Neural Switching Mechanism in the late Korean-English bilinguals by Event-Related fMRI

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Abstract

Functional MRI technique was used in this study for examining the language switching mechanisms between the first language (L1) and the second language (L2). Language switching mechanism is regarded as a complex task that involves an interaction between L1 and L2. The aim of study is to find out the brain activation patterns during the phonological process of reading real English words and English words written in Korean characters in a bilingual person. Korean-English bilingual subjects were examined while they covertly read four types of words native Korean words, Korean words of a foreign origin, English words written in Korean characters, and English words. The fMRI results reveal that the left hemispheric language-related regions at the brain, such as the left inferior frontal, superior temporal, and parietal cortices, have a greater response to the presentation of English words written in Korean characters than for the other types of words, in addition, a slight difference was observed in the occipital-temporal lobe. These results suggest that a change in the brain circuitry underlying the relational processes of language switching is mainly associated with general executive processing system in the left prefrontal cortex rather than with a similarity-based processing system in the occipital-temporal lobes.

Key words: Langauge Switching; Korean words; Left prefrontal cortex; Event-related fMRI

Ⅰ. INTRODUCTION

Understanding how the brain processes words is a key issue in cognitive neuroscience. Research using functional neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) has yielded considerable insight into the networks of the cortical areas involved in the process of word recognition [1]. Language use consists of the socially and cognitively determined selection of behaviors according to the goals of the speaker and the context of the situation, and exists in the form of several different languages. Researchers have turned to neuroimaging techniques to investigate how multiple languages are represented in the brain and to determine the nature of cognitive control between language switching in bilingual subjects. Some studies have revealed that bilinguals show activity in the left frontal areas of the brain for the semantic and phonological analysis of words in both languages [2,3]. In bilinguals, the fact that two different word forms are mapped on the same semantic concept considers word recognition to be a process involving two types of representations. Several PET and fMRI studies [4-7] have revealed that similar patterns of cerebral representation across languages in bilingual individuals are activated by common cortical substrates. However, Klein [6] suggested that the patterns of representation for L1 and L2 may vary within the hemispheric language-related regions of bilingual subjects. The different patterns are attributed to the age of acquisition for L2 [3,8] and the level for proficiency in each language [9]. Such different views have been tried to move in harmony with neuroimaging techniques, together with increasingly sophisticated methods of data analysis. According to the model of bilingual representation [10](Fig. 1), we can explain the effect of switching within the bilingual lexico-semantic system in that forward switching (from L1 to L2) be mediated by conceptual memory, whereas backward switching (from L2 to L1) involves a direct lexical mechanism. Bilinguals develop a weak link from their L1 to their L2 because they scarcely translate from their L1 to their L2, to the contrary, they develop a strong lexical connections postulated from their L2 to their L1 with increased L2 proficiency. L1 is represented as larger than L2 because for most bilinguals, even those who are relatively fluent, more words are known in the native than in the second language

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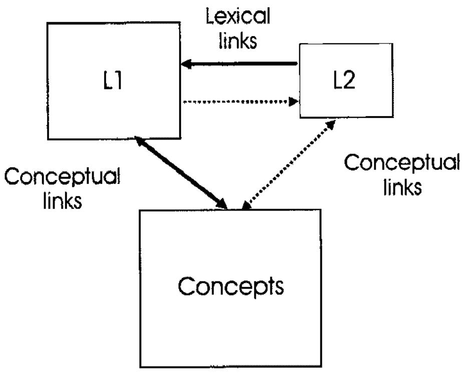


Fig. 1. Revised hierarchical model of lexical and conceptual representation in bilingual memory [10]. Solid lines represent stronger links than dotted lines.

[10]. This asymmetry effect has been observed both for relatively proficient and for less proficient bilingual subjects even though it is greater in the latter group of subjects [10] and motivates our study that the two-step switching at a single-word level is preferable for examining the language-specific switching process. The aim of this study is to investigate the neural substrates of translation, the switching mechanisms is subserved by the left inferior frontal cortex due to high semantic selection demands [11], and whether overlap exists in the brain regions responsible for switching at a single-word level in L1 and L2.

In order to find out the specific switching effect at the single word level with L1 and L2, we intend to manipulate the presentation of stimuli by event-related fMRI, which is a technique that permits the more specific isolation of particular psychological events than a block design, making psychological inference easier and making it possible to image an entire new class of psychological events. It would be of interest to elucidate the cross-linguistic nature of the switching associated with the neural-anatomical network engaged in reading across languages in terms of the two-step processing involving forward switching followed bybackward switching (L1->L2->L1).

II. MATERALS AND METHODS

Nine right-handed normal, Korean-English bilingual subjects(5 males, 4 females; mean age, 33.67; SD, 5.71) were enrolled in this study. The subjects had a graduate-school-level education, Korean was their native language, and they were proficient in English, which had been acquired after the age of 14 years (mean age, 13.1 years). They showed proficiency in the tests that required the generation of synonyms in L2(mean, 94.2; SD, 2.39), and switching from L1 to L2(mean, 95.1; SD, 2.1) and also measured by the TOEFL (CBT) test between 230 and 283(average, 249). All the subjects were healthy, with no prior history of psychiatric or neurological illnesses and were not taking any medications. All the subjects provided written informed consent. This study was approved by the Kangnam St. Mary's Hospital Subcommittee on Human Studies in the College of Medicine, the Catholic University of Korea.

The stimuli consisted of gray-word presentations of 50 native Korean words, 50 Korean words of a foreign origin, 50 English words and 50 English words written in Korean characters. Each group comprised three-syllable noun sets of high-frequency, concrete-meaning words that are used in daily life. The order of presentation of these four types of words [i.e., native Korean words (KW), Korean words of foreign origin (KF), English words written in Korean characters (EK), English words (EW)] was random. To understand which types of stimuli were used, the description of Korean words of a foreign origin, English words written in Korean characters is especially necessary. Korean words of a foreign origin mean the words imported from other languages such as English, French or Japanese; the semantics and phonology remain identical, only orthography is different, i.e., an English word "chocolate" is written in Korean character. These were widely used in the current Korean language. English words written in Korean characters mean that only the phonology of the English words is written or described in Korean character. English words written in Korean characters mean that the phonology of real English words is expressed by Korean character orthography. The words were presented for duration of 1000 ms at the baseline such that a fixation cross-hair that was present throughout the interstimulus interval was replaced with the image of the word. This was accomplished using a stochastic distribution of the stimulus onset asynchrony (SOA), as determined by a minimal SOA of 4.5 s and 100 randomly intermixed null events [12]. All the visual stimuli were projected onto a half-transparent screen using a projector connected to a personal computer. The subjects observed the stimuli through a tilted mirror that was attached to the head coil of the scanner, and the images were scanned during one session. In the session denoted as the retrieval of the lexical semantic information from words, the subjects were instructed to press one of two buttons with their right index finger to indicate whether or not they understood the word. An incorrect answer included any response that was not registered between 200 and 4000 ms from the onset of the stimulus, and any false responses (after each subject completed the experiment, it was checked whether they understood the words they considered correct among the four categories) were ignored.

Imaging was performed on a 1.5 Tesla whole body MRI System (Siemens Corps., Iselin, NJ). The functional images consisted of echo-planar image volumes that were sensitive to BOLD contrast (TE 60 ms, TR 3 s). The volume covered the entire brain with a 64x64 matrix and 24 slices. After discarding the first 5 volumes because of uneven longitudinal magnetization, 450 volumes were collected with an effective repetition time (TR) of 3 s/volume. Prior to functional scanning, high-resolution T1-weighted anatomical data was acquired to provide an anatomical reference.

SPM99 (Wellcome Department of Cognitive Neurology, London) was used for data processing and statistical analysis. The data was realigned with respect to the first volume, and temporally adjusted for slice timing. This was followed by spatial normalization to a standard EPI template, resulting in a functional voxel size of $3 \times 3 \times 3$ mm^3. The normalized images were smoothed with an isotropic 8 mm full-width at half-maximum Gaussian kernel. The time series in each voxel were high-pass-filtered to 1/230Hz to remove the low-frequency noise. For fMRI group data analysis, the images of all subjects were analyzed in a one-design matrix, which generated a fixed effect model for the hemodynamic responses to the stimulus onset for the 10 event types. Four of these hemodynamic responses represented the correct responses to the four basic event types (KW, KF, EK, EW) when they were matched to the time of occurrence. The BOLD impulse response to the events of each type was modeled using a canonical hemodynamic response function (HRF) [13]. This function was convolved with a sequence of delta functions for the events of each type in high-resolution time space, and was then downsampled at the midpoint of each scan to form covariates for the general linear model. Six covariates were also includedin the task for capturing the residual movement-related artifacts (the three rigid-body translations and rotations determined from the realignment stage), and a single covariate represented the mean of the scans. The parameter estimates for each covariate obtained from the least-mean-square fit of the model to the data were stored as separate contrast images. The individual contrast images for the effect of each word type (KW, KF, EK, and EW compared with the base image such as thecross-hair) during the task denoted as the retrieval of lexical semantic information from the words were entered into one-sample t-tests, with the subjects being treated as a random variable, and the group-level activation map for each type was created. The resulting t-statistics at each voxel were normalized to Z values, and clusters of significant activation were defined using the joint expected probability distribution of height ($Z > 3.11$; $P < 0.001$) and spatial extent ($P < 0.05$) of the activation. For some interesting areas, the functionally defined region varied across the range of individuals, but it was defined by the automated anatomical labeling of the activations with group analysis [14]. The corresponding areas were chosen and measured using the peak as an average of the three highest consecutive values in the event-related data (after the onset of the stimulus at which the measured BOLD signal change reached its peak at 2TR time points).

Ⅲ. RESULTS

Table 1 show the mean (±SD) percentage of the correct responses and the mean reaction times (RTs). The subjects responded slower to English words written in Korean characters than to the other types of words and more errors were made for English words written in Korean characters than for the other types of words. The RTs were subjected to an ANOVA following by post-hoc analysis (Bonferroni) for the four groups and there was a significant difference except two groups (KW vs KF) [$F(1,3) = 456.996$, $P < 0.0000$]. The corrected rates were tested by the same ANOVA procedure and a significant difference for only EK among four types groups [$F(1,3)=42.976$, $P<0.0001$] was found.

The areas of significant activation for covert single-word reading among the four word groups were the left precentral

Table 1. Behavioral performance of Korean-English bilingual subjects.

	KW	KF	EK	EW
Reaction time(ms)	828(±34)	829(±41)	1409(±49)	1210(±37)
Correct rate (%)	94.2(±1.56)	93.3(±2.0)	84.7(±2.6)	93.5(±1.94)

Reaction time (ms) and accuracy (all values given as mean±standard error) for the Korean-English bilingual subjects covertly reading a single word of one of the four types: native Korean words (KW), Korean words of foreign origin (KF), English words written in Korean characters (EK), and English words (EW)

Table 2. Talairach coordinates of the brain region with significant activation during covert single word reading in the designated paradigm.

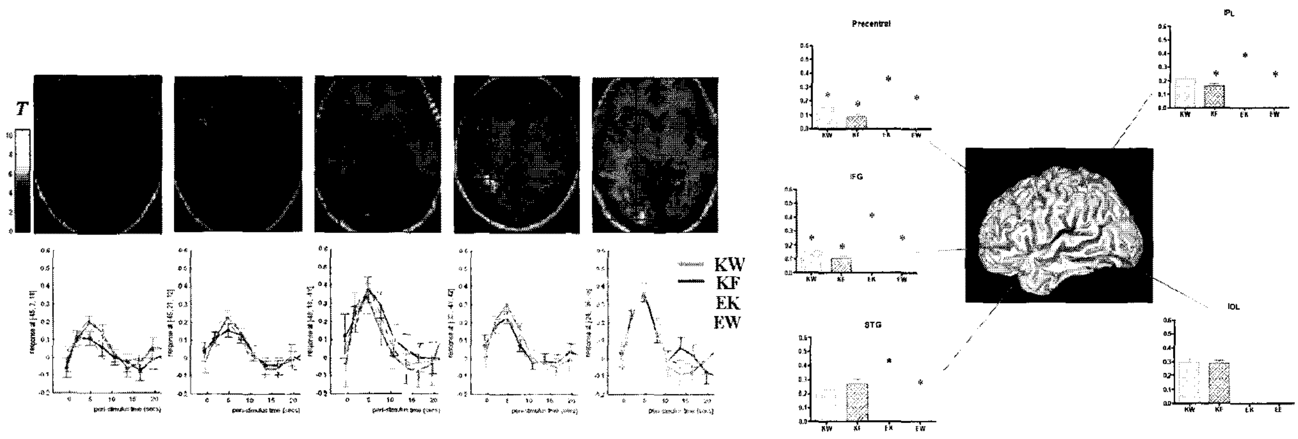
Anatomical location (Approximate BA)	L/R	Coordinates, mm			
		x	y	z	Z-score
Precentral (6)	L	−45	3	18	3.47
Inferior frontal (46/47)	L	−45	21	12	3.49
Supplementary motor (6)	L	−6	21	45	3.52
Supperior temporal (38)	L	−48	18	−18	3.55
Inferior parietal (39/40)	L	−33	−48	42	4.17
Inferior occipital (17)	L	−24	−96	−9	3.61
Inferior occipital (17)	R	21	−96	−6	3.59
Lingual (18)	L	−15	−90	−15	3.51
Cerebellum	L	−39	−66	−33	3.65
Cerebellum	R	21	−69	−36	3.63

L = Left, R=Right, BA=Brodmann area. XYZ coordinates of the local maxima are listed according to the MNI coordinate system [14].
This contrast was performed using a threshold at P < 0.001 (spatial extent threshold at P < 0.05).

lobe(BA 6), the left inferior frontal gyrus (BA 46/47), the left supplementary motor cortex(BA 6), the left superior temporal lobe (BA 38), the left inferior parietal lobe (BA 39/40), the bilateral inferior occipital lobes (BA 17), the left lingual gyrus (BA 18), and the bilateral cerebellums ($P < 0.001$, spatial extent threshold at $P < 0.05$ Table 2). The language-related specific regions, such as the left frontal and parietal areas, showed a greater response to the presentation of English words written in Korean characters than to the other types of words, whereas there was no significant difference in the occipital-temporal lobes, which are similarity-based processing regions, among the four types of stimuli (Fig. 2a). These patterns were confirmed through ANOVA following by post-hoc analysis (Bonferroni) for the four groups after obtaining the mean percentage signal change (±SE) from the corresponding regions in the above method (Fig. 2b).

Ⅳ. DISCUSSION

For the behavioral results on the analysis of the response



(a) (b)

Fig. 2. (A) Left-hemispheric language-related regions, such as the left inferior frontal, superior temporal and parietal cortices among the transverse slices (the group activation maps) derived from Table 2. A low statistical threshold was used ($P < 0.001$, spatial extent threshold at $P < 0.05$). The event-related data, adjusted for confounding (four types; KW, KF, EK, EW), was binned every 3 s and averaged over the subjects forthe corresponding regions based on the peristimulus time (PST). (B) Surface rendering of the brain activation showing the regions related to the left-hemispheric language-related regions, such as the left inferior frontal, superior temporal and parietal cortices. After obtaining the mean percentage signal change (±SE) from the corresponding regions in the Korean-English bilingual subjects, ANOVA following by post-hoc analysis (Bonferroni) were performed for the four groups [($F(1,3)=9.167$, the mean difference is significant at $P < 0.05$, except for the case of EK vs KW; x=-33, y=-48, z=42), ($F(1,3)=21.381$, the mean difference is significant at $P < 0.05$; x=-45, y=21, z=12), ($F(1,3)=16.765$, the mean difference is significant at $P < 0.05$; x=-45, y=3, z=18), ($F(1,3)=3.095$, the mean difference is only significant at $P < 0.05$, only the case of EK vs EW x=-48, y=18, z=-18), ($F(1,3)=0.363$, the mean difference is not significant at $P < 0.05$, for the four groups; x=-3, y=33, z=39)].Asterisks indicate significant difference.

time, the longer response times for English words written in Korean characters may be due to the greater effort needed and hence, a slower, lexico-semantic system process involved in the two-stage processing of forward switching (from L1 to L2) and backward switching (from L2 to L1) (Table 1).

These results show that the cortical regions, which correlate with the processing of distinct scripts of words, encompass an extensive left-hemisphere language system involving the frontal, temporal, and parietal regions. As a part of the language function associated with the cognitive process, the neurobiology of processing single words and nonwords has been studied in several groups, including skilled and impaired children, and adult readers [15-17]. Converging results from these studies indicate that skilled readers are prone to depend on a left-hemisphere network for reading single- words, which includes the inferior frontal gyrus and occipital-temporal and temporal parietal cortices [18]. The data from functional imaging studies [19,20] suggest that these regions mediate semantic processing. Our finding that a word switch activates a dorsal region of the left inferior frontal cortex is similar to the finding [7]. This region of the left frontal and parietal cortices in our study has often been associated with semantic processing. In such regions, the greater activation for English words written in Korean characters compared with other types of words could be interpreted considering the fact that the neural mechanisms for reading single words of the four types were reflected by different levels of demand on the cortical resources, rather than by linking discrete processes to specific anatomical areas. It might be closely related to semantic involvement and is consistent with the results of other studies [2,21]even though our bilingual participants had slightly different proficiency levels. These results can be explained on the basis of psycholinguistic data that suggest two routes for switching single words: a direct lexical route and an indirect semantic route, the latter being more functionally relevant during forward switching (from L1 to L2) than during backward switching (from L2 to L1). In these areas associated with semantic processing, the decreasing activation for Korean words of a foreign origin (KF) or English words (EW), similarly to native Korean words compared with English words written in Korean characters (EK), suggests that our bilingual participants could switch by a direct route in a similar manner to monolinguals i.e., such activation patterns were mediated through a unitary neural system (i.e., fronto-parietal region) that is capable of recruiting the surrounding cortical resources to meet the decreased computational demand due to the very high L2 proficiency even though late bilinguals, and indicates that the brain activation patterns are clearly modulated by the direction of switching.

The lack of a significant difference in the occipital-temporal lobes among the four word groups suggests that forward (from L1 to L2) or backward switching (from L2 to L1) over the bilingual representation is not associated with the visual analytic process. This is consistent with a study [22] that revealed that the length effects on reading French words and pseudo-words are characterized, at the neurobiological level, by a significant and specific increase in activity for pseudo-words, compared with words, in the occipital-temporal lobes but not for lexical decision, which reflects the associations with the visual features and the associations with linguistic attributes. In addition, it could be interpreted as being based on the knowledge of the hemispheric asymmetry, which might mediate the coordinated visual processes that maximize the individualization between examples in a category, and also mediates the categorical visual processes that maximize the similarities between examples within a category [23].

It is to be noted that the presence or absence of a morphological effect that can be caused by the different morph in the English words compared with the other types of words. Davis [24]reported that there were no differences between morphologically complex and simple words when reading single English words, but the morphological richness of a language affects the processing mode used with polymorphemic words because the recognition of polymorphemic words requires additional processing operations for decomposition [25]. Korean words consist of a mixture of pure Korean words and Chinese characters, Chinese-derived words roughly make up 69.32 percent of the Korean vocabulary and Chinese-derivative words can be used either in the form of Chinese ideograms or their corresponding Korean words [26]. There are no significant differences in the cortical areas (i.e., prefrontal language areas) activated between Mandarin (Chinese) and English at a single-word level, irrespective of the age of acquisition of either language [4]. Taken together, it seems that there was no morphological effect between Korean and English words according to our fMRI results. In general, a critical point should be discussed. Each Korean letter represents phonological information, not semantic information. However, effects of such manipulation should depend on every-day habits of usage of languages. In Korean language, such words are actually not used in real life. This is therefore possible that such stimulus words are very unfamiliar and novel for participants, thus it naturally should lead to more cognitive load, brain activation, and longer response time. The influence of such facts in our experimental results remains unclear. Future studies are necessary to clarify the roles of such type of words in terms of switching in L1 and L2.

In conclusion, the mechanism of switching, with both a behavioral and a neural basis, during covert reading of English words written in Korean characters closely involves the language-specific areas associated with semantic processing. In addition, the occipital-temporal lobes, called the similarity-based processing regions, may play a role in the visual analytic processingin neural-cognitive systems. Further work is needed to clarify the influence of different task-related (visual reading or auditory listening) and participant related factors, such as the recruiting of the neural system (i.e., frontoparietal region) related to the cortical resources, and the levels of proficiency, on the pattern of neural activation during switching.

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