Implicit and explicit processing of kanji and kana words and non-words studied with fMRI

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Using functional magnetic resonance imaging (fMRI), we investigated the implicit language processing of kanji and kana words (i.e., hiragana transcriptions of normally written kanji words) and non-words. Twelve right-handed native Japanese speakers performed size judgments for character stimuli (implicit language task for linguistic stimuli), size judgments for scrambled-character stimuli (implicit language task for non-linguistic stimuli), and lexical decisions (explicit language task). The size judgments for scrambled-kanji stimuli and scrambled-kana stimuli produced activations on the bilateral lingual gyri (BA 18), the bilateral occipitotemporal regions (BA 19/37), and the bilateral superior and inferior parietal cortices (BA 7/40). Interestingly, besides these areas, activations of the left inferior frontal region (Broca's area, BA 44/45) and the left posterior inferior temporal cortex (PITC, BA 37), which have been considered as language areas, were additionally activated during size judgment for kanji character stimuli. Size judgment for kana character stimuli also activated Broca's area, the left PITC, and the left supramarginal gyrus (SMG, BA 40). The activations of these language areas were replicated in the lexical decisions for both kanji and kana. These findings suggest that language processing of both kanji and kana scripts is obligatory to literate Japanese subjects. Moreover, comparison between the scrambled kanji and the scrambled kana showed no activation in the language areas, while greater activation in the bilateral fusiform gyri (left-side predominant) was found in kanji vs. kana comparison during the size judgment and the lexical decision. Kana minus kanji activated the left SMG during the size judgment, and Broca's area and the left middle/superior temporal junction during the lexical decision. These results probably reflect that in implicit or explicit reading of kanji words and kana words (i.e., hiragana transcriptions of kanji words), although using largely overlapping cortical regions, there are still some differences. Kanji reading may involve more heavily visual orthographic retrieval and lexical–semantic system through the ventral route, while kana transcriptions of kanji words require phonological recoding to gain semantic access through the dorsal route.
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Introduction

Some psycholinguistic studies have reported that the presence of words in the visual field automatically activates phonological and semantic access even when the subjects are not required to perform these processes explicitly (Coltheart et al., 1994; MacLeod, 1991; Van Orden et al., 1988). Direct neuroimaging evidence for this phenomenon was shown by Price et al. (1996). Using PET, they demonstrated that the visual detection of the occurrence of specific letters of visually presented words and pseudowords activated a widespread neural network including left frontal, parietal, and temporal areas considered as classical language areas. This obligatory processing of language stimuli is called the implicit processing of language. However, the reported reaction time (RT about 550 ms) of their study was significantly shorter than the exposure duration of stimuli to the subjects (1000 ms), allowing "undesigned" time (after the response and before the removal of the stimulus) during which subjects could deliberately read the words. Thus, it may have been that the "automatic" activation of language areas in their study was not entirely a consequence of obligatory or implicit word processing.

With regard to neurolinguistic studies of Japanese language, the outstanding and still controversial question is whether Japanese native speakers use common cortical networks for reading kana (syllabograms or phonograms) and kanji (morphograms). It is well known that a kanji character is a morphogram with multiple phonetic values attached to it. When Japanese subjects read two or

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three character compound kanji words, they have to recognize these compound words as a unit for correct reading. In contrast, a kana character is a syllabogram with a single and invariant phonetic value. With the very different characteristics of kanji and kana scripts, and from systematic research on lesion patients who demonstrated some dissociation between kanji and kana, Japanese psycholinguistic researchers have inferred that these two scripts could be processed in different mechanisms involved in different inter- and intrahemispheric routes (Benson, 1985; Friedman et al., 1993; Iwata, 1984; Sasanuma, 1974, 1975, 1987; Yamadori, 1975). The dual coding model has been proposed to explain the mechanism of kanji and kana processing (Sasanuma and Fujimura, 1971; Yamadori, 2000). Kanji accesses the semantic system first, before invoking phonological aspects. Kana, on the other hand, accesses the phonological system first. However, an alternative viewpoint states that kanji phonology can be accessed directly from kanji orthography without first recourse to semantics (Sakuma et al., 1998; Sasanuma et al., 1992; Wydell et al., 1993) and kana can also have orthographic representations just like kanji, hence kana phonology can be addressed rather than assembled (through character-to-sound translation) (Besner and Hildebrandt, 1987; Yamada et al., 1990). Anatomically, the two routes implied are as follows. The ventral route, involving the inferior occipital, fusiform, and posterior inferior temporal gyri, is essential for orthographic and semantic processing of kanji (Iwata, 1984; Sakurai et al., 2000), and the more dorsal route of visual information through the temporoparietal areas has been suggested to play a role in character-to-sound conversion of reading kana words, which were transcribed from conventional kanji words (Iwata, 1984; Law et al., 1991; Sakurai et al., 2000). However, by studying a large group of Japanese aphasics, Sugishita et al. (1992) demonstrated that the kanji–kana dissociation in oral reading varied among patients so much that correlation of functional disturbance with damage to definite neuroanatomical structures has proven difficult to demonstrate. Among these contradictory views, the important role of the left posterior inferior temporal cortex (PITC) in kanji orthographic and semantic processing has been shown relatively frequently through lesion and neuroimaging studies (Iwata, 1984; Kawamura et al., 1987; Nakamura et al., 2000; Sakurai et al., 1992). Kana reading, by contrast, has been claimed to involve different areas. For instance, Iwata (1984) reported that the dorsal pathway involving the angular gyrus (AG) and Wernicke area is essential for kana processing. From PET studies, kana was reported to activate the inferior parietal areas such as the supramarginal gyrus (SMG) and angular gyrus (AG) stronger than kanji (Law et al., 1991; Sakurai et al., 2000), and kana words activated the left PITC more strongly than kana non-words (Sakurai et al., 1993).

Although several neuroimaging studies have been conducted to identify the neural activity related to explicit phonological and lexical–semantic processing of kanji and kana scripts, there has been no imaging evidence about their implicit processing.

The present study can be summarized as follows. We attempted to demonstrate implicit activation of language areas involving kanji and kana scripts by using functional magnetic resonance imaging (fMRI) in normal native Japanese, including a size judgment task for character stimuli as the implicit language task for linguistic stimuli. We also used a size judgment task for pseudocharacter stimuli as the implicit language task for non-linguistic stimuli and a lexical decision task as the explicit language task. To avoid "undesigned" time, we used a 500-ms stimulus exposure.

We employed a 3 × 2 factorial design for the fMRI experiment in which the effects of script type (kanji vs. kana) in one task and between tasks (lexical decision vs. size judgment) could be analyzed to determine whether the reading processes of kanji and kana scripts recruited the same cortical networks. Because the different spatial complexities of kanji and kana scripts may differentially affect their processing, we created scrambled-character stimuli from the original character stimuli and employed these to control for the effect of general visual properties of kanji and kana scripts on brain activation, using them as the non-linguistic stimuli in the size judgment task.

Materials and methods

Subjects

Twelve healthy university student volunteers (age range 22–30 years, eight males and four females) were recruited from Kyoto. All were native Japanese speakers with no history of neurological or psychiatric disorders. Handedness of the subjects was tested by the handedness inventory for Japanese people from the Neuropsychology of left-handedness book (in Japanese) (Hatta, 1996), and all of them were classified as right-handed (mean handedness score = 9.5 ± 0.9). The subjects were fully instructed on the details of the experiment and informed written consents were obtained from all of them in accordance with the guidelines approved by the institutional review board.

Stimuli

Stimuli were two kanji characters (task 1) and two hiragana characters (task 2) (Fig. 1). Half of the stimuli represented words and the other half non-words. In each stimulus, the size of one character was 25% bigger. The right character was bigger than the left one in one-half of the stimuli, and the left one was bigger in the other half. Kanji characters were selected from the vocabulary of the Japanese language teaching workbook (1992). Each kanji character consisted of 5–10 strokes. Kana words were prepared by transcribing words that are normally written in kanji, composing of two kana characters. None of the kana words had any homophones among the stimuli. Scrambled-character stimuli, created from the original characters by using Adobe Photoshop® (Adobe System Inc. San Jose, CA, USA), had the same luminance and contrast as the original ones (Fig. 1A). Due to the variety of shape of kana scripts, which contain mainly curved lines, not straight lines as with kanji characters, in creation of the scrambled characters we could not avoid the problem that in some scrambled-kana stimuli, the sizes of two characters were almost the same (Fig. 1B). To avoid priming effects, all items presented to each subject within scanning sessions were novel, and none of them was used in the training sessions.

A Macintosh® computer (Apple Computer Inc., Cupertino, CA, USA) running SuperLab® software (Cedrus, Phoenix, AZ, USA) controlled the presentation of the stimuli to the subjects with a rate of one per second (0.5-s exposure time and 0.5-s intervals) and measured the reaction times and accuracy of task responses. Two response keys, which were connected to the above-described Macintosh computer through optic fibers, were placed under the index and middle fingers of the subjects' left hand.
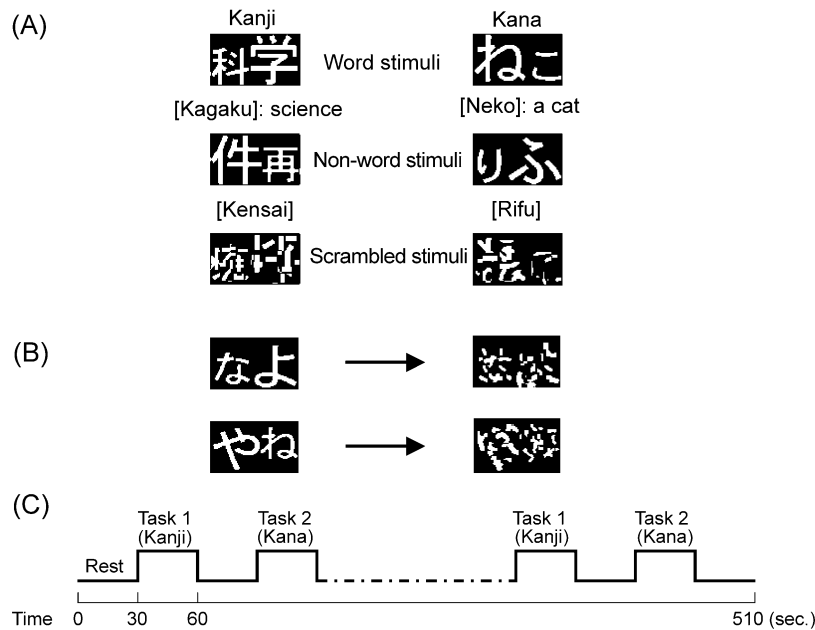
Fig. 1. Examples of stimuli and experimental block design used in the present study. (A) Examples of stimulus materials used in the present fMRI study. (B) Due to the shape of kana scripts, in some scrambled-kana stimuli, two characters had nearly the same sizes. (C) Experimental block design. Numbers indicate the time course in seconds after the beginning of functional imaging. Each block lasted 30 s. Rest (0), task 1 (kanji), and task 2 (kana) were alternately repeated (01020102010201020 for six subjects and 02010201020102010 for the other six). Each item was shown for 500 ms with a 500-ms interstimulus interval.

Experimental design

Each subject participated in three experiments. Each experiment consisted of one fMRI scanning run with three conditions: two activation conditions; task 1 (kanji), task 2 (kana), and a baseline rest condition (Fig. 1C). During the rest condition, the subjects were instructed to relax and fix their eyes on a closed circle presented in the center of the screen. Each subject underwent three consecutive fMRI runs on the same day, with a time interval between each run of 2 min.

Experiment one—implicit experiment: size judgment for character stimuli (implicit language task for linguistic stimuli)

The subjects were asked to judge on which side the presented character was bigger and to respond by pressing the key under the index finger if the right character was bigger and the key under the middle finger if the left character was bigger.

Experiment two—scrambled experiment: size judgment for scrambled-character stimuli (Implicit language task for non-linguistic stimuli)

Experimental details were the same as Experiment one, except that scrambled characters were used as stimuli.

Experiment three—explicit experiment: lexical decision (explicit language task)

The subjects were asked to pay attention to the meaning of the presented stimulus, read it silently, decide whether two different size characters of the presented stimulus formed a word or a non-word, and to press the key under the index finger if it was a word and the key under the middle finger if it was a non-word.

In each experiment, subjects were asked to response as quickly and correctly as possible following the presentation of a target stimulus.

There were two sets of word stimuli. Half of the subjects performed set one for the size judgments and set two for the lexical decision, while for the other half, the word sets were exchanged. The order of the three fMRI runs was counterbalanced across the subjects.

fMRI procedure

After three training sessions, the subjects lay supine in the MRI scanner. Head motion was minimized by using foam padding. The fMRI scanning was performed with a 3-T MR scanner (3.0-T Signa VH/i, General Electric, Milwaukee, MI, USA). Anatomical images of each subject, T2-weighted images (echo time (TE) = 85 ms, repetition time (TR) = 5000 ms, field of view (FOV) 220 × 220 mm, thirty 4-mm thick axial slices without gap), and T1-weighted 3D images (inversion time = 400 ms, flip angle (FA) = 15°, FOV 220 × 220 mm, 256 × 256 matrixes, sixty 2-mm thick axial slices) were obtained before the functional measurements. For functional imaging, we used a single-shot, gradient echo planar imaging (EPI) sequence with the following parameters: TR = 5000 ms, TE = 30 ms, FA = 90°, FOV 220 × 220 mm, 64 × 64 matrix. Thirty 3-mm thick axial slices with 1-mm gaps were obtained for

Table 1
Behavioral data

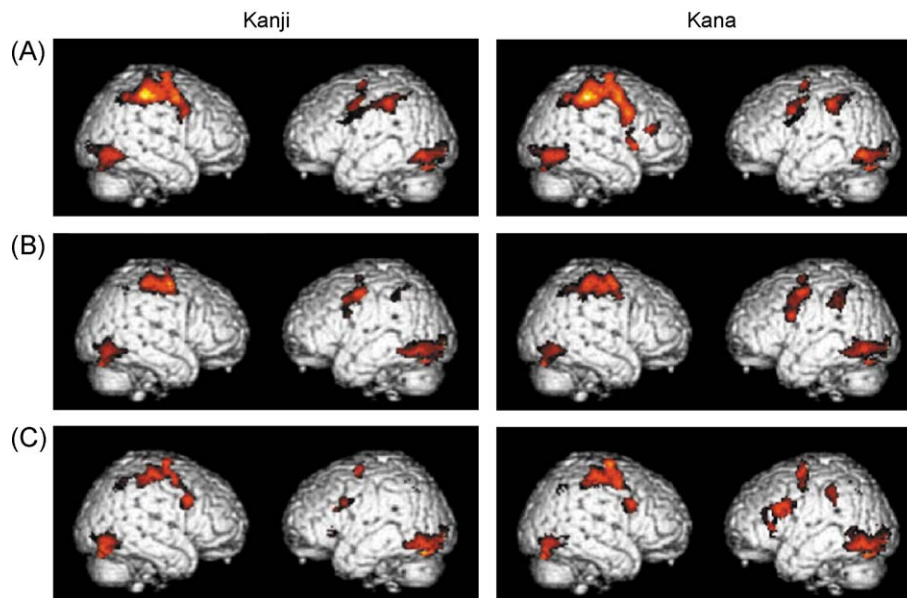|	Accuracy (percent correct)		Reaction time (ms)	
	Mean	SD	Mean	SD
Kanji implicit	98.7	1	506	30
Kana implicit	98.1	1.4	511	24
Kanji scrambled	98.3	2.9	493	20
Kana scrambled	97.6	1.9	529	18
Kanji explicit	89.2	6.1	646	23
Kana explicit	88.5	5.7	649	31

Fig. 2. Brain areas activated in each task for the three experiments, rendered onto a standard 3D anatomical template. The figures are generated by random effects analysis at a threshold of $P < 0.005$, uncorrected. (A) Scrambled experiment, (B) implicit experiment, (C) explicit experiment.

each subject. In each functional run of 530-s duration, 102 images were acquired (the initial 20 s of data was discarded to ensure a stable equilibrium magnetization). Beginning and ending with a rest block, each run comprised a sequence of nine rest blocks alternating with four kanji blocks and four kana blocks. Kanji blocks and kana blocks were alternately repeated (Fig. 1C). Each of the 17 blocks lasted 30 s.

Data analysis

The functional imaging data were analyzed using SPM99 (Wellcome Department of Cognitive Neurology, UCL, London, UK) implemented in Matlab (Mathworks Inc., Sherborn, MA, USA). All images from each subject were realigned using the first image as a reference to correct for head movements, normalized to the standard brain space defined by the Montreal Neurological Institute (MNI) (Friston et al., 1995a) and spatially smoothed in three dimensions with an isotropic 8-mm full width at half-maximum Gaussian kernel to account for individual variation in gyral anatomy and to improve the signal-to-noise ratio. Specific effects were investigated using appropriate contrasts to create statistical parametric maps of t statistics based on the general linear model (Friston et al., 1995b).

A random-effects model was applied to detect the brain areas commonly activated among 12 subjects (Friston et al., 1999). The fMRI time series of the three experiments for each subject were put together into a blocked-design session. The data were then correlated initially with a box-car reference function to which a

Table 2
Brain regions activated during size judgments for scrambled-character stimuli

Location (BA)	Scrambled kanji				Scrambled kana			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
Rt primary sensory motor cortex (3/4)	+47	−30	+51	5.89	+42	−28	+48	5.23
Rt medial frontal gyrus (6)	+6	−1	+52	3.35				
Lt medial frontal gyrus					−2	+6	+48	4.08
Rt middle frontal gyrus (6)					+28	−5	+54	4.98
Lt middle frontal gyrus	−24	−3	+52	3.55	−22	−3	+50	3.99
Rt dorsolateral prefrontal cortex (46)					+48	+38	+18	3.47
Rt superior parietal lobule (7)	+34	−55	+48	4.43	+34	−57	+50	5.03
Lt superior parietal lobule	−24	−56	+51	3.83	−26	−54	+51	4.29
Rt inferior parietal lobule (40)	+61	−32	+26	3.21	+61	−34	+24	3.24
Lt inferior parietal lobule	−46	−31	+37	4.17	−30	−41	+41	3.72
Rt occipitotemporal junction (19/37)	+50	−64	−5	4.41	+50	−65	−5	4.17
Lt occipitotemporal junction	−40	−62	−5	4.72	−44	−64	−2	5.15
Rt posterior lingual gyrus (18)	+27	−87	+1	4.56	+22	−87	+3	4.04
Lt posterior lingual gyrus	−26	−88	−2	4.7				
Bilateral medial occipital areas and cerebellum	−10	−63	−12	4.77	−10	−63	−11	4.87
Bilateral basal ganglia/thalamus	−12	0	+15	3.53	+12	−17	+10	3.55

BA = Brodmann area; Lt = left; Rt = right. The Talairach coordinates are presented in millimeters.

Table 3
Brain regions activated during size judgments for character stimuli

Location (BA)	Kanji				Kana			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
Rt primary sensory motor cortex (3/4)	+34	−19	+49	4.85	+34	−21	+47	4.17
Rt medial frontal gyrus (6)	+11	−3	+57	4.48	+10	−3	+55	4.31
Lt medial frontal gyrus	−4	+4	+50	3.27	−4	+4	+51	3.61
Rt middle frontal gyrus (6)	+34	−3	+54	6.13	+30	−3	+53	5.45
Lt middle frontal gyrus (9)	−46	+10	+38	4.03	−50	+8	+38	4.06
Lt inferior frontal gyrus (44)	−55	+7	+24	4.12	−55	+9	+23	4.26
Rt superior parietal lobule (7)	+24	−55	+54	3.94	+24	−54	+54	3.40
Lt superior parietal lobule	−20	−62	+46	4.00	−22	−62	+44	3.94
Rt inferior parietal lobule (40)	+28	−48	+48	3.31	+30	−50	+47	3.49
Lt inferior parietal lobule	−20	−48	+45	3.96	−32	−39	+39	4.05
Lt inferior temporal gyrus (37)	−42	−60	−9	4.6	−44	−60	−7	4.47
Rt middle occipital gyrus (19)	+42	−71	−5	4.55				
Lt middle occipital gyrus	−30	−69	−4	4.75	−40	−68	−4	4.66
Lt inferior occipital gyrus (18)					−38	−76	−1	4.55
Bilateral medial occipital areas and cerebellum	−10	−63	−12	5.18	−10	−61	−11	5.48
Right basal ganglia/thalamus	+22	+4	+7	4.82	+24	−4	+6	3.83

high pass filter (0.5 cycles/min) and temporal smoothing were applied to remove low frequency noise or drift of MRI signal and to increase the signal-to-noise ratio. To test the hypothesis regarding regionally specific condition effects, comparisons were made: kanji vs. fixation, kana vs. fixation, kanji vs. fixation contrasted with kana vs. fixation (simply called kanji vs. kana), and kana vs. kanji. The comparisons between tasks were also examined: explicit vs. scrambled tasks, implicit vs. scrambled tasks, explicit vs. implicit tasks. A height threshold of $P < 0.05$ at voxel level, corrected for multiple comparisons, was used for these contrasts. These condition-specific mean images were subject to a group-based statistics using one sample t test. The threshold of $P < 0.001$ ($Z > 3.09$) uncorrected for multiple comparison was used to determine the presence of significant activation foci. Activated brain structures were identified by transforming MNI coordinate into the standard brain atlas of Talairach and Tournoux (Evans et al., 1994; Talairach and Tournoux, 1988).

Reaction times (RTs) and response accuracy of all tasks in the three experiments were analyzed by two-way analysis of variance.

Results

Behavioral data

Reaction times (RTs) and response accuracy (mean ± standard deviation: SD) for the three experiments are shown in Table 1. Accuracy of all tasks exceeded 85%. For RT, there was a main effect of task. The RTs for the explicit tasks with both kanji and

Table 4
Brain regions activated during lexical decisions

Location (BA)	Kanji				Kana			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
Rt primary sensory motor cortex (3/4)	+36	−21	+53	4.31	+36	−23	+52	4.60
Rt medial frontal gyrus (6)	+20	+5	+53	3.49	+14	−3	+64	4.25
Lt medial frontal gyrus	−2	+4	+48	4.4	−2	+4	+50	4.16
Rt middle frontal gyrus (6)	+42	+5	+53	3.49	+40	+4	+48	3.53
Lt middle frontal gyrus					−26	−3	+55	3.62
Rt dorsolateral prefrontal cortex (46)	+46	+34	+20	3.77	+47	+36	+24	3.49
Lt dorsolateral prefrontal cortex (46)					−44	+34	+17	3.51
Lt inferior frontal gyrus (44/45)	−36	+16	+21	3.9	−36	+17	+19	5.08
Rt superior parietal lobule (7)	+26	−53	+52	3.42	+34	−52	+46	3.82
Lt superior parietal lobule	−30	−54	+49	3.23	−24	−62	+42	3.82
Rt inferior parietal lobule (40)	+34	−48	+45	3.82				
Lt inferior parietal lobule	−22	−54	+45	3.83	−46	−38	+33	3.67
Lt posterior middle temporal gyrus (21)					−49	−53	+8	3.27
Lt inferior temporal gyrus (37)	−38	−59	−10	4.92	−40	−62	−7	5.58
Lt middle occipital gyrus	−38	−68	−8	5.89	−36	−74	−7	4.72
Rt posterior lingual gyrus	+18	−87	+3	3.86	+20	−87	+3	3.49
Bilateral medial occipital areas and cerebellum	−10	−65	−10	4.93	+20	−77	−13	5.11
Lt basal ganglia/thalamus	−28	+10	+5	3.61	−28	+18	+8	3.78

kana were significantly longer than RTs of their corresponding implicit and scrambled tasks (explicit vs. implicit $F(1, 46) = 317.7$, $P < 0.0001$, explicit vs. scrambled $F(1,46) = 329.1$, $P < 0.0001$). The RTs for the implicit and scrambled tasks were not significantly different. In terms of script effects, RTs for kanji and kana were not significantly different in the explicit and implicit experiments. However, RTs of scrambled kana were significantly longer than scrambled kanji ($F(1, 22) = 21.7$, $P < 0.0001$).

fMRI findings

Fig. 2 illustrates the activation sites rendered onto the standard brain for each task of the three experiments. The locations of the activation on the Talairach and Tournoux coordinates are listed in Tables 2–4 for the scrambled, implicit, and explicit experiments, respectively.

The size judgment for scrambled kanji and scrambled kana stimuli using the left finger-press response produced activation in the right primary sensorimotor area, the bilateral supplementary motor and premotor areas, the bilateral superior parietal (Brodmann's area: BA 7) and inferior parietal (BA 40) lobules, bilateral posterior lingual gyri (BA 18), and occipitotemporal regions (BA 19/37) (Fig. 2A). In addition to cortical areas, activation was seen in the cerebellum, thalamus, and the basal ganglia.

The size judgment for kanji character and kana character stimuli yielded similar activation to the scrambled experiment (Fig. 2B). In addition, the left inferior frontal gyrus (BA 44) was also activated. Moreover, in the left occipitotemporal regions, the activation extended anteriorly and laterally to produce another activation focus on the left posterior inferior temporal cortex (PITC, BA 37) as shown in Fig. 3A. The character-specific activation in the left PITC was confirmed through comparison between the implicit and the scrambled experiments (Fig. 3B and Table 5A).

In the lexical decision tasks for kanji and kana, the recruited brain areas were almost the same as the ones recruited by the size judgments for the kanji and kana character stimuli (Fig. 2C). Furthermore, kana lexical decision activated the left posterior middle temporal gyrus (BA 21). In addition to the left PITC, the explicit experiment relative to the scrambled experiments activated the left inferior frontal gyrus (both kanji and kana) and the left middle temporal gyrus (only kana) (Figs. 3A and C; and Table 5B).

We also examined the contrast between task 1 (kanji) and task 2 (kana), named kanji minus kana and kana minus kanji for each experiment. The comparison between the scrambled kanji and the scrambled kana gave no significant activation (Fig. 4A). Kanji

minus kana with size judgment for character stimuli showed activation in the bilateral fusiform gyri (BA 19/37), with the left side dominant (Fig. 4B). We got the same results for kanji vs. kana with lexical decisions (Fig. 4C). The locations of the activation on the Talairach and Tournoux coordinates of these results are listed in Table 6. As shown in Fig. 5, the size judgment for the scrambled-
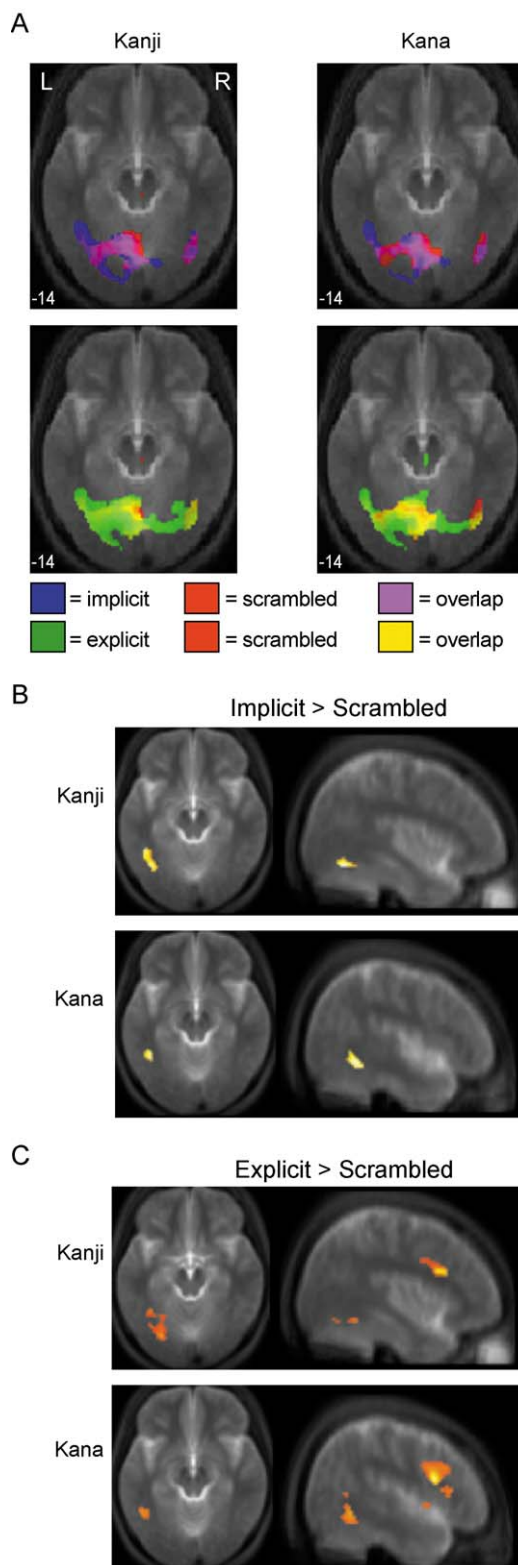

Fig. 3. Activation of the left PITC during implicit and explicit experiments. (A) Activations are projected onto horizontal slices of the mean normalized T2-weighted MRI of 12 subjects. Slices are shown at the level of $z = -14$ mm relative to AC–PC line. Areas presented in red always portray activation for size judgment for scrambled-character stimuli (scrambled experiment). Areas presented in blue portray activation for size judgment for character stimuli (implicit experiment). Areas presented in green portray activation for lexical decision (explicit experiment). Areas shown in purple portray the overlap of activations between the implicit and the scrambled experiments. Areas shown in yellow portray the overlap of activations between the explicit and the scrambled experiments. (B) Comparison between the implicit and the scrambled experiments. The implicit kanji task vs. the scrambled kanji and the implicit kana minus the scrambled kana activated the left PITC. (C) Comparison between the explicit and the scrambled experiments. Besides the left PITC, the explicit vs. the scrambled tasks (both kanji and kana) also activated the left inferior frontal gyrus.

Table 5
Brain regions activated in comparisons between three experiments

Location (BA)	Kanji				Kana			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
A. Implicit experiment vs. scrambled experiment								
Lt inferior temporal gyrus (37)	−38	−62	−10	3.93	−43	−52	−9	3.36
B. Explicit experiment vs. scrambled experiment								
Lt inferior frontal gyrus (44/45)	−40	+16	+21	4.98	−43	+15	+18	4.62
Lt posterior middle temporal gyrus (21)					−52	−48	+6	3.21
Lt inferior temporal gyrus (37)	−38	−49	−11	3.42	−46	−51	−8	3.24

kana stimuli produced more activation in the bilateral superior parietal lobule (BA 7/40) than the scrambled kanji (Fig. 5A). Kana minus kanji with the size judgment for the character stimuli showed activation focus on the left supramarginal gyrus (SMG, BA 40) (Fig. 5B). Kana vs. kanji with the lexical decisions activated the left inferior frontal gyrus (BA 44/45), the left dorsal prefrontal cortex (BA 46), and the left middle/superior temporal junction (BA 21/22) (Fig. 5C). The locations of the activation on the Talairach and Tournoux coordinates of these results are listed in Table 7.

The effects of script types were further demonstrated. The comparison of the size judgment and the lexical decision for kanji character stimuli, relative to the size judgment and the lexical decision for kana character stimuli, identified the different activation between kanji vs. kana scripts (kanji effect activation), irrespective of task. Similarly, comparison of the size judgment and the lexical decision for kana character stimuli, relative to the size judgment and the lexical decision for kanji character stimuli, identified the different activation between kana vs. kanji scripts (kana effect activation). Kanji vs. kana activation was demonstrated in the bilateral fusiform gyri (BA 19/37) (left side
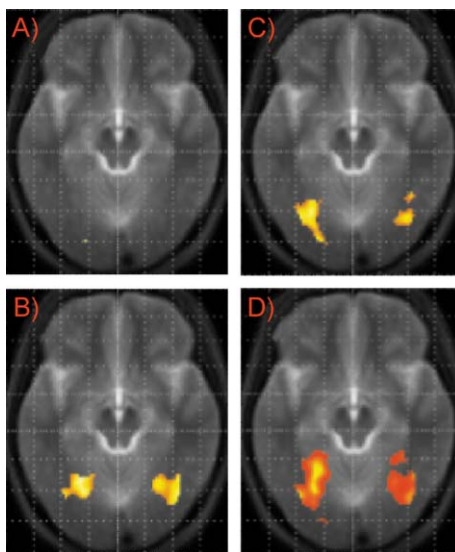

Fig. 4. Kanji minus kana comparison. (A) Scrambled experiment showed no significant activation. (B) Implicit experiment, (C) explicit experiment, (D) implicit experiment plus explicit experiment showed significant activation in the bilateral fusiform gyri.

predominant) (Fig. 4D). Kana script relative to kanji script gave enhanced activation in the left inferior frontal gyrus (BA 44/45), the left SMG (BA 40), and the left middle/superior temporal junction (BA 21/22) (Fig. 5D). The locations of the activation on the Talairach and Tournoux coordinates of these results are listed in Table 8.

Discussion

The present study was conducted to investigate the implicit activation of the language neural network involved in kanji and kana scripts of Japanese language. The most striking finding of this study was that only the use of the character stimuli, not the scrambled-character stimuli, in the size judgments was able to activate the wide cortical networks, covering the left inferior frontal gyrus (Broca's area), the left inferior temporal gyrus (BA 37), the left inferior parietal lobule (BA 40), which have been considered as language areas for Western and Japanese language systems from previous studies (Binder et al., 1997; Damasio, 1989; Kiyosawa et al., 1995; Makabe et al., 1997; Petersen et al., 1988; Sakurai et al., 2000; Wise et al., 1991). We also found that while implicit as well as explicit processing of kanji and kana activated many common areas, there were still different activations between them.

Activation associated with size judgment for scrambled-character stimuli

This study clearly showed activations of the bilateral posterior lingual gyri, the bilateral occipitotemporal, and the bilateral superior and inferior parietal regions when the subjects were performing the size judgments for the scrambled-character stimuli. These findings are consistent with the view that both the dorsal visuospatial pathway of visual information toward the parietal cortex and the ventral object recognition pathway of visual information toward the inferior temporal cortex serve for visual feature detection of objects (Baizer et al., 1991; Goodale and Milner, 1992; Price et al., 1996). We suppose that the activation observed in bilateral superior parietal cortex (SPC) (the right-side predominant) in the subtraction between the scrambled kana and the scrambled kanji is associated with the difficulty in visuospatial analysis. When we made the scrambled-character stimuli from the original character stimuli, in case of kana, two scrambled characters in some stimuli had almost the same sizes (Fig. 1B). The longer reaction times for the scrambled kana

Table 6
Activations in kanji vs. kana comparison

Location (BA)	Implicit experiment				Explicit experiment			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
Lt fusiform gyrus (19/37)	−30	−65	−10	4.25	−26	−67	−10	4.13
Rt fusiform gyrus (19/37)	+40	−71	−10	3.77	+40	−73	−10	3.75

compared with the scrambled kanji support this hypothesis. Furthermore, Carpenter et al. (1999), in their fMRI study, have reported that activation in the bilateral parietal regions increased linearly with the increase of angular disparity. With regard to this observed activation, it was especially prominent in the right hemisphere. Previous fMRI study of our laboratory has shown the crucial role of the right SPC for the spatial transformation in Japanese kana mirror reading (Dong et al., 2000). The right SPC might also play a more essential role in substantial visuospatial transformation, which is required in the size recognition of novel stimuli such as the scrambled characters. Therefore, in size judgments for novel objects, more complex stimuli may be more demanding as regards visuospatial analysis than as regards object recognition. This may explain the increased activity of bilateral SPC, especially the right SPC, in the size judgment for the scrambled kana.

Activation of language network during size judgment for character stimuli

Previous lesion studies on Japanese patients with specific language deficits and previous PET studies of explicit semantic and phonological Japanese processing disclosed the essential role of the left lateral fusiform gyrus and the left PITC in visual kanji reading as well as the important role of the left temporoparietal area (BA40/22) in visual kana processing (Iwata, 1984; Kiyosawa et al., 1995; Law et al., 1991; Sakurai et al., 1992, 1993, 2000; Sasanuma, 1975). The fact that size judgment for the character stimuli, not the scrambled-character stimuli, activated the left PITC, the left SMG, and the left inferior frontal gyrus (BA 44/45) strongly implied that the subjects processed kanji and kana words obligatorily beyond the demand of the size judgment tasks. Moreover, our results that showed the activation of the left inferior frontal gyrus, the left PITC, and the left middle/superior temporal junction in the explicit lexical decision experiment replicates the result of the previous studies and confirms the results of the implicit word processing during the size judgment for the character stimuli.

There has been some evidence from psycholinguistic studies that visual word is obligatorily processed to the extent that it can interfere with the explicit task that a subject is asked to perform (Lupker, 1985; MacLeod, 1991). For example, the subjects named the word RED printed in red color faster than the word RED printed in green color—the Stroop effect, because words are read automatically while color requires considerably more attention to be named. Many "priming" studies have shown that even when subjects are unaware of a visually presented masked word, the orthographic, phonological, and semantic properties of the masked words can be extracted and influence explicit semantic and phonological processing of
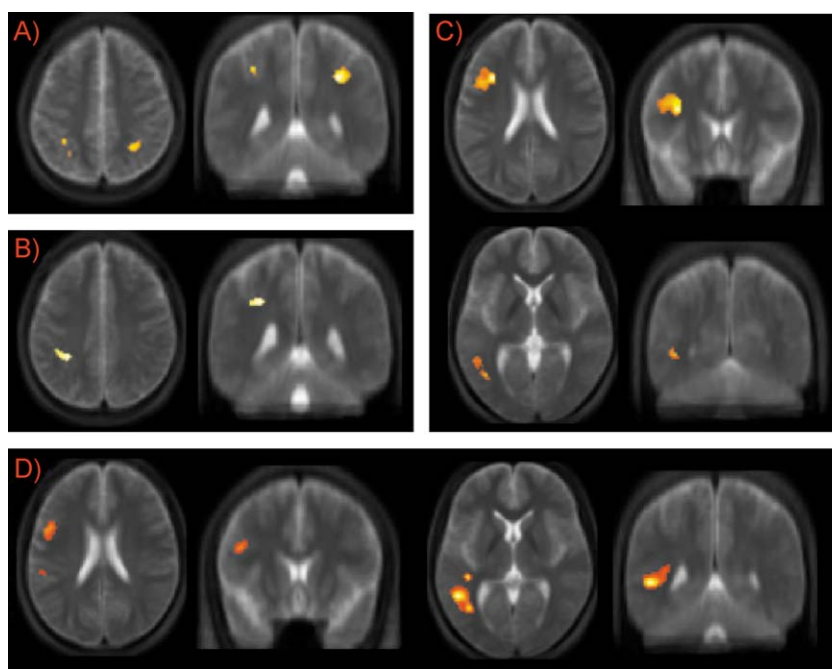

Fig. 5. Kana minus kanji comparison. (A) Scrambled experiment. Significant activation was observed in the bilateral superior parietal lobules. (B) Implicit experiment. The left SMG was activated. (C) Explicit experiment. The left inferior frontal gyrus and the left middle temporal gyrus were activated. (D) Implicit plus explicit experiments showed the activations in the left inferior frontal gyrus, left SMG, and the left middle temporal gyrus were activated.

Table 7
Activations in kana vs. kanji comparison

Location (BA)	Scrambled experiment				Implicit experiment				Explicit experiment			
	Coordinates				Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score	x	y	z	Z score
Lt dorsolateral prefrontal cortex (46)									−41	+25	+26	3.73
Lt inferior frontal gyrus (44/45)									−34	+18	+19	4.37
Rt superior parietal lobule (7/40)	+34	−50	+52	4.05								
Lt superior parietal lobule (7/40)	−32	−48	+45	3.19								
Lt supramarginal gyrus (40)					−30	−44	+37	3.14				
Lt middle/superior temporal junction (21/22)									−50	−48	+6	3.30

subsequently presented words (Bowers et al., 1998; Holender, 1986; Marcel, 1983). The fact that the language neural network was activated during size judgment for kanji as well as kana character stimuli of this study is broadly consistent with these views and agrees more specifically with previous functional imaging study that has reported this phenomenon on alphabetic language (Price et al., 1996). By shortening the exposure time of the stimuli to the subjects, our study also overcame the "undesigned" time in Price's study. The mean reaction time (RT) for character size detection (510 ms) was longer than the 500-ms presentation time of the stimuli. It seems that all of our subjects read the words without awareness, because the 510 ms (SD = 24) RT of the size judgment for the character stimuli was significantly shorter than that of the lexical decisions (640 ms). We suppose that if some of our subjects read the words with awareness while performing the size judgment for character stimuli, the SD would become much larger. Therefore, it is more likely that the observed activation in the language areas of our study was entirely a consequence of obligatory or implicit word processing.

Dissociation of kanji and kana reading

We found that although processing of kanji and kana character stimuli during either the implicit or the explicit experiment recruited largely similar cortical regions, there were remaining differences between them. The neural processing for kanji and kana appears to be different. One possible factor contributing to the discrepancy could be the different visuospatial or configurational complexities of the two types of scripts. The "number of strokes" has been proposed as an index for measuring the complexity of kana scripts (Kabashima and Satake, 1973). All the basic kana scripts are formed with no more than five strokes. For measuring the visuospatial complexity of kanji characters, the number of strokes is also used as the standard index. Because each kanji character

employed in this study ranged from 5 to 10 in its number of strokes, it could be considered graphically more complex than a kana character. The use of the scrambled-character stimuli in this study also helped to evaluate the possible effects of this graphic complexity on processing of general visual properties. The comparison of brain activity in the size judgment tasks for scrambled-kanji stimuli and scrambled-kana stimuli revealed no significant difference. Moreover, there was no significant difference in RT for size judgment between kanji and kana character stimuli. These findings might imply that the different visuospatial complexity of kanji and kana characters (evaluated based on stroke numbers) had no effect on neuronal activities necessary for visual property processes of kanji and kana scripts.

Our results showed that all six tasks of three experiments activated the bilateral occipitotemporal regions. These findings are in accordance with the view that the occipitotemporal regions crucially support the recognition of various kinds of visual object images, including verbal as well as non-verbal ones (Bly and Kosslyn, 1997; Menard et al., 1996; Sergent et al., 1992). Interestingly, in the size judgments for kanji and kana character stimuli, and the lexical decisions, the activation in the left occipitotemporal regions extended anteriorly and laterally to produce another peak activity focus on the left PITC. This finding suggests that the left PITC works as a lexical orthographic retrieval system of the two types of kanji and kana scripts. Our result may conflict with some previous lesion studies reporting selective kanji alexia following the localized damage in the left PITC (Iwata, 1986; Kawamura et al., 1987) and studies suggesting that another area such as the left angular gyrus (Iwata, 1984) or the left posterior occipital region (Sakurai et al., 2000, 2001) is specialized to recognize orthography of kana characters. However, there has been some evidence that the left PITC is crucial for visual processing of letter or word form in both alphabetic and non-

Table 8
Effect of script types on brain activation

Location (BA)	Kanji				Kana			
	Coordinates				Coordinates			
	x	y	z	Z score	x	y	z	Z score
Lt fusiform gyrus (19/37)	−28	−65	−10	4.82				
Rt fusiform gyrus (19/37)	+40	−70	−10	3.92				
Lt inferior frontal gyrus (44/45)					−46	+15	+21	3.46
Lt supramarginal gyrus (40)					−48	−47	+37	3.26
Lt middle/superior temporal junction (21/22)					−50	−48	+6	4.45

Note. Effects of kanji script are qualified by comparison of the size judgment and the lexical decision for kanji character stimuli, relative to the size judgment and the lexical decision for kana character stimuli. Effects of kana script are identified by comparison of the size judgment and the lexical decision for kana character stimuli, relative to the size judgment and the lexical decision for kanji character stimuli.

alphabetic language systems (Cohen et al., 2000; Fujimaki et al., 1999; Goldenberg et al., 1989; Nobre et al., 1994). Furthermore, we have seen activation in this area with other fMRI activation studies from our laboratory: in mental translation of visually presented kana words into kanji script (Nakamura et al., 2000) and in kanji writing task and mental recall of kanji and kana scripts in corresponding to auditory stimuli (Nakamura et al., 2002). Taken together, it is likely that this left PITC area works as an association cortex for converging the perceptual information of both kanji and kana scripts, recognizing and differentiating their lexical constituent features, preparing for higher-order verbal processing.

Regardless of orthographic difference of language (i.e., alphabetic or nonalphabetic system), psycholinguistics have tried to address the issue that whether printed word reading follows phonologically mediated access or direct access. The former supposed that orthographic information would be first recoded into a corresponding phonological representation, which was a necessary preliminary source for access to meaning. The latter argued that phonological code was not necessary and that access to meaning proceeded directly from an orthographic representation. It is now widely accepted that these two processes, phonologically mediated access and direct access to meaning, are not mutually exclusive, but operate in parallel (Morton and Patterson, 1980; Seidenberg and McClelland, 1989). With regard to reading of kanji words, several experimental and lesion studies have suggested that for kanji words, meaning is directly accessed from orthographic representation, and access to phonology follows access to meaning (Feldman and Turvey, 1980; Goryo, 1987; Kimura, 1984; Sasanuma, 1975; Seidenberg and McClelland, 1989). However, a recent neuropsychological study of Japanese patients of Alzheimer disease reported that phonology of kanji words could be accessed directly from orthography without semantic mediation (Sasanuma et al., 1992). More recently, other experimental studies on kanji word recognition showed that both orthography and phonology contributed to the meaning activation of kanji words (Sakuma et al., 1998; Wydell et al., 1993). In the present study, the finding that processing of the kanji character stimuli consistently showed greater activation in the bilateral fusiform gyri by comparison with the kana (i.e., hiragana transcription of kanji words) processing suggests that these areas are essentially more important for kanji processing. Activation of the fusiform gyri has been demonstrated in other studies that have compared kanji to kana (Iwata, 1984; Sakurai et al., 2000). The fusiform gyri appear to be important for orthographic and lexical–semantic processing of kanji because damage to this area is known to cause lexical agraphia (Croisile et al., 1989) or alexia with agraphia for kanji (Sakurai et al., 1994). However, there is also some neuropsychological evidence that the left basal temporal language area (including inferior temporal and fusiform gyri) is crucial for name retrieval tasks. For example, some patients with infarcts in the left posterior cerebral artery territory are unable to read or name objects in response to visual presentation, tactile presentation, or verbal descriptions (De Renzi et al., 1987). Furthermore, a recent study by Usui et al. (2003) reported the case of a Japanese patient with cortical stimulation of the basal temporal language area before surgery for epilepsy who showed a transient failure in reading kanji words and naming objects or pictures but not copying kanji and reading kana words. Thus, the greater activation of the fusiform gyri in kanji word processing may reflect the role of this area in orthographic and lexical–semantic processing of kanji, or in converting kanji orthographic information to their phonetic values. The current

data do not allow us to resolve this issue completely. Further studies need to be conducted to clarify this issue.

For kana processing, a common view stated that kana reading was based on phonological recoding (i.e., character-to-sound recourse) (Iwata, 1986; Morton and Sasanuma, 1984; Saito, 1981; Sasanuma, 1980). However, in these studies, kana words, which were transcriptions of kanji words, were used. Therefore, these kana words may lack their normal orthographic representations, almost like pseudohomophones in English (e.g., 'brane' for brain). The optimal way of reading these kana transcriptions of kanji words may be by recourse to character-to-sound conversion and it is irrelevant to conclude whether orthographic representation normally plays any role in kana reading. Recently, Besner and Hildebrandt (1987) showed that orthographically legal kana words, which are assumed to have orthographic representations in the lexicon just like Kanji words, such as katakana words (e.g., /ka-me-ra/ for camera) were named faster than katakana transcriptions of Kanji words and katakana nonwords. Besner and Hildebrandt concluded that kana proper words must also have orthographic representations in the lexicon, thus affording whole word reading rather than character-by-character reading strategy. However, it might have been that the naming latencies of legal katakana words (in the study of Besner and Hildebrandt) was shorter just because the legal katakana words were so overlearned that their constituents were assembled more quickly, even though no orthographic lexicon was utilized. Thus, the conclusion of Besner and Hildebrandt may be unjustified. More recently, Yamada et al. have provided a predominant view about this issue. They have demonstrated that reading legal kana words is based on phonological assembly or orthographic lexicon, depending on an individual subject (Yamada et al., 1990). In the present study, because of the need of a large number of two-script kana words, we had to employ hiragana words, which were transcriptions of normally written kanji words. For the purpose of this study, the crucial finding is that there is activation of the left SMG in the size judgment for kana character stimuli but not for kanji. This result suggests that kana words, that is, hiragana transcriptions of kanji words, have a phonological advantage over kanji words by implicit sublexical links between orthography and phonology, because the left SMG is essential in grapheme-to-phoneme conversion of alphabetic as well as non-alphabetic language (Law et al., 1991; Price, 1998). The activation of the left middle temporal gyrus in kana lexical decision may reflect semantic access. This is consistent with the observation of Sakurai et al. (2000)). With regard to activation of Broca's area, recent neuroimaging studies provided some evidences that Broca's area serves for subvocal rehearsal and articulatory programming (Herbster et al., 1997; Rumsey et al., 1997). Thus, the greater activation of the Broca's area and the left dorsal prefrontal cortex may reflect greater phonological requirements on articulatory assembly for kana.

Conclusion

The present study used fMRI to demonstrate the implicit activation of language areas involved in kanji and kana scripts of the Japanese language system. Even with careful design to avoid "undesigned" time, the results implied that the processing of kanji and kana words was obligatory for literate Japanese subjects. Our results also demonstrated some differences in cortical activation for kanji and kana processing, which may reflect the different mechanisms of reading kanji words and kana words (i.e., hiragana

transcriptions of kanji words). The left PITC may show a crucial role in integrating the perceptual information, recognizing the lexical feature of both kanji and kana scripts. From the left PITC, the lexical information of kanji stimuli may follow the ventral route to gain their semantic or phonological access, while kana stimuli (i.e., hiragana transcriptions of kanji words) may require character-to-sound conversion to gain their semantic access through the dorsal route. The remaining question that whether reading legal kana words, which may or may not require character-to-sound conversion, activates this dorsal route is needed to be clarified in further studies.

Acknowledgments

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