



## Neural substrates of phonological selection for Japanese character Kanji based on fMRI investigations

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### ABSTRACT

Japanese and Chinese both share the same ideographic/logographic character system. How these characters are processed, however, is inherently different for each language. We harnessed the unique property of homophone judgment in Japanese kanji to provide an analogous Chinese condition using event-related functional magnetic resonance imaging (fMRI) in 33 native Japanese speakers. We compared two types of kanji: (1) kanji that usually evokes only one pronunciation to Japanese speakers, which is representative of most Chinese characters (monophonic character); (2) kanji that evoked multiple pronunciation candidates, which is typical in Japanese kanji (heterophonic character). Results showed that character pairs with multiple sound possibilities increased activation in posterior regions of the left, middle and inferior frontal gyri (MFG and IFG), the bilateral anterior insulae, and the left anterior cingulate cortex as compared with those of kanji with only one sound. The activity seen in the MFG, dorsal IFG, and ventral IFG in the left posterior lateral prefrontal cortex, which was thought to correspond with language components of orthography, phonology, and semantics, respectively, was discussed in regards to their potentially important roles in information selection among competing sources of the components. A comparison with previous studies suggested that detailed analyses of activation in these language areas could explain differences between Japanese and Chinese, such as a greater involvement of the prefrontal language production regions for Japanese, whereas, for Chinese there is more phonological processing of inputs in the superior temporal gyrus.

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### Introduction

Recent neuroimaging studies have shown that the language environment during development modulates brain activation (Fiez, 2000; Paulesu et al., 2000; Kochunov et al., 2003; Tan et al., 2003; Siok et al., 2004; Tan et al., 2005). For example, Tan et al. (2003) demonstrated that Chinese speakers activated the posterior part of the left middle frontal gyrus (MFG), whereas English speakers activated the posterior part of the superior temporal gyrus (STG) intensely for the same English rhyming tasks (Tan et al., 2003). Differences in brain activation including the inferior frontal gyrus (IFG) and STG were also found between English and Italian (Paulesu et al., 2000). By inference, Japanese and Chinese speakers may also have

a different pattern of activation for characters (kanji) in spite of the fact that both character systems appear similar. The phonology system in Chinese is largely different from that in Japanese. One character in Chinese mostly maps to only one sound with the exception of about 10% of the characters (i.e. the character is monophonic, see National Institute for Compilation and Translation, 1967; Hue, 1997; Hue, 2003). On the other hand, the majority of Japanese kanji have multiple possibilities for pronunciation (i.e. the character is heterophonic). Here, note that this difference between Chinese and Japanese is not true for the opposite direction of “sound-to-character” mappings, where one sound tends to map to a variety of characters in both language systems (i.e. two different characters may have the same pronunciation; homophonic). Although in Chinese, as well as in Japanese, there are many homophone characters, one character basically maps to only one single pronunciation. In Japanese, however, a definitive pronunciation of an ideographic character is determined according to its context; furthermore, people in some cases could assign an arbitrary sound to a character, which frequently

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occurs in names, lyrics or advertisements. Thus, Japanese speakers sometimes remain pensive on selecting sounds when they see characters; if necessary, they have to memorize them visually, but not phonologically, which may be referred to as a kind of “morphology dependence.”

In such a language environment, Japanese speakers may develop a specific neural strategy for the retrieval of characters' sounds. For example, Japanese speakers would experience an increased neural demand in the selection of information among competing sources, which has been referred to as the “domain-general” theory (Thompson-Schill, 2005)—a demand which has been shown to involve the left IFG—to judge homophony as compared with Chinese speakers for their respective native languages. We directly compared this difference of phonology in brain activation using the unique property of Japanese kanji, which allowed a condition that is analogous to the pronunciation of the majority of Chinese logographic characters. We designed an fMRI homophone judgment task of character pairs (Tan et al., 2001b; Kuo et al., 2004; Siok et al., 2004) based on a rhyme judgment paradigm from the English language (Kareken et al., 2000; Lurito et al., 2000). In the rhyme judgments, participants decided whether words in a word pair rhymed with each other (such as in “weight” and “date”). An advantage of such an fMRI language task is that it allowed collecting participants' responses as a way to monitor their behavior while in the scanner. This is in contrast to other often-used language tasks such as word generation and the listening of narrations where verification of the participants' actual performances during those tasks is difficult (Lurito et al., 2000). Moreover, the rhyming tasks are in many cases easy to perform and familiar to the general population.

In this regard, we developed a comparable fMRI paradigm for Japanese kanji using homophone judgment. In the homophone judgments, subjects decided whether a pair of characters presented shared an identical pronunciation. The abundance of homophones in characters allows us to apply this task relatively easily when assessing speakers of character-based languages. There is, however, an important difference between this task and an alphabetical rhyming task; in the homophone judgment of characters, subjects do not necessarily have to segment consonants and vowels, which is needed for alphabetical rhyming tasks (such as in b/ee and t/ee, “segmented phonology”; Paulesu et al., 1996; Burton et al., 2000). Unlike alphabetic words, segmentation between consonants and vowels are not explicitly required in Japanese, even for syllabic characters. Admittedly, Japanese speakers sometimes use a Romanized spelling system, whereas Chinese speakers sometimes use pinyin (analogous to alphabets) for representing language sounds (Fu et al., 2002). The elderly population in Japan, however, is not always familiar with such explicit segmentation of phonetics. Therefore, the use of homophone judgments of characters seems to be more preferable for the Japanese than usual rhyme judgments, which would appear relatively difficult.

Language can be specified into three major components of phonology, semantics and orthography. The topographic mapping of these functions to prefrontal regions has been demonstrated in a substantial body of research. Based on these findings, it is plausible that the three language categories would be respectively related to three different locations in the left posterior prefrontal area; the middle frontal gyrus (MFG) for the visual form of characters orthography (Matsuo et al., 2001; Tan et al., 2001a; Tan et al., 2001b; Siok et al., 2004), the upper part of IFG for phonology, and the lower part of IFG for semantics (Costafreda et al., 2006). In Japanese, the selection of the phonology is mandatory to perform the homophone judgments. In addition, a homophone effect has been observed during a semantic decision task (Morita and Saito, 2007), suggesting the involvement of semantic processing. The visual processing (orthography) of kanji would also play an important role. Based on previous studies of English and Italian (Paulesu et al., 2000) where varied degrees of activation differences among multiple language areas were found between consistent (Italian) and incon-

sistent (English) grapheme-to-phoneme mapping systems, it is quite possible that similar weighted activation would be also found between monophonic (Chinese) and heterophonic (Japanese) character-to-sound mapping systems. Understanding similarities and differences in the print-to-sound conversion between Japanese and Chinese may help to elucidate the basic neural mechanism underlying the orthography to phonology conversion in human language system in general.

Therefore, in our current study, we hypothesized that the characters that have multiple pronunciations, representing regular kanji processing, would show greater demands in the print-to-sound conversion processes as compared with the characters that usually map to only one pronunciation, reflecting Chinese character processing, because the former required the selection among multiple sound candidates. We also hypothesized that there would be topographic mapping of these regions to functional segregated areas related to the different language categories, specifically expecting increased activation in the dorsal IFG in conditions emphasizing phonological processing.

## Materials and methods

### Volunteers

Thirty-five healthy native Japanese speakers were recruited from universities and graduate schools around Nagoya, Japan (ages 20–24, 20 females and 15 males). All of them were right-handed as measured by a Japanese handedness inventory (Hatta, 1996; Hatta, 2007). All gave written informed consent approved by the local Institutional Review Board, which adheres to the declaration of Helsinki. Two of the participants' behavioral performance, as measured within the scanner, were 2SD below the group mean and were excluded from the data analysis. Subsequent data analyses were conducted on the remaining 33 participants (19 females and 14 males, average age 22.0 years old).

### Stimuli

A preliminary examination was conducted using a questionnaire to optimize the stimuli list for fMRI. First, we chose a total of 480 characters from the national list of “characters designated for everyday use (jouyou kanji)” that appeared on the Agency for Cultural Affairs of Japan's website (<http://www.bunka.go.jp/>) in 2006, according to the following criteria; (1) characters for which the website listed only one pronunciation (210 characters), and (2) characters of which the website had three or more entries for the pronunciations (270 characters). All chosen characters are a part of compulsory education in elementary school. Second, we administered a questionnaire containing the chosen characters, asking participants to write down the pronunciation that first came to mind when they saw the character. This was to confirm which characters tended to evoke one or multiple pronunciations. The questionnaires were collected from 160 undergraduate students within three universities. The 480 characters were divided into two lists that were counter-balanced for character types (one or multiple pronunciations based on the website corpus) to decrease the response burden. Each questionnaire consisted of one of the two character lists and respondents answered at the rate of 24 characters per minute for a total of 10 minutes. Each character list had two versions that differed in character order to minimize sequence effects. The number of responses filled in by the respondents was summarized for each character, and the percentage of participants that provided the primary pronunciation as indexed in the national list above was calculated. Characters were considered to have only one pronunciation (ONE characters) if greater than 90% of the participants provided the primary pronunciation, and multiple pronunciations (MUL

characters) if less than 70% of the participants did so. We selected 175 characters based on this criterion for each character group.

The resultant character lists acted as stimuli pools for generating the character pairs needed for the fMRI task. There were four types of character pairs: (1) homophonic single pronunciation (ONE\_H), where each character had one pronunciation and the pair sounded the same, (2) non-homophonic single pronunciation (ONE\_NH), where each character had one pronunciation and the pair sounded different, (3) homophonic multiple pronunciations (MUL\_H), where each character had multiple pronunciations and the pair sounded the same, and (4) non-homophonic multiple pronunciations (MUL\_NH), where each character had many pronunciations and the pair sounded different. Thirty character pairs were selected for each of the four character types and used in the current event-related fMRI study (120 pairs, 240 characters in total). To minimize unexpected confounds, we presented characters according to the following rules; (1) there was no overlap of the characters among the four character groups in this event-related fMRI, (2) the four character groups of the current study were matched in character frequency based on their appearance in a major newspaper (Yokoyama et al., 1998; mean = 617.8; SD = 399.7 for ONE, mean = 553.7; SD = 421.2 for MUL, Mann–Whitney  $U = 6407$ ,  $p > 0.05$ ), (3) the ratios of coincidence with which respondents filled in the identical pronunciations in the questionnaire above were matched within the character groups (mean = 97.9; SD = 2.8 for ONE, mean = 38.1; SD = 19.1 for MUL,  $t(238) = 33.99$ ,  $p < 0.001$ ), (4) the number of moras was balanced among the four groups (mean = 1.8; SD = 0.4 for ONE, mean = 1.8; SD = 0.4 for MUL,  $t(238) = 0.45$ ,  $p > 0.05$ ). Table 1 shows a summary of the attributes of the characters used in this study.

#### fMRI paradigm

Volunteers made homophone judgments of white character pairs presented vertically with a black background (Fig. 1). They pressed a button under their left index finger when the character pairs were homophonic, and a button under the left middle finger when non-homophonic. We applied the genetic algorithm provided by Wager and Nichols (2003) to help to jitter the stimuli presentation during the event-related fMRI scan. We designated each event type (120 character pairs), including the null event (60 events), as conditions to appear every 5 s. The inter-stimulus-interval [ISI] lasted 2.5 s. As



**Fig. 1.** Sample stimuli of two types of kanji pairs. The right side of the figure shows Romanized spellings of pronunciations corresponding to the characters represented on the left side. Each of the ONE characters evokes only one pronunciation in Japanese speakers in general. In the upper panel, volunteers were to respond “different” (with the left middle finger) because the character pair did not share the same pronunciation (non-homophonic). On the other hand, each of the MUL characters has multiple candidates for pronunciation. In the lower panel, volunteers were to respond “same” (with the left index finger) because the paired characters share the same pronunciation “ryoku” (homophonic).

a consequence, the stimulus onset asynchrony (SOA) for trials of one of the four task conditions was varied from 5 s to 110 s. A fixation cross was displayed during the ISI and the null events. The whole series (5 s for each event, total 900 s) was divided into three runs, each of which lasted 5 min to minimize volunteers' fatigue. The order of the three runs was counterbalanced across subjects. Subjects were not informed of the two types of characters (ONE and MUL). An MRI compatible integrated system (IFIS-SA, MRI Devices Corporation, WI, USA) was used for stimulus presentation and response collection.

#### Image acquisition

All imaging was performed on a 1.5 Tesla MR scanner (MAGNETOM Avanto, Siemens, Erlangen, Germany). An EPI sequence was used for functional images to measure blood oxygenation level dependency (BOLD) effects (Ogawa et al., 1990a; Ogawa et al., 1990b) using the following parameters: repetition time (TR) 2000 ms, echo time (TE) 56 ms, flip angle (FA) 90 deg, field of view (FOV) 220 mm, 64 × 64 matrix, slice thickness 6 mm with no gap interleaved, 20 axial slices, and 150 images per slice for a run. Each run was preceded by 12 s of dummy scans to avoid initial signal instability. After the acquisition of functional images, T2-weighted anatomy images were obtained at the same locations with the functional images using the following parameters: TR 5000 ms, TE 93 ms, FA 180 deg, FOV 220, 256 × 128 matrix, 5 mm thick with 1 mm gap, and 20 axial slices.

#### Data analysis

Behavioral data: accuracy (i.e. percentage of expected responses) and the reaction time of the responses collected within the scanner were analyzed for each subject. The responses were divided into six categories: Hit, Correct rejection (CR), Miss, False alarm (FA), No response and Irrelevant input. Here, note that the Hit corresponded to the events for which volunteers responded “same” for homophonic pairs (ONE\_H and MUL\_H). The CR corresponded to the events for which volunteers responded “different” for non-homophonic pairs (ONE\_NH and MUL\_NH). The Miss and FA were the reverse of the Hit and CR, i.e., “different” for homophonic pairs and “same” for non-homophonic pairs, respectively. The Irrelevant inputs were inapplicable button responses to the device such as when the subjects used any finger other than the left index and middle fingers. All events

**Table 1**  
Summary of character attributes.

	ONE_H	ONE_NH	MUL_H	MUL_NH
Number (1)	60	60	60	60
Frequency (2)	616.2	619.5	553.5	553.9
(SD)	(418.9)	(383.1)	(391.5)	(452.3)
Coincidence (3)	98.0	97.9	38.6	37.7
(SD)	(2.7)	(3.0)	(19.4)	(18.8)
Mora (4)	1.8	1.8	1.7	1.8
(SD)	(0.4)	(0.4)	(0.4)	(0.4)

(1) There was no overlap of the characters among the four groups (see text).

(2) “Frequency” is the frequency rank of the character appearance in a major newspaper (Yokoyama et al., 1998). There is no significant difference among the four conditions (Kruskal–Wallis  $H = 2.36$ ,  $p > 0.05$ ).

(3) “Coincidence” refers to coincident responses to a character presented in the questionnaire asking the first pronunciation that came to mind (see text). There is no significant difference between ONE\_H and ONE\_NH ( $t(118) = 0.06$ ,  $p > 0.05$ ), as well as between MUL\_H and MUL\_NH ( $t(118) = 0.24$ ,  $p > 0.05$ ), although there is a strong significant difference between “one-to-one” characters (ONE\_H/ONE\_NH) and “one-to-multiple” characters (MUL\_H/MUL\_NH) (see text).

(4) “Mora” was examined to balance the numbers of the phonological units in characters. Here, we used the indices in the table from the website (<http://www.bunka.go.jp/>) by the Agency for Cultural Affairs of Japan, showing the pronunciations (readings) of the characters, to count the mora. There was no significant differences among the four conditions ( $F(3, 236) = 2.64$ ,  $p > 0.05$ ).

**Table 2**  
Summary of response types.

	Hit	CR	Miss	FA	Irrel	No res	Total
Mean event number	51.2	53.5	4.4	1.6	8.8	0.5	120.0
(Percentage)	(42.7)	(44.5)	(3.7)	(1.3)	(7.3)	(0.4)	(100.0)

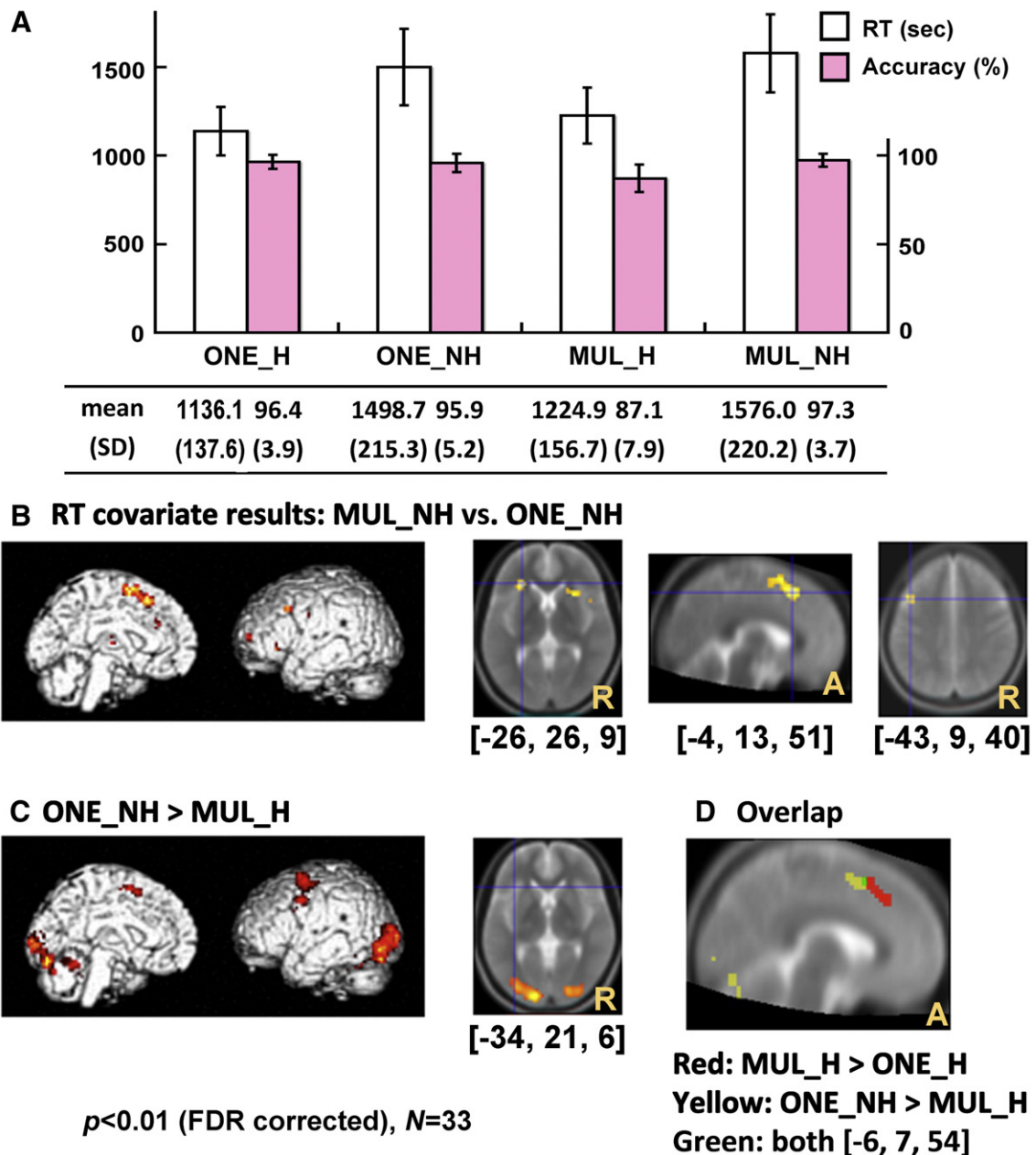
Notes. Hit: “same” for homophonic pair, CR: correct rejection i.e. “different” for non-homophonic pair, Miss: “different” for homophonic pair, FA: false alarm i.e. “same” for non-homophonic pair, Irrel: irrelevant input, No res: no response,  $N = 33$ . Breakdown of Hit: 26.8 for ONE\_H and 24.4 for MUL\_H. Breakdown of CR: 26.5 for ONE\_NH and 27.0 for MUL\_NH.

except those corresponding to the Irrelevant input were used for the accuracy rate computation. For the RT computation, only events corresponding to expected responses, i.e., Hit and CR, were used.

These behavioral data were also entered into the fMRI statistical models (see below).

#### Imaging data

The functional images were analyzed using Statistical Parametric Map software (SPM5, University College London, UK). The data were first realigned to the last five volumes of fMRI with unwarp processing to improve the performance of coregistration between functional and the T2 structural images. Slice timing correction was then applied to the realigned volumes. The T2 anatomy images were segmented and spatially normalized into a standard brain template space (Montreal Neurological Institute, MNI template). The MNI coordinates were later transformed into Talairach's coordinates (Talairach and Tournoux,



**Fig. 2.** Examination of RT and accuracy effects. The top panel A shows a graph for RT and accuracy with error bars of the standard deviation (SD). The second panel B shows activation augmented according to the increase of RT in the MUL\_NH vs. ONE\_NH contrast, which shows activated regions similar to our main contrast, MUL\_H > ONE\_H. The similarity might have a possibility that the main results of MUL\_H > ONE\_H were affected by RT effects. However, the panel C shows very different maps from B and the MUL\_H > ONE\_H, in spite of a significant difference in RT for this contrast ONE\_NH > MUL\_H. The only overlapping region was shown in green in the panel D, the coordinates of which shown are in Talairach space. R: right, A: anterior.



1988) using a non-linear algorithm (Lancaster et al., 2007). Finally, the data was spatially smoothed using an 8-mm full-width at half-maximum (FWHM) isotropic Gaussian kernel.

After the above preprocessing, condition-specific effects were assessed for individual volunteers by employing a general linear model using the canonical hemodynamic response function with time derivatives as reference functions. All three runs, each containing four task conditions, were included into a design matrix for each subject. In this individual design matrix, we separated trials where the participants responded in an expected fashion (i.e. “Hit” and “CR” above) from other trials (i.e. Miss, FA, No response and Irrelevant input) to reflect only “Hit” and “CR” trials in the activation maps for all contrast computations in SPM. This technique has been often used in fMRI to control for unexpected confounds due to the participants' erroneous responses. We also included the head motion regressors into the individual design matrix to remove residual effects of the head movements.

A conjunction analysis (Price and Friston, 1997) was conducted to obtain activation between contrasts of “MUL\_H vs. ONE\_H” and “MUL\_NH vs. ONE\_NH” for multiple vs. one pronunciation effects (i.e. MUL vs. ONE), as well as, “MUL\_NH vs. MUL\_H” and “ONE\_NH vs. ONE\_H” for non-homophonic vs. homophonic pair effects (i.e. NH vs. H) at a threshold of  $p < 0.05$  using the false discovery rate (FDR) criterion (Genovese et al., 2002). However, because possible interaction effects between the specified contrasts may exist to mask the conjunction results, we also conducted a random-effects group analysis to estimate the overall general effects of the fMRI event conditions by employing an analysis of variance (ANOVA). Individually averaged RT and accuracy data were entered as covariates separately, and examined for identifying areas of increased activation explained by changes in RTs and accuracy. The SPM[T] maps were generated at a threshold of  $p < 0.01$ , FDR corrected. In the comparison between conditions in ANOVA, “inclusive masks” of subtracted contrasts ( $p = 0.001$ , uncorrected) were applied to generate maps (e.g. for the computation of MUL > ONE, only the area activated in the MUL was considered). The areas surviving the extent threshold of corrected  $p = 0.05$  at the cluster level were considered in the results and discussion.

### Selected literature review

We selected previous papers including homophone judgments of characters, letter rhyming, English rhyming and other tasks that were closely related to the current study, to explore the commonality and differences among Japanese, Chinese and English. The standardized brain coordinates as well as  $t$ - or  $Z$ -values of local maxima were summarized for the anterior insula, ventral and dorsal IFG, MFG and posterior part of the superior temporal gyrus and sulcus (STG/S) in the left hemisphere. All MNI coordinates were transposed to Talairach's space.

## Results

### Behavioral data

Behavioral responses within the scanner were summarized in Table 2 and Fig. 2A. A two-way repeated-measures ANOVA (character type [ONE or MUL] × pair type [H or NH]) was conducted independently for reaction time and accuracy. Analyses yielded a significant interaction effect ( $F(1,32) = 4.4796$ ,  $p < 0.05$ ) for RT, showing longer RT for MUL character type ( $F(1, 32) = 88.235$ ,  $p < 0.001$ ) and NH character pairs ( $F(1, 32) = 172.44$ ,  $p < 0.001$ ). A significant interaction effect for accuracy ( $F(1, 32) = 33.886$ ,  $p < 0.001$ ) was also observed. Subjects were more accurate on ONE character type ( $F(1, 32) = 15.120$ ,  $p < 0.001$ ), and NH character pair ( $F(1, 32) = 23.849$ ,  $p < 0.001$ ). A post-hoc analysis showed that accuracy was lower only for the MUL\_H condition ( $p < 0.001$ ). Their effects on brain activation were further examined in detail because of the significant differences in these behavioral data.

### Imaging data

All four conditions produced very similar activation maps. The most extensive activation was observed in the bilateral visual areas including the primary visual area, lateral occipital gyri, lingual and fusiform gyri. The bilateral IFG and MFG were also robustly activated. Table 3 provides a summary of our areas of focus showing peak activations in the left IFG and MFG. The left posterior STG/S, corresponding to Wernicke's area, was also observed to be activated, but to a relatively weaker extent. The bilateral premotor areas, cerebellum, supplementary motor areas, anterior cingulate cortex, thalamus and the left primary motor cortex were also highly activated. Activation in the bilateral intraparietal areas and posterior superior parietal cortex was also observed.

To estimate the effects of significant differences found in behavioral data, we examined RT and accuracy effects on the activation during each condition in addition to comparisons between MUL and ONE, MUL\_H and ONE\_H, as well as MUL\_NH and ONE\_NH using a one-sample  $t$ -test. The application of the individually averaged accuracy as a covariant in the design matrix produced no activation in any of the above contrasts. For the RTs, only the MUL\_NH vs. ONE\_NH contrast showed considerable activation with the increase of the individually averaged RT differences (Fig. 2). Other contrasts did not show intensity variation with the RTs at the employed threshold of  $p < 0.01$ , FDR corrected.

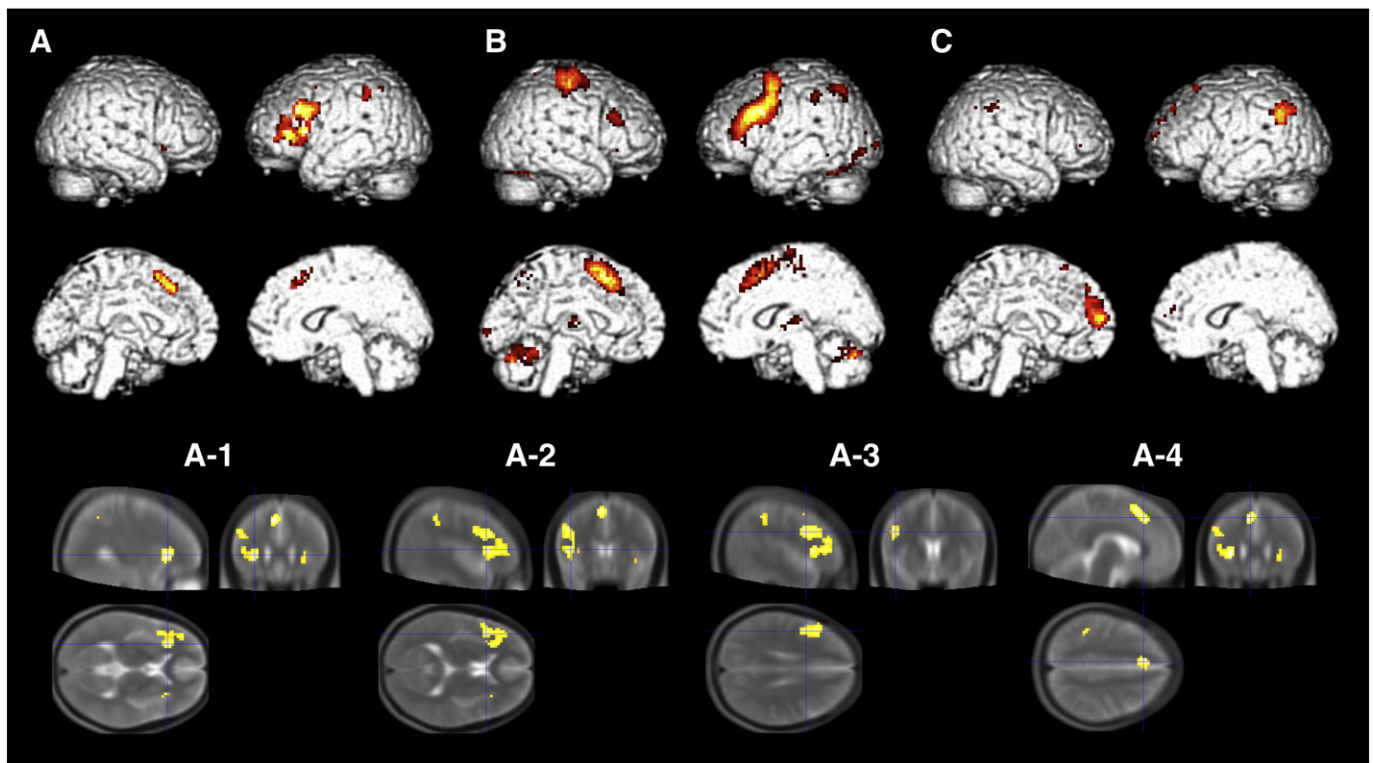
The conjunction analysis yielded significant activations for “MUL\_H > ONE\_H and MUL\_NH > ONE\_NH” at  $p < 0.05$  (FDR corrected) but did not survive at a higher threshold of  $p < 0.01$  (FDR corrected) (Fig. 3). The lowered sensitivity in the conjunction of multiple vs. one pronunciation effects could be due to the non-homophonic character-pair effects; the non-homophonic (NH) pairs

**Table 3**

Left inferior and middle frontal activation peaks in each condition.

Region	Brodmann	ONE_H				ONE_NH				MUL_H				MUL_NH			
		x	y	z	T	x	y	z	T	x	y	z	T	x	y	z	T
M/IFG	6/9	−49	4	36	12.84	−46	4	34	15.97	−46	4	34	15.09	−46	4	34	18.77
M/IFG	9/44					−43	15	32	10.7					−43	15	32	13.17
M/IFG	9/44/46					−40	18	30	10.62					−40	19	27	13.02
IFG	44/45/46	−37	19	22	6.53					−34	16	21	9.25	−43	28	22	11.43
IFG	6/44	−51	5	20	8.79					−51	8	18	10.72				
IFG/Ins.		−37	−6	17	10.37												
NC/Pu		−18	3	15	10.07												
Ins./NC						−29	20	11	8.08	−32	15	8	9.76	−29	20	8	10.84

Notes. Local maxima in the left inferior and middle frontal gyri and surrounding regions are summarized.  $N = 33$ .  $p < 0.01$ , FDR corrected. Coordinates are in Talairach space. T: T-value of the peak voxel. M/IFG: middle to inferior frontal gyri. Ins.: insula. NC: caudate nucleus. Pu: putamen.



**Fig. 3.** Activation maps from conjunction analysis ( $p < 0.05$ , FDR corrected,  $N = 33$ ). The first and second rows of the figure display the lateral and medial views, respectively, of activation peaks that survived the cluster-level threshold of  $p < 0.05$ , corrected. (A) Conjunction of “MUL\_H>ONE\_H” and “MUL\_NH>ONE\_NH.” (B) Conjunction of “MUL\_NH>MUL\_H” and “ONE\_NH>ONE\_H.” (C) Conjunction of “MUL\_NH<MUL\_H” and “ONE\_NH<ONE\_H.” A-1 to A-4: orthogonal views from the conjunction A. Coordinates of intersections are as follows (Talairach's). A-1:  $x = -29$ ,  $y = 23$ ,  $z = 9$  (anterior insula). A-2:  $x = -40$ ,  $y = 14$ ,  $z = 13$  (IFG). A-3:  $x = -43$ ,  $y = 4$ ,  $z = 31$  (IFG/MFG). A-4:  $x = -7$ ,  $y = 19$ ,  $z = 47$  (pre-SMA).

might induce superfluous activation such as for the rejection of unmatched phonology candidates and/or rushed motor responses. The different activation maps seen between conjunctions of NH>H (Fig. 4B) and H>NH (Fig. 4C) also suggest the involvement of different neural systems between the NH and H. This might indicate a possibility of interactions among the conditions, specifically in terms of the “selection” of phonology, which may confound the findings of the conjunction analysis for MUL>ONE. Therefore, we decided to focus on the MUL\_H>ONE\_H contrast in ANOVA for the detailed investigation of the multiple vs. one pronunciation effects in characters.

For the condition comparisons in ANOVA, the contrast between MUL and ONE conditions, i.e. MUL\_H plus MUL\_NH>ONE\_H plus ONE\_NH, showed activation maps similar to the conjunction of MUL\_H>ONE\_H and MUL\_NH>ONE\_NH ( $p < 0.01$ , FDR corrected). Augmented activation was observed in the medial frontal region including the anterior cingulate cortex (ACC) predominantly on the left, bilateral anterior insulae, left IFG, a posterior part of the left MFG, the left parietal cortex around the intraparietal sulcus, bilateral caudate nuclei, and part of the left thalamus around the ventral lateral nucleus (Fig. 4, Table 4). The reversed contrast of ONE>MUL yielded no significant augmentation. For the “Hit” only analysis, the MUL\_H>ONE\_H contrast produced conservative activations as compared with the MUL>ONE contrast above, showing activation in the bilateral anterior insulae (left dominant), the left IFG and MFG, the left medial frontal areas including the ACC and the pre-supplementary motor area (pre-SMA) (Fig. 4, Table 4). On the other hand, increased activation was specifically observed in the right medial occipital and temporal areas including the lingual gyrus (LG), fusiform gyrus (FG), and parahippocampal gyrus (PH) for the comparison of ONE\_H>MUL\_H. Contrasts between MUL\_NH and ONE\_NH were also computed as a reference. The areas of increased activation were the bilateral anterior insulae, left IFG and MFG, ACC to pre-SMA (left dominant), left intraparietal cortex, bilateral caudate

nucleus and thalamus, and the cerebellum. The reversed contrast (ONE\_NH>MUL\_NH) did not yield significant differences.

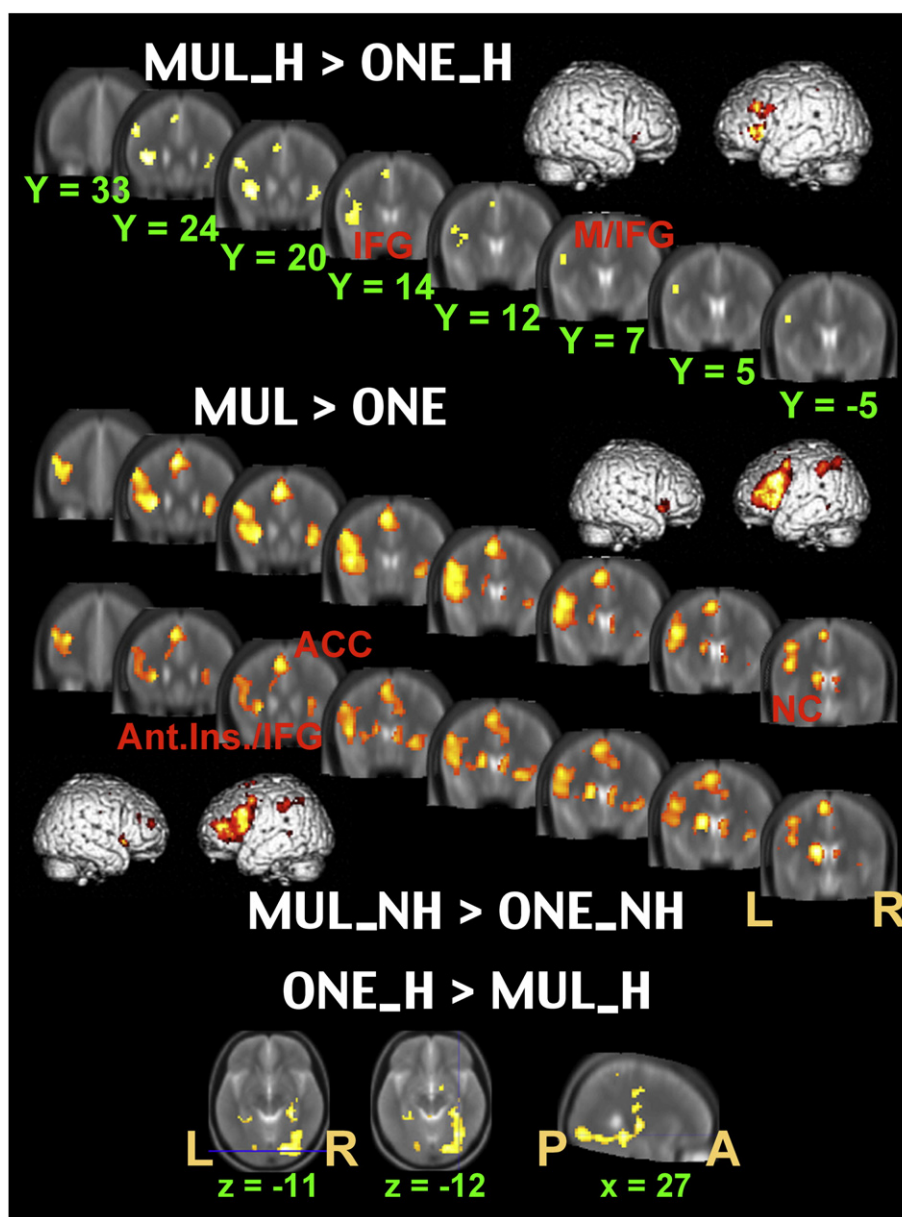
#### Coordinates in related literature

Table 5 summarizes standardized brain coordinates of activated foci reported in reviewed studies, with the coordinates from the current study included in the first rows. Fig. 5 is a schematic representation of the reported coordinates. The character processing (#1–6) and the alphabetic letter rhyming (#7) tended to increase  $t$ - or  $Z$ -values in the MFG as compared with other prefrontal areas, whereas English word rhyming tasks (#8–12) did not. Homophone and rhyming judgments generally tended to activate the dorsal IFG rather than the ventral IFG with some exceptions. It seems that Japanese homophone judgment (#1) induced more extensive activation in the anterior insula than other areas, whereas Chinese tasks (#2–3, #5–6) did not show such pattern. Interestingly, homophone judgment in Chinese Korean also induced extensive activation in this region (#4), which shows a similarity to Japanese (#1). English rhyming tasks apparently have a tendency to induce more intense activation in the STG/S. It also appears possible that Chinese speakers activated this area more intensely than Japanese speakers, which may represent another possible difference between Japanese and Chinese.

#### Discussion

##### Selecting phonological information of characters among multiple possibilities

Our hypothesis of increased activation in the frontal areas related to the selection of phonology was confirmed with the observed



**Fig. 4.** Contrast maps by ANOVA superimposed onto averaged T2 anatomy images ( $p < 0.01$ , FDR corrected,  $N = 33$ ). x, y, z: Talairach coordinates of intersections. Labels in red indicating the anatomical interpretation of the intersections are the same as in Table 4. In the coronal sections, peak activations were observed in the posterior part of the M/IFG, the anterior insula, and the IFG in the left prefrontal cortex.

augmented activation in the MUL\_H>ONE\_H contrast. Our findings not only suggested a “domain-general” selection function but also a topographic region-related functional segregation in the posterior part of the left lateral prefrontal area, specifically, the MFG for orthography and the dorsal IFG for phonology. The MUL\_H>ONE\_H contrast essentially yielded only the frontal activation including the left IFG and MFG, bilateral anterior insulae, as well as the left ACC and adjacent pre-SMA, whereas other related contrasts (MUL>ONE and MUL\_NH>ONE\_NH) induced additional activations (Fig. 4, Table 4). Notably, these contrasts showed only limited activation around the posterior part of the STG/S, whereas many of the previous rhyming tasks for alphabet languages (Paulesu et al., 1993; Paulesu et al., 1996; Price et al., 1999; Kareken et al., 2000; Lurito et al., 2000; Seghier et al., 2004; Burton et al., 2005) and homophone judgment tasks for Chinese characters (Tan et al., 2001b; Kuo et al., 2004) have shown activation around this area.

Intensive activation in the posterior part of the left lateral prefrontal cortex was often observed in most of the rhyming and

homophone judgment tasks. Two distinct foci were found in this area in the MUL\_H>ONE\_H comparison. One in the dorsal IFG (Brodmann's areas [BAs] 44/45), whereas the other in a posterior region of the MFG (BAs 9/44) (Fig. 4, Table 4). Although the latter blob extended ventrally into the IFG, its peak coordinates (MNI:  $-48, 24, 33$ ; Talairach:  $-46, 18, 35$ ) were located in the MFG, as their probability of being in the IFG was less than 0.25 according to a recent probabilistic map (Hammers et al., 2007). Its coordinates were similar to the location specifically related to the processing of Chinese logographs (Tan et al., 2001b; Tan et al., 2003; Kuo et al., 2004; Booth et al., 2006) as well as Japanese kanji (Matsuo et al., 2001; Matsuo et al., 2003). On the other hand, the IFG focus seemed to be located in the phonological area (dorsal IFG) with a 95% confidence interval (Costafreda et al., 2006). Recent neuroimaging studies have revealed two distinctive locations segregated in the left IFG along with the dorsal–ventral axis. The ventral region is associated with semantic processing, whereas the dorsal region is for phonological processing (Fiez, 1997; Poldrack et al., 1999; Costafreda et al., 2006). The

**Table 4**

Maxima of activated regions for contrasts studied.

Region	Brodmann	MUL>ONE				MUL_H>ONE_H				MUL_NH>ONE_NH				ONE_H>MUL_H			
		x	y	z	T	x	y	z	T	x	y	z	T	x	y	z	T
Lateral frontal areas																	
Ant. Ins./IFG	45/47	−29	23	7	6.79	−34	21	6	5.23	−26	24	6	5.12				
M/IFG	6/9/44	−43	5	28	6.37	−46	18	35	5.11	−46	7	34	5.11				
IFG	44/45	−43	15	11	6.69	−40	14	13	4.75	−43	14	16	5.30				
M/IFG	10/46									−32	33	20	5.60				
Ant. Ins./IFG	45/47	27	20	3	5.40												
Ant. Ins./IFG	45	30	20	10	5.16	32	20	9	4.63								
Ant. Ins./Pu										21	12	3	4.90				
Medial frontal areas																	
SFG/ACC	8/32	−7	19	47	7.23	−7	19	47	4.77	−7	19	49	5.82				
pre-SMA	6					−7	10	54	4.57	−7	−5	63	5.70				
Parietal areas																	
IPS	40	−32	−47	36	5.65					−32	−50	37	5.18				
IPS	40	−43	−41	41	5.38					−43	−45	43	3.96				
IPS	40									−43	−44	35	4.04				
Thalamus/caudate nucleus																	
NC		−12	1	17	5.27					−15	3	18	6.88				
Thalamus		−9	−10	6	4.86					−7	−11	9	5.48				
Thalamus		−7	−21	6	3.84					−7	−22	5	5.24				
NC		7	7	5	4.62												
NC		7	0	14	3.88												
NC		7	8	14	3.74					4	9	13	4.53				
NC										15	−9	20	4.59				
Post.Ins.										32	−17	14	4.83				
Cerebellum																	
Vermal IV										2	−51	−11	4.88				
Hemispherical IX										10	−48	−16	4.58				
Hemispherical V										−6	−50	−20	4.12				
Medial occipital & and temporal areas																	
LG	18													16	−79	−11	4.93
FG	19/37													32	−60	−12	4.66
PH/Hi	36/37													27	−35	−7	4.61

Notes. Local maxima of contrasts between one-to-multiple and one-to-one character pairs.  $N = 33$ ,  $p < 0.01$ , FDR corrected. Coordinates are in Talairach space. T: T-value of the peak voxel. Ant. Ins.: anterior part of the insula. IFG: inferior frontal gyrus. M/IFG: middle to inferior frontal gyri. Pu: putamen. ACC: anterior cingulate cortex. SFG: superior frontal gyrus. Pre-SMA: pre-supplementary motor area. IPS: intraparietal sulcus. NC: Caudate Nucleus. Post. Ins.: posterior part of the insula. LG: lingual gyrus. FG: fusiform gyrus. PH/Hi: parahippocampal cortex to hippocampus. Cerebellum nomenclature is based on the MRI Atlas of the Human Cerebellum (Schmahmann et al., 2000).

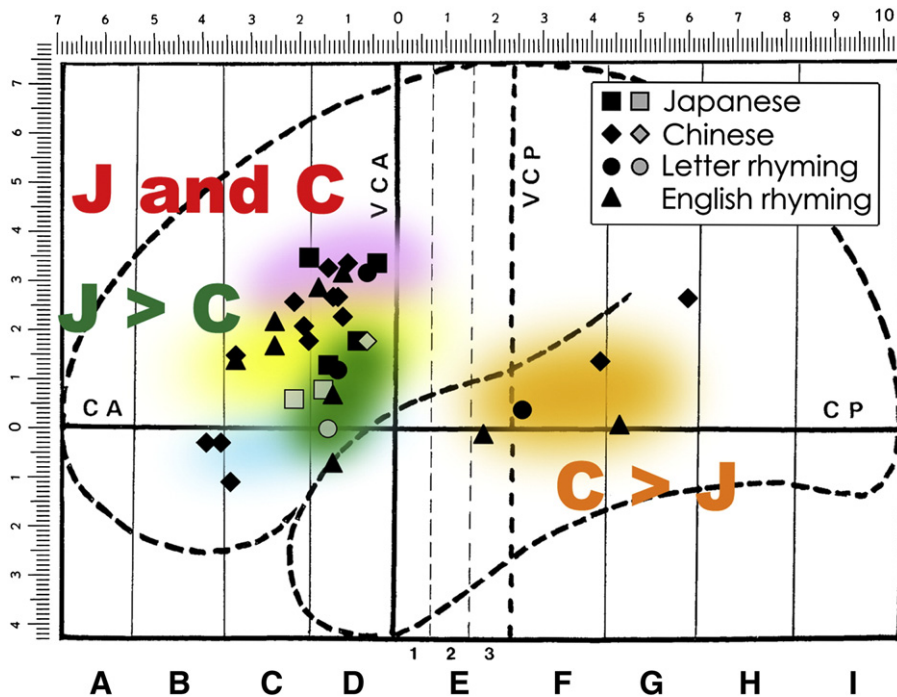
**Table 5**

Summary of Talairach coordinates in related studies.

		Ant. Ins.		IFG ventral		IFG dorsal		MFG		STG/S	
		Coord	t (Z*)	Coord	t (Z*)	Coord	t (Z*)	Coord	t (Z*)	Coord	t (Z*)
#1	Homophone judge (MUL_H>ONE_H, Japanese)	−34 21 6	5.23	NR		−40 14 13	4.75	−46 18 35	5.11	NR	
	Homophone judge (MUL_H, Japanese)	−32 15 8	9.76	(NR)		−51 8 18	10.72	−46 4 34	15.09	NR	
#2	Homophone judge (Chinese)	(NR)		−47 3 −11	2.94	−58 19 21	2.98	−43 13 27	3.42	NR	
#3	Homophone judge (Chinese)	NR		(NR)		−48 11 23	11.96	−42 14 33	11.45	NR	
#4	Homophone judge>Character form judge (Chinese Korean)	−42 6 18	5.29*	NR		−46 18 18	6.75*	−44 10 34	6.83*	−54 −42 14	3.61*
#5	Rhyming judge (Chinese)	(NR)		(NR)		(NR)		−44 21 26	6.43	NR	
#6	Judge for character attributes (Chinese)	NR		NR		−45 33 15	3.41	−42 12 27	3.25	−33 −60 27	2.62
	Phonological>orthographic judge (Chinese)	NR		−39 3 −3	3.10	NR		NR		NR	
	Semantic>orthographic judge (Chinese)	NR		−45 36 −3	2.85	NR		NR		NR	
#7	Letter rhyming (Alphabets)	−38 14 0	3.8*	NR		−46 12 12	6.5*	−38 6 32	7.4*	−46 −26 4	6.1*
#8	Rhyming judge (English written words)	NR		−55 13 7	23.5	(NR)		−49 11 32	21.0	−57 −46 1	16.1
#9	Rhyming judge (English written words)	NR		−55 13 −7	24.23	(NR)		−49 11 32	21.60	−57 −46 1	17.88
#10	Rhyming judge (English written words)	NR		NR		−50 33 14	7.272	NR		NR	
#11	Rhyming judge (English written words)	NR		(NR)		−43 25 17†	5.35*	NR		(NR)	
	Rhyming judge (English spoken words)	NR		(NR)		NR		−48 16 29†	4.35*	−51 −18 −1†	4.61*
#12	Rhyming judge (English written words)	NR		(NR)		−43 25 22†	5.2*	(NR)		NR	

Notes. #1–6: studies in characters, #7–12: studies in alphabets. #1: Current study, #2: Tan et al., 2001a,b, #3: Siok et al., 2004, #4: Kuo et al., 2004, #5: Tan et al., 2003, #6: Liu et al., 2006, #7: Paulesu et al., 1996, #8: Lurito et al., 2000, #9: Kareken et al., 2000, #10: Crosson et al., 1999, #11: Booth et al., 2002, #12: Bitan et al., 2005. Clusters in the table were based on Talairach's coordinates and not necessarily using the authors' labels. If the authors listed several foci in the area, the foci with larger  $t$ - or  $Z$ -values were selected. The border of the ventral and dorsal IFGs was estimated in terms of the level of  $z = 10$ , whereas the border of the dorsal IFG and the MFG was defined in terms of the level of  $z = 25$ . This table covers only the left hemisphere of normal subjects. Ant. Ins.: anterior insula. IFG ventral: ventral part of the posterior inferior frontal gyrus. IFG dorsal: dorsal part of the posterior inferior frontal gyrus. MFG: posterior middle frontal gyrus. STG/S: superior temporal gyrus and/or sulcus. NR: no report, (NR): no report of coordinates but activation in the region was seen in the figure or mentioned in the text,  $t$ :  $t$ -value,  $Z^*$ :  $Z$ -value, †: The coordinates were converted from those of Montreal Neurological Institute (MNI) into Talairach's.





**Fig. 5.** A schematic representation of the current and reviewed studies (see Table 5). Coordinates are plotted onto Figure 62 from Talairach and Tournoux (1988), modified to include a z scale for the ordinate axis. The abscissa indicates y coordinates, whereas the ordinate indicates z coordinates. The empty shapes (gray) indicate that the loci are in the anterior insula. Square: current study (Japanese). Diamond: Chinese tasks. Circle: alphabet letter rhyming task. Triangle: English rhyming tasks. J: Japanese. C: Chinese. The purple shaded region represents middle frontal gyrus; yellow, dorsal inferior frontal gyrus (IFG); blue, ventral IFG; green, anterior insula; and orange, superior temporal region. The middle frontal gyrus is intensively used both in Japanese and Chinese. The anterior insula, as well as, the dorsal IFG tends to be more involved in Japanese, whereas the superior temporal region tends to be more involved in Chinese.

coordinates in the left IFG for our study were located in areas consistent with phonological processing, whereas those in the left MFG were related to character morphology. The above type of interpretation identifies certain specific linguistic functions for the left IFG rather than a general function.

In contrast, another kind is a “domain-general” explanation, including that of “selecting information among competing sources of information” (Thompson-Schill et al., 1997; Thompson-Schill et al., 1999; Thompson-Schill, 2005; Snyder et al., 2007). Kan and Thompson-Schill (2004) examined name agreement effects of picture naming, demonstrating that the naming of pictures that had many candidates (low agreement pictures) activated the left IFG more extensively than pictures that invoked similar names in most people (high agreement pictures). This situation of selection is very similar to our multiple vs. one candidate of character sounds, where subjects selected a pertinent sound from competing candidates in the MUL conditions. The picture naming has another resemblance to kanji reading, in that subjects provide a phonological label to a visual representation without using spelling rules explicitly. Moreover, the brain coordinates Kan and Thompson-Schill (2004) reported for the naming of line drawings in their Table 3 (MNI:  $-56.25, 3.75, 35.00$ ; these corresponds to Talairach coordinates  $-53, -1, 35$ ) are located beyond the 95% confidence interval of the dorsal phonology-related IFG area (Costafreda et al., 2006) and tend to fall into the MFG (a border area of the IFG according to Hammers et al., 2007). With these considerations, it seems reasonable to regard the activation in the left MFG in this study to be closely related to that of the picture naming in Kan and Thompson-Schill (2004). The function corresponding to this activation seems to be the selection of language information among competing alternatives, specifically information extracted from visual materials.

Based on the competing nature of our contrasts of interest, we believe our results are consistent with the domain-general theory, however, with the addition of specific segregated topography of

functional components. That is, the ventral IFG is considered to be associated with the “selection” of semantic information, whereas the dorsal IFG is associated with the “selection” of phonological information. The posterior MFG may also be associated with the “selection” of information related to visual representation such as logographic character, as in the association or conversion between character and sound/semantics (Matsuo et al., 2001; Tan et al., 2001a; Tan et al., 2001b; Siok et al., 2004). On the whole, it is plausible to model the function of the posterior prefrontal cortex as follows. This area generally plays a role in the selection of language information from competing sources. It contains three functional segments: semantic, phonological, and morphological, which correspond to the posterior ventral, dorsal IFG, and the foot of the MFG, respectively. Semantics, phonology, and written word processing are three major components of language. It is reasonable that the multiple possibilities for phonology generated in the current homophone judgment specifically activated the phonological and morphological locations. This is because the MUL pairs required selections from competing phonological information corresponding to a character.

The left IFG is also associated with the phonological segmentation demand (Paulesu et al., 1996; Burton et al., 2000), which is of specific interest to our study. Burton et al. (2000) demonstrated that the initial consonants in their discrimination task, a condition with higher phonological segmentation demand (e.g. dip-ten) induced extensive activation in the left IFG as compared with less demanding segmentation conditions of initial consonant discriminations (e.g. dip-tip). In their experiments, the difference in the vowel (and consonant) following the initial consonant worked unfavorably in the discrimination. In our study, however, the difference in the phonemes worked favorably because they could utilize any of the differences in phonemes, such as in “ten” and “dai,” to judge (non-)homophony. The judgment of the “homophony” in the “ten-dai” in our study was much easier than the judgment of the “difference” of the initial consonant in “dip-ten” in Burton et al. (2000). Segmentation of phonemes could

have also occurred in our study, but more implicitly than in [Burton et al. \(2000\)](#), specifically in the homophonic pairs (MUL\_H and ONE\_H). In these regards, the augmented activation in the IFG, specifically in the MUL\_H, was most likely induced by the demand to select from multiple phonological possibilities, but not necessarily by the segmentation demand.

#### *Other processing of language production*

Activation in the anterior insula appears to be a feature of this homophone judgment study of characters, because involvement of the area has not always been reported in previous alphabetic rhyming tasks. The exception was in an alphabetic letter-rhyming task such as in B and T ([Paulesu et al., 1993](#); [Paulesu et al., 1996](#)). [Paulesu et al. \(1996\)](#) found that people with dyslexia did not activate the left anterior insula during the letter rhyming but non-dyslexics did, suggesting that the area played a role in the connection between the anterior and posterior language areas. Another line of patient studies has shown the area to be related to higher order auditory processing ([Bamiou et al., 2003](#); [Bamiou et al., 2006](#)). A lesion in the anterior insula often induces “apraxia of speech,” a speech articulation disorder ([Dronkers, 1996](#); [Ogar et al., 2006](#); but see [Hillis et al., 2004](#)). Neuroimaging studies also have shown activation in the left anterior insula during overt speech production ([Rumsey et al., 1997](#); [Riecker et al., 2000](#); [Riecker et al., 2005](#); [Bohland and Guenther, 2006](#); [Carreiras et al., 2006](#)). These findings suggest that the left anterior insula is involved in the motor execution of overt speech production. The homophone judgment in the current study, however, as well as in [Kuo et al. \(2004\)](#), did not require vocalization, nor in the letter rhyming in [Paulesu et al. \(1993, 1996\)](#). Taken together, the left anterior insula appears to be involved in, at least, a kind of language sound production process for phonology. Subjects cannot rely on spelling rules in the homophone judgments of characters and letter rhyming; they have to retrieve pronunciation of the characters and to hold the phonological information in the working memory buffer to decide if they are the same. Such a process may evoke some sort of language production such as inner speech ([Loevenbrucka et al., 2005](#)) and/or articulatory planning ([Carreiras et al., 2006](#)). In line with this interpretation, intensive demands on the comparison between similar phonology without vocalization also activated the anterior insula ([Burton et al., 2000](#); [Mechelli et al., 2007](#)). As this area can be associated with traditional Broca's area and “motor word representations” ([Price, 2000](#)), the anterior insula may have a production and/or initiation role, whereas the lateral prefrontal cortex may have a selection and/or inhibition role in language processing. The right anterior insula may play a role in helping the left because it was activated in overt or covert articulation ([Riecker et al., 2000](#); [Kato et al., 2007](#); [Mechelli et al., 2007](#)).

The ACC and pre-SMA have often been associated with response selection and/or inhibition ([Paus et al., 1993](#); [Braver et al., 2001](#); [Nelson et al., 2003](#); [Simmonds et al., 2008](#)). [Kan and Thompson-Schill \(2004\)](#) discussed the functional difference between the ACC and the left IFG, maintaining that whereas the left IFG is associated with the selection on a representational level, the ACC reflects the selection on a response level.

#### *Possible similarities and differences between Japanese and Chinese*

Previous studies not only support our observation but also suggest possible similarities and differences in cortical activation among languages ([Table 5](#), [Fig. 5](#)). The intensive involvement of the MFG might represent a similarity between Japanese and Chinese. The reversed tendencies in the anterior insula and the STG/S between Japanese and Chinese are remarkable. The STG/S, which seems to be more involved in Chinese than in Japanese, has been associated with classical Wernicke's area and “auditory word representations,”

whereas the anterior insula, which seems to be more intensively activated in Japanese, has been associated with Broca's area and “motor word representations” ([Price, 2000](#)). The difference may partly be caused by a “morphology dependent” nature of Japanese. Japanese speakers cannot assign sounds to characters until they understand the contexts; they cannot depend on phonological representations. In such a situation, they may instead develop a strategy to avoid phonological routes including the STG/S, rather than a route including the prefrontal areas intensively. Chinese speakers, however, may be trained to use the posterior route with the STG/S because there is no need to use the prefrontal areas so extensively, as most of their characters have only one candidate for pronunciation. The large amount of syllabic sounds (as compared with Japanese, which has about 100 moras, whereas Chinese has about 400 syllabic sounds) may also further develop the ability for the STG/S in auditory discrimination.

In addition to the above regions, the parietal lobe and the cerebellum are also noteworthy because these regions are involved in verbal working memory (e.g. [Chen and Desmond, 2005](#)), which has a close relationship with the current experimental paradigm. The contrasts of MUL>ONE as well as MUL\_NH>ONE\_NH yielded activity around the intraparietal sulcus ([Fig. 4](#)), which is often found during character processing, specifically writing ([Matsuo et al., 2001](#); [Sugihara et al., 2006](#)). The contrast of MUL\_NH>ONE\_NH also induced activity in the cerebellum, but this time the scan volumes could not be prescribed for the whole cerebellum. The current study provides a foothold to explore the effect of language experience on cortical differentiation and modification. Further examination of the weighted activation patterns in these regions may help to elucidate the language differences not only between Japanese and Chinese but also between alphabetic and character languages.

#### *The ventral visual areas for visual character form processing*

Although both the ONE\_H and MUL\_H conditions activated the bilateral ventral visual areas, activation in the right LG, FG, and PH was augmented during the ONE\_H as compared with the MUL\_H. This was consistent with previous studies by Tan et al. ([Tan et al., 2000](#); [Tan et al., 2001b](#)), where the dominant activation in the right ventral visual areas was thought to suggest an intensive spatial analysis of logographs. Two possible explanations can be provided in our study. One is that the ONE\_H evoked more visual attention to characters than the MUL\_H did. There seems to be no reasonable account, however, for why visual attention would increase specifically during the ONE\_H. Instead, it may be more likely that the hemodynamic response in the right visual areas was lower during the MUL\_H than the ONE\_H, probably as a consequence of the increased demand of the phonology-related areas in the left hemisphere. Recent studies have demonstrated such a “balance” between the activation and deactivation of the brain ([Tomasi et al., 2006](#)). Tomasi and colleagues proposed that fMRI deactivation results as a consequence of the cross-modal inhibition of neural processes by the need for focused attention toward a difficult task that engaged activated regions (“Model 2” of [Tomasi et al., 2006](#)). Applying the model to our current study, the neural process for the visual stimuli in the right ventral areas might be moderated because the MUL\_H requires more sophisticated procedures and attention resources in the left hemisphere. Interestingly, these findings appear to be in accordance with a resting state fMRI study demonstrating intrinsically organized two networks; “task-negative network” that included the ventral areas and “task-positive network” that included the insula/frontal operculum and the pre-SMA ([Fox et al., 2005](#)). Similar phenomena were also found in other language studies in syllable repetitions ([Riecker et al., 2005](#)) as well as in stimuli presentation rate ([Noesselt et al., 2003](#)), showing negative and/or positive correlations of signals according to task demands. These results appear to indicate a kind of attention

modulation; if subjects attend to a certain aspect of language (such as phonological processing), then activation in some other areas unrelated to that aspect is reduced. Details of the mechanism of such hemodynamic balance should be elucidated in future research.

### Limitations of this study

There is a possibility that the increase in activation seen in our main effect of interest, the MUL\_H vs. ONE\_H contrast, could be related to RT effects such as motor inhibition (Leung and Cai, 2007), which are unrelated to language. We, however, concluded that this was not likely in our study according to the following reasons. First, our *post-hoc* analysis using RT as a covariate showed only correlated activations in the MUL\_NH vs. ONE\_NH contrast (Fig. 2b), although a lower threshold ( $p < 0.001$ , uncorrected) induced RT correlated activation for the MUL\_H vs. ONE\_H in the anterior insula. Second, if the increase of the RT was the only cause of the activation in the anterior insula in the MUL\_H > ONE\_H, then the contrast of ONE\_NH > MUL\_H should also produce activation in this region, because the RT was longer in the ONE\_NH than in the MUL\_H (Fig. 2A). But the contrast of ONE\_NH > MUL\_H yielded no activation around the anterior insula (Fig. 2C). A similar pattern was also observed in accuracy performance; although the accuracy was lower in the MUL\_H condition than in the ONE\_NH or MUL\_NH conditions, no activation was found in the contrasts of the MUL\_H > ONE\_NH as well as the MUL\_H > MUL\_NH. With these considerations, we reasoned that the augmented activation in the contrast of MUL\_H > ONE\_H was most likely caused by the multiple pronunciations of the characters and not by non-language aspects of task performance alone. The possible existence of the causality between RT and brain activity in general, however, is beyond the scope of the present study, and should be clarified in future research.

Another limitation of the study is that we were not able to provide a direct comparison between Japanese and Chinese word recognition processes, which would be necessary to form a conclusion on the activation differences between them. Nevertheless, this study provides preliminary implications for future research, specifically in the selection of phonology for a character.

### Summary

We compared two types of Japanese character kanji employing a within-subject design by native Japanese speakers judging the homophony of kanji pairs. One type was heterophonic kanji with multiple sound candidates, which simulated typical Japanese kanji. The other was monophonic kanji with a single sound candidate, which was a simulation of many of characters in Chinese. The contrast of homophonic-heterophonic with homophonic-monophonic kanji pairs induced activation in the left, middle, and inferior frontal gyri, the bilateral anterior insula, and the left anterior cingulate cortex. The results suggested a neural demand when selecting language information of kanji to judge homophony. As an adaptation from alphabetic rhyming tasks, our findings on the homophone judgment of characters will contribute not only to the development of sophisticated diagnoses of language impairments by character users, but also to the understanding of possible neural differentiation and cortical modification through language experiences in their native linguistic environments.

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