Neuroanatomical analysis for onomatopoeia : fMRI study

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Abstract

The purpose of this study is to examine the neuroanatomical areas related with onomatopoeia (sound-imitated word). Using the block-designed fMRI, whole-brain images (N=11) were acquired during lexical decisions. We examined how the lexical information initiates brain activation during visual word recognition. The onomatopoeic word recognition activated the bilateral occipital lobes and superior mid-temporal gyrus.

Key word : fMRI, onomatopoeia, superior temporal gyrus, occipital lobe

1. Introduction

Onomatopoeia is a figure of speech in which the sound of word is imitative of the sound of thing which the word represents like “ya-ong (Korean)” to mean “meow (English)”. By comparison between Korean and Japanese, Katsuta (2001) concluded that onomatopoeia have special linguistic characteristics. Phonetically they exchange consonant and vowel sounds. In form, many onomatopoeic words were made by duplication, and derived from an adjective or a verb by adding an affix. Korean language has abundant expressions for onomatopoeia(Chae, 2003; Kim; 1995; Satoshi, 2001). Chae(2003) insisted that onomatopoeia and phainomime words show syntactic and morphological similarities, in some sense they belong to a same category. English and French don't have the special terminology about phainomime words.

Generally speaking, words are composed of arbitrary symbols to represent meanings, but onomatopoeia is different in the sense that they imitates and represents referents directly by sounds. Onomatopoeia is different according to language characteristics. “Bowwow” (English) of dog is equivalent to “mung-mung” (Korean), “wang-wang” (Chinese), and “oua-oua” or “toutou” (French).

Naoyuki et al. (2003) reported that an emotion-based facial expression word significantly activates both the extrastriate visual cortex near the inferior occipital gyrus and the premotor (PM)/ supplementary motor area (SMA) in the superior frontal gyrus. Activationin extrastriate visual cortex and PM/SMA would be modulated by images formation of laughter. Naoyuki O. et al. (2004) also found that an onomatopoeia expressing affective pain significantly activates the anterior cingulate cortex (ACC). They concluded that the ACC would be a pivotal locus for perceiving affective pain evoked by an onomatopoeia word. They suggest that ACC-prefrontal cortical interactions modify cognitive evaluation of emotions associated with word-induced pain.

Pulvermueller(1999) proposed that some action verbs will activate parts of the motor cortex, whereas nouns for animal will activate parts of the visual cortex. Posner and DiGirolamo(1999) said that brain activation depends on the semantic and task context of words. Reading or hearing a word activates linguistic (lexical, grammatical, and phonological) representations as well as associated nonlinguistic information (motor representations in the case of action verbs, visual representations in the case of object nouns, emotional representations in the case of emotion adjectives). The subjects used to assemble a mental image of a three-dimensional object, when they were exposed to verbal input like propositions. Relative to non-spatial words, dorsal route of spatial processing (superior occipital and parietal regions) was activated by prepositions (Mellet et al, 1996). Pictures and verbal descriptions showed bilateral activation of superior occipito-parietal areas that reflect the spatial processing required for the task and activation of the right inferior temporal gyrus from complex images (Mellet, et al. 2000).

Pugh et al. (2000) suggested that the ventral pathway is involved in mapping orthographic lexical representations onto phonologicallexical representations, whereas the dorsal pathway is involved in the sublexical analysis of printed stimuli, and the establishment of lexical-semantic representations. The ventral pathway includes the lateral and medial extrastriate, and fusiform gyrus (BA 17, 18, and 19) in the occipital lobe, and the inferior and medial temporal gyri (BA 20, 21, and 30) in the temporal lobe. Fusiform gyrus is an extremely long convolution extending lengthwise over the inferior aspect of the temporal and occipital lobes (BA 19/37). In comparison, the dorsal pathway includes the lateral extrastriate in the occipital lobe, andthe posterior portion of the superior temporal gyrus, supramarginal and angular gyri (BA 22, 39, and 40) of the temporalparietal regions. The inferior frontal gyrus (BA 44/45) is involved in lexical-phonological output and semantic processing.

Recent neuroimaging studies showed brain areas used in spatial processing and imagery (Robertson, et al. 2000; St. George, Kutas, Martinez, & Sereno 1999). Those researches indicated that verbal input involves not only traditional language area but also areas in the right hemisphere. There was a greater BOLD signal change in medial temporal/medial superior temporal (MT/MST) with motion. Zoe K. and Nancy K. (2000) explained that perceptual analysis involved in the inference of motion from still images showed high level perceptual inferences. Recent brain imaging researches try to clarify the differences between motion-related stimulus and sound-related stimulus. Onomatopoeia is sound-related word. When the onomatopoeia is presented visually, which area on the brain is activated? With the data from sound-related word recognition, how could we conceptualize onomatopoeia words recognition process? To investigate these questions, we conducted block-designed fMRI test.

2. Method

2-1. Subject and Stimulus

Four right-handed male undergraduate students free of medical or neurological problems volunteered to the Experiment. 30 sound-imitated words (onomatopoeia) were selected as experimental stimulus. 36 real words and 24 non-words were selected as control stimulus.

Block Designed fMRI and Procedure

The Experiment consists of three sessions and each session has 9 blocks (4 activations and 5 controls). Each block lasts 30 seconds. Each session consists of 75% of real words and 25% of non-words. Stimuli were drawn from the set of Korean onomatopoeia list. Thirty sound-imitated words were selected. Lexical judgments were required to avoid habituation effects during MRI scanning. Sessions were randomized across subjects. Subjects were asked to press a "True" or "False" button to make a lexical decisionwhile they watch the word presentation on the screen during fMRI scanning. For analysis, we subtract the parts involving the process of lexical decision from whole activation.

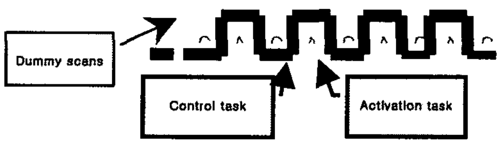


Figure 1. Schematic overview of the Block Designed fMRI paradigm

2-2. Acquisition of Magnetic Resonance Images and Data Analysis

A 1.5T magnetic resonance imaging system (GE medical system, Milwaukee, USA) was used. Before acquiring fMRI, anatomical images of 40 slices (which are necessary for obtaining the whole brain image) were acquired using EPI BOLD (Echo Planar Imaging-Blood Oxygenation Level Dependent) technique (TR/TE 3000/64msec, matrix 256256, slice thick 5mm, no slice gap, FOV 2424cm). The EPI-BOLD technique was used for acquiring the fMRI of 20 axial slices, in which AC-PC (Anterior commissure -Posterior commisure) was the standard line. A dummy scan of 4 phases (for 12 seconds) was also obtained for correcting any inappropriately high signals before equilibrium state. Parameters for acquiring images are as follows : 3000msec for TR, 64msec for TE, flip angle of 90 degrees, a 64X64 matrix size, slices 5mm thick without separation, and a resolution of 3.75 3.75 5 mm. The EPI image data acquired with these parameters were, offline-analyzed with the SPM99 (Statistical Parametric Mapping, version 99, MRC cyclotron Unit, London, UK) program, fMRI analysis software. Followingsare the procedures with the SPM program. Foremost, individual image data were realigned with the reference of the whole brain image obtained prior to the experiment, smoothed (FWHM=10mm) and normalized according to the standard axis SPM provided.

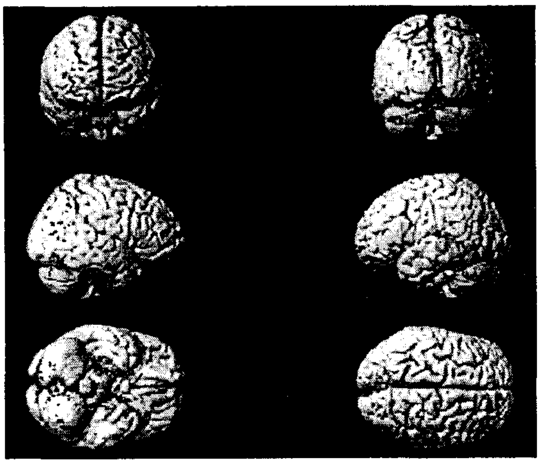
Statistical analyses were done with these normalized data : 11 individual data were conjuncted and ultimate functional imaging was obtained through overlapping brain maps (acquired with the significant level p<. 0001, or p<. 0.00001) to standardized T1 image.

3. Results and discussion : Brain activation for onomatopoeia

Analysis of word presentations in our study revealed following brain activation : Bilateral posterior lobes of cerebellum, bilateral inferior frontal gyrus (BA47), Left middle and superior temporal gyrus (BA41, BA42), Right superior occipital gyrus (BA19).

Especially onomatopoeia words were associated with common cognitive processes like bilateral fusiform gyrus (BA19), right middle temporal occipital gyrus (BA19) and left transverse temporal gyrus. Fusiform gyrus is considered with face-related information (Druzgal T.J. and D'esposito, 2001). According to William (2004) even the word recognition processes of pseudohomophone naming activated the insular cortex and inferior frontal gyrus. Our result for onomatopoeia study also showed the brain activation on bilateral inferior frontal gyrus (BA47).

Picture-1. Brain regions activated by onomatopoeia (sound-imitated word)



DiGiolamo (1999) said even by the word presentation activated linguistic representation and non-linguistic information. This means our result also showed that onomatopoeia activated sound-sensitive area. J. Price et al. (2003) conducted both reading and auditory word repetition task. They found the brain activation at left lateralised regions in the frontal operculum (Broca's area), posterior superior temporal gyrus (Wernicke's area), posterior inferior temporal cortex, and a region in the mid superior temporal sulcus. Their results showed no activation for cortical sites dedicated to visual or auditory word form processing.

Motor control is the way we remember spatial memory. Joe K. & Nancy K. (2000) said brain regions involved in the visual analysis of motion are engaged in processing implied dynamic information from static images. They found stronger fMRI activation within medial temporal/medial superior temporal cortex(MT/MST) during viewing static photographs with implied motion.

Anthony S. D. & Carl S. (2000) concluded the motion-sensitive cortex is involved in inferring motion, so the mental imagery or mental rotation involve premotor and supplementary motor in relation to mental transformation. They explained that "Apparent motion" activated BA 9/46 and "Mental rotation" activated BA 8, 19, 39. Zoe K. & Nancy K. (2000) also suggested brain regions involved in the visual analysis of motion are engaged in processing implied dynamic information from static images. Our results showed no activation at BA 9/46 and BA 8/19/39, but interestingly cerebellum was activated. This means cerebellum was modulated by image formation of onomatopoeia. Even by the word presentation of onomatopoeia, subjects associate the onomatopoeia with movement.

In conclusion, our results suggest that superior temporal gyrus (BA41, BA42), inferior frontal gyrus (BA47) and fusiform gyrus (BA19) are involved in high-level recognition of onomatopoeia.

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