Statistical Analysis of rCBF Positron Emission Tomography Images for the Functional Mapping of Human Memory

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Abstract

By measuring the increase of regional cerebral blood flow (rCBF) during the activation tasks, we can describe the brain regions that participate in certain specific functions. In this study, we composed the functional maps of verbal and nonverbal memory by performing the rCBF positron emission tomography (PET) activation studies and analyzing the differences between control and each activation state. Successive four tasks, which consist of one control state and three different activation tasks, were performed on 6 normal volunteers. All images were spatially normalized on standard atlas and the differences between control and activation states were statistically analyzed. The verbal memory activated predominantly left-sided structures, especially left superior temporal cortex, and the nonverbal short-term memory activated the right frontal cortex. Also, some regions ,where is thought to be related with short-term memory system, such as cingulate gyrus and hippocampus were activated. We conclude that biological validity of the brain regions for verbal and nonverbal memory could be tested using rCBF PET imaging technique and statistical analysis.

Introduction

Functional mapping of human brain is a anatomical description of the brain regions that participate in certain specific function. The researches and clinical applications of functional mapping have grown as a important areas in neuroscience. Measurement of rCBF using PET have proved as a useful tool for this purpose because of its sensitivity and spatial localizing power. Memory system in human brain have become the subject of interest and been thought to be localized to specific regions of the brain. Recently, some works have been carried out to show that there are different type of memory and certain regions of the brain are much more important for some type than for others.

In this study, we composed the functional maps of the verbal and nonverbal memory by performing the rCBF PET activation studies and analyzing the differences between control and each activation state.

Method

Subject

Subjects were 6 normal volunteers. All were male, right-handed, and free of neurologic, psychiatric, or medical disorders.

Activation study and Data acquisition

PET scanning were carried out on the ECAT EXACT 47 (Siemens-CTI, Knoxville, USA) scanner. Successive four tasks, which consist of one control state and three different activation tasks, were performed on each subject during 2 minute with bolus injections of 25mCi $H_2{}^{15}O$ and

separated by 30 minute. During each activation task, thirteen matching trials were performed to activate the brain regions associated with verbal or nonverbal memory. Before tasks, subjects had been asked to push the button if the same object were contained among the four objects shown previously. At first and second activation tasks, short meaningful words and common objects, which enable the subjects to associate certain specific words in his mind, were used as the objects to test the verbal memory, and at task for the test of nonverbal memory, human faces were used as the objects to be recalled. One control task, to remove the effect of visual stimulation by watching the LCD monitor and activation due to the movement of finger to push the button, were performed before the activation tasks per each subject.

Transaxial images were reconstructed with Shepp filter (cutoff = 0.30 cycles/pixel) as 128 × 128 × 47 matrices with a size of 2.1 × 2.1 × 3.4 mm. All images were corrected for attenuation by means of a transmission scans performed on during 20 minute.

Data analysis

All PET images were transferred to a UNIX workstation, Indigo 2 (Silicon Graphics Inc., USA), where all data analyses were performed. Image data were analyzed using SPM (Statistical Parametric Mapping) implemented in Matlab (Mathworks Inc., USA). ECAT image files were converted to Analyze format used in SPM. Prior to statistical analysis, images from same subject were spatially registered to correct the error of movement between different scans and all images were normalized using linear and nonlinear transformation on the standard atlas to remove the inter-subject anatomical variability. As a final pre-processing, all images were smoothed using Gaussian kernel with 16 mm FWHM (full width at half maximum). The aim of smoothing is to increase the signal-to-noise ratio and account for the variations in subtle anatomical structures. Significant differences between control and each activation state were estimated at every voxels based on general linear model. Differences of global counts were removed using analysis of covariance with global activity as covariate at each voxel. Using the means and variances for every conditions that adjusted with analysis of covariance, t-statistics were performed on every voxels. For the sake of easy interpretation, the t-values were transformed to the standard Gaussian distribution (Z-score).

Result

The rCBF increases in each activation task compared to the control task were mapped on 3D surface (Fig 1, 2, 3). Voxels shown in black are voxels with significantly increased rCBF ($Z>1.66$, $p<0.05$).

In the case of verbal memory activation with short words, increased rCBF were seen in the left superior temporal cortex, left cerebellum, and both cingulate gyrus (Fig 1). In the activation of verbal memory with common object, increased rCBF in larger regions including where is activated in activation with short words and right infero-lateral frontal cortex and left hippocampus was seen (Fig 2).

On the other hand, nonverbal memory tasks activated right infero-lateral frontal lobe, where is more strongly activated by comparison with that in verbal memory task, and both cingulate gyrus. (Fig 3)

This result suggests that the verbal memory activates predominantly left-sided structures, especially left superior temporal cortex, and the nonverbal short-term memory activates the right frontal cortex. Laterality shown in this study is consistent with the results of the researches performed invasively. Also, cingulate gyrus, hippocampus, and frontal cortex are thought to be associated with the short-term memory system in human brain.

Conclusion

We conclude that biological validity of the brain regions for verbal and nonverbal memory could be tested using rCBF PET imaging technique and statistical analysis.

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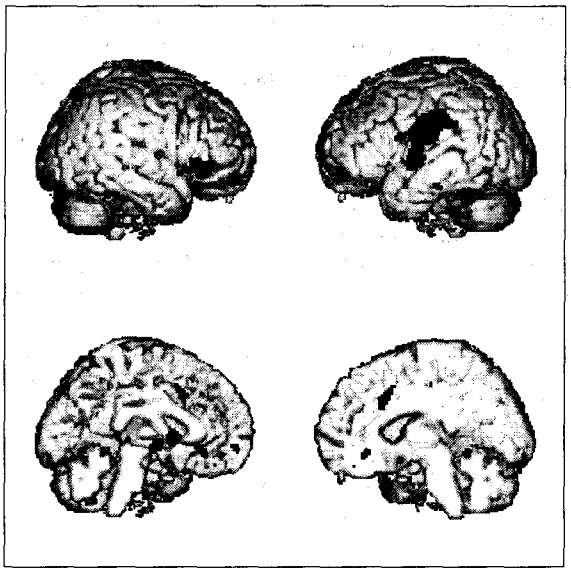

Fig 2. Increased rCBF (Z>1.66, p<0.05) in verbal memory activation with common objects which enable the subjects to associate certain specific words in his mind. Right infero-lateral frontal cortex and left hippocampus as well as the regions where is activated with short words were activated.

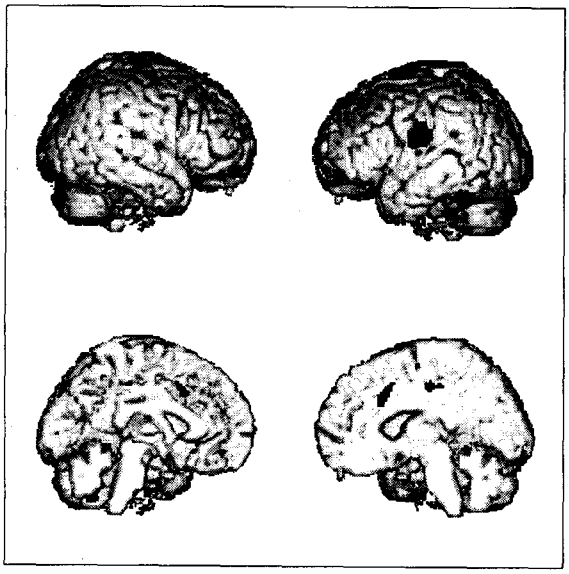

Fig 1. Increased rCBF in verbal memory activation with short words. Voxels shown in black are voxels with significantly increased rCBF (Z>1.66, p<0.05). Left superior temporal cortex, left cerebellum, and both cingulate gyrus were activated.

Fig 3. Increased rCBF (Z>1.66, p<0.05) in nonverbal memory activation with human faces. Right infero-lateral frontal cortex and both cingulate gyrus were activated.