Cooperation of bilateral inferior frontal cortices in accent judgment as revealed by functional magnetic resonance imaging

K. Matsuo[1], Y. Ohgami[1,2], K. Toma[3], K. Oishi[4,5], C. Sumiyoshi[6], T. Nakai[1]

[1]National Institute of Advanced Industrial Science and Technology, Ikeda, Osaka, Japan, [2]Ochanomizu University, Bunkyo-ku, Tokyo, Japan, [3]Institute of Biomedical Research and Innovation, Kobe, Hyogo, Japan, [4]Kobe University, Kobe, Hyogo, Japan, [5]Kyoto University, Kyoto, Kyoto, Japan, [6]Fukushima University, Fukushima, Fukushima, Japan

Introduction

While the left inferior frontal cortex (IFC) is dominant in the propositional (lexical) aspect of language, the right IFC is important for the prosody of speech [1] or social and/or emotional context of linguistic communication [2]. Accent of words conveys not only social [2] but also propositional information of language, specifically for a tonal language [3] and/or a pitch-accent language such as Japanese. For example, in standard Japanese, /ha-shi/ in a high pitch - low pitch accent pattern means “chopsticks” while the same phonetic sequence in a low pitch - high pitch pattern means “bridge”. Thus accent can be propositional because its pattern determines lexical meaning of a word, involving the left IFC. The right IFC can be also involved because accent patterns indicate social and cultural backgrounds of the speaker [2]. Moreover, the right prefrontal cortex was also activated during pitch judgments of songs [4]. We performed fMRI to examine the brain activation during accent judgment, expecting bilateral involvement of the IFC (Broca’s area and its homologue).

Materials and Methods

Subjects were ten native Japanese-speaking volunteers in the Kansai area (a western part of Japan, age 21-39, F/M = 5/5, all right-handed, all gave written informed consent). All imaging was performed on a 3T MR scanner (GE Signa VH/i 3.0T). A spiral sequence [5] was used for the functional studies (TE = 30 ms, TR = 3000 ms, FA = 15 deg, FOV = 220 mm, 30 axial slices, 4 mm thick interleaved). An fMRI series consisted of rest (R), target (T) and control (C) periods (30 sec each) where their sequence was RTCTCTCTCR (total 5 min). Four experiments were conducted in separate fMRI series; accent (A), phonological (P) and semantic (S) judgments and silent reading (sr). During the target periods of the accent judgment experiment (A), subjects judged whether words written in 3 syllabic characters (hiragana script) had a high-low-low accent pattern in standard (common) Japanese. Subjects had to recall accent patterns by themselves because the words were displayed on a screen but not spoken. In the phonological judgment (P), subjects detected sounds including /e/ represented in the same 3-character words. This condition was employed to compare an accent judgment with another type of phonological judgment. In the semantic judgment (S), subjects judged whether the words meant food or not. In the control periods, subjects detected “$$$” among other nonsense sequences like “&%#”. This condition was for subtraction of motor responses (the right index and middle finger button pressing) from the target periods. In the silent reading (sr), subjects silently read the displayed words (no response). This condition was employed to subtract a basic written language processing. The fMRI data were analyzed using SPM2 (http://www.fil.ion.ucl.ac.uk/spm/). The data were realigned, spatially normalized and smoothed (FWHM 8 mm). A random-effect model was applied for a group analysis. Activation maps were generated for (A) > (sr), (P) > (sr) and (S) > (sr) contrasts with a height threshold of $p = 0.005$ (uncorrected).

Results and Discussion

Generated maps for all contrasts exhibited activation in the left IFC (Broca’s area, Fig. 1). In addition, the accent judgment specifically augmented activation in the right IFC and the left superior temporal/supramarginal area (Fig. 1A). Activation in the right IFC might be related to a pitch processing of words [4]. Another explanation may be a social and/or contextual processing of language because our subjects usually speak a Kansai dialect so that they had to employ their knowledge of the common (standard) Japanese [2]. Activation in the left superior temporal/supramarginal area might be related to an additional phonological processing. The phonological judgment experiment augmented activation in the bilateral lateral occipital areas and the left superior parietal lobule (Fig. 1P), indicating intensive character processing to extract the /e/ sound from displayed words. The semantic judgment also augmented activation in multiple regions including the left anterior cingulate cortex and middle frontal gyrus (Fig. 1S), suggesting the demand on semantic processing of words.

Conclusions

Our fMRI measurement clearly demonstrated the bilateral but left-predominant involvement of the inferior frontal cortex during accent judgment. The left inferior frontal activation suggested the propositional or lexical processing combined with accent, whereas the right inferior frontal activation might be related to the pitch and/or contextual processing of language. These findings suggest that as a pitch-accent language, Japanese employs both sides of the inferior frontal cortices intensively for its efficient processing.

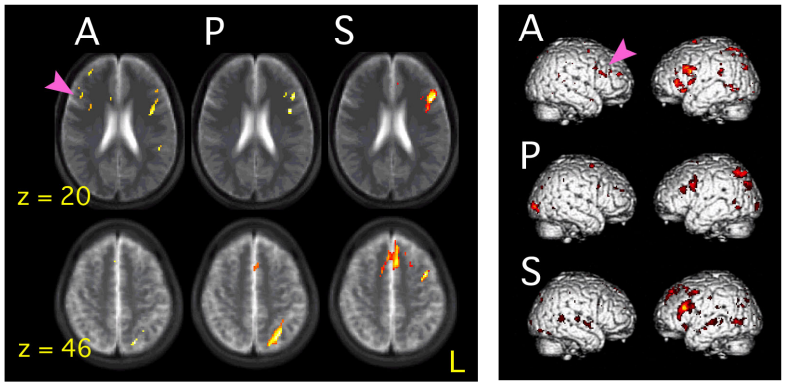

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Fig. 1. Activation maps generated by a random effect model (n = 10, $p < 0.005$ uncorrected). A: accent > silent reading (sr), P: phonology > sr, S: semantic > sr, L: left. Zs indicate the z-coordinates of Talairach brain templates. Pink arrows indicate the right inferior frontal activation.