

Electroencephalographic Activity in a Flanker Interference Task Using Japanese Orthography

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Abstract

■ The neural activities for color word interference effects were investigated using event-related brain potentials (ERPs) recorded in a flanker-type interference task. Kanji words (Japanese morphograms) and kana words (Japanese phonograms) were used as the flanker stimuli to obtain insights about hemispheric specialization for processing two types of Japanese orthographies. Interference effects in reaction time were larger when kanji words were presented in the left visual field and when kana words were in the right visual field. ERPs were modulated by the incongruent flankers, which generated a negative ERP component with the different onset and offset depending on flanker attributes. Consistent with the behavioral

data, the interference-related negativity was observed for kanji words presented in the left visual field and for kana words in the right visual field. The negativity distributed maximally over the fronto-central site. The early part of the negativity distributed strongly over the frontal midline area, whereas it extended bilaterally over the frontal area in the late phase. The present results support the view of preferential processing of kanji in the right hemisphere and that of kana in the left hemisphere. The temporal profile of scalp topographies for the interference-related neural activity suggests that the medial and dorsolateral prefrontal regions may be involved in maintaining attentional set and conflict resolution. ■

INTRODUCTION

Attention plays a crucial role in coherent, organized behavior of organisms destined with limited capacity for information processing. The Stroop task is now frequently used as an index of attentional deficits, and serves as a neuropsychological measure for investigating the integrity of the neural network for attention (MacLeod, 1991; Stroop, 1935). Subjects are required to concentrate on the color of the printed words, while ignoring the word meaning. If subjects have a problem in the capacity to selectively attend to specific stimuli (color), the distracting information (word) may interfere with the processing of relevant information, resulting in larger interference effects. There have been long arguments regarding neural mechanisms of interference effects. These include the stage of information processing responsible for the interference of conflicting information and its neuroanatomical basis (MacLeod & MacDonald, 2000).

Functional neuroimaging techniques have explored the neural correlates of the Stroop interference effect (Leung, Skudlarski, Gatenby, Peterson, & Gore, 2000; Taylor, Kornblum, Minoshima, Oliver, & Koeppel, 1994; Pardo, Pardo, Janer, & Raichle, 1990). Interference

conditions yield consistent activation of the anterior cingulate cortex (ACC), suggesting its critical contribution to cognitive processes in the Stroop task (Bush, Luu, & Posner, 2000; Carter et al., 2000; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999). Other brain regions including inferior and middle prefrontal cortex, orbital frontal cortex, superior and inferior parietal lobule, and insular cortex were also activated in the Stroop task (Peterson et al., 1999; Taylor, Kornblum, Lauber, Minoshima, & Koeppel, 1997; Carter, Mintun, & Cohen, 1995; Bench et al., 1993). Among these structures, considerable attention has been given to the interaction between the ACC and dorsolateral prefrontal cortex (DLPFC) (MacDonald, Cohen, Stenger, & Carter, 2000). Differential time courses of fMRI signal changes in the two regions suggest their distinct roles during the Stroop task (Leung et al., 2000).

Because of the slowness of hemodynamic response, PET and early fMRI techniques have limited inferences about cognitive processes unfolding in the subsecond range. Event-related evoked brain potentials (ERPs) provide enhanced temporal resolution of brain activity. Whereas early ERP studies focused on the processing stage responsible for Stroop interference (Duncan-Johnson & Kopell, 1981), recent studies have attempted to identify neural correlates for interference effects in conjunction with the time course of brain activity using scalp topography and source analyses (Khateb, Michel,

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Figure 1. Actual letter forms of kanji and kana words used in the experiment.

Pegna, Landis, & Annoni, 2000; Liotti, Woldorff, Perez, & Mayberg, 2000; West & Alain, 1999). In the present ERP study, we attempted to confirm the contribution of multiple frontal areas in a Stroop-type interference task and to clarify the temporal relationship among their neural activities.

Another aim of the study was to investigate hemispheric specialization for Japanese language processing. The Japanese language system has two distinct orthographies, kanji and kana. Kanji characters are graphic symbols for lexical morphemes and kana characters are phonetic symbols for syllables (see Figure 1). Clinical findings and experimental studies have suggested that these characters are processed differently in the two hemispheres. The left hemisphere is involved in phoneme-dependent characters such as kana characters, whereas kanji processing is more dependent on the right hemisphere (Nakagawa, 1994; Sasanuma, 1977). There have been few studies in which brain activity was measured directly on reading of kanji and kana characters. A flanker type of interference task is a suitable method for examining hemispheric specialization of the processing of interfering language stimuli (Weekes & Zaidel, 1996). The present study used a color patch as

a target in the center of the screen and a color word as a flanker in either visual field (Henik, Ro, Merrill, Rafal, & Safadi, 1999). This paradigm enabled us to examine interactions between and within stimulus attributes (i.e., word and color) as well as hemispheric specialization of word processing.

RESULTS

Behavioral Data

Table 1 shows mean reaction times (RTs) for all experimental conditions including experimental block (kanji and kana), flanker side (left and right), word congruency (congruent and incongruent), and color congruency (congruent and incongruent). There were two significant main effects: for word congruency, $F(1,9) = 6.73$, $p < .05$, and for color congruency, $F(1,9) = 9.32$, $p < .02$. RTs were significantly slower for incongruent flankers than for congruent flankers in both word and color attributes. The interaction between word and color congruency was not significant ($p > .3$), suggesting these two flanker congruencies affected independently to RTs. The three-way interaction of Experimental block \times Word congruency \times Color congruency was also not significant ($p > .9$). RTs were marginally faster in kana block compared to kanji block, $F(1,9) = 5.11$, $p = .0501$, but the congruency effects for both word and color attributes were similar between kanji and kana blocks (interaction of Experimental block \times Word congruency, $p > .9$; interaction of Experimental block \times Color congruency, $p > .7$).

The important finding is a significant three-way interaction of Experimental block \times Word congruency \times Visual field, $F(1,9) = 14.3$, $p < .005$. This effect was based on the fact that the congruency effects by kanji and kana words were dependent on the side of visual field in which each type of words was presented. Further analysis demonstrated that the congruency effect was significantly larger when kanji words were presented in the left visual field compared to when they were shown in the right visual field [interaction of Visual field \times Word congruency in kanji block; $F(1,9) = 12.1$, $p < .01$], whereas the word congruency effect was larger when kana words were presented in the right visual field

Table 1. Mean RTs (*SE*) (in msec) to a Central Patch as a Function of Experimental Block, Side of Visual Field, and Congruencies of Word and Color Attributes

	Kanji				Kana			
	Right Visual Field		Left Visual Field		Right Visual Field		Left Visual Field	
	Word Congruency		Word Congruency		Word Congruency		Word Congruency	
Color Congruency	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent	Congruent	Incongruent
Congruent	426 (15)	432 (14)	425 (16)	428 (19)	409 (14)	420 (17)	408 (15)	406 (16)
Incongruent	434 (17)	434 (14)	431 (16)	456 (14)	413 (13)	429 (13)	416 (14)	420 (12)

compared to when they appeared in the left visual field [interaction of Visual field \times Word congruency in kana block; $F(1,9) = 5.14, p < .05$]. The color congruency effect was also dependent on the side of visual field [interaction of Visual field \times Color congruency; $F(1,9) = 5.35, p < .05$]. The color effect was significantly larger when flankers were presented in the left visual field compared to in the right visual field. The three-way interaction of Experimental block \times Visual field \times Color congruency was not significant ($p > .2$), indicating that the left visual field dominance of the color congruency effect was similar for kanji and kana blocks. In sum, the left visual field predominance was observed for both kanji word and color interference and the right visual field was predominant for kana word interference.

Electrophysiological Data

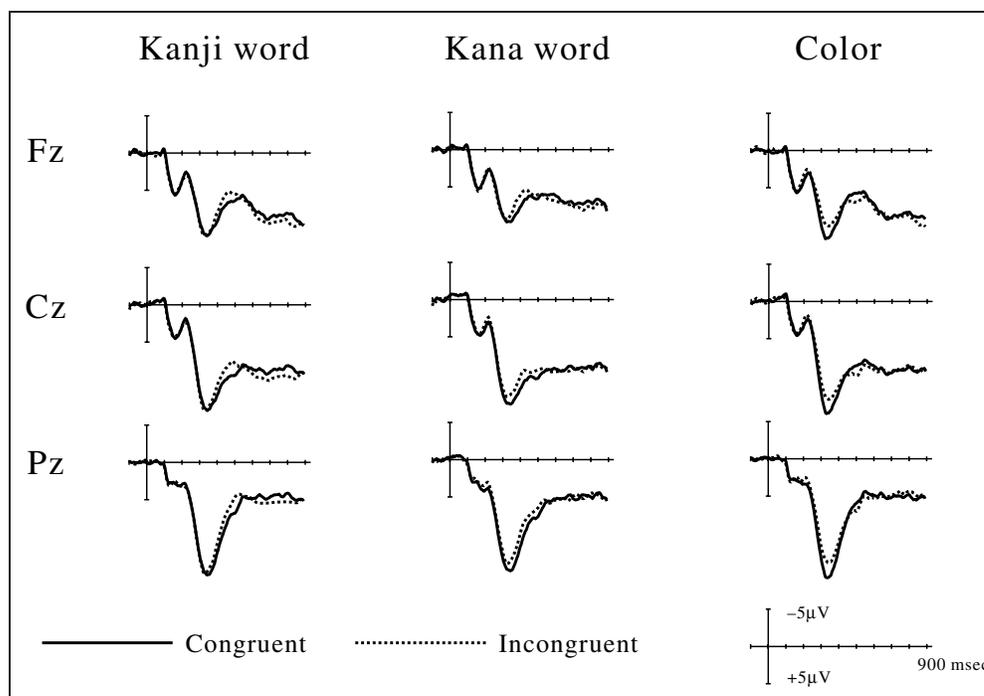
Figure 2 shows the grand average ERPs at the Fz, Cz, and Pz electrode sites for congruent and incongruent flankers. The data are presented separately according to flanker attribute (i.e., kanji word, kana word, and color), but the data from each visual field presentation of the flanker stimuli are collapsed in Figure 2. Regarding the color attribute, we collapsed ERPs in kanji and kana blocks, because no difference was observed in the ERPs to the color attribute between two blocks. The behavioral data also demonstrated no interaction of Experimental block \times Color congruency effect. As seen in Figure 2, the two waveforms for congruent and incongruent flanker conditions were comparable until ~ 300 msec after stimulus onset. After 300 msec, the ERP for the incongruent condition diverged negatively rela-

tive to the ERP for the congruent condition although the onset of divergence was dependent to the flanker attribute. This negative shift by the incongruent flankers seems to result from overlapping of a negative potential associated with inhibitory mechanisms for suppressing incongruent information derived from flanker stimuli.

To clarify this wave shift, the ERP for the congruent condition was subtracted from that for the incongruent condition for each flanker type. This procedure yielded a negative component maximally along the midline electrodes. Figure 3 shows difference ERPs for each flanker type presented at the right or left visual field. The onset latency of the negativity for kanji word interference was 400 msec and it continued until 480 msec. For the kana word condition, the negativity started 360 msec and lasted up to 440 msec in the right flanker condition. Finally, the onset of the negativity related to color interference was 300 msec and continued until 380 msec in the left flanker condition. Thus, the duration of the negativity are similar (i.e., 80 msec) for all types of flanker interference, but its onset and offset latencies were different. The negativity was generated earliest for the color condition, then for the kana word condition, and latest for the kanji word condition.

The mean amplitudes were subjected to a repeated measure ANOVA. The main effect of congruency was significant, $F(1,9) = 52.8, p < .0001$, but the interaction of Congruency \times Flanker attribute was not significant ($p > .7$), indicating no difference in the congruency effect among the three flanker attributes. The critical finding was a significant three-way interaction of Congruency \times Flanker attribute \times Flanker side, $F(2,18) = 4.71, \epsilon = .90, p < .05$. This interaction indicates that the

Figure 2. Grand averaged ERPs elicited by kanji word, kana word, and color attributes at the Fz, Cz, and Pz sites. The waveforms are presented separately for congruent and incongruent conditions but collapsed for the stimuli in the left and right visual fields.



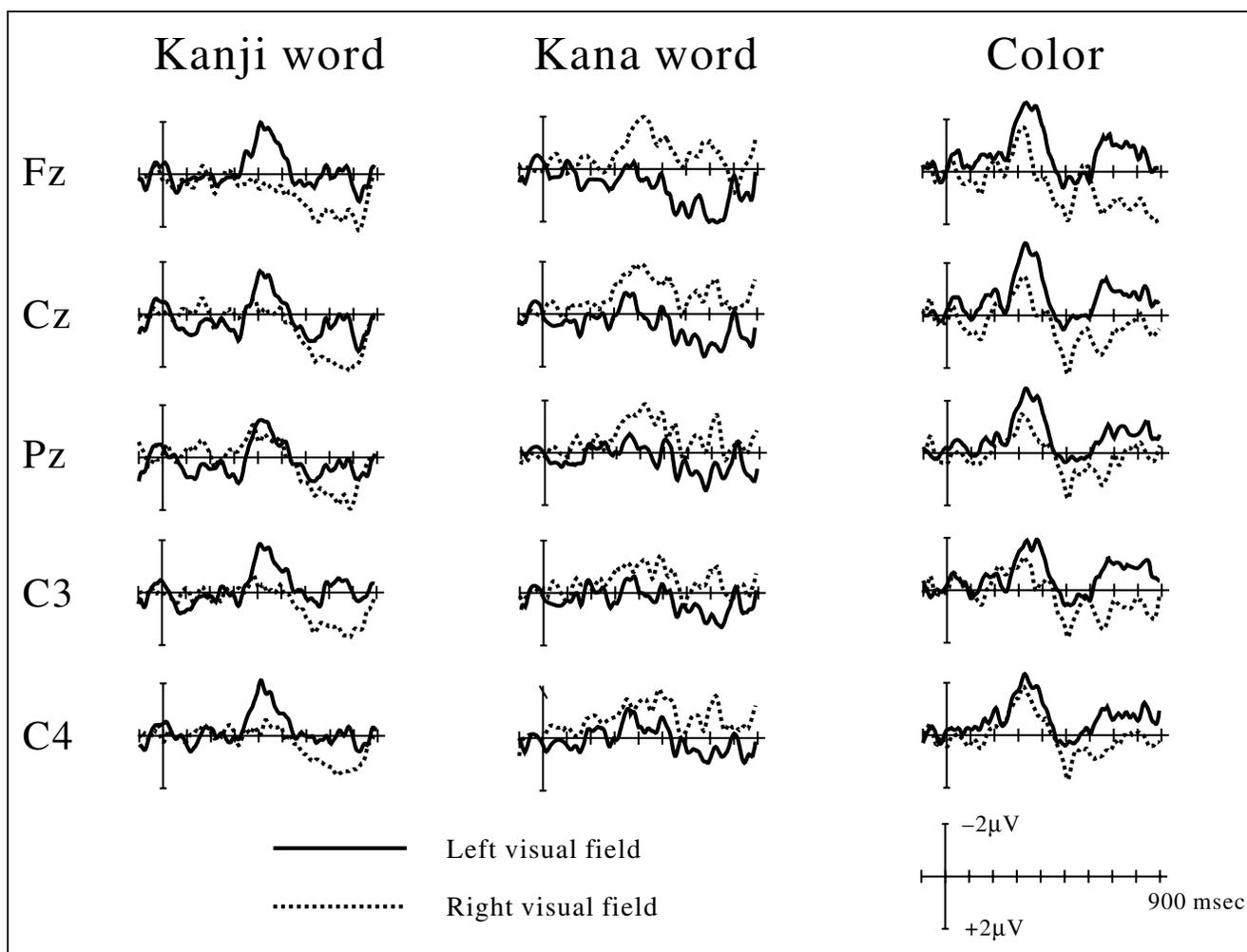


Figure 3. Grand averaged difference ERPs (incongruent condition – congruent condition) elicited by kanji word, kana word, and color attributes. The data are presented separately for the stimuli in the left and right visual fields.

interference effect (incongruent – congruent) of each flanker attribute was different depending on the side of flanker presentation. Further analysis demonstrated that the interference effect for kanji word was marginally larger when the flanker was presented in the left visual field compared to when it appeared in the right visual field [interaction of Congruency \times Flanker side; $F(1,9) =$

5.07, $p = .051$]. The effect size was 1.3 μV for the left presentation [main congruency effect; $F(1,9) = 14.3$, $p < .005$] and 0.3 μV for the right presentation (main congruency effect; $p > .4$). On the other hand, the interference effect by incongruent kana word was significantly larger when they were presented in the right visual field compared to in the left visual field, $F(1,9) = 9.70$,

Figure 4. Scalp topographic maps of difference ERPs (incongruent condition – congruent condition) elicited by left kanji word, right kana word, and left color attributes. The ERP data were normalized within each condition and each subject. L = left; R = right.

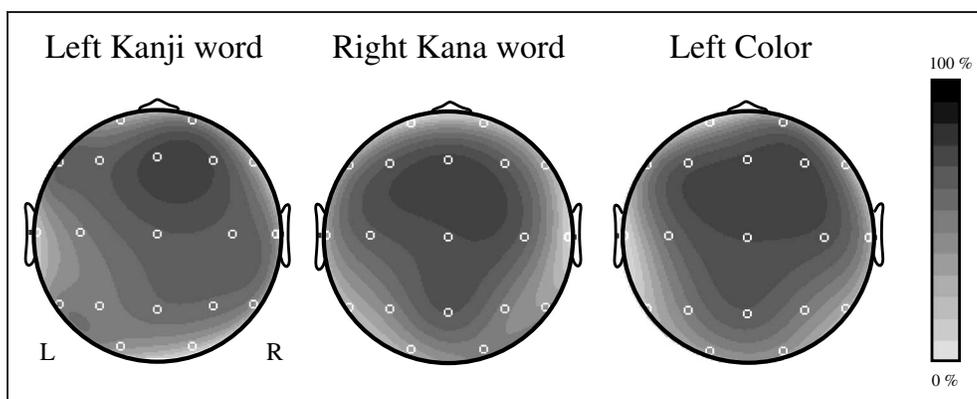
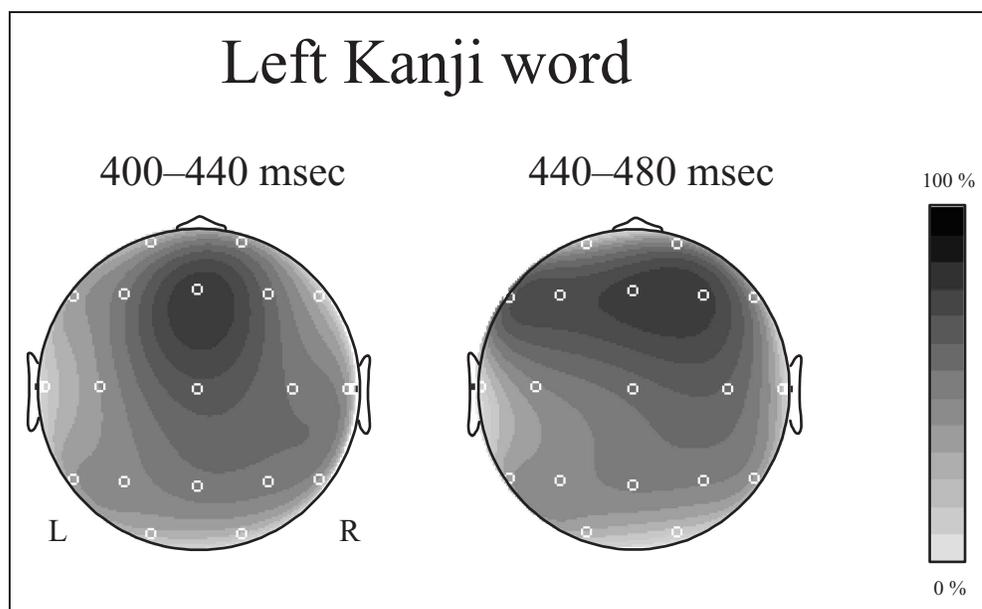


Figure 5. Scalp topographic maps of difference ERPs (incongruent condition – congruent condition) elicited by left kanji word at the early (400–440 msec) and late (440–480 msec) latency ranges. L = left; R = right.



$p < .02$. The effect size was $1.1 \mu\text{V}$ for the right presentation [main congruency effect; $F(1,9) = 36.5, p < .001$] and $0.4 \mu\text{V}$ for the left presentation (main congruency effect; $p > .1$). Regarding the color interference effect, a significant congruency effect was observed for the left flanker condition, $F(1,9) = 9.53, p < .02$, but not for the right flanker condition ($p > .1$). The interaction of Congruency \times Flanker side was not significant ($p > .2$) for the color attribute.

Then we analyzed scalp topographies of interference effects in the ERPs in relation to the flanker attribute and the side of visual field. Because the significant interference effects were observed in three flanker conditions, that is, left kanji word condition, right kana word condition, and left color condition, mean amplitudes in the three conditions were subjected to the topographical analysis. We conducted a repeated measure ANOVA using congruency, flanker condition, and electrode site as factors after normalization of mean amplitudes within each subject and each flanker condition (McCarthy & Wood, 1985). There was a significant main effect of electrode site, $F(18,162) = 12.8, \epsilon = .16, p < .0001$. This effect was due to the maximal distribution of the ERPs along the midline electrode sites for all conditions. Importantly, the interaction of Congruency \times Electrode site was also significant, $F(18,162) = 4.66, \epsilon = .18, p < .01$. As seen in Figure 4, this effect was due to the fact that the congruency effect (incongruent – congruent) was most evident over the fronto-central site. There was no significant interaction of Congruency \times Flanker condition \times Electrode site ($p > .6$), suggesting that the ERP congruency effect in the three flanker conditions showed similar scalp distributions (Figure 4).

Furthermore, we analyzed temporal changes of the interference-related ERP modulations. For this purpose,

we measured mean amplitudes separately in the first and second half of the time window in which significant interference effects were observed for each flanker condition. A repeated measure ANOVA was performed after the normalization of the mean amplitudes using the following factors: timing (early and late time window), congruency, flanker condition (left kanji word, right kana word, and left color), and electrode site. In addition to a main electrode effect, $F(18,144) = 11.7, \epsilon = .15, p < .0001$, there was a significant interaction of Timing \times congruency \times Electrode site, $F(18,144) = 3.77, \epsilon = .14, p < .05$. This interaction indicates differences in the scalp topography of interference-related ERPs modulations between the early and late phases of the measurement window. As seen in Figure 5, the topographical difference resulted mainly from distinct ERP distributions over the frontal area. In the early phase, the difference wave (incongruent – congruent) distributed strongly over the frontal midline area, whereas it extended bilaterally over the frontal area in the late phase. This temporal change in the topography was commonly observed in other two flanker conditions, and there was no statistical significance in the interaction of Timing \times Congruency \times Flanker condition \times Electrode ($p > .2$).

DISCUSSION

Hemispheric Difference in Kanji and Kana Processing

One of the aims of the present study was to examine hemispheric differences in kanji and kana words processing. The interference effect was larger in the left flanker condition (processing in the right hemisphere) for kanji words and in the right flanker condition

(processing in the left hemisphere) for kana words. The ERP recordings demonstrated that kanji word interference generated larger negativity for the left presentation whereas kana word interference generated larger negativity for the right presentation. Thus, the ERP data confirmed differential processing of kanji and kana words between the two hemispheres. These results are consistent with previous reports regarding hemispheric specialization for kanji and kana processing using behavioral and blood flow indices. In tachistoscopic experiments (Sasanuma, Itoh, Mori, & Kobayashi, 1977), kana was significantly better recognized when it was presented to the right visual field than to the left visual field, whereas kanji was recognized better in the left visual field presentation. Dyer (1973) examined hemispheric dominance of English words in a Stroop paradigm using English color words and color patches, which were presented in each visual field. The mutual interference was greatest when the color names were presented to the right visual field and the color patches to the left. This suggests that English words are predominantly processed in the left hemisphere, while colors are processed in the right hemisphere. Because both English and kana consist of phonetic orthographies, it is reasonable to suppose that they are processed in a same manner. Actually, Hatta (1981) compared Stroop effects between kanji and kana words presented in each visual field, and documented the specialization of the right hemisphere for kanji processing. A cerebral blood flow study (Sakurai et al., 2000) suggested that distinct posterior brain regions in the left hemisphere were involved in reading of kanji and kana words. In addition, the temporal–parietal junction of the right hemisphere was more active for reading of kanji compared to reading of kana, whereas the left homologous region was equally activated in reading of kanji and kana words.

The hemispheric difference between kanji and kana processing may be explained by the notion of hemispheric difference in global and local processing (Yamaguchi, Yamagata, & Kobayashi, 2000; Ivry & Robertson, 1998; Fink et al., 1996). Nakagawa's study (1994) suggested that the hemispheric advantage depends on whether the stimulus word consists of one or two characters. When kanji words consisted of more than two letters, the left hemisphere is dominant for their processing, which was contrasted to right hemispheric dominance in the case of reading one-letter kanji. In the present experiment, kanji words consisted of just one character, which was suitable for holistic processing in the right hemisphere. On the other hand, kana words consisted of two or three characters, and local processing in the left hemisphere may be necessary. The current behavioral and electrophysiological data are providing strong evidence for hemispheric specialization in kanji and kana processing.

Processing Stage for the Interference Effect

The current study provided further insights regarding the processing stage at which the interference effect is produced. If interference occurs in an early stage of information processing, kanji words are predicted to show larger interference effects than kana words, because color and kanji word are processed in the same hemisphere. However, the present RT and electrophysiological data demonstrated comparable interference effects for kanji and kana words, suggesting that the interference effect is independent of early perceptual processes. The current study does not employ a conventional Stroop task, but rather a flanker interference task. We must consider spatial filtering in this type of task. Drysdale, Fulham, and Finlay (1998) reported interference effects on the N2 component (200- to 316-msec latency range), but not on earlier components generated by unattended stimuli in a bilateral stimulus task. They claimed that filtering at the early processing stage by spatial attention is not exclusive, but some of unattended information can “break through” the early filtering even when two stimulus locations are separated by 11.5°. The current study showed that the onset latency of the interference-related negativity was in a P300 latency range (300–400 msec), and this finding seems to fit well with the notion of the late occurrence of interference effects. Duncan-Johnson and Kopell (1981) examined electrophysiological indices for Stroop interference effects. They found no difference in P300 latency between congruent and incongruent stimuli and concluded that interference effects occurred after the P300. Ilan and Polich (1999) also reported the discrepancy between RT and P300 latency and argued that interference occurred after the stimulus evaluation. The data from the present topographical analysis also supported the late selection theory. If the interference occurs at the perceptual stage, substantial hemispheric differences in the topography of the negativity are predicted because the interference effects depends on visual fields of flanker presentation. The comparable distributions of field potentials independent of stimulus attributes suggest that interference effects occur in a late stage of information processing. Thus, both the RT and ERP data support the late selection hypothesis for the Stroop interference effect.

Neural Mechanism of Interference Effect

The topographical analysis demonstrated a fronto-central distribution of the interference-related negativity. This topographical finding is consistent with previous ERP studies (West & Alain, 1999; Rebai, Bernard, & Lannou, 1997). The distribution was similar for the three types of flanker attributes: left kanji word, right kana word, and left color. The stronger distribution

along the frontal midline area suggests that the negativity reflects neural activities from the prefrontal midline structure such as the ACC. There have been longstanding discussions regarding the critical neural structures for interference effects in the Stroop paradigm, but the ACC activation in this paradigm was a common finding in almost all PET and fMRI studies. It has been proposed that the ACC participates in motor control by facilitating the execution of appropriate responses and suppressing the execution of inappropriate ones (Paus, Petrides, Evans, & Meyer, 1993). Neuropsychological and electrophysiological studies have provided evidence of the involvement of the ACC in response selection (Turken & Swick, 1999) and response monitoring (Gehring & Knight, 2000). The contribution of the ACC to the interference-related negativity was also presumed in the electrophysiological studies using dipole analysis (Liotti et al., 2000). Furthermore, the interference-related negativity also extended laterally over the frontal site. This suggests that the negativity may be contributed from the DLPFC in some degree. The DLPFC has also been implicated in attentional control mechanisms in human behaviors. Behavioral data demonstrated that patients with lateral prefrontal lobe lesions made more errors or larger interference effects than normal controls in the Stroop task (Kingma, Heij, Fasotti, & Eling, 1996; Vendrell et al., 1995; Perret, 1974). Recent fMRI studies also reveal contributions of a distributed neural network including the DLPFC to the Stroop interference (Leung et al., 2000; Peterson et al., 1999).

The time course of brain activation is also an important issue for interference-related process. Leung et al. (2000) delineated the time course of activation in several brain structures during the standard Stroop task using an event-related fMRI technique. According to their findings, the ACC activation had an earlier onset compared to the activation of the inferior and middle frontal gyri, and the prefrontal activation lasted longer than that of the ACC in turn. The present ERP study demonstrated temporal and spatial dynamics of brain activation. The topographical changes of the interference-related negativity suggest that neural activities in the medial frontal and dorsolateral prefrontal regions contribute to the earlier part and later part of the negativity, respectively. The different time course of activation suggests functional segregation of the medial frontal and dorsolateral prefrontal regions, and their associated activation indicates functional interactions between them. An event-related fMRI study in a modified Stroop task also suggested functional segregation between these two structures (MacDonald et al., 2000) and provided a working model according to which the ACC monitors competition between conflicting information during task performance and drives the executive control system in DLPFC for increasing selective attention and suppressing task-irrelevant information. Further ERP studies com-

bined with imaging studies may help to delineate the functional integration of frontal neural structures for the executive control system.

METHODS

Subjects

Ten normal right-handed male volunteers were recruited from the university community. All participants were native Japanese. They ranged from 32 to 48 years of age (mean 36.8 years) and all had normal or corrected-to-normal visual acuity. All signed consent forms before the experiment. None had any history of neurological disorders or head injury.

Stimuli and Task

Subjects were seated in a comfortable chair with a neck support in an electrically shielded, sound-attenuated room with dimmed lights. All stimuli were presented on a 20-in. cathode ray tube (CRT) with black screen color, 60 cm in front of the subject's eyes. Each stimulus was composed of a red or green square in the center of the CRT and a flanker word to the left or the right of the square. The flanker was the word "red" or the word "green" colored in red or green, using either kanji or kana characters. Kanji and kana were used in a separate experimental block. Thus, regarding the two flanker dimensions (i.e., word and color), the flanker could be congruent (e.g., central square red and flanker word "red" or flanker color red) or incongruent (e.g., central square red and flanker word "green" or flanker color green). In addition to the two-flanker dimensions, the visual field of flanker presentation was manipulated orthogonally so that there were eight flanker conditions (2 word levels \times 2 color levels \times 2 visual fields) for each block, and each condition occurred with equal probability.

All subjects participated in two experimental blocks, one was a kanji block and the other was a kana block. Half of the subjects started with the kanji block first; the other half with the kana block. On half of the trials in each block, the central square was red, and on the other half, it was green. Each of the eight flanker conditions was repeated 40 times. Thus, each experimental block contained 320 trials (2 central square colors \times 8 flanker conditions \times 20 repetitions). The practice block contained 32 trials (four trials from each of the eight flanker conditions).

The size of the central square patch was 1.5° on a side. The closest edge of the flanker word was 2.0° from the CRT center. Both kanji words, "red" and "green," were made of one letter (see Figure 1a) with the visual angle of $1.5^\circ \times 1.5^\circ$. The word "red" in kana consisted of two letters and "green" of three letters (see Figure 1b), which were displayed in a vertical arrangement with

a visual angle of $2.0^\circ \times 1.0^\circ$ for “red” and $3.0^\circ \times 1.0^\circ$ for “green.”

Each trial started with the presentation of a fixation cross in the center of the CRT. After 800-msec display of the fixation, a square patch and a flanker word appeared simultaneously for 500 msec. The interval between offset of the square with the flanker and onset of the next fixation was 1400 msec. Subjects were instructed to respond to the color of the central square patch, as fast as possible, by pressing one of two buttons of a corresponding color on a game pad, one button in each hand. The designation of colors to buttons was counterbalanced across subjects.

Electroencephalographic (EEG) Recording

EEGs were recorded using Ag/AgCl electrodes at 19 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2). Vertical and horizontal eye movements were monitored by electrodes, placed below and lateral to the left eye. All electrodes were referenced to linked ear lobes. Electrode impedance was kept below 5 k Ω . The EEG was amplified (band pass 0.05–100 Hz), digitized (250 Hz/channel), and stored on a computer hard disk for offline analysis. EEGs were averaged over 1024 msec and time-locked to the square patch and flanker stimuli, including 100 msec of prestimulus baseline. In order to examine congruency effects separately for word and color attributes, averaging was performed separately for word and color congruencies in each experimental block. Thus, the trials to congruent and incongruent word flankers were separately averaged irrespective of color congruency, and vice versa. This procedure was justified by the behavioral data indicating independence of word and color congruency effects on RTs. The data to red and green square patches were collapsed because of irrelevance of patch colors to interference effects. Grand averaged ERPs were also generated across 10 subjects for each flanker condition. Individual trials with excessive muscle activity (greater than 100 μ V peak-to-peak amplitude) or eye movement (greater than 100 μ V peak-to-peak amplitude) were excluded from the averages. Only the ERP data from correctly performed trials were included (i.e., RTs between 150 and 900 msec after the onset of the square and flanker).

Statistical Analysis

Eight flanker conditions (2 word levels \times 2 color levels \times 2 visual fields) and two experimental blocks (kanji and kana blocks) were orthogonally manipulated within subjects in the present experiment. Then, behavioral data were subjected to a repeated measure ANOVA using word congruency (congruent and incongruent), color congruency (congruent and incongruent), visual

field (right and left), and type of orthography (kanji and kana) as factors.

Eight distinct ERP waveforms were generated as a function of flanker condition (i.e., congruent word, incongruent word, congruent color, and incongruent color for each side) in each experimental block. Interference effects in ERPs were estimated by comparing ERPs to incongruent stimuli with those to congruent stimuli. To determine the onset and offset of interference effects on ERPs, paired *t* tests were performed consecutively on mean amplitudes of congruent and incongruent ERPs in 20-msec time window from 200 to 600 msec at the Fz site, where maximal interference effects were observed for all flanker categories. That time window was applied to all electrode sites for measuring mean amplitudes. The mean amplitude during the time window showing interference effects was evaluated statistically by a repeated measure ANOVA with the following sources of variance: congruency (congruent and incongruent), flanker attribute (kanji word, kana word, and color), flanker side (right and left), and electrode site (19 locations). The actual time windows used for the ANOVA were 400–480 msec for the kanji word interference effect, 360–440 msec for the kana interference effect, and 300–380 msec for the color interference effect. To obtain information about cortical distributions of ERP changes related to interference effects, topographic maps of the ERPs over the scalp were calculated using spherical spline functions (Perrin, Pernier, Bertrand, & Echallier, 1989). A level of $p < .05$ was accepted as statistically significant and significance levels were adjusted with the Greenhouse–Geisser correction when appropriate. The original degree of freedom and its epsilon value (ϵ) were reported.

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