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Running Head:HEMISPHERIC DIFFERENCES BETWEEN KANJI AND KANA

Abstract

Reaction times to match words to pictures were obtained from 48 Japanese adults, to see whether Japanese Kanji (logographic) and Kana (syllabic) characters are processed preferentially in the right (RH) and left (LH) hemispheres respectively. This was so; when words and pictures were lateralized to the same hemisphere, Kanji was processed faster by the RH, and Kana by the LH, although all hemisphere effects disappeared when the picture was presented centrally. (To minimize any intrinsic LH advantage, overt phonological processing was not required. There was no intrinsic RH advantage for picture processing; pictures were processed equally well by both hemispheres.) It seems that the RH has special semantic capabilities.

Introduction

Are the two hemispheres specialized for different types of written scripts? Does the right hemisphere have some linguistic capacity? Japanese orthography is a good tool with which to answer these questions because it has both syllabic characters, Kana, and logographic characters, Kanji. Since the same lexicon can be represented by both Kanji and Kana, it is interesting to investigate whether access to the lexicon represented by either Kanji or Kana involves one hemisphere more than the other. These questions have gained considerable attention in the last two decades and are still being debated.

It has been known from alphabetic-based studies that letters and words are usually recognized more accurately and faster in the right visual field (RVF)/ left hemisphere (LH), under tachistoscopic presentation (e.g. Benton, Hannay & Varney, 1975; Goodglass & Barton, 1963; Kimura, 1961; Mishkin & Forgays, 1952). However, visuo-spatial stimuli, such as nonsense geometric shapes and dots, are typically identified better in the left visual field (LVF)/right hemisphere (RH) (Bryden, 1976; Kimura, 1961, 1966, 1969).

Perhaps, then, the hemispheres are specialized for Japanese orthography. Presumably the syllabic characters, Kana, which represent vowels or consonant-vowel pairs, are processed similarly to phonetic or alphabetic letters, while the logographic characters, Kanji, which are pictorial and do not have fixed sound values, are processed similarly to visuo-spatial stimuli.

Indeed, the earlier studies of performance (e.g. recognition accuracy or latency) supported the specialization hypothesis (e.g. Hatta, 1976, 1977a, 1978, 1981a; Hirata & Osaka, 1967; Sasanuma, Itoh, Mori & Kobayashi, 1977). Color-word Stroop tests have also supported the specialization hypothesis, albeit weakly, by showing a greater interference effect for Kanji in the LVF than in the RVF, but no difference in Kana (Hatta, 1981b; Morikawa, 1981). However, the performance advantage of Kanji can shift to the LH, depending on the number of characters in a word (Hatta, 1978; Tzeng, Hung, Cotton and Wang, 1979), the task required (phonological, visual matching or semantic) (Hatta, 1979, 1981a,c; Hayashi and Hatta, 1982; Sasanuma, Itoh, Kobayashi and Mori, 1980), the level of processing required to perform the task (Hatta, 1981a), and concreteness (Elman et. al., 1981; Hatta, 1977b; Ohnishi & Hatta, 1980).

For example, when reporting single Kanji characters verbally, or physically matching single Kanji characters, a LVF advantage was reported (Hatta, 1977a, 1978, Hatta, 1981a). However, when Kanji was presented as a compound word of two characters, a RVF advantage was found (Hatta, 1978; Tzeng et al., 1979 for Chinese subjects), either because the LH is better at sequential or analytical tasks (Tzeng et al., 1979), or because (unlike single character Kanji) two-character Kanji typically have only one pronunciation and can be more easily identified by the LH (Hatta, 1978). Indeed, reading Kanji phonologically yields a LH advantage (Sasanuma, et al.,1980).

Hatta (1979, 1981a) has also suggested that Kanji processing is predominantly LH functioning when higher level processing is required. The results of his research show a RH advantage in simple physical recognition of single Kanji, no significant difference in a lexical decision task, and a LH advantage in a semantic congruence task and in a semantic categorization task (Hayashi & Hatta, 1982). These results suggest a progressive shift towards the LH involvement in Kanji processing as the task moves from simple visual identification to making linguistic decisions (Hatta, 1981a).

There are many differences between Kana and Kanji, which further complicates interpretation of performance studies. For instance, content words are mainly written in Kanji while function words are mostly written in Kana, although Japanese children initially learn all words in Kana. An entire sentence written only in Kana would be difficult for normal adult Japanese readers, but Kana written words are familiar in childhood. Thus, Kana and Kanji differ in expressing function versus content words, educational history, and precision of semantic and phonological information, as well as in the dimension (spatial versus phonetic) thought to lie behind hemispheric differences (See Aoki (1990); Sasanuma (1980); Iwata (1984)).

Considerable evidence for the phoneticity (and hence LH specialization) of Kana and less phoneticity of Kanji exists. For instance, concurrent vocal activity, such as counting the numbers from 1 to 5, interferes with reading in Kana but not in Kanji (Kimura, 1984), suggesting that access to the lexicon for Kana words might require prelexical phonology, while access to the lexicon for Kanji words can be achieved without phonological mediation. Moreover, Goryo (1987) found that short-term memory for Kanji words is less interfered with by auditory stimuli (listening to nonsense sentences) than for Kana words. However, the idea that Kana is processed only via phonological codes has been challenged by recent research. It has been suggested that lexical access in Kana also can be achieved without phonological processing when Kana words are highly visually familiar (e.g. Besner & Hildebrandt, 1987; Hirose, 1984,1985). Therefore, employing unfamiliar Kana words, such as Kana transcription of Kanji words, in word recognition tasks may force phonological processing.

Selective losses in Kana or Kanji processing have also been reported in studies of alexia and aphasia (Iwata, 1984; Iwata et al., 1982; Sasanuma, 1974, 1975; Sasanuma and Fujimura, 1972; Sasanuma and Monoi, 1975; Yamadori, 1975) as summarized in Sasanuma (1980) and Paradis et al. (1985).

In addition, studies of partial split-brain Japanese patients also suggest that phonological processing is dominantly handled in the LH, while some semantic processing might be handled in the RH (Sugishita et al., 1978; Sugishita, Yoshioka, & Kawamura, 1986; Sugishita and Yoshioka, 1987). This is consistent with the results from English-speaking split- brain patients (Zaidel, 1978; Zaidel & Peters, 1981, but see Patterson and Besner, 1984).

Semantic processing of the right hemisphere

Although research with normal Japanese subjects suggests that the semantic processing of Kanji takes place in the LH, this is not fully established. The parameters of the stimuli in early studies, such as concreteness, familiarity and the number of characters in a word, were not well controlled (see Paradis et al., 1985); the clinical evidence suggests a possible involvement of the RH in comprehension of meaning of Kanji words (Iwata et al., 1982; Sugishita et al, 1978) and the semantic tasks used in tachistoscopic studies required judgments about the spatial position of the word or the superordinate category of the word as well as the comprehension of meaning. It may be that the RH could perform a simple semantic task, such as the picture-word matching task used in the clinical research (e.g. Sugishita et al, 1978; see Sasanuma, 1980).

Jones and Aoki (1988) tested this possibility. Pictures were matched to words in the same visual field in their study. If the visual presentation of Kanji evokes the meaning of the concept without requiring phonological processing, the RH might perform this task as well as or better than the LH. Kana were also employed for comparative purposes.

Many studies, before Jones and Aoki (1988), have employed reaction time to demonstrate lateralization (e.g. Elman et al., 1981; Hatta, 1979, 1981a, b; Hayashi & Hatta, 1982) to discover whether latency differences co-vary with hemisphere specialization, as they might do if callosal transmission time is not negligible. The aim in accuracy studies (e.g. Hatta, 1976, 1977a, b, Hirata & Osaka, 1967; Sasanuma et al., 1977, 1980) is to find out if low-quality (degraded) stimuli show hemispheric specialization, independent of processing time. In Jones and Aoki's study (1988), however, the staircase method was used to determine the stimulus duration required for picture-word matching at an accuracy of 75% (chance was 50%). The results, replotted to include additional unpublished data, indicate that the threshold stimulus duration is lower in the LVF than in the RVF for Kanji words (209 msec vs. 227 msec, respectively), while the threshold for Kana words is lower in the RVF than in the LVF (88 msec vs. 102 msec, respectively) (Figure 1a). This suggests that the RH processes the highly concrete, highly hieroglyphic and highly familiar single Kanji words more efficiently, even in a semantic task when phonological processing is not required. Kana was, as usual, processed better in the LH. However, once the stimulus information was visually and linguistically encoded, further processing did not seem to depend on the hemisphere, as shown by the lack of hemisphere effect on reaction time (Figure 1b).

Insert Figure 1 about here

The experiment showed clear-cut hemispheric effects, but it was not clear if subjects performed the task based on semantic decision, lexical decision or visual discrimination, because errors made in response to these three types of mis-match were not distinguished. Therefore, to isolate the semantic level of processing, it is necessary to examine if a RH advantage would be still obtained in a semantic task when errors are predominantly semantic.

General Method

Subjects in the current study were Japanese men and women. Since no gender difference was found in a major parallel study done in the same lab (Aoki, 1990), no attempt was made to balance the numbers of men and women in each of these studies.

Four experiments were performed to compare processing of Kanji and Kana in a picture-word matching task. The picture was always presented first; the task was to indicate whether the subsequent word matched it in meaning, or did not match, by pressing the appropriate response keys. In these experiments, reaction time was employed to discover whether latency would also show a hemisphere effect; high contrast stimuli were used so that stimulus quality would not be at issue. Error rates were also analyzed as performance was not perfect. As the stimuli were above threshold, the ability of the visual system to encode them was generally not in doubt, so errors are unlikely to have a purely sensory origin. It was predicted from the hemispheric specialization hypothesis that Kanji characters would be relatively favored in the RH while Kana characters would be relatively favored in the LH.

In Experiment 1 and 2, both a picture and a word were lateralized to the same side of the visual field (as in Jones and Aoki, 1988). The picture presentation durations, however, were different in the two experiments to vary picture clarity. Clarity may play a role in lateralization, as suggested by Sergent (1982, Sergent and Hellige, 1986), who reported that low clarity stimuli were better analyzed in the RH, but high clarity better in the LH.

In Experiments 3 and 4, characters were still lateralized, but the picture was presented at fixation, to the center of the screen. If lateralization still occurred, one could conclude that it reflected the processing of the character alone. If not, one might assume that priming or activation by the picture was required for lateralization of the character.

In Experiment 5, we examined if picture processing was equally good in the two hemispheres, as a control for Experiments 1 and 2.

Experiment 1: a picture-word matching task with a brief presentation of a lateralized picture

Method

Subjects

Subjects were twelve Japanese (4 males and 8 females), with mean age of 25, who regularly read and spoke Japanese. They had resided in Boston for, on average, one and half years, ranging from 1 to 54 months. According to the standards of the simplified Edinburgh Handedness Inventory (see Bryden, 1977; Oldfield, 1971), all of the subjects were right handed and none of their immediate family members were left handed. All of the subjects had normal or corrected to normal vision (at least 20/20). The subjects were paid $6.00 per hour to participate in the experiment.

Apparatus

A Gerbrand G1171 two-channel projection tachistoscope, which consisted of two Kodak Ektagraphic projectors and electrical shutters with a 4-channel digital millisecond timer (Gerbrands "300-C" series), was used to deliver stimuli to a translucent rear projection screen set 66 cm away from the subject at eye level. The stimulus field subtended 24 degrees of visual angle horizontally and 16 degrees vertically. The field was white during a stimulus flash. Otherwise, the field was dark. Room lights were on but dim.

The reaction time was measured in milliseconds by Hunter Klockcounter (Model 120 A series D) from the onset of the stimulus presentation to the subject's key press. Two microswitches, for "matched" and "mismatched" responses, served as the response keys.

Stimuli

There were 40 single character Kanji words, 40 Kana words which were transcriptions of the Kanji, and 40 pictures which depicted the Kanji. Kanji characters were selected using Kitao et al.'s list (1977) of 881 Basic Kanji characters. Selected Kanji were high on concreteness (the mean score was 90.7 out of 100), hieroglyphicity (the mean score was 4.59 out of 7), and familiarity (the mean score was 4.72 out of 7).
Being highly concrete and highly familiar should favor the RH (e.g. Day, 1977; Elman et al., 1981; Ellis & Shepherd, 1974; Hines, 1976, 1977). These Kanji characters also tend to be more pictorial and consequently should be more efficiently processed in the RH.

Each picture or character was hand-written with black ink in a two centimeter square on a white paper, and photographed with black and white film under constant illumination. The pictures and Kanji words were 1.5 degrees of visual angle in width and height. Kana words were 1.5 degrees in width and 3.5 degrees in height. A single small 0.4 degrees digit was placed at the center of, each picture or word, to help control fixation (see below).

The stimuli were rear projected onto the screen. Each stimulus appeared at 5 degrees from the central fixation point, on the left or right. The luminance of the background was 41 ft.-L., and the contrast of the stimuli on the background was 94% .

Procedure

Each subject was instructed to sit at a table facing the translucent screen with his/her head on a chin-rest to minimize head movement. The subjects viewed the stimuli binocularly. Prior to the experiment, the subject saw all 40 pictures and correctly identified them. This was necessary in order to make sure that the subject understood all the pictures.

Each trial consisted of sequence in which a fixation point was presented for 2 sec, followed by the presentation of a picture for 150 msec, then by an interstimulus interval of 1 sec, after which a word was presented for 150 msec.

The subject's task was to indicate whether the picture and the word were matched or mismatched by pressing the appropriate response key as fast and accurately as possible. Half the time, they did match, and half the time, they did not. The matched and mismatched pairs were randomly selected. These responses were made by the index and middle finger of the right hand. The use of fingers for yes and no was counterbalanced across the subjects.

As a control for fixation, subjects were asked after each trial to report the fixation digit. On half the trials, the fixation point was replaced by a cross when the picture was presented and by a digit (from 2 to 9) when the word was presented. On the remaining trials, the cross and digit were reversed. If the subject incorrectly reported the digit, the results for that trial were omitted. This happened on less than 2% of the trials, in all the experiments.

The experimenter recorded reaction time, and whether the response and the reported fixation digit were correct or incorrect. The experiment took approximately one hour.

Design

The 40 picture-word pairs were presented once in each visual field, resulting in 80 trials in one block. Kanji and Kana words were tested in separate blocks. Subjects were given 20 practice trials to familiarize them with the task. This practice run was followed by testing either picture-Kanji or picture-Kana. After the first block of trials, subjects were given a 10 minute break and then were tested for the other character type after another 20 practice trials. The order of presentation was counterbalanced across the subjects.

Results

Reaction times

Reaction times for correct responses were used in the following analysis. These reaction times were transformed logarithmically prior to the analysis. This made the distributions approximately normal and homogeneous, permitting the use of ANOVA. The means of the transformed reaction times were then transformed back to reaction times in milliseconds by taking antilogarithms. Consequently, the means indicated in tables and graphs are geometric instead of arithmetic means.

An ANOVA with two within-subject factors was performed on the log reaction times. The two factors were visual field (LVF vs. RVF) and character type (Kanji vs. Kana). The ANOVA showed no main effect of visual field ($F(1,11) = 1.28$, $p > .05$), and no main effect of character type ($F(1,11) = 2.31$, $p > .05$), but a significant interaction between visual field and character type ($F(1,11) = 20.3$, $p < .001$), as shown in Figure 2(a) and Table 1.

Insert Figure 2 (a,b,c,d) about here

Insert Table 1 about here

Planned comparisons showed that Kana was faster in the RVF than in the LVF (841 msec and 894 msec, respectively, $p < .01$) while Kanji was faster in the LVF than in the RVF (811 msec and 831 msec, respectively, $p < .05$ with a one tailed test). These trends were clear for 12 out of 14 subjects in Kana and 13 out of 14 in Kanji. The interaction supported the hypothesis that Kana is processed better in the LH while Kanji is processed better in the RH in the picture-word type of semantic task.

<u>Error rates</u>

The overall error rate was about 3.5%. An ANOVA with two within factors of visual field and character type showed that there was no main effect of character ($F(1,11) < 1$), but there was a main effect of visual field (4.2% for RVF and 2.8% for LVF $F(1,11) = 6.44$,
$p < .05$). Thus, although there were fewer errors in the LVF than in the RVF, the difference was very small (1.4%). More importantly, there was no interaction between character type and visual field ($F(1,11) < 1$). (See Figure 3(a).)

Insert Figure 3(a,b,c,d) about here

Discussion

We found that reaction time is an indicator of laterality between Kanji and Kana, in the picture-word semantic task, when the stimuli are clearly presented and error rates are low. Kanji characters are processed faster in the RH while Kana characters are processed faster in the LH. This extends Jones and Aoki (1988), who found the same pattern of interaction in stimulus duration which was varied to obtain constant accuracy. The magnitude of difference between the two hemispheres was larger in Kana than in Kanji. This may mean that Kana processing is relatively more lateralized in the LH than Kanji is in the RH, or as Exp.2 will show, it may reflect differential error rates.

The data in our study show a different processing pattern for Kanji and Kana, even when the words represent the same meaning. These results are consistent with earlier work on physical identification of Kanji, which showed a RH advantage (Hatta, 1981a), and with the earlier picture-word matching study by Jones & Aoki (1988), but differ from the results from the previous semantic tasks (e.g. Hatta, 1981a; Hatta, Honjoh, & Mito, 1983; Hayashi and Hatta, 1982), which showed a LH advantage for Kanji.

In Exp.1, some subjects reported that pictures were hard to identify due to the brief presentation (exposure time of 150 msec). This might have differentially activated the RH, which is superior for blurred and briefly exposed stimuli (Pring, 1981; Sergent, 1982; Sergent & Hellige, 1986), and might possibly account for the small but reliable difference in error rates between the visual fields. In order to check this possibility, the picture duration was extended in Exp. 2 so that all the pictures were easily identified.

Experiment 2: a picture-word matching task with a long presentation of a lateralized picture

This experiment was designed to examine the effect of picture duration on

Kanji and Kana lateralization, in conjunction with Experiment 1.

Method

Subjects

Twelve new right handed Japanese people (3 males, 9 females), who resided in Boston for, on average, 1 year (ranging from 1 to 48 months), served as subjects. The mean age of the subjects was 27. The criteria for selecting subjects were the same as in Exp.1.

Apparatus, Stimulus and Procedure

The apparatus and stimuli were the same as in Exp.1. The procedure was the same as in Exp.1 except that picture duration was 500 msec. Since the picture duration was more than 200 msec, there was a possibility that the subject moved his/her eyes to the picture. To reduce this possibility, the subject was frequently reminded to fixate centrally. Fixation digits were also presented to control for eye movements, as in Exp. 1.

Results

The results were essentially the same as those in Exp.1, but now both Kanji and Kana showed strongly significant differences between the visual fields.

Reaction times

An ANOVA with two within-subject factors was performed on log reaction times for the correct responses, as in Exp. 1. The two factors were visual field (LVF vs. RVF) and character type (Kanji vs. Kana). The ANOVA showed no main effect of character type ($F(1,11) < 1$), and no main effect of visual field ($F(1,11) = 3.69$, $p > .05$), but a significant interaction between visual field and character type ($F(1,11) = 5.96$, $p < .05$) (See Figure 2(b) and Table 1).

Planned comparisons showed that Kana was faster in the RVF than the LVF (908 msec and 940 msec, respectively, $p < .01$) while Kanji was faster in the LVF than the RVF (827 msec and 863 msec, respectively, $p < .01$). This trend was reversed for only 1 subject in Kanji but for four of the 12 subjects in Kana.

Error rates

The overall error rate was about 2.6%. An ANOVA with two within factors of visual field and character type showed that there was no main effect of character type, 2.1% for Kanji and 3.1% for Kana ($F(1,11) = 2.53$, $p > .05$), no main effect of visual field, 2.5% for RVF and 2.8% for LVF ($F(1,11) < 1$, $p > .05$), and no significant interaction between character type and visual field ($F(1,11) < 1$, $p > .05$). (See Figure 3(b).) The smaller error rate in the LVF obtained in Exp. 1 disappeared when the picture was more clearly presented in Exp. 2.

Discussion

The reaction time results indicate that Kanji words were responded to faster in the RH than in the LH, while the opposite occurred with Kana words.

The results from the Experiment 1 and 2 strongly support the hemispheric specialization hypothesis, as did the previous research on thresholds (Figure 1(a)). These results suggest in addition that the RH has a semantic capacity, especially in the case of processing logographic characters, such as Kanji. These two experiments, however, lateralized both pictures and words as input stimuli.

The next two experiments were designed so that the picture presentation would activate both hemispheres equally, prior to word presentation. This was done to determine whether the lateralization observed in Experiments 1 and 2 would still occur since laterality effects can disappear with centrally presented primes in word priming studies (Chiarello et al., 1990). If the character-visual field interaction was reduced or eliminated, one might assume that priming or activation by the picture was required to make lateralization manifest. For comparison with Experiment 1, Experiment 3 used a brief picture duration while Experiment 4 used a long duration for comparison with Experiment 2.

Experiment 3: A picture-word matching task with a brief presentation of a centered picture

Method

Subjects

Twelve Japanese women (mean age of 19.3) who resided in the U.S. for about 2 months served as subjects. The criteria for selecting subjects were the same as in Exp.1.

Apparatus, Stimuli and Procedure

The apparatus and stimuli were the same as those used in Exp. 1. Pictures and words were presented for 150 msec, as in Experiment 1. The procedure was the same as in Exp. 1, except that pictures were presented in the center of the visual field. As in Experiment 1, fixation digits were used to prevent eye movement, except that these digits could only be shown with the words.

Results

Reaction times

An ANOVA with two within factors on log reaction times for correct responses was performed. The two factors were visual field (LVF vs. RVF) and character type (Kanji vs. Kana).

The ANOVA showed no main effect of character type ($F(1,11) < 1$, $p > .05$), and no main effect of visual field ($F(1,11) = 3.69$, $p > .05$), but a significant interaction between visual field and character type ($F(1,11) = 5.96$, $p < .05$). (See Figure 2(c) and Table 1.) Planned comparisons showed that Kana words were responded to faster in the RVF than the LVF (861 msec and 906 msec, respectively, $p < .01$); the trend for Kana was reversed for only one subject. However, Kanji did not show any significant difference between the visual fields (879 msec and 877 msec, respectively, $p > .05$).

Error rates

The overall error rate was about 1.4%. An ANOVA with two within factors of visual field and character type showed that there was no main effect of character type (1.3% for Kanji and 1.6% for Kana, $F(1,11) < 1$) and no main effect of visual field (1.2% for RVF and 1.6% for LVF, $F(1,11) < 1$). The ANOVA also showed no significant interaction between character type and visual field ($F(1,11) < 1$) (See Figure 3(c)).

Discussion

The results of Experiments 1 and 3 show that when the picture was centered, the LH advantage was somewhat reduced for Kana, and the RH advantage for Kanji disappeared altogether, relative to when the picture was on the side. This suggests that central presentation of the picture reduces hemispheric differences. Perhaps prior presentation of a picture to one or other hemisphere tends to activate that hemisphere and increase any lateralization effect. Putting the picture in the center would tend to activate both hemispheres equally and reduce lateralization. However, the reduction of the LH advantage for Kana, from 53 msec to 45 msec, was small and not significant.

The next experiment was conducted for comparison with Exp. 2 to examine whether a similar result would be obtained with a long duration of the centrally presented picture. The representation of a picture should be clearer when it is presented in the fovea for one second (Exp.4) than when presented in fovea for 150 msec (Exp.3), or when presented peripherally for 500 msec (Exp. 2).

Experiment 4: a picture-word matching task with a long presentation of a centered picture

Method

Subjects

Twelve Japanese women (with a mean age of 24.6), who had resided in the U.S. for about 2 years (ranging from 1 to 60 months), served as subjects. The criteria for selecting subjects were the same as in the previous experiments.

Apparatus, Stimulus and Procedure

The apparatus and stimuli were the same as those used in the previous experiments. The procedure was almost the same as in Exp. 3, except that the picture duration was 1 sec.

Results

Reaction times

An ANOVA with two within-subject factors was performed on log reaction times for correct responses. The two factors were visual field (LVF vs. RVF) and character type (Kanji vs. Kana).

The ANOVA showed no main effect of character type ($F(1,11) < 1$), and no main effect of visual field ($F(1,11) = 1.90$, $p > .05$), but showed a significant interaction between visual field and character type ($F(1,11) = 4.92$, $p < .05$). (See Figure 2(d) and Table 1.)

Planned comparisons indicated that the LVF was faster than the RVF for Kanji (863 msec and 897 msec, respectively, $p < .01$) while there was no visual field difference for Kana (883 msec for LVF and 886 msec for RVF, $p > .05$). One of the 12 subjects showed an extreme RH advantage for Kanji (about 160 msec comparing with 60 msec, the average of the other 11 subjects). When this subject was excluded from the analysis, the character-visual field interaction was not significant ($F(1,10) = 2.37$, $p > .10$).

Error rates

The overall error rate was about 1%. An ANOVA with two within factors of visual field and character type showed that there was a main effect of character type, 1.6% for Kanji and 0.5% for Kana, ($F(1,11)= 9.58$, $p < .05$). However, since the error rates for Kanji and Kana were both very small, the difference between them is probably not revealing. The ANOVA showed no visual field difference ($F(1,11)< 1$) and no interaction between character type and visual field ($F(1,11) < 1$) (See Figure 3(d)).

Discussion

The results in Exp. 4 were different from those in Exp. 3. When the picture was presented for a short duration in the center of the visual field in Exp. 3, Kana characters showed a LH advantage (11 among 12 subjects showed this tendency), while Kanji characters did not show any overall hemispheric difference. However, when the picture was presented for a longer duration in the center of the visual field in Exp. 4, the result was the opposite, i.e., no overall hemispheric difference for Kana and a RH advantage for Kanji. The large subject variability suggests that the significant RH advantage in Kanji in Exp. 4 might be due to chance. In fact, without the one subject with an extreme RH advantage for Kanji, the interaction was not significant.

The strong laterality effect obtained with the lateralized pictures in Exp. 1 and 2, which decreased or disappeared with the central pictures in Exp. 3 and 4, might partly reflect preferential processing of pictures by one or other hemisphere, somewhat independently of the semantic processing revealed by the picture-word matching task on which the research is focused.

However, we do not know if the pictures used in these experiments are actually processed preferentially in one or other hemisphere. To find out, picture presentation durations needed to achieve the same accuracy were measured in each visual field.

Experiment 5: picture recognition (control)

The purpose of this experiment was to examine whether or not there is a preferred visual field for picture recognition. We tested this by varying the stimulus duration needed to make error rates equal in each visual field.

Method

Subjects

Subjects were 9 female and 7 male Northeastern University undergraduate students selected based on the same criteria as in Experiment 1.

Apparatus & Stimuli

The apparatus and stimuli were the same as in the previous experiments. Only the pictures were used.

The subject viewed the stimuli monocularly in either the LVF or the RVF. Monocular vision was used, as in Jones and Aoki (1988). To counterbalance the order of presentation, half of the subjects viewed the stimuli in the LVF first with his/her left eye, and the other half viewed the stimuli in the RVF first with his/her right eye.

Procedure

The procedure was the same as before, except that stimulus duration was lowered towards threshold to induce errors. The subject's task was to name a picture as fast and accurately as possible. A staircase procedure was used. The initial stimulus duration was 200 milliseconds. This was increased by 10 milliseconds following an incorrect response or decreased by 10 milliseconds following two consecutive correct responses. Stimulus duration, response correctness, and the reported fixation number were recorded after each trial. Each 80 trial staircase was run in one block of trials. Reaction time was not recorded.

There was a five minute break between the two conditions. The experiment took approximately one hour.

Results

The data used for the analysis were stimulus durations and error rates. Approximately 2% of the data for each subject was discarded because of incorrect numeral responses. Each dependent variable was analyzed by 2 way Analysis of

Variance (order of presentation and visual field). The order of presentation was between-subject factors, while the visual field was a within-subject factor.

Stimulus duration

The first 10 trials of the staircase were excluded from the overall stimulus duration analysis because it took 10 trials or so to reach the neighborhood of the final threshold. Consequently, the means of the stimulus durations for the last 70 trials in each condition were used for the analysis. The ANOVA showed no main effects. That is, there was no overall significant difference between orders of presentation ($F(1,14) < 1$), and no significant difference between the LVF and RVF, 117 msec and 112 msec respectively ($F(1,12) < 1$). The analysis, however, showed a significant interaction of visual field with order of presentation ($F(1,14)=13.4$, $p<.01$). A post hoc comparison indicated that this was entirely due to a practice effect ($p<.05$). That is, the subjects who started with the LVF showed a shorter stimulus duration for the RVF than the LVF, and vice versa for the subjects who started with the RVF. Thus, by the threshold measure, the visual fields do not differ at all.

Error rates

Accuracy was equated at around 81% for all conditions by design, and this was confirmed by ANOVA. The error rates for the LVF and the RVF were 17.5% and 18.6%, respectively ($F(1,14)<1$). This non-significant difference in error rates demonstrated the success of the procedure employed here.

Discussion

The results from this experiment suggest that the stimulus durations required to name pictures at a certain level of performance were the same for both visual fields. Therefore, the picture naming task used here were not intrinsically lateralized.

This result does not imply equality of processing at all levels in each hemisphere; a RH advantage for recognizing a picture might have been offset by a LH advantage for naming task. However, since the same pictures and same recognition strategy were required as in the earlier experiments, the results indicate that picture recognition per se is unlikely to have produced the processes involved in the laterality effects we found in Experiments 1 and 2.

General Discussion

In a semantic (picture-word matching) task, Kana characters are processed faster in the LH than in the RH while Kanji characters are processed faster in the RH than in the LH. This dissociation is clear when both a picture and a word were presented to the same side of the visual field, as in Exp. 1 and Exp. 2. When the picture was presented in the center of the visual field and the word to the side in Exp. 3 and Exp. 4, however, the hemispheric differences weakened. When the picture duration was short, the hemispheric differences in Kanji disappeared whereas those in Kana still remained. When the picture duration was long, the hemispheric differences in Kana also disappeared (the marginal effect in Kanji in Exp.4 was due to one subject.) The location, and perhaps duration, of the picture help determine whether hemispheric differences will be manifest in processing Kanji and Kana.

Figure 4 is a scattergram of visual field effects for Kanji and Kana, taken across subjects. The abscissa represents the difference of reaction times between RVF and LVF for Kanji, whereas the ordinate shows the same difference for Kana. Positive numbers indicate a RH advantage (the LVF is faster than the RVF); negative numbers indicate the opposite. The overall scatter shows that no simple generalizations apply equally well to all subjects. However, for Kanji, the majority of the subjects showed RH advantages in Exp.1 and Exp.2, while some subjects showed RH advantages and the others showed LH advantages in Exp.3 and Exp.4. For Kana, the majority of the subjects showed LH advantages in Exp.1, Exp. 2., and Exp.3, while most subjects showed no hemispheric advantage in Exp. 4.

Insert Figure 4(a) and 4(b) about here

The upward slope of the data in general shows that for some subjects one visual field or hemisphere dominates for both Kana and Kanji; for other subjects the other visual field or hemisphere dominates. However, the predominance of data in the fourth quadrant for lateralized picture presentations (Figure 4(a)) means that for most subjects in this situation, Kana still tends to be faster in the LH, and Kanji in the RH.

To determine if the differences across experiments concerning picture location were truly significant, an additional 2-way ANOVA was performed with picture location and character type as factors (picture duration was collapsed over). The

ANOVA showed no main effect of picture location ($F(1.46)<1$), but showed a significant main effect of character type ($F(1.46)=47.6$ $p<.001$) and a significant interaction between picture location and character type ($F(1.46)=4.55$, $p<.05$). Kanji and Kana showed opposite directions of advantage (20 msec LVF advantage for Kanji and 33 msec RVF advantage for Kana). Post hoc tests showed that the advantages for both Kanji and Kana were larger in the lateralized picture condition than in the centered picture condition (28 msec and 13 msec for Kanji, and 41 msec and 24 msec for Kana, respectively). Therefore, the character-visual field interaction was larger in the lateralized picture condition than in the centered condition.

This pattern of results is consistent with the now traditional view of hemispheric activation, introduced by Kinsbourne (1970, 1973). The lateralized picture presentation seems to enhance the activity of one hemisphere, and hence an incoming stimulus would be processed better in the already activated hemisphere, especially when the hemisphere favors the stimuli. Therefore, the interaction between character and visual field would be increased. On the other hand, the centered picture presentation would reduce the interaction because both hemispheres are already activated by the picture. Activations of the RH and LH may have had enough time to stabilize in Exp. 4, when the picture duration was particularly long, so that the laterality effect virtually disappeared in that experiment.

An alternative is that in Exp.4, the subject might have used visual imagery generated by the picture to permit a visual matching strategy as well as phonological strategy for Kana. A semantic comparison task, in which subjects judged whether the physical sizes of two concrete Kanji characters were congruent with the relative sizes of real life objects, yielded a RH advantage (Hatta, 1983). Hatta suggested that in this task subjects used imagery in the semantic judgment. The use of Kanji and Kana imagery may also account for some of the results in Experiment 4, but we have no direct evidence on this point. In Experiment 3, when the picture was presented for a short period, some subjects might not have enough time to generate a useful image, and so phonological processing dominated overall.

The overall results from the experiments above revealed that in a semantic task Kanji characters can be processed better in the RH than in the LH while Kana characters can be processed better in the LH than in the RH. Hatta (1981a) had concluded that higher levels of linguistic processing such as semantic decision require LH function. However, the semantic tasks used by Hatta (and others) were a semantic categorization task and a semantic congruency task, which require more abstract processing and a step beyond the comprehension of word meaning. The semantic task used in this study is a concrete semantic task which requires matching the meaning of a picture with a word. The pattern of results showed that the LH can be better for this task in Kana whereas the RH can be better in Kanji.

Another difference between the previous studies and this study is that this study only used highly concrete, highly familiar, and highly hieroglyphic characters, whereas Hatta (1981a) and Hayashi and Hatta (1982) used abstract characters as well as concrete characters. Therefore, the stimuli used in this study might be more favorable to the RH. If we used more abstract characters, the results might be different. However, concreteness alone cannot explain the RH advantage of Kanji because the same concrete words written in Kana showed the LH advantage. Therefore, some other aspect of Kanji, such as visual complexity, pictorialness, familiarity and the level of mapping from print to sound, must favor the RH.

Visual complexity does not account for the different hemispheric advantages between Kanji and Kana in the current study, although this might have been expected from Sergent's (1982) hypothesis. An analysis of the Kanji characters including those used here showed no correlation between visual complexity and the extent of visual field preference (Aoki, 1990). Further evidence comes from two studies with German subjects, who were not familiar with Japanese written language, in which physical matching of Kanji and Kana characters were required (Bussing et al., 1987; Hartje et al., 1986). Again, there was no interaction between visual complexity of the two types of character and visual field. Thus, any difference in visual complexity between the two types of character does not introduce hemispheric asymmetries in a purely perceptual task.

Osaka (1992) recently found two spatial-frequency channels tuned for detecting single Kanji and Kana: 2 c/c for Kana and 4-6 c/c for Kanji (50 % recognition threshold). He suggested that a higher spatial-frequency component was an important determinant of global detection of Kanji in the parafovea. His results suggest that Kana is more robust for blurring than Kanji. Osaka's results make sense, because Kanji characters have finer details (with more high spatial frequencies) than do Kana characters, at least on average. This suggests an effect of character complexity on recognition performance. Indeed, Aoki (1990) shows that the more complex the character, the slower the reaction time ($r = 0.372$, $p < .05$). However, this effect was the same in both hemispheres. There was no interaction between character complexity and visual field. Therefore it is highly unlikely that spatial-frequency effects can account for our results.

Familiarity might be an important factor for the laterality effect obtained with Kana. The Kana words used in this study and some of the previous studies (e.g. Hatta, 1978, 1981b; Jones & Aoki, 1988) were visually unfamiliar to Japanese adult readers since the Kana words were transcribed from Kanji words (see Introduction). Reading visually unfamiliar or lower-frequency words must be mediated by phonological processing (e.g. Besner & Hildebrandt, 1987; Waters & Seidenberg, 1985). Besner and Hildebrandt (1987) found that familiar Kana words (i.e., Katakana words) were named faster than unfamiliar Kana words (i.e., Kana transcriptions from Kanji words), which, they argued, means that lexical access to familiar Kana words may be achieved without phonological mediation. Hirose (1984) also found in a semantic categorical task that response time to categorize high-frequency Kana was faster than that to categorize low-frequency Kana, but was not different from the time to categorize Kanji (assuming high-frequency Kanji). This suggests that high-frequency Kana and Kanji are processed in similar ways. If pre-lexical phonology is not necessary for familiar Kana words, use of these words may result in a RH advantage.

In order to test this hypothesis (lexical access to Kana without phonological mediation), one could use Katakana characters (square scripts) which are normally used for loan words, such as television or radio, or visually familiar Hiragana words (cursive scripts used in the current study). If familiarity alone favors the RH, then Katakana or Hiragana familiar words in a picture-word matching task would yield a RH advantage. However, if some other factors than familiarity are responsible for the results, then both Katakana and Hiragana words should yield a LH advantage.

Whatever the final outcome of the Kana studies, the current work (and Jones and Aoki, 1988) shows strong evidence for a RH advantage for Kanji in a semantic (picture-word) task. This depends on prior activation by the picture, although the pictures we used were not themselves lateralized (Exp. 5). The location of the picture presented prior to the character plays an important role in the picture-word matching task.

Chiarello et al. (1990) showed a similar effect in their priming experiments. They found that priming for unassociated words in the same semantic category (prime: Deer; target: Pony) was strong in the RH but weak or absent in the LH, when both primes and targets were presented to the same hemisphere. Interestingly, priming between associated different-category words (Bee-Honey) did not occur in either hemisphere. These results, which held true for both lexical decision and naming tasks, strongly suggest that the RH has semantic categorical knowledge.

The pattern of their results for centralized primes and lateralized targets was quite different; there was little visual field effect, and priming occurred for both unassociated same-category and associated different-category words. Our results, showing stronger effects for lateralized than central presentations of the picture, are in agreement with this pattern.

We conclude that the RH may have some semantic capacity and showed this in our Experiments at least for understanding concrete highly hieroglyphic Kanji. The alternative, classic, view is that the LH processes all semantic information. If this were so, the RH advantage we found for Kanji would have to be a consequence of that hemisphere's superior visual abilities. However, we have found no evidence that the RH is in fact superior than the LH for recognizing pictures of about the same visual extent and at the same eccentricity. More critically, the simplest Kanji still show RH superiority, and as they are not much different from the more complex Kana, which themselves show LH superiority, it is not possible to account for the cross-over interaction on the basis of complexity alone. We, therefore, conclude that semantic knowledge in the RH may be demonstrated in picture-word matching, as well as in priming experiments.

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Table 1

Mean reaction times of correct responses in Exp. 1-4

	Exp.1: Lateralized picture (150 msec)		Exp.3: Centered picture (150 msec)	
	RVF	LVF	RVF	LVF
Kanji	831 (154)	811 (143)	879 (179)	877 (202)
Kana	841 (194)	894 (188)	861 (144)	906 (180)

	Exp.2: Lateralized picture (500 msec)		Exp.4: Centered picture (1 sec)	
	RVF	LVF	RVF	LVF
Kanji	863 (142)	827 (156)	897 (283)	863 (242)
Kana	908 (157)	940 (154)	886 (136)	883 (140)

Figure Captions

Figure 1. (a) Mean stimulus durations to reach 75 % correctness for Kanji and Kana in the RVF and LVF. Jones and Aoki's (1988) data were replotted after adding new data. (b) Mean reaction times for Kanji and Kana in the RVF and LVF when stimulus durations were varied to reach 75 % correctness. The data previously not published in Jones and Aoki's(1988) study was plotted.

Figure 2. Mean reaction times for Kanji and Kana in the RVF and LVF in Exp. 1 - 4. (a) Lateralized picture presentation for 150 msec in Exp.1 (p <.05). (b) Lateralized picture presentation for 500 msec in Exp.2 (p <.05). (c) Centered picture presentation for 150 msec in Exp.3 (p <.05). (d) Centered picture presentations for 1 sec in Exp.4 (p <.05).

Figure 3. Error rates for Kanji and Kana in Exp 1 - 4. (a) Lateralized picture presentation for 150 msec in Exp.1 (p >.05). (b) Lateralized picture presentation for 500 msec in Exp.2 (p >.05). (c) Centered picture presentation for 150 msec in Exp.3 (p >.05). (d) Centered picture presentation for 1 sec in Exp. 4 (p >.05).

Figure 4. Scattergrams of visual field effects for Kanji and Kana, taken across subjects. The visual field advantages are calculated by subtracting a mean reaction time in the LVF from that in RVF for each subject. Positive numbers indicate LVF-RH advantages while negative numbers indicate RVF-LH advantages. (a) Lateralized picture presentation (Exp.1 & 2). (b) Centered picture presentation (Exp.3 & 4).

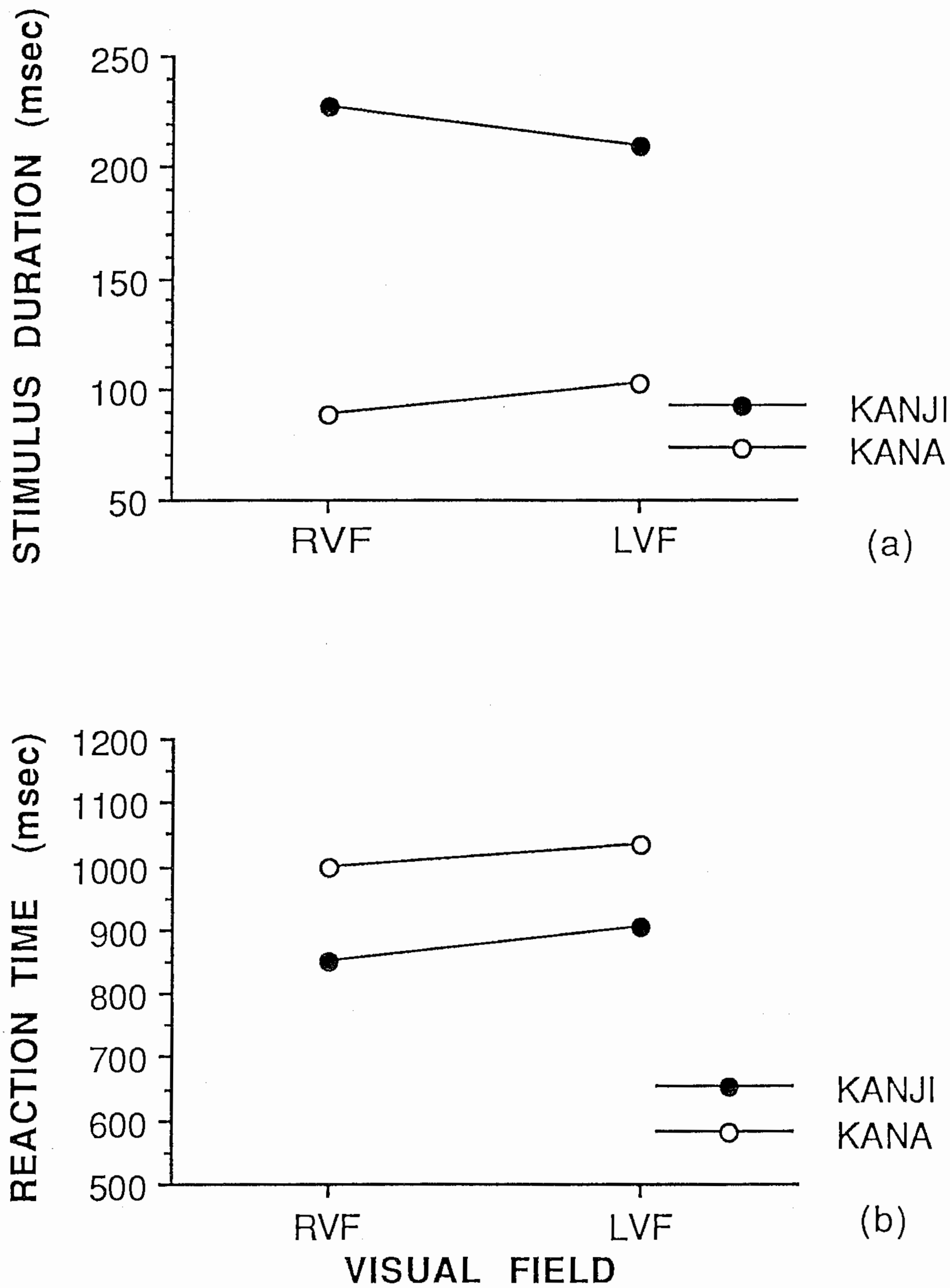

STIMULUS DURATION (msec)
250
200
150
100
50
RVF
LVF
KANJI
KANA
(a)
REACTION TIME (msec)
1200
1100
1000
900
800
700
600
500
RVF
LVF
KANJI
KANA
(b)
VISUAL FIELD

Figure 1

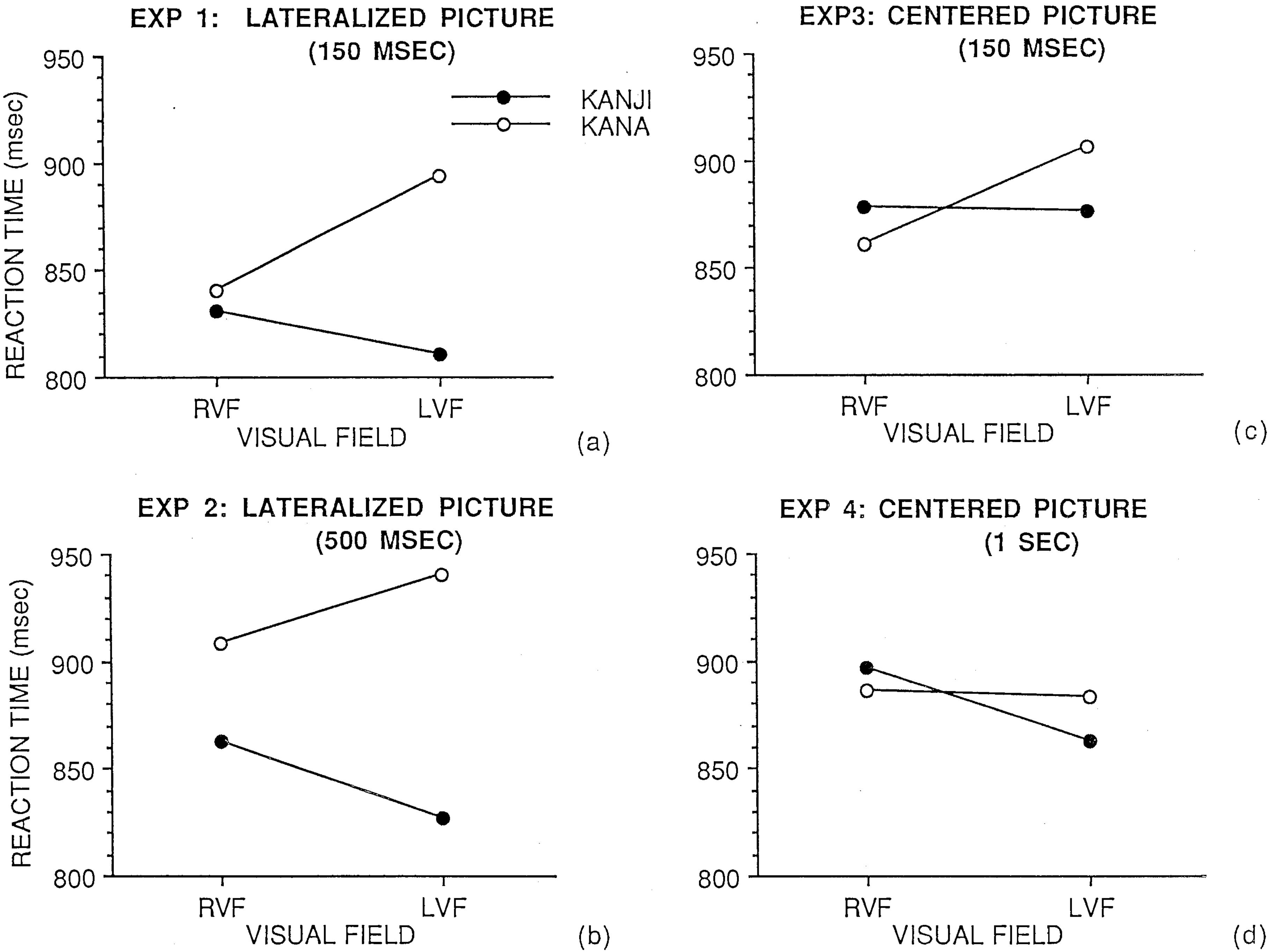
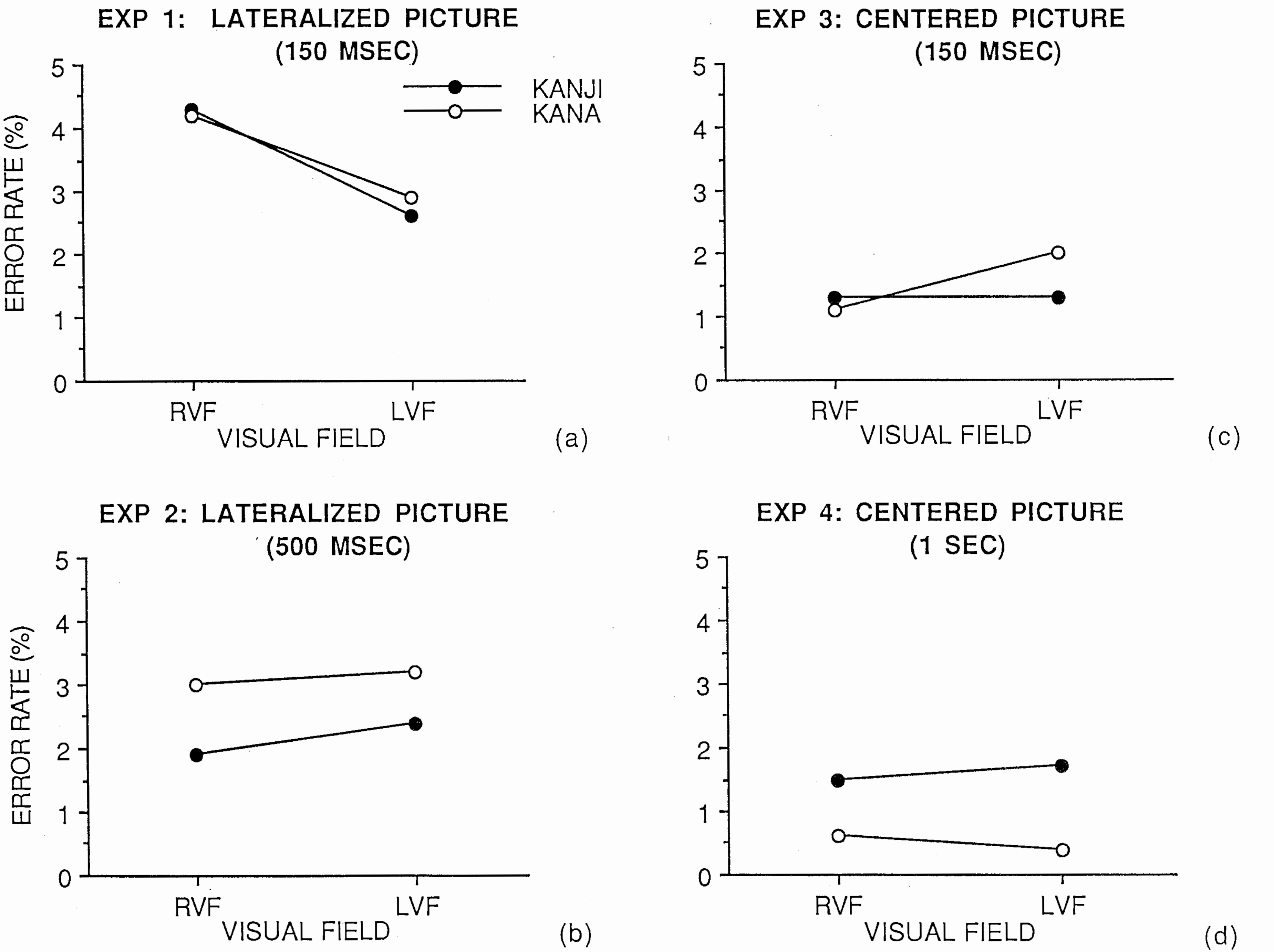
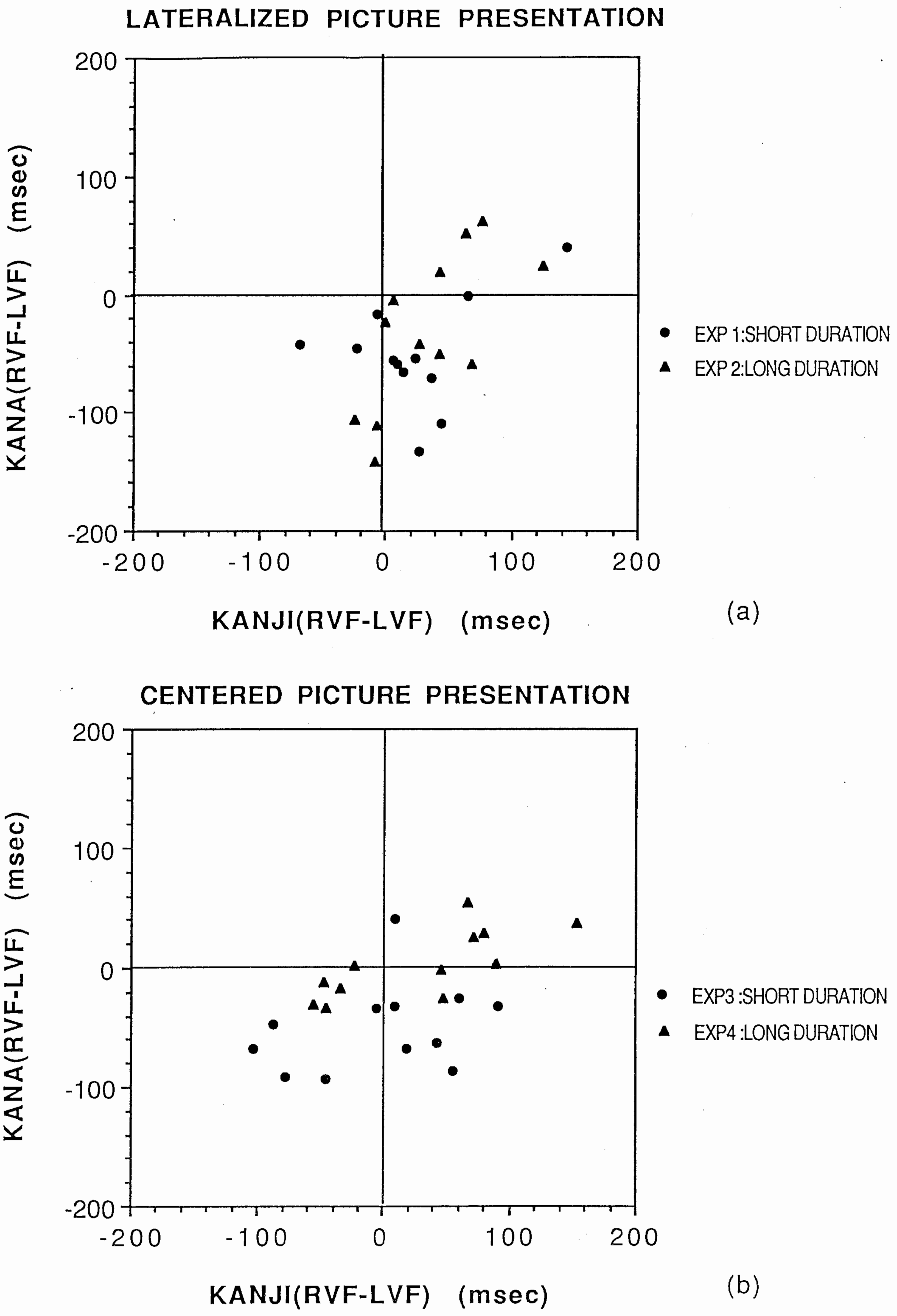

EXP 1: LATERALIZED PICTURE (150 MSEC)
KANJI
KANA
REACTION TIME (msec)
950
900
850
800
RVF
LVF
VISUAL FIELD
(a)
EXP3: CENTERED PICTURE (150 MSEC)
950
900
850
800
RVF
LVF
VISUAL FIELD
(c)
EXP 2: LATERALIZED PICTURE (500 MSEC)
REACTION TIME (msec)
950
900
850
800
RVF
LVF
VISUAL FIELD
(b)
EXP 4: CENTERED PICTURE (1 SEC)
950
900
850
800
RVF
LVF
VISUAL FIELD
(d)

Figure 2



EXP 1: LATERALIZED PICTURE
(150 MSEC)
KANJI
KANA
ERROR RATE (%)
0
1
2
3
4
5
RVF
LVF
VISUAL FIELD
(a)
EXP 3: CENTERED PICTURE
(150 MSEC)
(c)
EXP 2: LATERALIZED PICTURE
(500 MSEC)
(b)
EXP 4: CENTERED PICTURE
(1 SEC)
(d)

Figure 3



LATERALIZED PICTURE PRESENTATION
200
100
0
-100
-200
KANA(RVF-LVF) (msec)
-200
-100
0
100
200
KANJI(RVF-LVF) (msec)
EXP 1:SHORT DURATION
EXP 2:LONG DURATION
(a)
CENTERED PICTURE PRESENTATION
200
100
0
-100
-200
KANA(RVF-LVF) (msec)
-200
-100
0
100
200
KANJI(RVF-LVF) (msec)
EXP3 :SHORT DURATION
EXP4 :LONG DURATION
(b)

Figure 4