroop also tested word-reading tasks in congruent and incongruent colors (Stroop, 1935). Specifically, he tested whether the color name written in an incongruent ink color would cause interference in word reading. In this study, participants read the color words written in the matching (congruent stimulus) or unmatching (incongruent) ink color. The interference or facilitation caused by different ink colors is called the reverse-Stroop effect. With word-reading tasks, there was no interference with incongruent stimuli (Stroop, 1935). Thus, the incongruent or congruent ink colors did not influence the reaction times of the participants.

To date, a number of researchers tested the Stroop effect in different languages with a variety of settings and explained its implications from a wide range of perspectives. The vast majority of these Stroop studies have used alphabet-based orthographic systems, and a relatively small number of studies has been reported in non-Western scripts. Ideographic writing systems, such as Chinese characters, provide interesting research opportunities for the Stroop effect because the linkage between phonology and orthography is less regular than that in many of the alphabetic writing systems. In particular, the Japanese orthographic system is unique. It consists of multiple orthographical systems including a set of ideograms (Kanji) and two sets of syllabic writing systems (Kana). Kana scripts are based on the sounds that each script corresponds to a mora, which generally most often represents equally timed syllables with exceptions for open syllables with a single vowel (Kess & Miyamoto, 1999). Kanji scripts are essentially Chinese scripts adapted from the Chinese language, and Kana scripts are syllabaries. There are two types of Kana scripts, including Hiragana and Katakana. Hiragana pertains to Japanese word lexicons, and Katakana relates those of foreign loan words (Kess & Miyamoto, 1999). Some researchers argue that Japanese readers process the two types of Kana scripts differently; however, research study results to date are inconclusive (Hatta, Katoh, & Kirsner, 1984; Komendzinska, 1995; Coderre, Filippi, Newhouse, & Dumas, 2008). The Japanese writing system uses these different sets of orthography in combination. The general understanding is that Kana scripts (syllabaries: phonograms) function similarly to the phoneme-based English alphabet, whereas Kanji scripts (ideograms) function differently. In reading Kana, Japanese readers construct the meanings from the sounds of each syllabary with the exception of frequently used function words that could be perceived more visually. In reading Kanji, however, the Japanese readers seem to use mainly a conceptual approach because they often perceive semantic representations from Kanji's visual appearances while recognizing their phonological representations. Thus, by using Japanese, it is possible to contrast the variables of phonology-based and more concept-based writing systems within a single language. According to Paradis (2013), Japanese Kanji and Kana words are ideal in investigating orthography-specific effects.

Early work using the Stroop interference paradigm with Japanese orthography suggested possible differences between concept-based Kanji features and phonology-based Kana properties. Morikawa (1981) examined the hypothesis that Stroop interference (color-naming) would be greater for Kanji than Kana. In his study, native Japanese participants were timed as they named the color of the presented Kanji, Hiragana, Katakana, and color patches (as the control) printed on gray cards. The gray cards portrayed different conditions in a blocked fashion. Specifically, the participants read a series of congruent or incongruent color words on each separate sheet. The total reading times with separate sets of sheets involving differing conditions and script types were recorded for analyses. The results showed significant differences in processing times between the Kanji and two types of Kana scripts. The results of Hiragana and Katakana were very much alike. Morikawa and colleagues also conducted the reverse-Stroop effects, by asking the participants to read the color names of congruent and incongruent stimuli (Morikawa, 1981, Moriguchi & Morikawa, 1998). The result demonstrated interference only with the Kanji on incongruent cards. These early data are compatible with the notion that phonetic and visual codes may contribute differentially to the processing of syllabaries and ideograms, although the interaction or integration of this information was not specified.

Yamada, Kayamoto, and Morita (1999) proposed that Kanji would have a much stronger tie to meaning than Kana, since the characters are generally mapped more with morphemes rather than syllables. In their study, participants completed a timed word-judgment task in which they had to rapidly judge whether to pronounce written Kana and Kanji the same or different. The subjects' reaction times were longer when two words were semantically related (i.e., the Kana represented a meaning related to the Kanji) as opposed to when the two characters were both phonologically and semantically different, suggesting that the sound patterns in Kana could produce semantic errors in Kanji pronunciation. The authors explained that these error patterns are common in everyday Kanji reading (Yamada, 1998; Yamada, Kayamoto, & Morita, 1999). The data suggest a role of prior phonology affecting semantic access, supporting the Universal Phonology Principle (Perfetti et al., 1992).

In summary, additional data are needed to further examine the role of phonological information during the processing of different script types. To address this issue, the present study investigated both inhibitory and facilitative processing in the Stroop (color-naming) and the reverse-Stroop (word-reading) experiments with 21 native speakers of Japanese. Stimuli included Kanji color words, Kanji homophones (characters having the same sound as the Kanji color words but with different meaning), and Hiragana (phonological) color name scripts.

The major interest was on the outcome of Kanji homophones. Significant interference of the Kanji homophone scripts with color-naming and word-reading would suggest that Japanese Kanji reading is constrained by phonological processing, as the Universal Phonology Principle explains (Perfetti et al., 1992). In contrast, an absence of Stroop effects and reverse-Stroop effects for Kanji homophones would be more compatible with parallel models (Coltheart, 2000; Coltheart et al., 2001), in which access to Kanji meaning could be reached without prior phonological processing. It was predicted that the phonological information in the Kanji homophones would cause significant inhibition and facilitation effects.

1. METHOD

1.1 Participants

Twenty one native speakers of Japanese participated in the present study (*M*age = 34.3, *SD*=3.18, age range: 29-41years), including 17 females and 4 males. The participants were recruited through the University of Texas at Dallas, the University of Texas Southwestern Medical Center, and the Japanese Association of Dallas/Fort Worth in Texas. All participants were right-handed, with an average of 17 years of formal education (range=14-22 years), and had lived in the U.S.A. for an average of 21 months (range=0-78 months). Participants reported 20/20 vision (corrected, if necessary) with no history of color blindness, neurological disorders, language/speech deficit, or reading impairment. To qualify for the study, all participants completed a brief color perception test including the colors used in the present experiment. The present study used a within-subject repeated measure design with which each participant took part in both the color-naming and word-reading paradigms. A balanced male/female ratio was not considered in recruiting participants for the present study, because previous studies reported no sex-based difference in the reaction times of the Stroop effect trials (Golden, 1974; Sarmány, 1977; Sladekova & Daniel, 1981).

1.2 Stimuli

The stimuli consisted of three Japanese color words (red, white and yellow) written in three different Japanese script types (see Tables 1 and 2). These included some of the original Kanji color words used by Morikawa and colleagues (Morikawa, 1981; Moriguchi & Morikawa, 1998). The color names were matched with high-familiarity homophonous Kanji (“tree,” “castle,” and “dead skin”) based on the seven-scale familiarity index (greater figures indicate higher familiarity) described by Amano and colleagues (Amano & Kondo, 1999; Amano, Kasahara, & Kondo, 2007). The mean familiarity index for the three Kanji color words was 6.19 (range: 5.84-6.43), and that for the Kanji homophones was 5.85 (range: 5.00-6.59). The familiarity scores for Hiragana have not been published because Hiragana is the elementary writing format the Japanese learn before progressing to the study of Kanji scripts. Two other Kanji color words (green and blue) served as practice stimuli to help the participants familiarized with the experimental procedures. To summarize, three types of scripts were used: Kanji color words, Kanji homophones, and Hiragana (the Hiragana phonograms for the color names).

Following Morikawa’s landmark Stroop study with Japanese (1981), the poster color in “X” was used as the neutral control condition for the color-naming tests to distinguish inhibition from facilitation. Similarly, the scripts written in black ink were used as the neutral control condition for the word-reading tests (refer to Tables 1 and 2).

Table 1
Stimuli Used in the Color-Naming Task

	Red	White	Yellow
Kanji color words	赤	白	黄
Kanji homophones	垢	城	木
Hiragana	あか	しろ	き
Neutral	X	X	X
Pronunciation (identical for all script types)	“aka”	“shiro”	“ki”

Table 2
Stimuli Used in the Word-Reading Task

	Red	White	Yellow
Kanji color words	赤	白	黄
Kanji homophones	垢	城	木
Hiragana	あか	しろ	き
Neutral: Kanji 1 in black ink	赤	白	黄
Neutral: Kanji 2 in black ink	垢	城	木
Neutral: Hiragana in black ink	あか	しろ	き
Pronunciation (identical for all script types)	“aka”	“shiro”	“ki”

In the color-naming task (Stroop effect test), participants responded to 42 stimuli, including 18 congruent trials (six for each of the three script types), 18 incongruent trials (six for each of the three script types), and six neutral X color patch controls (two for each of the three colors). In the word-reading paradigm (reverse-Stroop effect), participants responded to 54 stimuli, including 18 congruent trials (six for each of the three script types), 18 incongruent trials (six for each of the three script types), and 18 black ink characters (six for each of the three script types).

1.3 Instrumentations

The data were collected with a single participant at a time in a sound-treated room at the University of Texas at Dallas Callier Center for Communication Disorders in Dallas, Texas. The stimuli were presented on the Direct

RT subject testing system (Empirisoft, version 2004) screens one at a time on a Microsoft Windows-based personal computer equipped with a 17-inch color SVGA monitor. Each participant spoke into a microphone-activated Direct RT software program (Empirisoft, version 2004), which digitally audio recorded the participants' responses. A headphone microphone (Labtec, p.342) was used. A video camera recorded the entire experimental processes, and the recording was later reviewed to identify any error responses.

1.4 Procedures

Each participant sat in front of the personal computer and responded verbally to the stimuli presented on the Direct RT on-screen slide formats. Participants were requested to name the color of the stimulus in color-naming tasks and to read the words in word-reading tasks. In both tasks, participants were asked to provide responses as quickly and accurately as possible. The interval between stimulus presentation and response was measured as the reaction time. The inter-trial intervals (ITI) were set to three seconds. Each stimulus stayed on screen at least two seconds regardless of the participants' shorter reaction times. When no response occurred within three seconds, the display waited three more seconds before proceeding to the next screen. The order of the two experimental paradigms (color-naming and word-reading) was randomized across participants to avoid systematic bias (Jadad et al, 1996; Gravetter & Forzano, 2012). Prior to the experiments, a short practice session was introduced to familiarize the participant with the procedure. As noted previously, these practice set stimuli included the color words "green" and "blue" and their homophones. Within each color-naming and word-reading session, the order of the stimuli presented was randomized by the automatic randomization function of the Direct RT (v. 2004).

2. RESULTS

Before the data analyses, the recorded responses were inspected for errors. Out of a total of 2,016 expected responses (=21 participants X 96 stimuli), there were 63 instances (approximately 3%) of missing data. These were predominantly recording errors due to extraneous noises triggering the voice-activated microphone system. Mean reaction times and standard deviations are shown in Tables 3 and 4.

Following Logan and Zbrodoff (1998), the differences between congruent and incongruent stimuli were first compared to obtain an index of the Stroop effect. A two-way ("Congruency" x "Script type") repeated-measures analysis of variance (ANOVA) with Bonferroni correction was performed for statistical analyses with both color-naming and word-reading data.

Table 3
Color-Naming Task: Mean Reaction Time (ms) (*n* = 21)

		Kanji color words	Kanji homophones	Hiragana
Congruent	*M*	611.25	646.16	640.68
	SD	(84.85)	(75.67)	(75.88)
Incongruent	*M*	710.53	661.77	697.45
	SD	(93.80)	(78.92)	(84.62)
X (color tile)	*M*		658.73	
	SD		(70.57)	

Table 4
Word-Reading Task: Mean Reaction Time (ms) (*n* = 21)

		Kanji color words	Kanji homophones	Hiragana
Congruent	*M*	638.15	677.80	627.12
	SD	(103.02)	(93.88)	(96.00)
Incongruent	*M*	661.49	710.00	649.14
	SD	(81.59)	(114.64)	(127.42)
Black ink	*M*	627.24	669.28	607.25
	SD	(91.81)	(98.07)	(90.45)

2.1 Color-Naming Task (Stroop Effect Test)

There was a statistically significant main effect of "Congruency" [$F(1, 20)=19.87$, $p < 0.001$], with shorter reaction times for congruent stimuli. There was a significant interaction between "Congruency" and "Script type" [$F(2, 40)=8.96$, $p < 0.001$]. The subsequent tests of within-subject contrasts revealed the significant interactions between Kanji color words and Kanji homophones [$F(1,20)=16.66$, $p < 0.001$], and between Kanji Homophones and Hiragana [$F(1,20)=5.79$, $p < 0.05$]. There was no significant difference between Kanji color words and Hiragana.

To analyze facilitation and inhibition, the participants' reaction times for the congruent and incongruent stimuli were each compared with the neutral "X" color patch using paired *T*-tests (95% Confidence interval). Facilitation with congruent stimuli was significant only with Kanji color words: [$t(20)=-3.60$, $p=0.002$]. Interference with incongruent stimuli was significant with Kanji color words: [$t(20)=3.69$, $p=0.001$]; and with Hiragana: [$t(20)=2.72$, $p=0.013$]. There was no significant difference between the other character/stimuli type combinations.

2.2 Word-Reading Task (Reverse-Stroop Effect Test)

There was a statistically significant main effect of "Congruency" [$F(1, 20)=15.27$, $p < 0.001$] and "Script type" [$F(2, 40)=15.48$, $p< 0.001$]. There was no interaction between "Congruency" and "Script type." Thus, the results demonstrated only main effects of the "Congruency." Hiragana presented the shortest reaction times followed by Kanji color words, and the Kanji homophones required the longest reaction times. The differences between congruent and incongruent stimuli were similar across the three script types, as well as the absence of interactions.

Similar to the color-naming data, paired *T* tests (95% Confidence interval) were performed to examine facilitation and interference, using the experimental stimuli and the neutral stimuli written in black ink. Facilitation with congruent stimuli was not significant across all three script types. Interference with incongruent stimuli was observed with all three script types: Kanji color words: [$t(20)=3.78$, $p=0.001$]; Kanji homophones: [$t(20)=2.73$, $p=0.013$]; and Hiragana: [$t(20)=2.67$, $p=0.015$].

DISCUSSION

Color-naming interference tests (Stroop) were conducted with Kanji color words, Kanji homophones, and Hiragana read by a group of native Japanese-speaking adults. The results yielded the strongest effects for the Kanji color words, significant effects for Hiragana, and rather strikingly, no significant effects for Kanji homophones. The mean differences between congruent and incongruent stimuli with the color-naming task were 99.27 ms, 15.60 ms, and 56.76 ms for the Kanji color words, Kanji homophones, and Hiragana, respectively. The mean interference times with incongruent stimuli (computed by: reaction time for incongruent stimuli–reaction time for neutral stimuli) were 51.79 ms, 3.03 ms, and 38.71 ms, for the Kanji color words, Kanji homophones, and Hiragana. The finding of the greater Stroop interference for Kanji color words than Hiragana replicated previous studies with Japanese (e.g., Morikawa, 1981; Moriguchi & Morikawa, 1998), although these earlier studies used the original Stroop paradigm (Stroop, 1935) of having subjects read multiple words on cards with total reading time (in seconds) as the dependent variable.

A word-reading (reverse-Stroop) task was conducted to investigate whether phonetic and visual codes contribute differentially to the processing of various script types. Although expected patterns were observed with “Congruency” (e.g., significantly longer reaction times for incongruent stimuli compared to those for congruent stimuli), there was no reverse-Stroop facilitation for Kanji color words (as noted by Morikawa, 1981). Thus, the present word-reading data could not be used to further address this hypothesis. The word-reading data demonstrated only main effects of congruency for three script types, suggesting that the interference of incongruent stimuli presented across all the script types including the Kanji homophone.

The results of the color-naming tasks did not demonstrate the significant effects of phonology with Kanji homophone, tentatively supporting the view that phonology is not central to accessing meaning from Kanji characters (Chen & Shu, 2001; Wu & Chen, 2000; Chen, Yamauchi, Tamaoka, & Vaid, 2007). In contrast, the results of the word-reading tasks suggest the effects of phonology with Kanji homophone with the similar patterns of interference as those for two other script types, supporting the Universal Phonology Principle (UPP). Taken together, the data suggest different processing routes may be accessed in color-naming and word-reading tasks. However, the results of the present study must be interpreted with caution. The present experiment used a small set of materials and repetitions for this type of study. The early Stroop studies involved a number of stimuli in a blocked fashion on one sheet, and the response times were recorded collectively. Although this method made it possible to record a greater number of data points, the response time delays for reasons other than the experimental conditions, such as hesitation due to fatigue, lack of attention, and pauses for breathing, could be included in the response times. Taking advantage of recent advances in technology, the present study recorded the response time for each individual stimulus using the DirectRT software program (Empirisoft, version 2004). In addition, the different conditions and script types were presented in a randomized fashion with a single set of paradigms. Although the computerized program provided a greater level of control, it operated with preset Inter-trial intervals (ITI) and times for each stimulus to appear on the screen, regardless of the participant’s rate of response. Consequently, the number of trials was deliberately set relatively small in order to avoid participant fatigue and compromised attention that would have been attributable to longer-lasting procedures. The results need to be replicated with a larger stimulus set and a greater number of participants with a reduced ITI and/or in a blocked fashion with multiple sets of paradigms with approximately five times the number of stimuli.

In addition, some researchers explain the onset effects in priming that related to the left-to-right orientation of the writing (Coltheart, Woollams, Kinoshita, & Perry, 1999; Rastle, Havelka, Wydell, Coltheart, & Besner, 2009). Japanese can be written in both horizontal and vertical orientations. When it is written in a horizontal orientation, Japanese sentences maintain a left-to-right orientation. In contrast, Japanese sentences proceed right-to-left when they are written vertically. Future studies should investigate the potential difference in the degree to which the Stroop facilitation/interference effects non-left-to-right scripts with Japanese. Nevertheless, the present case report provided some additional information about the way phonetic and semantic codes are activated in language processing and it necessitates investigation on a greater scale.

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