Cross-linguistic influence on brain activation during second language processing: An fMRI study*

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The goal of this study was to examine the effect of the linguistic distance between a first language (L1) and a second language (L2) on neural activity during second language relative to first language processing. We compared different L1–L2 pairs in which different linguistic features characterize linguistic distance. Chinese and Korean native speakers were instructed to perform sentence comprehension tasks in two L2s (English and Japanese) and their respective L1s. Activation while understanding English sentences relative to understanding sentences in L1 was greater for the Korean group than the Chinese group in the left inferior frontal gyrus, bilateral posterior superior temporal gyri, and right cerebellum. Activation while understanding Japanese sentences relative to understanding sentences in L1 was greater for the Chinese group than the Korean group in the anterior portion of the left superior temporal gyrus. The results demonstrated that the location of the L2–L1 processing-induced cortical activation varies between different L1–L2 pairs.

Introduction

Several recent neuroimaging studies have investigated the neural circuits of L2 processing. They have mainly focused on whether the neural representation of L2 processing differs from that of L1 processing (see for review Perani and Abutalebi, 2005; Stowe and Sabourin, 2005). The following two general findings have emerged. First, L2 and L1 are likely processed in the same brain network, but the activity of this network may be higher during L2 processing than during L1 processing (Hasegawa, Carpenter and Just, 2002; Perani et al., 2003; Indefrey, 2006). Second, the semantic processing of L1 and L2 may show similar brain activation patterns (Chee, Tan and Thiel, 1999; Rüschemeyer et al., 2005), but the syntactic processing of L1 and L2 (particularly, an L2 learned late) may employ some different neural networks to different degrees (Luke et al., 2002; Wartenburger et al., 2003; Rüschemeyer et al., 2005). These differences in brain activation between L1 and L2 processing have been primarily explained in terms of the age of L2 acquisition (Kim, Relkin, Lee and Hirsch, 1997; Wartenburger et al., 2003), the level of L2 proficiency

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(Dehaene et al., 1997; Perani et al., 1998), and the amount of L2 exposure (Perani et al., 2003).

It seems common sense, and consistent with the psycholinguistic literature (Odlin, 1989; Cenoz, Hufeisen and Jessner, 2001; Gass and Selinker, 2001; Koda, 2005), that the acquisition and processing of an L2 may be influenced by the linguistic similarity and difference between L1 and L2 (i.e., transfer). This cross-linguistic issue is not new to neuroscience research (Vaid, 1983; Paradis, 1989) but has been researched infrequently (Sasanuma and Park, 1995; Sabourin, 2003; Jeong et al., 2007). For example, studies of bilingual aphasics have shown that the structural distance between a patient's two languages affects the patterns of deficit and recovery (Sasanuma and Park, 1995). By measuring event-related potential (ERP), Sabourin (2003) investigated two aspects of syntactic processing (verb feature agreement and syntactic gender agreement) in Dutch. Four groups of subjects participated in that study: Dutch native speakers and English–, Romance– and German–Dutch L2 speakers. Sabourin found that the German–Dutch bilinguals showed brain response patterns similar to those of the Dutch native speakers, despite the similar L2 proficiency level between these three L2 groups. Sabourin argued that differences in the processing of an L2 might have resulted from the structural similarity between L1 and L2 (see also Stowe and Sabourin, 2005).

In a recent neuroimaging study, Jeong et al. (2007) investigated the effect of linguistic distance between L1 and L2 on cortical activation in Korean native speakers who had learned two typologically different L2s (English and Japanese). They found that the brain activation pattern during Japanese sentence processing was similar to that during Korean sentence processing. In contrast, the brain activation during English processing was significantly greater than that during Korean and Japanese processing in several brain areas. These findings were most likely attributable to the linguistic distance between L1 (Korean) and L2 (English and Japanese).

Functional modular systems show a correlation between increased activity in specific cortical areas and the processing of specific linguistic functions (see for review Price, 2000; Friederici, 2002). If the brain activation during L2 sentence processing is influenced by the L1–L2 linguistic distance, brain activation involved in L2 processing may be reflected in different brain regions depending on the linguistic features that differ between L1 and L2. Accordingly, we examined whether the linguistic features that differ between L1 and L2 affect the cortical activation patterns during L2 processing relative to L1 processing. To clarify this issue, we compared two native-speaker groups (Korean and Chinese) who have learned the same L2s (English and Japanese) and controlled the level of L2 proficiency, age of L2 acquisition, and the amount of L2 exposure between the two groups. We investigated brain activation during tasks in which subjects comprehend auditory sentences that consist of only four phrases. We contrasted brain activation (a) during English processing relative to L1 processing, and (b) during Japanese processing relative to L1 processing in the Chinese and Korean native speaker groups. In so doing, we attempted to control possible biographical factors between these two groups.

We predicted differences in brain activation patterns during English-L1 processing between the Korean and Chinese groups. We expected greater activation in cortical areas involved in the processing of word order information in the Korean group than in the Chinese group. The reason for this expectation is that the basic word order and the way to assign the thematic role are more different between English and Korean than between English and Chinese. Syntactically, Chinese and English have Subject–Verb–Object (SVO) basic word order and this word order is generally used to indicate grammatical relationships of sentence constituents (Comrie, 1989). These characteristics contrast with those of Korean, which has the SOV word order. In Korean and Japanese, case particles are used to signal the subject–object relationship in a sentence (Shibatani, 1990; Sohn, 1999). We also predicted activation differences between the Korean and Chinese groups as they processed Japanese, rather than L1, sentences. We expected greater activation in brain areas involved in the processing of morphosyntactic features (e.g., case particle) in the Chinese group than in the Korean groups. This is because case particles do not exist in Chinese whereas they do in Korean. Indeed Korean and Japanese have similar syntactic systems.

Materials and methods

Subjects

Native Chinese and Korean speakers (hereafter called the Chinese and Korean groups, respectively) participated in this experiment. All the subjects have learned two different L2s, namely English and Japanese, after puberty. The Chinese and Korean groups came from mainland China and South Korea, respectively. The Chinese group consisted of 12 healthy right-handed subjects (3 men and 9 women; mean age 26 years; age range 19–35). The Korean group consisted of 18 healthy right-handed subjects (9 men and 9 women; mean age 27 years; age range 22–35). Original data for the Korean group were pooled from a previous study by Jeong et al. (2007). For the current experiment, we selected 18 subjects who had never lived in an English-speaking country from the 30 subjects who participated in the previous study by Jeong et al. (2007). All the subjects applied to participate in this study through a website that described the language requirements for participation.

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The application process included an evaluation using a background screening questionnaire. The educational and linguistic backgrounds and proficiency levels for each L2 were similar between the two groups. The Chinese and Korean groups had not lived outside China and Korea, respectively, before the age of 10. The Chinese and Korean groups started learning English at average ages of 12.1 years ($SD = 1.2$) and 12.7 years ($SD = 1.0$), respectively. The Chinese and Korean groups started learning Japanese at average ages of 20.0 years ($SD = 3.4$) and 21.3 years ($SD = 2.4$), respectively. Thus, the ages at which each group learned English and then Japanese were comparable.

The subjects had never been to an English-speaking country but at the time of this experiment, both the Korean and Chinese subjects were pursuing their degrees in Japan. They had been also exposed to Japanese in informal settings. The mean lengths of stay in Japan for the Chinese and Korean groups were 23.9 months (length of stay range 2–60; $SD = 19.2$) and 18.9 months (length of stay range 1–48; $SD = 14.5$), respectively. We assessed their proficiency in both Japanese and English using the level 2 Japanese Language Proficiency Test (JLPT) and the level 2 Society for Testing English Proficiency (STEP) test, respectively. JLPT is administered by Japan Education Exchanges and Service, and STEP is authorized by the Japanese Ministry of Education, Culture, Sports, Science, and Technology. The English proficiency test (STEP) scores were similar between the Chinese (90.4%, $SD = 6.5$) and Korean (90.9%, $SD = 7.3$) groups. The Japanese proficiency test (JLTP) scores were similar between the Chinese (89.8%, $SD = 5.0$) and Korean (93.0%, $SD = 5.0$) groups. There were no statistically significant differences in the factors examined (i.e., age of L2 acquisition, level of L2 proficiency, amount of L2 exposure) between the Chinese and Korean groups (all *t*-tests, $p > 0.1$). We evaluated handedness using the Edinburgh Handedness Inventory (Oldfield, 1971). None of the subjects had a history of neurological or psychiatric diseases. We obtained written informed consent from each subject.

Stimuli

We used the auditory sentences previously used by Jeong et al. (2007) as stimuli. Chinese sentences were translated from Japanese and English sentences. Below is a sample set of sentenes:

(1) *English* John met the teacher at school.

(2) *Japanese*

Tarou-wa	gakkou-de	sensei-to	a-tta.
Tarou-TOPIC	school-at	teacher-with	meet-PAST

(3) *Korean*

Chelswu-nun hakkyo-eyse

Chelswu-TOPIC school-at

sensayngnimkwa manna-ss-ta.

teacher-with meet-PAST

(4) *Chinese*

Zhāngsān zài xuéxiào jiàn-le lǎoshī.

Zhāngsān at-school meet-PERFECT teacher

Each sentence consisted of four phrases comprising high-frequency words. All stimuli consisted of active sentences whose grammatical subject is the name of a person. We digitally recorded (16 bit, 44.1 kHz) the sentences, which were read by a female native speaker of each language. The mean duration of the sentences was 2.7 seconds ($SD = 0.18$). We adjusted the mean amplitude of all the sentences across the three languages using MATLAB (the Math Works, Natick, MA). For the baseline condition, we prepared a white noise stimulus with the same mean amplitude and duration as a typical sentence stimulus. To avoid interference from the scan noise of magnetic resonance imaging (MRI) machine, we presented each auditory stimulus during an inter-scan interval of three seconds.

Task design

As shown in Figure 1, each block consisted of five trials of a task, followed by four trials under the baseline condition, with inter-trial intervals of 5 s. In one trial, one sentence was presented for 3 s to the subjects, followed by 2 s for their response. Three blocks (one for each language) comprised a triplet, which was repeated eight times during an fMRI session of 1,115 s. The order of the languages in the triplets was counterbalanced across the subjects. Each subject was instructed to listen to the sentences via headphones and then to press one of two buttons within 2 s with their thumb to indicate whether or not they understood the sentences. Under the baseline condition, each subject was required to press the button after listening to each presentation of the white noise stimulus. During fMRI, the subjects were instructed to fix their gaze on a cross presented at the center of the visual field on the screen, and to avoid any vocalization or body movement. After the scanning, we interviewed the subjects and confirmed that all of them were able to understand all the stimuli. Note that the task design for this experiment was exactly the same for the Chinese and Korean groups. The only difference was in the L1materials.

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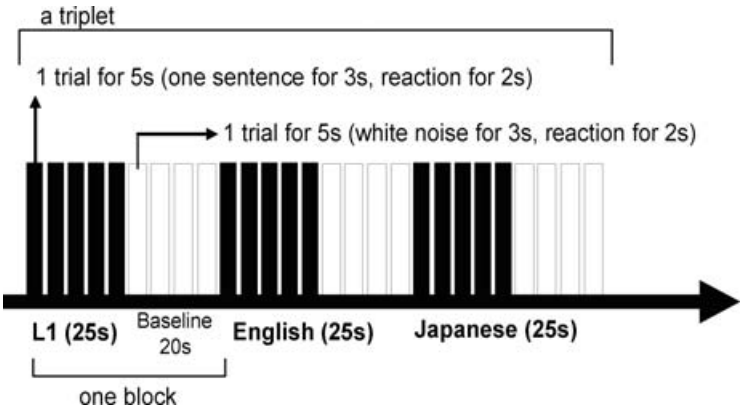


Figure 1. Task design in this fMRI experiment.

Data acquisition and pre-processing

We conducted a series of experiments separately for the Korean group and Chinese group in different institutes (Tokyo and Sendai), but used the same MRI machine (1.5T Siemens Symphony, Erlangen, Germany). Twenty-one transaxial slices (slice thickness = 6 mm, gap = 0 mm) covering the entire brain were acquired using a gradient–echo–planar sequence (TR = 5000 ms, TE = 50 ms, TD = 3000 ms, acquisition time = 2000 s, flip angle = 90°, FOV = 256 mm, voxel size = 4×4 mm, matrix = 64 × 64). Excluding the initial three dummy scans obtained to equilibrate the state of magnetization, a total of 223 EPI volumes were acquired. A T1-weighted structural image was also acquired for each subject (192 slices, slice thickness = 1.0 mm, slice gap = 1.0 mm, TR = 2200 ms, TE = 3.93 ms, FOV = 256 mm). The fMRI data obtained were pre-processed using SPM2 software (Wellcome Department of Cognitive Neurology, University College of London, UK). Pre-processing included slice timing adjustment, correction for head movements, spatial normalization using T1-weighted anatomical images, and smoothing with a 12 mm FWHM Gaussian filter.

Statistical analysis

We adopted a conventional two-level approach in fMRI data analysis. For each subject in the Chinese and Korean groups, we applied a voxel-by-voxel multiple regression analysis of the expected signal changes to the pre-processed images for the four conditions: L1 (Chinese or Korean), English, Japanese and the baseline. For this analysis, we employed a standard box-car convolution model using the hemodynamic response function provided by SPM2. We then performed a statistical inference on the contrasts of parameter estimates with a second-level between-subjects (random effects) model, using the one-sample t-test.

We first analyzed the L1, Japanese, and English conditions and compared them with the baseline condition in each group (Korean and Chinese). The activation revealed by these contrasts reflected neural activation during the processing of each language in each group. Then, to extract the neural activation during the processing of L2 relative to that of L1 in each group, we carried out direct comparisons of brain activation (a) between English and L1 processing conditions and (b) between Japanese and L1 conditions. The direct contrast of brain activation between L2 and L1 conditions was masked by the corresponding L2 – baseline contrast. Assuming a search area encompassing the entire brain, the statistical threshold in the voxel-wise analysis was set at $p < 0.001$ and corrected to $p < 0.05$ for multiple comparisons in the cluster size (using $p < 0.05$ for height for the masks). The resulting activation maps were superimposed on the mean normalized T1-weighted MR images of each group.

To compare differential L2–L1 activation between the Chinese and Korean groups, we performed region of interest (ROI) analysis in each of the local maxima of the activated areas in the L2–L1 contrast in each group. To investigate the effect of exposure to L2, we analyzed the correlation analysis between the brain activation during Japanese sentence processing and the length of stay in Japan at each of the local maxima of all the activated areas in the L2–L1 contrast. In the ROI analysis, we tested the significance of differences at a region-level threshold ($p < 0.05$, without correction for multiple comparisons).

Note that we could validate the results of ROI analysis because we did not find any statistically significant differences in the parametric estimates of the peak of brain area activity between the Chinese and Korean groups during the L1 sentence comprehension task. Therefore, the effects of using different MRI machines in two different places could be negligible.

Results

Behavioural data

The comprehension rates during the fMRI experiment were high under all conditions (the Chinese group:

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Chinese 98.8%, $SD = 1.4$; English 98.5%, $SD = 1.5$; Japanese 98.6%, $SD = 1.6$; the Korean group: Korean 99.0%, $SD = 1.5$; English 98.2%, $SD = 1.5$; Japanese 98.8%, $SD = 1.9$). After the experiment we also interviewed the subjects and concluded that they had understood all the sentences.

fMRI results

Table 1 shows a significant brain activation under each condition in contrast to the baseline condition in the Chinese group (see Figure 2a, b and c). We found a significant activation in the left superior, middle temporal gyrus and right superior temporal gyrus under L1 and L2 conditions compared with the baseline. Under the Japanese and English conditions, the pars opercularis of the inferior frontal gyrus (IFG) and the precentral sulcus were also activated. We also found a significant activation in the medial part of the superior frontal gyrus during the English task.

Table 2 shows a significant activation under each condition in contrast to the baseline condition in the Korean group (see Figure 2d, e and f). We found a significant activation in the left superior, middle temporal gyrus and right superior temporal gyrus under L1 and L2 conditions compared with the baseline condition. An additional activation was found in the medial superior frontal gyrus and the left inferior frontal gyrus only under the English condition.

Table 3 shows the results of the direct comparison between the English and L1 conditions in the Chinese and Korean groups. In the Chinese group, a significant activation was found in the medial superior frontal gyrus, left precentral sulcus, left pars opercularis of IFG, left insula, and left caudate. In the Korean group, we observed a significant activation in the bilateral superior temporal gyrus, left medial superior frontal gyrus, pars opercularis and pars triangularis of the left IFG, left caudate, right IFG, and right cerebellum.

Table 4 shows the results of the direct comparison of cortical activation between the Japanese and L1 conditions in the Chinese and Korean groups. In the Chinese group, a significantly strong activation was found in the left anterior portion of superior temporal gyrus. On the other hand, there were no significant differences in the Korean group.

In the ROI analysis, the Korean group showed a significantly stronger differential English-L1 activation than the Chinese group in the bilateral posterior superior temporal gyrus, left inferior frontal gyrus (two peaks out

Table 1. *Activation during each language task in contrast to that under the baseline condition in the Chinese group.*

	Talairach coordinates (mm)			
Structure	*x*	*y*	*z*	*t* value (cluster size)
Chinese vs. baseline				
Left superior/middle temporal gyrus	−66	−34	2	12.2 (1472)
	−56	−12	0	10.61 (1472)
Right superior temporal gyrus	58	−26	2	10.13 (1175)
Japanese vs. baseline				
Left superior/middle temporal gyrus	−62	−18	−2	14.31 (2060)
	−56	−4	−6	10.35 (2060)
Left precentral area	−48	2	46	13.44 (765*)
Left inferior frontal gyrus	−50	10	20	8.13 (765*)
Right superior/middle temporal gyrus	64	−12	6	13.86 (1148)
	66	−28	−4	7.38 (1148)
English vs. baseline				
Left superior /middle temporal gyrus	−62	−18	2	10.77 (1804)
	−66	−26	4	9.42 (1804)
Left medial part of superior frontal gyrus	−6	10	66	8.61 (341)
Left precentral area	−54	−6	50	10.40 (2242)
	−46	10	36	8.17 (2242)
Left inferior frontal gyrus	−44	6	28	7.57 (2242)
Right superior/middle temporal gyurs	60	−10	6	8.97 (1320)
	68	−24	−8	7.64 (1320)

Note: Talairach coordinates (x, y, z), t value of peak activation, cluster size and value in the same contrast for the other group at the same voxel are shown. * indicates the peak is involved in the same cluster.

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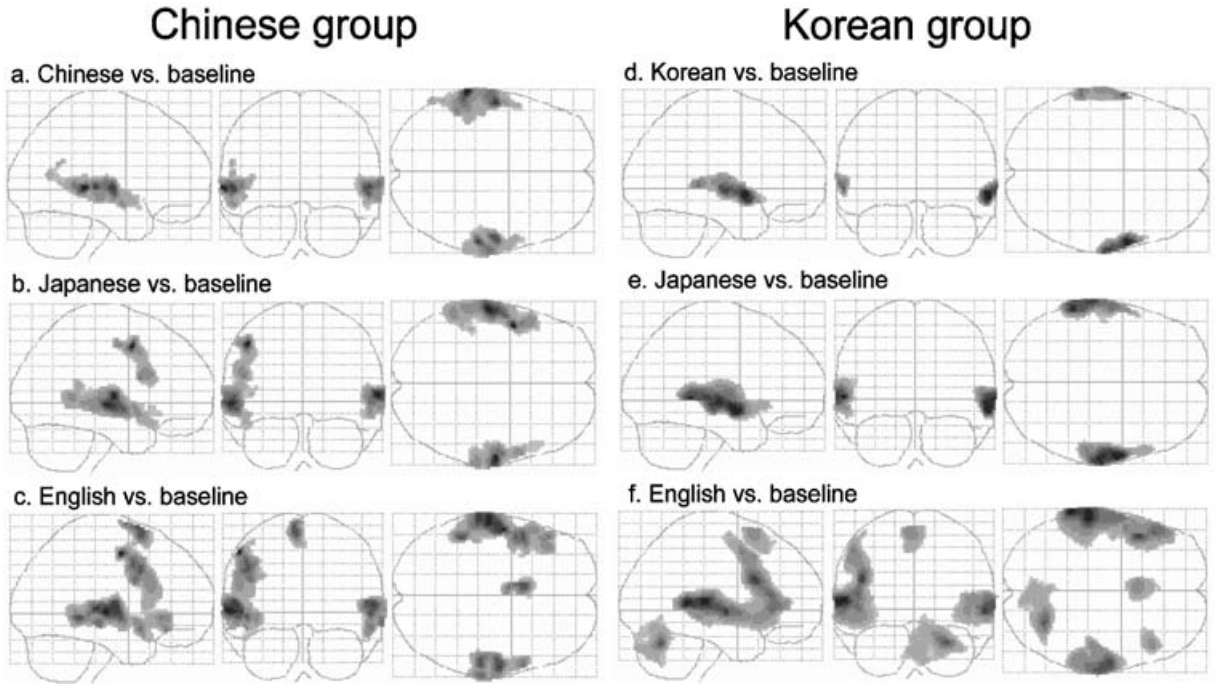


Figure 2. Images showing brain areas significantly activated during each language task in Chinese and Korean groups. Statistical parametric maps in glass-brain presentation for each task in Chinese (a, b, c) and Korean (d, e, f) groups.

Table 2. *Activation during each language task in contrast to that under the baseline condition in the Korean group.*

	Talairach coordinates (mm)			
Structure	*x*	*y*	*z*	*t* value (cluster size)
Korean vs. baseline				
Left superior/middle temporal gyrus	−62	0	0	5.47 (415*)
	−64	−36	2	5.09 (415*)
Right superior temporal gyrus	62	2	−6	6.85 (439)
Japanese vs. baseline				
Left superior/middle temporal gyrus	−60	−42	2	8.64 (1176*)
	−62	−10	4	6.51 (1176*)
Right superior/middle temporal gyrus	62	−2	−8	9.31 (1246†)
	66	−24	−4	7.94 (1246†)
English vs. baseline				
Left superior/middle temporal gyrus	−66	−42	6	11.10 (5358*)
	−62	−28	6	10.92 (5358*)
Left medial part of superior frontal gyrus	−6	14	66	6.25 (571)
Left inferior frontal gyrus	−44	16	24	9.52 (5358*)
Right inferior frontal gyrus	46	26	−2	5.99 (462)
Right superior/middle temporal gyrus	60	−10	−2	9.16 (1810†)
	60	−40	2	6.55 (1810†)
Right cerebellum	28	−66	−28	8.16 (1646)

Note: Talairach coordinates (*x*, *y*, *z*), *t* value of peak activation, cluster size and value in the same contrast for the other group at the same voxel are shown. * and † indicate the peak is involved in the same cluster.

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Table 3. *Activation during English task relative to L1 task in each group.*

Structure	*x*	*y*	*z*	*t* value (cluster size)	*t* value for the other group
Chinese group					*Korean group*
Left medial superior frontal gyrus	−4	14	54	6.19 (313)	3.73
Left precentral sulcus	−38	−2	34	8.32 (273)	2.47
Left inferior frontal gyrus (pars opercularis)	−52	14	6	6.05 (70)	2.89
Left insula	−30	28	10	5.71 (240)	2.71
Left caudate	−16	−18	22	5.88 (110)	3.68
Korean group					*Chinese group*
Left superior temporal gyrus	−48	−34	8	6.98 (936)	n.s.
Left medial superior frontal gyrus	−4	12	64	5.67 (640)	3.28
Left inferior frontal gyrus (pars opercularis)	−40	14	28	6.16 (696*)	1.61
Left inferior frontal gyrus (pars triangularis)	−54	30	8	5.12 (696*)	0.72
Left caudate	−12	−6	22	5.66 (1518)	2.87
Right superior temporal gyrus	64	−30	4	5.83 (410)	n.s.
Right inferior frontal gyrus	44	26	2	5.31 (499)	n.s.
Right cerebellum	16	−56	−34	5.38 (1124)	n.s.

Note: Talairach coordinates (*x*, *y*, *z*), *t* value of peak activation, cluster size and *t* value in the same contrast for the other group at the same voxel are shown. * indicates the peak is involved in the same cluster.

Table 4. *Activation during Japanese task relative to L1 task in each group.*

Structure	*x*	*y*	*z*	*t* value (cluster size)	*t* value for the other group
Chinese group					Korean group
Left superior temporal gyrus	−64	−14	0	4.90 (94)	n.s.
Korean group				Non-significant activation	

Note: Talairach coordinates (*x*, *y*, *z*), *t* value of peak activation, cluster size and *t* value in the same contrast for the other group at the same voxel are shown.

of three), right inferior frontal gyri, and right cerebellum (see Figure 3). A significantly stronger English-L1 activation in the Chinese group than in the Korean group was not found in any brain area (see Figure 3). Differential Japanese-L1 activation in the anterior portion of the superior temporal gyrus was significantly stronger in the Chinese group than Korean group (see Figure 4). A significant negative correlation was found between activation in the left caudate during Japanese sentence processing and the length of stay in Japan (−16, −18, 22: $r = -0.42$, $p < 0.05$) for the Chinese group (see Figure 5). However, such a correlation was not observed for the Korean group.

Discussion

We observed significantly greater English-L1 activation in the Korean group than in the Chinese group in the bilateral posterior superior temporal gyri, left inferior frontal gyrus, right inferior frontal gyrus, and right cerebellum. However, significantly greater Japanese-L1 activation was observed in the anterior portion of the superior temporal gyrus in the Chinese group only. These findings are consistent with our assumption that L2-related activation depends on linguistic features that differ between L1 and L2.

Areas showing English-L1 activation in Korean group

Two out of the three activation peaks in BA44 and BA45 within the left inferior frontal gyrus showed a significantly greater differential English-L1 activation in the Korean group than in the Chinese group. There is consensus based on previous neuroimaging studies that increased efforts necessary for syntactic processing produce a strong activation in the inferior frontal gyrus (see for review Bookheimer, 2002; Stowe, Haverkort and Zwarts, 2005). The left inferior frontal gyrus (BA44/45)

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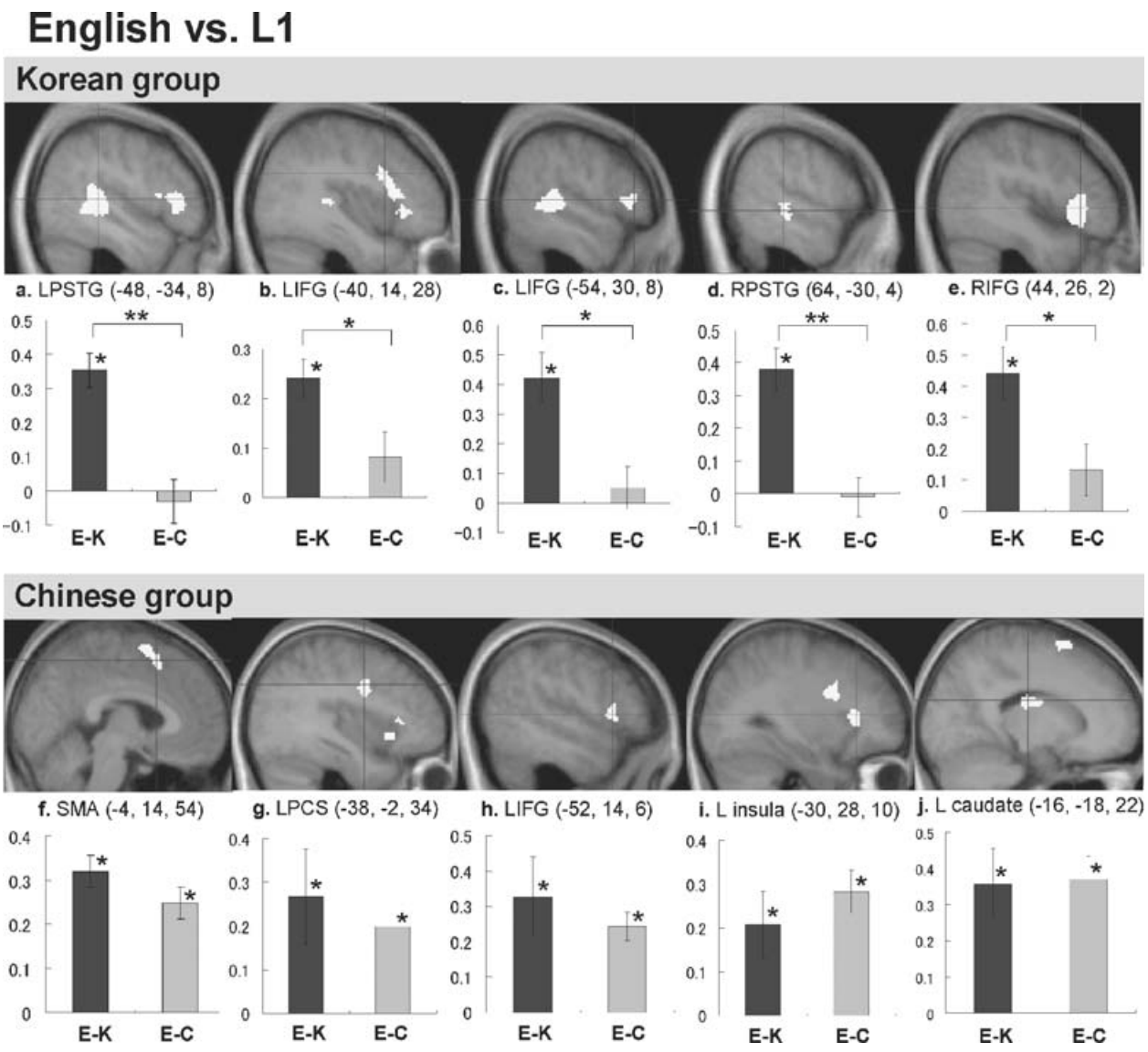


Figure 3. Images showing differential activation during English vs. L1 processing in each group. Activation is superimposed on the sagittal slices of the mean normalized T1-weighted MR images of all the subjects in each group. Activation was thresholded at $p < 0.001$ in all the contrasts, and corrected to $p < 0.05$ for multiple comparisons using the cluster size for mean activation only. In the upper image, areas that showed a significant difference in English–Korean contrast are presented: a. left posterior superior temporal gyrus; b. left inferior frontal gyrus; c. left inferior frontal gyrus; d. right posterior temporal gyrus; e. right inferior temporal gyrus. In the bottom image, areas that showed a significant difference in English–Chinese contrast are presented: f. superior frontal gyrus (supplementary motor area); g. left precentral sulcus; h. left inferior frontal gyrus; i. left insula; j. left caudate. For each activation peak, activation profiles (differential parameter estimates English–Korean (E–K), and English–Chinese (E–C)) are shown at the bottom. Error bars indicate standard error of the mean (SEM). Note. *: $p < 0.05$.

has been implicated in the processing of syntactically complex sentences (Just et al., 1996; Stromswold et al., 1996; Caplan, Alpert and Waters, 1998) and word order permutation (Fiebach, Schlesewsky and Friederici, 2001; Röder et al., 2002; Ben-Shachar, Palti and Grodzinsky, 2004), and selective attention to syntactic structures (Friederici, Meyer and von Cramon, 2000). Furthermore, recent studies showed that activity in the left inferior frontal gyrus (particularly the pars opercularis: BA44) increases when subjects assigned thematic roles (e.g., Actor, Undergoer) in sentences through word order information (Bornkessel et al., 2005). Activation in the left posterior superior temporal gyrus and right cerebellum is also observed, as well as in the left inferior frontal gyrus, when sentence complexity or syntactic processing load increases (Röder et al., 2002; Ben-Shachar et al., 2004;

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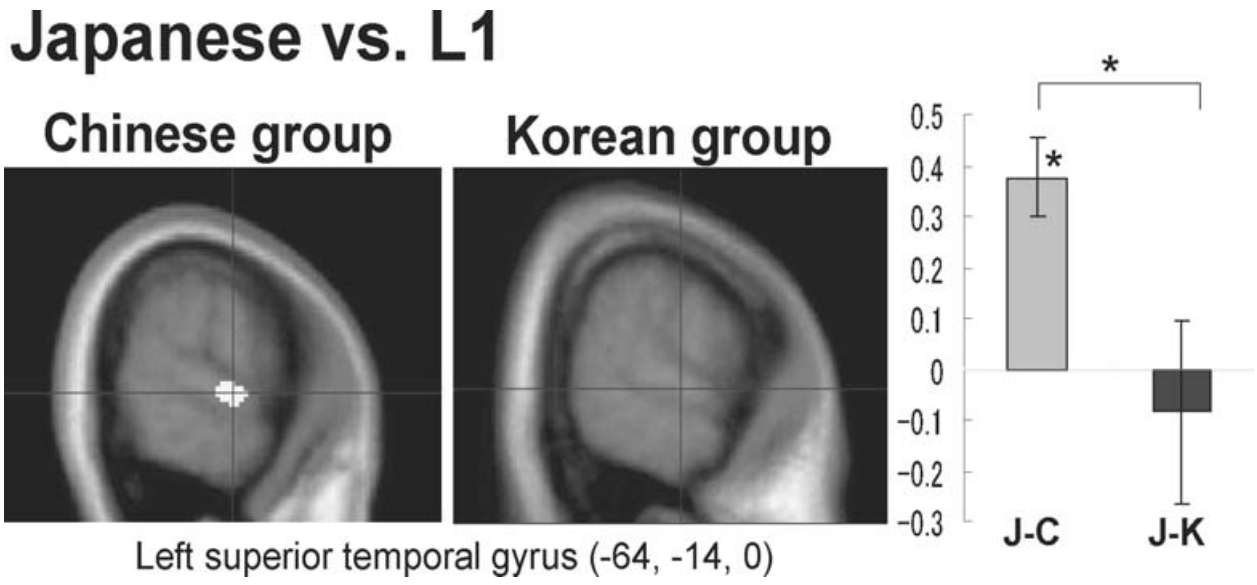


Figure 4. Images showing differential activation during Japanese vs. L1 processing in each group. Activation is superimposed on the sagittal slices of the mean normalized T1-weighted MR images of all the subjects in each group. Activation was thresholded at $p < 0.001$ in all the contrasts, and corrected to $p < 0.05$ for multiple comparisons using the cluster size for mean activation only. Areas that showed a significant difference in Japanese–Chinese contrast are presented: left superior temporal gyrus. Activation profiles (differential parameter estimates Japanese–Chinese (J–C), and Japanese–Korean (J–K)) are shown on the right. Error bars indicate standard error of the mean (SEM). Note. *: $p < 0.05$

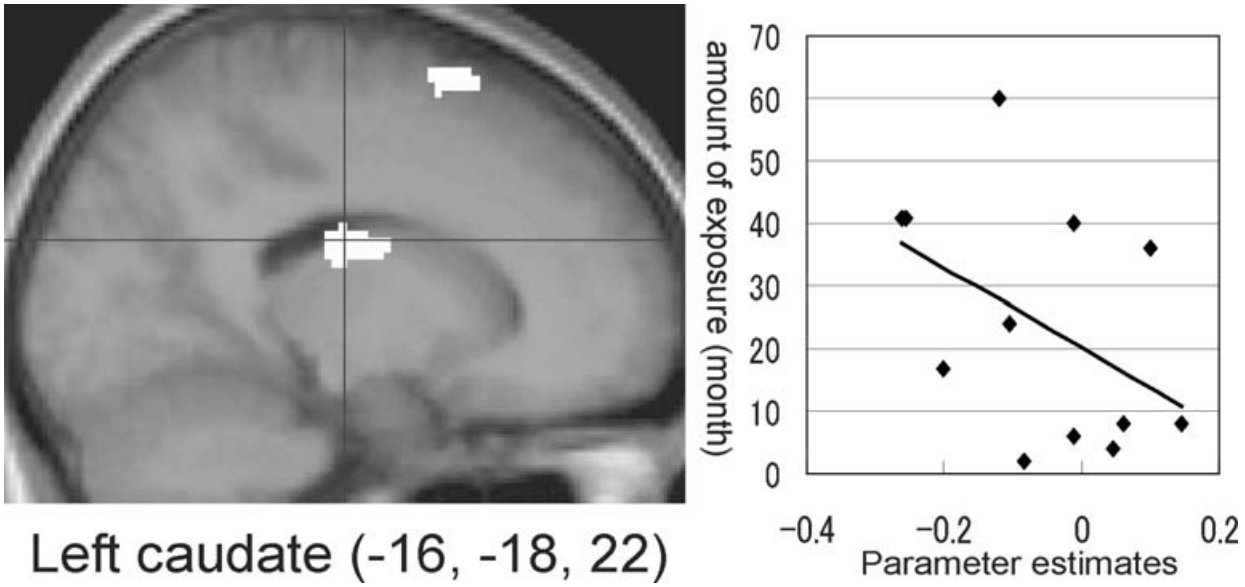


Figure 5. Figure shows the result of correlation analysis between the length of stay in Japan and the means of parameter estimates of the Japanese – baseline contrast. Significant correlation between brain activation during the Japanese comprehension task and the length of stay in Japan was found in the left caudate for the Chinese group (−16, −18, 22; $r = -0.42$, $p < 0.05$).

Stowe et al., 2004). Following these lines of neuroimaging evidence, a greater differential English-L1 activation in the Korean than Chinese groups might have occurred because the Korean group required more effortful word order processing during English sentence comprehension than did the Chinese counterpart. As described earlier, Korean is different from English in terms of word order and in the way thematic role is assigned in a sentence.

The differential English-L1 activation in the right posterior superior temporal gyrus and the right inferior

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frontal gyrus was also stronger in the Korean group than in the Chinese group. It is suggested that the right hemisphere is involved in speech prosody perception (Zatorre et al., 1992; Johnsrude, Penhune and Zatorre, 2000; Gandour et al., 2004; Meyer et al., 2004). The right posterior superior temporal gyrus has been implicated in the processing of pitch contour information or speech melody (Johnsrude et al., 2000; Meyer et al., 2004). The right inferior frontal gyrus is also sensitive to auditory attention that modulates pitch perception (Klein et al., 2001; Gandour et al., 2004). Phonological cues (e.g., stress in English; tone and pitch in Chinese) may be more important in comprehending sentences in English and Chinese than Korean (Jun, 2005). Taken together, differential English-L1 activation in the right temporal frontal network observed in this study may indicate an increase in cognitive demands necessary for the Korean subjects to process English phonological information (e.g., intonation and stress).

Area showing Japanese-L1 activation in Chinese group

Differential Japanese-L1 activation was observed only in the anterior portion of the superior temporal gyrus in the Chinese group. The anterior portion of the superior temporal gyrus has been shown to play an integral role in morphosyntactic processing (Dronkers et al., 2004; Rüshemeyer et al., 2005) during auditory sentence comprehension. Chinese does not have morphosyntactic features that indicate grammatical functions and relationship among sentence constituents. Therefore, activation observed in this area reflects an increase in cognitive demands necessary for Chinese subjects to process Japanese morphosyntactic features.

An alternative explanation for the differential Japanese-L1 activation in this area is that the Chinese group might have kept track of word order in Japanese, which is different from that in Chinese. In a Japanese and a Korean sentence, the verb is located in the final position of the sentence, whereas the verb precedes the grammatical object in Chinese. This explanation is supported by the review of Friederici and Kotz (2003) the anterior portion of the superior temporal gyrus is associated with the processing of the phrase structure. Therefore, activation observed in the anterior portion of the superior temporal gyrus may reflect an increase in cognitive demands necessary for Chinese subjects to process the Japanese syntactic structure, which differs from their L1.[1]

Areas commonly showing English-L1 activation in Korean and Chinese groups

In both the Chinese and Korean groups, activity in the left insula, left precentral sulcus, left medial superior frontal area (supplementary motor area), and left caudate increased to a greater extent during the English task than during their respective L1 tasks. Previous bilingual neuroimaging studies showed that these brain areas may be involved in L2 acquisition and processing for late L2 learners (Chee et al., 2004; Crinion et al., 2006; Gandour et al., 2007). The left insula is associated with phonological working memory in L2 acquisition (Chee et al., 2004). The medial part of the superior frontal gyrus and the left insula are involved in articulatory rehearsal (Paulesu, Frith and Frackowiak, 1993) or L2 phonetic processing (Gandour et al., 2007). The left precentral sulcus is involved in auditory attention (Shaywitz et al., 2001). The left caudate, as Ullman (2005) suggested, is associated with procedural memory for rule-based L2 learning. Recently, Crinion et al. (2006) have reported that the left caudate is sensitive to a change in the language in use, suggesting that this area plays an important role in monitoring and controlling two languages. Based on these previous findings, our findings suggest that the Chinese and Korean subjects might have equally employed these brain areas during phonetic processing or articulatory rehearsal in English. In contrast, Japanese-L1 activation did not produce any significant differences in these brain areas for the Chinese and Korean groups. This may be caused by the fact that our subjects had been living in Japan at the time of this experiment, while they had never lived in English speaking countries. In other words, the effect of L2 exposure might have played a role in determining brain activation during L2 processing. We will discuss this issue below.

Effects of the amount of L2 exposure on brain activation during L2 processing

Both the Chinese and Korean subjects had been living in Japan at the time of this experiment. One might question whether the amount of L2 exposure affects cortical activation during L2 processing as demonstrated in previous studies (Perani et al., 2003; Jeong et al., 2007). The correlation analysis revealed a significant negative correlation between brain activation during Japanese processing in the left caudate and the length of stay in Japan for the Chinese group. That is, the longer Chinese subjects stayed in Japan, the less activated the

[1] There were no differences in activation patterns between Korean and Japanese comprehension tasks in the Korean group although the Korean subjects started learning Japanese after puberty (i.e., at 21.3 years on average). This finding seems inconsistent with that of previous neuroimaging studies (Kim et al., 1997; Hasegawa et al., 2002; Luke et al., 2002): processing of a late-learned L2 requires greater activation than that of L1. However, we argue that when L1 (e.g., Korean) and L2 (e.g., Japanese) are linguistically similar to each other, L2 processing may draw on efficient linguistic systems used for L1 processing. As a result, the contrast between Korean and Japanese did not produce any significant differences in brain areas activated (see Jeong et al., 2007 for details).

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left caudate was. However, there was no such correlation in the Korean group. Previous neuroimaging studies showed that the left caudate may play a role in controlled syntactic processing (Moro et al., 2001; Friederici et al., 2003) or controlling two languages (Crinion et al., 2006). Therefore, this contrasting finding between the Chinese and Korean groups suggest that the effect of L2 exposure may affect brain areas differently depending on the extent to which L1 linguistic properties are different from those of L2 (see also Jeong et al., 2007). That is, the amount of L2 exposure may play a less important role in determining cortical activation when L2 is typologically similar to L1 than when L2 is distant from L1. In the latter case, the effect of L2 exposure may strongly influence brain activation during L2 processing. Further neuroimaging research should clarify interactions between cross-linguistic difference and the amount of L2 exposure.[2]

Summary, limitations, and further inquiries

In this study, we demonstrated that the pattern of activation in a particular L1–L2 pair depends on a specific pattern of linguistic differences. The contrasts between English and subjects' respective L1s showed greater activation for the Korean group in the left inferior frontal gyrus, bilateral posterior superior temporal gyri, right inferior frontal gyrus and right cerebellum than for the Chinese group. The contrast between Japanese and L1 showed greater activation for the Chinese group only in the left anterior portion of the superior temporal gyrus. These differences in activation patterns might have been caused by linguistic similarities and differences between L1 and L2. They are not explicable in terms respective L2 learning background, age of L2 acquisition, L2 proficiency level, and amount of L2 exposure, which did not differ between the Chinese and Korean groups. We, therefore, argue that typologically more divergent L1–L2 pairs may increase brain activation during L2 sentence processing than similar L1–L2 pairs. Moreover, specific brain areas may be selectively engaged, at least partly, in processing L2 sentences, depending on the similarities and differences between L1 and L2.

The current study was limited in several ways. The results were obtained using an auditory comprehension task composed of simple sentences with high-frequency words. Therefore, the findings may not generalize to tasks such as those consisting of complex sentences or low-frequency words. The unique educational background of a particular L2 learner in a particular ethnic group may also affect cortical activation. A comparison of activation in many L1–L2 pairs as well as in many ethnic groups is important to clarify the relationship between cortical activation and a specific linguistic attribute. Further neuroimaging studies should examine different types of linguistic structures using various L1–L2 pairs. Nonetheless, this study shows that cross-linguistic differences between L1 and L2 are important in accounting for that the patterns of brain activation during L2 processing.

[2] The age of acquisition and the amount of exposure differ between English and Japanese in both groups. One may suspect that this difference might explain the differences in activation patterns between the English (L2) – Korean (L1) and Japanese (L2) – Chinese (L1) contrasts. However, we consider that this is not the case because the differences should affect each L2 processing in both groups; that is, the effect of the age of L2 acquisition and the amount of L2 exposure on brain activation during L2 processing should be cancelled between two groups, and not appear in the results of group comparisons.

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