The perception of Korean laryngeal contrasts by native speakers of English: Evidence from an fMRI study

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1 Introduction

It has long been observed that adult speakers have considerable difficulty recognizing nonnative allophones which correspond to a single phoneme or phonetic category in their own languages (as first reported by Lado 1957, followed up experimentally by Eckman et al. 2003). In support of these findings, event-related brain potential (ERP) studies exhibited different mismatch negativity between native and nonnative, hard-to-perceive categories (Winkler et al. 1999; Sharma and Dorman 2000). Also, recent fMRI (functional Magnetic Resonance Imaging) studies demonstrated a measure of reorganization in the brain regions involving specifically the learning of nonnative Hindi dental-retroflex contrasts (Golestani & Zatorre 2004) and Mandarin lexical tone distinctions (Wang et al. 2003). However, the former revealed that after learning the nonnative sounds, the second-language speakers produced no significant difference in the brain activation regions from the native-language speakers when both groups performed a perception task.

Recently, Callan et al. (2004) compared brain activation directly involving perception of the English /r/-/l/ contrast between English native speakers and Japanese native speakers who had learned to perceive the contrast over a period of one month. Unlike the result of Golestani and Zatorre (2004), Callan et al. found a result which seems to support the Internal Model they proposed. The Internal Model is a mechanism that simulates how various mappings between different brain regions are used for identifying difficult second-language phonetic contrasts. The model stipulates that the second language learners, in processing learned sounds that are difficult for them, will use articulatory-auditory mappings more,

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whereas native speakers will rely on the region of auditory-phonetic representation. The Japanese learners of the nonnative sounds through training produced a different activation in the brain from the native English speakers.

The present study contributes to this discussion by comparing brain activational patterns between native speakers of Korean and adult English speakers who have learned the Korean three-way laryngeal phoneme contrasts of tense /p' t' k'/ vs. lax /p t k/ vs. aspirated /p^h t^h k^h/. The study aims to localize the brain regions involved in the learning of these famously difficult phonetic categories, and investigate whether there is support for the Internal Model that Callan et al. (2004) proposed. The results of the experiment show that there is a significant difference in activation between the native and the second-language speakers, contradicting the findings of Golestani & Zatorre (2004). The preliminary results indicate, however, that perceptual identification of nonnative phonemes does not necessarily involve regions of the brain thought to instantiate articulatory-auditory and articulatory-orosensory internal models. This is because activation is not found not only in the superior temporal gyrus (STG), the region involved with auditory-speech representation, but also in the left STG and planume temporale (PT), the regions involved with articulatory-gestural speech representation. The most significant difference in native Korean speakers over native English speakers involved the Korean's activation of the cuneus in the occipital lobe and the right middle frontal gyrus, which are considered to be involved with pitch or tone perception. This points toward a special organization of the brain in younger speakers of Korean with respect to laryngeal processing.

2 Methods

2.1 Stimuli and procedure

Stimuli for this experiment consist of 168 monosyllabic words beginning with one of the 3-way Korean laryngeal contrasts (lax, tense, aspirated consonants) followed by one of five different vowels: /a/, /e/, /i/, /o/, and /u/. In addition, as a control, 56 words beginning with vowels are included. All of these stimuli were pronounced by a male speaker, and recorded in a silent room at the rate of 44100 Hz.

2.2 Subjects

5 English and 6 Korean speakers participated in this study. The English speakers consisted of 4 males and one female, and the Korean speakers consisted of 4 males and 2 females. Their ages ranged from 20 to 35. All subjects were right-handed. They were paid for the participation, and gave their written informed

consent in accordance with the Declaration of Helsinki.

2.3 Experimental design

An event-related design was used in order for the participants not to be able to predict the subsequent stimulus. The stimuli were presented in a pseudo-random order which was made using the OpSeq mechanism. Stimuli were presented every 2.5 seconds through an MR-compatible headphone set (Fig. 1). The given task was to indicate, using the left thumb, which among the three laryngeal consonants or a vowel they heard by pressing one of four buttons. Because of hemispheric cross-over, by having the participants use their left hand to press the button, we can see how the motor areas in the left hemisphere of the brain are activated without the results being affected by artifacts induced by button-press motor reactions. The subjects were required to respond as quickly as possible to minimize the difference in hemodynamic responses. Null trials where only silence occurs were included to be used as a baseline condition.

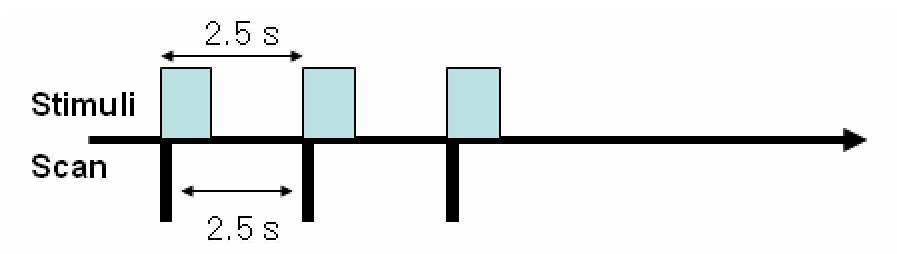

Fig 1. Protocol of Korean laryngeal contrast perception experiment

All participants had a practice session outside the scanner to familiarize themselves with the experiment. This experiment was one of several experiments that the subjects participated in while in an MRI scanner. The duration of the time that subjects stayed in a scanner ranged from 30 minutes to 1 hour depending on how many experiments they participated in. For this experiment, the session lasted 13 minutes.

2.4 FMRI data collection and preprocessing

Brain activity was measured using a Philips 3T MRI system for the acquisition of a T2-weighted gradient echo planar imaging (EPI) sequence sensitive to the BOLD contrast [TR = 2500ms, TE = 35ms, flip angle 90°, slice thickness =

4.5mm, scan image matrix of 80×80 and field of view of 220mm, voxel unit of 2.75x2.78x3 mm]. In order to facilitate later spatial normalization, a high-resolution T1-weighted MRI volume data set was also obtained from all subjects with a SENSE head coil configured with the following acquisition parameters: axial acquisition with a 256x256 matrix; 240 mm field of view; 0.9375×0.9375×1.5 mm^3 voxels; TE 4.6 ms; TR 20 ms; flip angle 25°; slice gap 0 mm; 1 averaging per slice.

3 Results

3.1 Behavioral performance

The scores of all subjects included in the study were significantly higher than chance performance (evaluated at 50% by a t test of $P < 0.05$) for the *lax-tense-aspirated* contrast. The native Korean-speaking participants performed significantly better than the native English ones for all stimulus conditions.

3.2 Statistical image analysis

At the random-effects level between subjects, the contrast image for the parameter estimates of the first-level analysis for each subject was utilized as input for a SPM model using a two-sample t-test. The location of active voxels was determined by referring to the Talairach atlas after transforming from the MNI to the Talairach coordinate system using a Matlab mni2tal function.

A random-effects one sample *t* test of the {(/lax/ +/tense/ + /aspirated/) – 3 * vowel} contrast for both native English and native Korean-speaking participants was conducted to locate brain regions involving the processing of Korean laryngeal contrasts by native English speakers; this is different from vowel processing and is not due to general processing differences among lax, tense, and aspirated consonants or of vowels as processed by native Korean speakers. The results of the random-effect one-sample *t* test of the {(/lax/ + /tense/ + /aspirated/) — 3* vowel} contrast for the native English speakers are shown in Fig 2 and Table 1. Activity for this contrast in the native English speakers was found bilaterally in the supplementary motor area (SMA), somatosensory association cortex (BA7), and the cerebellum as well as in the Broca's ares, the left ACC, left cingulate gyrus, right premotor cortex (PMC), right insula, and left supra marginal gyrus (SMG)

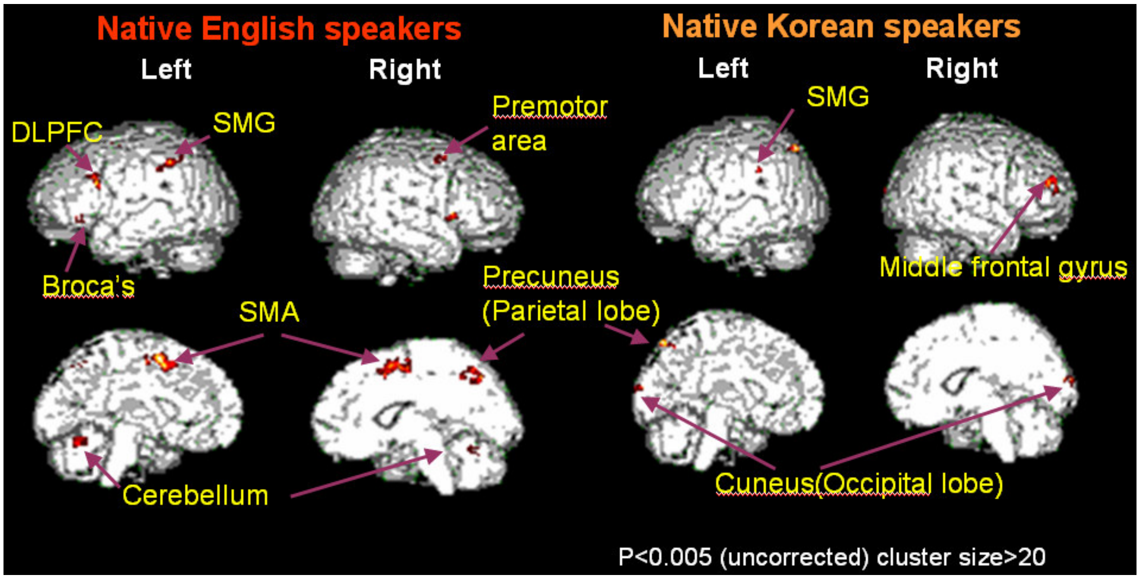

Fig 2. Native English (left) and Native Korean speakers (right) for /lax/, /tense/, and /aspirated/ perceptual identification relative to vowel perceptual identification.

Table1. Activation areas for **/lax/+/tense/+/aspirated/-3Vowel** in native English speakers, P<0.005 (T=2.85) and cluster size>20

Side	Region	Broad mann	MNI x,y,z (mm)	Zmax	Cluster size
Left	Inferior Parietal Lobule	BA 40	-40, -42, 44	4.35	445
	(SMG and Angular)	BA 40	-36, -37, 44	3.51	118
	Superior Parietal Lobule	BA 7	-32, -50, 49	3.62	118
	Occipital Lobe	BA 23			
	Left Cerebellum, Anterior Lobe, Culmen		-4, -61, -10	3.38	56
	Medial Frontal Gyrus (SMA)	BA 6	0, -5, 52	3.88	338
	Medial Frontal Gyrus (ACC)	BA 32	0, 10, 46	4.48	338
	Middle Frontal Gyrus (DLPFC)	BA 9	-36, 19, 29	3.21	90
	Superior Temporal Gyrus	BA 38	-44, 11, -7	3.26	23
	Inferior frontal gyrus,	BA 47	-30, 31, -5	3.62	46
	triangular part (Broca's area)	BA 47	-34, 25, -8	3.47	46
		BA 9	-46, 17, 23	3.80	90
Right	Superior Parietal Lobule	BA 7	24, -60, 44	3.79	142
	Cingulate Gyrus	BA 24	10, -1, 50	3.70	338
	Parietal Lobe, Precuneus	BA 7	18, -58, 53	3.47	142

		10, -66, 47	3.54	142
Right cerebellum, Anterior		23, -45, -21	2.96	41
Culmen		0, -58, -22	2.72	56
Middle Frontal Gyrus	BA 6	40, 4, 48	3.21	20
(premotor and SMA)		32, 10, 51	3.14	20
Insula	BA 13	42, 16, 5	4.66	35

The results of the random-effect one-sample t test of the {(/lax/ + /tense/ + /aspirated/) — 3* vowel} contrast for the native Korean speakers are shown in Figure 2 and Table 2. Activity for the same contrast in native speakers of Korean was found bilaterally in the cuneus in the occipital lobe as well as in the left supramarginal gyrus (SMG), the left angular gyrus, the right somatosensory association cortex (BA7) and the right middle frontal gyrus.

Table 2. Activation areas for **/lax/+/tense/+/aspirated/-3Vowel** in native Korean speakers, P<0.005 (T=2.85) and cluster size>20

Side	Region	Broadmann	MNI x,y,z (mm)	Zmax	Cluster size
Left	Occipital Lobe, Cuneus	BA 18	0, -88, 17	3.36	21
	Superior Parietal Lobule (Angular gyrus)	BA 39	-12, -69, 53	4.35	46
	Parietal Lobe, Precuneus	BA 7	-18, -60, 49	3.15	46
	Supramarginal gyrus	BA 40	-42, -37, 33	3.21	39
Right	Occipital Lobe, Cuneus	BA 18	8, -94, 18	3.67	21
	Frontal Lobe, Middle	BA 10	32, 49, 18	3.63	58
	Frontal Gyrus	BA 10	32, 57, 10	2.81	58

4 Discussion

The preliminary results of the experiment (Fig. 2) show that there is a significant difference in activation between the native speakers and the second-language speakers, consistent with the findings of Callan et al. (2004), not with those of Golestani and Zatorre (2004). Brain activity reflecting differences in the perception of /lax/, /tense/, and /aspirated/ phonemes relative to that of vowels between native English and native Korean speakers is shown in Fig. 2 and Tables 1 and 2. The results show, however, that perceptual identification of nonnative

Korean laryngeal contrast is not completely involved with regions of the brain thought to instantiate articulatory-auditory and articulatory-orosensory mappings of the Internal Model. This is due to the fact that activation in the superior temporal gyrus (STG), the region involved with auditory-speech representation, as well as activation in the left STG and planume temporale (PT), the regions involved with articulatory-gestural speech representation, is not found in both native English and Korean speakers (Hickok and Poeppel, 2000; Scott and Johnsrude, 2003; Scott et al., 2000). Thus, in spite of the presence of significant differential activity found in crus VI of the cerebellum[1], a region known to be involved with lip and tongue motor representation and speech production (Grodd et al., 2001; Wildgruber et al., 2001), the left SMG, a region involved with orosensory-articulatory speech representation (Guenther and Perkell, in press), and Boca's area as well as the premotor cortex (PMC), the regions involved with speech production planning, the Internal Model appears not to be totally supported by this experiment.

Some brain regions not incorporated in the Internal Model proposed by Callan et al. (2004) were found to have greater differential activity for identification of three-way Korean laryngeal contrasts relative to vowels for native English than the native Korean speakers. Those include the supplementary motor area (SMA), the right Dorsolateral Prefrontal cortex (DLPFC) and the right cingulate gyrus that are considered to be involved with attentional control and selection of responses (Desmond et al., 1998; Milham et al., 2003). This can be explained by the fact that greater attentional control in selecting a perceived nonnative phonetic contrast is to be anticipated for second- over native-language speakers.

The most significant difference in native Korean speakers over native English speakers involved the Korean speakers' activation of the cuneus in the occipital lobe and the right middle frontal gyrus. As Platel et al (1997) and Wong et al. (2004), among others, have shown, the cuneus in the occipital lobe and the right middle frontal gyrus are involved with tone or pitch perception. It is interesting to note that this fact supports Silva's 2006 finding that the laryngeal contrasts of Korean are distinguished via their pitch differences in the following vowel, not by their VOT differences, at least among young Koreans. This points

1 Unlike Callan et al. (2003; 2004) who have argued that the cerebellum is involved with instantiating articulatory-auditory and articulatory-orosensory internal models, the cerebellum may be involved with controlling the larynx along with the orosensory area (SMA) and somatosensory association cortex (BA7), based on the fact that the cerebellum is considered to be a region of the brain that plays an important role in the integration of sensory perception and motor output (www.en.wikipidia.org; Grodd et al., 2001; Wildgruber et al., 2001).

toward a new direction in the phonemic analysis of the Korean laryngeal contrast, and can form a basis for further investigation.

Given that differential activation in the acoustic-phonetic area or the STG and the articulatory-gestural speech representation area or the posterior STG and PT are not found in the native English speakers' perception of nonnative Korean laryngeal contrasts, the fact that the Internal Model does not apply completely to the Korean laryngeal contrast perception of native English speakers may be explained by hypothesizing that those areas, the STG and the left posterior STG, are only involved with oral gesture representation in speech, as opposed to its laryngeal gestures.

Further research involving more subjects needs to be conducted to discern whether behavioral results are correlated with brain activational patterns. Moreover, further study is required to see whether older speakers of Korean activate the cuneus and the right middle frontal gyrus in the same task, to verify Silva's claim that only young speakers are using pitch differences to distinguish Korean laryngeal contrasts.

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