Effect of Syntactic Similarity on Cortical Activation During Second Language Processing: A Comparison of English and Japanese among Native Korean Trilinguals

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Abstract: In this study of native Korean trilinguals we examined the effect of syntactic similarity between first (L1) and second (L2) languages on cortical activation during the processing of Japanese and English, which are, respectively, very similar to and different from Korean. Subjects had equivalent proficiency in Japanese and English. They performed auditory sentence comprehension tasks in Korean, Japanese, and English during functional MRI (fMRI). The bilateral superior temporal cortex was activated during the comprehension of three languages. The pars triangularis of the left inferior frontal gyrus (IFG) was additionally activated for L2 processing. Furthermore, the right cerebellum, the pars opercularis of the left IFG, and the posteromedial part of the superior frontal gyrus were activated during the English tasks only. We observed significantly greater activation in the pars opercularis of the left IFG, the right cerebellum, and the right superior temporal cortex during the English than Japanese task; activation in these regions did not differ significantly between Korean and Japanese. Differential activation of the pars opercularis of the left IFG and the right cerebellum likely reflects syntactic distance and differential activation in the right superior temporal cortex may reflect the prosodic distance between English from Korean and Japanese. Furthermore, in the pars opercularis of the left IFG and the right cerebellum, significant negative correlation between the activation and duration of exposure was observed for English, but not for Japanese. Our research supports the notion that linguistic similarity between L1 and L2 affects the cortical processing of second language. *Hum Brain Mapp* 28:194–204, 2007. © 2006 Wiley-Liss, Inc.

Key words: second language processing; syntactic similarity; fMRI

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INTRODUCTION

Syntactic properties that differ from language to language constrain the cognitive mechanisms involved in sentence comprehension and production [Bates and MacWhinney, 1989]. It is, therefore, not surprising that the acquisition and processing of a second or additional language is influenced by the linguistic similarity of the first (L1) and second (L2) languages [Gass and Selinker, 2001; Oldlin, 1989; Ramat, 2003]. Furthermore, the studies of bilingual aphasics have shown that in addition to such factors as the site and size of lesions and the history of the patient's linguistic experience, the structural distance between the patient's two languages influences the patterns of deficit and recovery [Sasanuma and Park, 1995].

So far, neuroimaging studies have shown that both age of L2 acquisition [Kim et al., 1997] and L2 proficiency [Perani et al., 1998] are major determinants of L2 cortical representation [see Perani and Abutalebi, 2005, for a recent review]. For example, Kim et al. [1997] showed that the regions in Broca's area activated during production tasks in L1 and L2 overlapped completely in early bilinguals, but differed in late bilinguals [see also Wartenburger et al., 2003]. Furthermore, Perani et al. [1998] found that changes in the strength of brain activation (particularly in the posterior language cortex) were more strongly related to subjects' L2 proficiency than to age of acquisition.

However, a few researchers have examined the effect of linguistic similarity on L2 cortical representation or the neural correlates of typological differences between L1 and L2 among bilinguals or trilinguals [Chee et al., 1999, 2001; Klein et al., 1999; Pu et al., 2001]. These studies comparing cortical representations between two typologically different languages (i.e., English and Chinese) have so far provided no evidence of a differential effect of linguistic distance. Klein et al. [1999] and Pu et al. [2001] investigated the word-level task of late bilinguals [see also Chee et al., 2001], while Chee et al. [1999] examined the sentence-level task of early bilinguals. However, limited studies have examined sentence processing of late bilinguals. Considering the fact that lexical and syntactic information is processed in distinct neural systems [Ullman, 2001], and the importance of the age of L2 acquisition for L2 cortical representation [Perani and Abutalebi, 2005], a possible effect of linguistic distance on cortical activation during sentence processing by late bilinguals is worth examination. Indeed, for late bilinguals different activation patterns between L1 and L2 processing were observed when the task adopted sentence processing [Dehaene et al., 1997; Hasegawa et al., 2002; Kim et al., 1997; Luke et al., 2002; Nakai et al., 1999; Perani et al., 1996], but not word processing, presumably because sentence processing additionally requires syntactic processing. In this study,

accordingly, we compared cortical activation during sentence comprehension between L1 and typologically different L2s using Korean trilinguals who learned English and Japanese after adolescence.

Cross-linguistic research shows that Japanese is typologically very similar to Korean, while English is very different from both Korean and Japanese [Shibatani, 1990]. First, both Korean and Japanese have a basic subject-object-verb (SOV) word order, while permitting a high degree of freedom in word order. This pattern contrasts with English, which employs a relatively fixed subject-verb-object (SVO) word order system. Second, Korean and Japanese mark noun phrases, including subject and object noun phrases, with specific case particles, allowing noun phrases to be omitted if they are contextually recoverable. English, by contrast, relies on word order to signal the subject-object relationship, and therefore does not readily allow for noun phrase omission. Third, Korean and Japanese are left-branching languages; that is, in both languages adpositions typically follow nouns, nouns follow relative clauses, and an auxiliary verb follows the main verb. In English, a right-branching language, the order of these constituents is reversed. Finally, Korean and Japanese are agglutinative languages, in which morphemes combine to form morphologically complex words, whereas English is largely an isolating language, in which words typically consist of a single morpheme.

To examine the effect of linguistic similarity between languages, we asked native Korean speakers who acquired English and Japanese after adolescence to perform auditory natural sentence comprehension tasks. Hasegawa et al. [2002] demonstrated that complex sentences are processed differently in L1 and L2. For each language, therefore, we used simple sentences consisting of only four phrases, thereby excluding the effect of task difficulty.

On the basis of the assumption that the degree of linguistic similarity between L1 and L2 affects cortical activation during sentence processing, we expected that 1) brain activation patterns for Korean (L1) and Japanese (L2) would be similar because of their linguistic similarities, and 2) those for Korean (L1) and English (L2) would differ because of the significant linguistic distance between them. To eliminate the possible effect of differences in proficiency between Japanese and English, we controlled it by screening subjects using language proficiency tests for each language. It is important to note that our subjects were living in Japan at the time of this experiment. Given that our subjects were exposed to Japanese in their daily lives, this factor may have partially shaped the neural organization of the languages we studied. In neuroimaging research, Perani et al. [2003] found that for early bilinguals language exposure affects brain activation patterns. Hence, we also considered the effect of language exposure on the cortical representation of English and Japanese. We examined correlations between brain activation and the duration of the subjects' stay in Japanese- and English-speaking countries.

*In this article the abbreviation "L2" refers to both Japanese and English. In the studies of second language acquisition, it is customary to refer to all additional languages beyond the first language as L2.

To our knowledge, this is the first neuroimaging study to examine the relationship between language similarity and cortical representation among trilingual subjects. Our study will help identify the neural correlates associated with the typological characteristics of similar and dissimilar languages among late trilinguals.

SUBJECTS AND METHODS

Subjects

Thirty healthy, right-handed subjects (13 men, 17 women; age range 22–35 years) participated in this study. None of the subjects had a history of neurological or psychiatric illness. We evaluated handedness using the Edinburgh Handedness Inventory [Oldfield, 1971]. All subjects were native speakers of Korean who had not lived outside Korea before the age of 10. They applied to participate in this study through a website that described the language requirements for participation. The application process included an evaluation using background screening questionnaire.

We assessed all applicants for proficiency in both languages using the level 2 Japanese Language Proficiency Test (JLPT) and the level 2 Society for Testing English Proficiency (STEP) test. JLPT is administered by the Japan Education Exchanges and Services and STEP is authorized by the Japanese Ministry of Education, Culture, Sports, Science, and Technology. We selected only those applicants whose scores on both JLPT (93.4; standard deviation [SD], 4.6) and STEP (93.3; SD, 6.3) were approximately equal ($P = 0.44$, paired t test).

The selected subjects started learning Japanese and English at an average age of 20.6 (SD, 2.8) and 12.3 years (SD, 1.5), respectively; i.e., our participants generally learned English before they learned Japanese ($P < 0.001$, paired t test). The mean length of time spent learning Japanese (6.5 years) was significantly shorter than that spent learning English (14.8 years) ($P < 0.001$, paired t test).

All subjects had studied Japanese and English primarily in a classroom setting. The subjects were living in Japan at the time of the experiment; their length of stay in Japan varied from 1 month to 48 months (average, 17 months; SD, 13.0). Only 12 of the 30 subjects had lived in English-speaking countries such as England, Canada, or the USA, with the length of stay ranging from 2 months to 24 months (average, 3.0 months; SD, 5.4). The length of stay in Japanese- and English-speaking countries was used to examine the effect of exposure on cortical activation.

We obtained written informed consent from each subject in accordance with the guidelines approved by Nihon University and the Helsinki Declaration of Human Rights, 1975.

Stimuli

We constructed short spoken sentences using basic vocabulary drawn from textbooks for beginners in Korean, Japanese, and English (these textbooks are used as part of the seventh curriculum, Ministry of Education, Korea, 2001). We used sentences with the same semantic content for each language. Below is a sample set of sentences:

- (1) Korean: Chelswu-nun hakkyo-eyse   sensayngnim-kwa   manna-ss-ta.
Chelswu-NOM school   teacher-ACC   meet-past
- (2) Japanese: Tarou-wa   gakkou-de   sensei-to   a-tta.
Tarou-NOM   school   teacher-ACC   meet-past
- (3) English: John met the teacher at school.

Abbreviations: NOM, Nominative case marker; ACC, Accusative case marker.

To ensure that the sentences were natural, we selected 40 of 70 candidate sets of sentences based on a screening test performed by at least eight native speakers of each language. Each sentence consisted of four phrases comprised of high-frequency words. We digitally recorded (16 bit, 44.1 kHz) the sentences, which were read by a female native speaker of each language. The mean length of the sentences was 2.7 s (SD, 0.18). We adjusted the mean amplitude of all the sentences across the three languages using MATLAB (MathWorks, Natick, MA). For the baseline condition, we prepared a white noise stimulus with the same mean amplitude and duration as those of the

sentence stimuli. To avoid interference from the MRI scan noise, we presented each auditory stimulus during an interscan interval of 3 s.

Task Design

Each participant listened to the sentences via headphones and then within 2 s pressed one of two buttons with a thumb to indicate whether or not they understood the sentence. The use of right and left hands/thumbs was counterbalanced across the subjects. Each block consisted of five trials of a task, followed by four trials under the baseline condition,

with intertrial intervals of 5 s. During the baseline condition, each subject pressed the button after listening to each presentation of the white noise stimulus. Three blocks (one in each language) comprised a triplet, which repeated eight times during an fMRI session of 1115 s. The order of the languages in the triplets was counterbalanced across the subjects. During fMRI scanning 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 movements. After the scanning we conducted an interview and confirmed that each of the participants was able to understand all the stimuli.

Data Acquisition and Preprocessing

Twenty-one transaxial slices (slice thickness = 6 mm; gap = 0 mm) covering the entire brain were acquired with a 1.5T Siemens Symphony MRI scanner (Siemens, Erlangen, Germany), 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 performed to equilibrate the state of magnetization, a total of 223 echo-planar imaging (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). fMRI data were preprocessed using SPM99 software (Wellcome Department of Cognitive Neurology, University College of London, UK), including adjustment of slice timing, correction for head movements, spatial normalization using T1-weighted anatomical images, and smoothing with a 12 mm full-width at half-maximum (FWHM) Gaussian filter.

Statistical Analysis

We adopted a conventional two-level approach for fMRI data. For each subject, we applied a voxel-by-voxel multiple regression analysis of the expected signal changes to the preprocessed images for the four conditions: Korean, Japanese, English, and baseline. This analysis employed a standard boxcar convolution model using the hemodynamic response function provided by SPM99. We then performed statistical inference on the contrasts of parameter estimates with a second-level between-subjects (random effects) model, using one-sample *t*-tests.

First, we analyzed the Korean, Japanese, and English tasks compared with the baseline condition. The activation depicted by these contrasts reflected neural activation during the processing of each language. Second, we carried out direct comparisons of brain activation among Japanese (L2), English (L2), and Korean (L1). Direct contrasts of brain activation between (1) the Korean and English conditions and (2) the Korean and Japanese conditions were masked on the voxels identified by English vs. baseline and Japanese vs. baseline, respectively. The activation depicted by these contrasts reflected neural activation during the processing of L2 compared with L1. Third, we directly compared the cortical activation be-

tween the English and the Japanese conditions using an inclusive mask of English vs. the baseline. The activation depicted by these contrasts reflected the difference in neural activation between the two L2s (English and Japanese). The resulting activation maps were superimposed on the standard T1-weighted MR image. The statistical threshold in the voxel-wise analysis, assuming a search area of the whole brain, 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).

Finally, we performed region of interest (ROI) analyses, to examine differential activation across the Korean, Japanese, and English tasks and correlation analysis between the brain activation in each L2 condition against the baseline and the duration of the subjects' stay in Japanese- and English-speaking countries, for each of the local maxima that had shown differential activation in the comparison between English and Japanese. For the ROI analyses, we tested significance at a region-level threshold ($P < 0.05$, without correction for multiple comparisons).

RESULTS

Behavioral Data

Comprehension rates during the fMRI experiment were high under all conditions (Korean, 99% [SD 1.55%]; English, 98.58% [SD 1.56%]; Japanese, 98.78% [SD 1.98%]), with no statistically significant effect of language difference (two-way analysis of variance (ANOVA), $P = 0.63$).

fMRI Results

Table I and Figure 1 show a significant activation during each language task in contrast to the baseline condition. The superior temporal cortex was bilaterally activated during all three language tasks compared with the baseline. During the Japanese and English tasks the pars triangularis of the left inferior frontal gyrus (IFG) was additionally activated. During the English task only, the right cerebellum, the pars opercularis of the left IFG, and the posteromedial part of the superior frontal gyrus were also activated.

Table II shows the results of the direct comparison of cortical activation between the two L2s and L1 conditions. The contrast of English vs. Korean revealed statistically significant activation in the following areas: (a) the pars opercularis and pars triangularis of the left IFG; (b) the bilateral posterior temporal cortex; (c) the posteromedial part of the superior frontal gyrus; (d) the left cerebellar vermis; and (e) the posterior lobule of the right cerebellum. The contrast of Japanese vs. Korean showed no significant differences in brain activation.

The direct comparison of brain activation between English and Japanese conditions revealed a significantly different activation in the following areas: (a) the pars opercularis of the left IFG (BA 44); (b) the middle portion of the right superior temporal cortex (BA 22); and (c) the right cerebellum. In these three areas we found five activated local max-

TABLE I. Activation during each language task in contrast to the baseline condition

		Talairach coordinates (mm):	
Area		<i>x, y, z</i>	<i>T</i>
Korean vs. baseline			
L	Superior temporal cortex	-62, -6, -4	5.7
R	Superior temporal cortex	64, -14, -4	8.5
Japanese vs. baseline			
L	Superior temporal cortex	-62, -10, 0	9.3
R	Superior temporal cortex	64, -10, -4	8.8
L	Inferior frontal gyrus (pars triangularis)	-54, 22, 12	4.4
English vs. baseline			
L	Superior temporal cortex	-62, -24, -2	10.6
R	Superior temporal cortex	64, -14, -4	9.5
L	Inferior frontal gyrus (pars triangularis)	-55, 22, 18	8.6
L	Inferior frontal gyrus (pars opercularis)	-48, 14, 22	8.1
L	Superior frontal cortex	-4, 18, 54	5.6
R	Cerebellum posterior lobule	32, -68, -28	6.6

Talairach coordinates and *t* value of peak activation are shown. L/R indicates left and right hemisphere, respectively.

ima. Two peaks were located in the pars opercularis of the left IFG (BA 44); one peak was located in the middle portion of the right superior temporal cortex (BA 22); and the remaining two peaks were located in the right cerebellum (see Table III; Fig. 2).

In these five ROIs the English condition produced a significantly greater activation than the Japanese and Korean conditions (paired *t* test, $P < 0.05$) (Fig. 2). However, we observed no significant difference between Korean and Japanese sentence processing in the comparison of the brain activity in these five ROIs.

In these five ROIs we also carried out correlation analysis between the brain activation in each L2 condition compared with the baseline and the duration of the subjects' stay in Japanese- and English-speaking countries. As illustrated in Figure 3, we found a significant correlation between brain activation during the English comprehension task and length of stay in English-speaking countries for two peaks in the posterior part of the inferior frontal cortex, the pars opercularis ($-46, 14, 16$; $r = -0.33$, $P < 0.05$) and the right cerebellum ($34, -66, -30$; $r = -0.37$, $P < 0.05$). However, we found no significant correlation between brain activation during the Japanese comprehension task and length of stay in Japan.

Figure 1.

Images showing brain areas significantly activated during each language task. Statistical parametric maps in a glass-brain presentation for Korean task vs. baseline (A), Japanese task vs. baseline (B), and English task vs. baseline (C).

DISCUSSION

In this study we investigated the effect of linguistic similarity between L1 and L2 on cortical activation using Korean native speakers who had learned two L2s (English and Japanese) after adolescence. The brain activation elicited during sentence comprehension was markedly different between the English and Japanese tasks; the brain activation pattern during Japanese sentence processing was similar to that during Korean sentence processing, whereas the activation pattern during English sentence processing was significantly different from Korean sentence processing. These findings lead us to argue that linguistic similarities between L1 and L2 are reflected in cortical activation during second language processing. Our discussion below focuses on three topics: 1) the brain areas observed in the direct comparison of English and Japanese; 2) alternative explanations for differential activation between English and Japanese; and 3) the effect of the linguistic similarity between L1 and L2 on cortical representation.

Comparison of Two Typologically Different L2s (English vs. Japanese)

In spite of the fact that all our subjects performed equally well in English and Japanese proficiency tests, English sen-

TABLE II. Activation during each L2 task in contrast to L1

		Talairach coordinates (mm): <i>x, y, z</i>	<i>T</i>
Area			
English vs. Korean			
L	Superior temporal cortex	-50, -36, 10	6.7
R	Superior temporal cortex	64, -28, 4	6.8
L	Inferior frontal gyrus (pars opercularis)	-46, 10, 24	7.8
L	Inferior frontal gyrus (pars triangularis)	-50, 24, 10	6.8
L	Superior frontal cortex	10, 14, 52	6.2
R	Superior frontal cortex	-4, 10, 52	5.9
L	Cerebellum vermis	-10, -58, -32	6.9
R	Cerebellum posterior lobule	6, -74, -42	6.4
Japanese vs. Korean		Nonsignificant differences	

Talairach coordinates and *t* value of peak activation are shown. L/R indicates left and right hemisphere, respectively.

tence comprehension tasks produced significantly greater brain activation in the following three areas: (1) the middle portion of the right superior temporal cortex; (2) the pars opercularis of the left IFG (BA 44); and (3) the right cerebellum. The significant activation in these areas suggests that Korean subjects faced greater cognitive demands during the processing of English sentences than that of Japanese sentences. Although the activation in these three areas is inter-related, we will discuss the individual role of each area.

In the left posterior inferior frontal area, we found two local maxima: one in the superior portion of the pars opercularis of the IFG (BA 44), and the other in the pars opercularis of the IFG (BA 44). Previous neuroimaging studies showed that the superior portion of the left IFG is sensitive to the effect of auditory attention [Giraud et al., 2004] and auditory lexical processing [Poldrack et al., 1999]. Based on these findings, we believe that the participants in our study may have paid more explicit attention to the English auditory stimuli than to the Japanese stimuli, even though the English comprehension task did not impose strong phonological processing demands.

Wartenburger et al. [2003] have found that activation in the left pars opercularis of the IFG (BA 44) is related to L2 syntactic processing, particularly among late bilinguals. Furthermore, recent studies have shown that the pars opercularis of the left IFG is associated with syntactic memory

[Fiebach et al., 2001; Röder et al., 2002; Stromswold et al., 1996] and the acquisition of syntactic rules [Optz et al., 2003]. Furthermore, Bornkessel et al. [2005] and Grewe et al. [2005] reported that this area is sensitive to the linearization structure; activation in this area increases when subjects are required to process sentences that deviate from the typical surface word order. Based on these findings, we consider that the greater activation we found in the left pars opercularis of the IFG during English sentence processing may stem from differences between word order in English relative to Japanese and Korean. In other words, our subjects may have more explicitly processed the syntactic structure of the English sentences than the Japanese sentences, given that English differs from both Korean and Japanese in linearization and syntactic structures.

Several studies [Awh et al., 1996; Baddeley, 1986; Paulesu et al., 1993] have emphasized the relationship between the right cerebellum and the left IFG. These areas collaborate in verbal working memory, the detection of morphosyntactic errors [Moro et al., 2001], and the comprehension of syntactically demanding sentences [Stowe et al., 2004]. Therefore, the observed activation in the right cerebellum, which synchronized with the activation in the left IFG, may be associated with the processing of linguistic structures that differ from the subject's L1. That is, in the comprehension of English sentences our subjects may have paid more conscious attention to syntactic processing than was the case with Japanese.

Finally, we consider that the greater activation in the right superior temporal cortex for English vs. Japanese sentence processing reflects prosodic differences between the two languages. Neuroimaging studies showed that the right superior temporal cortex is associated with the processing of intonation contours in spoken sentences [Meyer et al., 2004; Pöppel, 2003]. According to Jun [2005], the prosodic pattern of Korean and Japanese utterances is similar, in that both languages employ pitch accent as a primary prosodic feature, whereas English employs stress accent. Therefore, the English sentences may have demanded more conscious prosodic processing from our subjects than the Japanese sentences.

TABLE III. Differential activation during the English task relative to the Japanese task

L/R	Area	Talairach coordinates (mm): <i>x, y, z</i>	<i>T</i>
R	Superior temporal cortex	50, -24, 2	4.8
L	Inferior frontal gyrus	-40, 6, 28	4.3
	(pars opercularis)	-46, 14, 16	4.0
R	Cerebellum	12, -60, -40	4.5
		34, -66, -30	4.3

Talairach coordinates and *t* value of peak activation are shown. L/R indicate left and right hemisphere, respectively.

Figure 2.

Images showing differential activation of English vs. Japanese conditions. Activation is superimposed on the sagittal and coronal slices of the mean normalized T1-weighted MRI of all subjects. **A:** Right middle superior temporal cortex (50, -24, 2). **B:** Left superior pars opercularis of inferior frontal gyrus (-40, 6, 28). **C:** Left pars opercularis of inferior frontal gyrus (-46, 14, 16). **D:**

Right cerebellum (12, -60, -40). **E:** Right cerebellum (34, -66, -30). The activation profile of each area presents the parameter estimates in Korean-baseline, Japanese-baseline, and English-baseline. Error bars indicate standard error of the mean (SEM). * $P < 0.05$.

Figure 3.

The results of correlation analysis between the duration of subjects' stay in each L2-speaking country and the means of parameter estimates of English-baseline and Japanese-baseline for five ROIs obtained in contrast between English and Japanese. Significant correlation between the brain activation during the English comprehension task and the length of stay in English-speaking coun-

tries was found in two local maxima: (C) left pars opercularis ($-46, 14, 16$; $r = -0.33, P < 0.05$); and (E) the right cerebellum ($34, -66, -30$; $r = -0.37, P < 0.05$). * $P < 0.05$. A: Right middle superior temporal cortex ($50, -24, 2$). B: Left superior part of pars opercularis ($-40, 6, 28$). D: Right cerebellum ($12, 60, -40$).

Overall, we propose that the different activation patterns observed during the English and Japanese comprehension tasks stem from the typological differences between the two languages. The different activation patterns in each area likely reflect partially distinct linguistic features between the two languages.

Alternative Explanations for Differential Activation between English and Japanese

There were several factors that differed between two L2s in the learning situations in our subjects. First, our subjects started to learn English earlier (12.3 years old) than Japanese (20.6 years old) in a classroom. The neuroimaging literature has shown that the age of acquisition affects cortical representation in bi/trilingual speakers [Chee et al., 1999; Kim et al., 1997; Klein et al., 1999; Perani et al., 1998]. Second, L2 can be learned

not only in a classroom (i.e., formal setting) but also through exposure in daily life (i.e., informal setting). All our subjects were exposed to Japanese; however, only 12 out of 30 subjects were exposed to English in an informal setting. According to Perani and Abutalebi [2005], the level of language exposure is one of the important factors that influence brain activity in bilingual language processing. Finally, the amount of daily usage was likely to be larger for Japanese than English in our subjects, because they stayed in Japan at the time of this experiment. Perani et al. [2003] argued that daily usage might be a factor for determining the level of brain activation in early bilinguals. In this section, we discuss these three alternative explanations for differential brain activation between English and Japanese tasks observed in this study.

There is a growing consensus that the earlier language is acquired, the less the left frontal regions are activated [De-

haene et al., 1997; Hasegawa et al., 2002; Nakai et al., 1999; Perani et al., 2003; Wartenburger et al., 2003]. Contrary to this notion, the present study showed a greater activation in English than Japanese tasks, although English had been acquired earlier than Japanese. Therefore, it is not likely that differential activation between English and Japanese tasks is explained by the earlier age of acquisition of English than Japanese.

On the other hand, the observed relationship between a longer duration of exposure to Japanese than English and less activation during Japanese than English tasks is consistent with the finding of Perani et al. [2003]: the exposure to L2 caused a decreased activation during L2 processing. To examine the effect of L2 exposure on cortical representation in our subject, we examined correlations between brain activation during English and Japanese comprehension tasks and the duration of the subjects' stay in English- and Japanese-speaking countries, respectively.

We found a significant negative correlation between the duration of the subjects' stay in English-speaking countries and brain activation during the English comprehension task in the pars opercularis of the left IFG ($-46, 14, 16$) and the right cerebellum ($34, -66, -30$) (Fig. 3). Functional imaging studies shows that both areas are sensitive to syntactic processing, as discussed above [Bornkessel et al., 2005; Stowe et al., 2004; Stromswold et al., 1996; Wartenburger et al., 2003]. This result is in line with the findings of Perani et al. [2003], who showed that exposure to specific languages affects brain activation patterns for bilinguals.

Interestingly, however, we found no significant correlation between brain activation during the Japanese task and the duration of the subjects' stay in Japan. Limitation in statistical sensitivity is not likely to explain this lack of negative correlation, because we did find this correlation for English, in which only 12 subjects had exposure to an English-speaking environment (from 2 to 24 months). For Japanese, all our subjects were staying in Japan at the time of experiment, and the length of residence ranged from 1 to 48 months. If a greater amount of exposure to Japanese than English could explain the lesser extent of activation during the Japanese task than during the English task, we could expect a negative correlation between brain activation during Japanese comprehension and the length of stay in Japan. Our results, therefore, suggest that the duration of exposure did not explain the greater activation observed in the English comprehension task than the Japanese task.

There remains a possibility that the amount of daily usage between two L2s in days or weeks, not in months or years, before this experiment accounts for the observed differences in brain activation between the English and Japanese tasks. However, given no significant correlation between the duration of stay in Japan and the extent of activation during the Japanese task, this explanation requires an assumption that the amount of L2 usage for days or weeks only, but not months or years, affects cortical activation. We consider this assumption implausible, considering the accumulated evi-

dence of the effect of L2 usage for a long period on cortical representation of L2s [Perani et al., 2003].

Taken together, it is not likely that differential activation between English and Japanese observed in this study is explained by a difference in learning situations between English and Japanese in our subjects. Our results, therefore, indicate that the comprehension of simple sentences in L2 requires the same extent of activation as that in L1, when the languages are typologically similar, given a sufficient proficiency in L2. The duration and amount of exposure, accordingly, has a minimal significance for cortical activation. When L2 is typologically distant from L1, to the contrary, L2 comprehension requires additional syntactic processing, which results in an increased activation in the cortical areas responsible for this additional syntactic processing. This additional activation decreases as the amount of exposure increases, which is consistent with the observation by Perani et al. [2003] that language exposure decreases brain activation.

It is important to note that the current results were obtained using an auditory comprehension task composed of simple sentences constructed using high-frequency words. We do not preclude the possibility of a differential activation between Korean and Japanese, as well as the effect of exposure, when more complex sentences are used. In addition, we do not generalize the anatomical pattern of the differential activation between English and Japanese or Korean to all L1-L2 pairs. The results of our study rather suggest that the pattern of differential activation in a particular L1-L2 pair depends on a specific pattern of linguistic differences (e.g., syntax, phonology, orthography, semantics, and pragmatics). The unique educational background of a particular L2 in a particular ethnic group may also affect cortical activation. A comparison of differential activation in many L1-L2 pairs, as well as in many ethnicity groups, is promising to reveal the relationships between cortical activation and a specific linguistic attribute, as well as cultural background.

Linguistic Similarity Between Japanese and Korean

In the final section of our discussion, we will highlight the role of linguistic similarities between L1 and L2 in determining cortical representation. No significant difference in brain activation was found between the Japanese and Korean sentence comprehension tasks. We attribute these results to similarities in linguistic structure between the two languages, particularly the shared syntactic systems. We postulate that when L1 and L2 are syntactically similar, L2 processing draws on the efficient system used for L1 processing. In contrast, when L1 and L2 are typologically distant, L2 processing requires the use of additional language processing systems acquired after puberty, which are likely to be less efficient than L1 processing systems. Our Korean subjects were thus likely engaged in elaborate processing during English sentence comprehension, but efficient processing during Japanese sentence comprehension.

This notion is consistent with previous neuroimaging research and studies of second language acquisition. In neuroimaging studies, the learner's L1 dominates the neural and cognitive systems used in L2 processing, despite that learners may have attained advanced proficiency in L2 [Luke et al., 2002; Tan et al., 2003]. In second language acquisition research, there is a growing consensus that linguistic similarity between L1 and L2 affects L2 acquisition processes [Odlin, 1989; Ramat, 2003]. Juffs [1998], for instance, states that L1–L2 typological distance is a strong predictor of the efficiency of L2 syntactic processing.

Finally, our results and interpretation are consistent with the findings of previous lesion studies dealing with the three languages used in this experiment. Sasanuma and Park [1995] found a positive transfer of therapeutic benefits between Korean and Japanese, despite that their subjects were late learners of the two languages. In contrast, Watamori and Sasanuma [1978] found a limited transfer between English and Japanese.

In summary, we observed a significantly greater activation during the English than the Japanese sentence comprehension tasks in the pars opercularis of the IFG, the right cerebellum, and the right superior temporal cortex, consistent with our assumption based on the greater linguistic distance between English and Korean compared with Japanese and Korean. We consider that the differential activation in the pars opercularis of the IFG and the right cerebellum reflects an elaborate syntactic processing for English, prompted by the different linear word order of English relative to Japanese and Korean. The different activation patterns observed in the right middle superior temporal cortex may be associated with the prosodic distance of English from Korean and Japanese. In the pars opercularis of the IFG and the right cerebellum, a significant negative correlation between activation and amount of exposure was observed for English, but not for Japanese. These results suggest that the effect of exposure reported in a previous functional imaging study [Perani et al., 2003] likely exerts on this additional activation induced by an elaborate syntactic process caused by the syntactic distance. When L2 is typologically similar to L1, the shared syntactic system may allow L2 processing to draw on an efficient neural system for L1, exempting the effect of the amount of exposure. Our study is the first to support the notion that linguistic similarity between L1 and L2 affects the cortical processing of a second language.

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