Functional MRI Study of Correlation Between Cortical Activation Involved in Mental Calculation and Different Levels of Task Difficulty

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Introduction

Functional MRI (fMRI) is a recently developed noninvasive technology that uses local changes in brain blood oxygenation and flow to visualize neural activity [1]. Mental calculation is a complex cognitive operation with several functional processes. The aim of this fMRI study was to evaluate activation in the cerebral hemispheres in volunteers during the performance of internal mental addition with different levels of task difficulty.

Materials and Methods

10 healthy right-handed volunteers (six males and four females, mean age 35.6) participated in this study. All studies were performed using a 1.5T MR scanner with 23 mT/m gradients. A gradient recalled echo EPI sequence (TR/TE: 3000/50 msec; FA 90°; 64x64 matrix; 10mm slice thickness) was used to cover most of the cerebral cortex in the functional series. To aid in localization of the activation foci, high-resolution T1-weighted 3D-SPGR anatomical images (TR/TE: 33/5 msec; FA 45°; 256x192 matrix; 1.2mm slice thickness) covering the same area as the EPI images were acquired. Three block-designed experiments were employed. In each experiment, three odd-numbered control blocks (30 sec each) displayed pairs of Arabic digits of zero or one separated by a square (e.g. 00 □ 01) and two even-numbered task blocks (also 30 sec each) required mental calculation of the addition problems displayed in Arabic digits (e.g. 67 + 75). Each calculation task consists of serial presentation of 10 addition problems during a 30-second interval. Three tasks comprising 1-digit-addition, 2-digit-addition and 3-digit-addition were compared. The fMRI data were analyzed using SPM99. The data were realigned, spatially normalized into an MNI template, and smoothed. A box-car function was used as the reference. Only pixels with statistically significant correlation ($p<0.001$ uncorrected) were considered as activated areas.

Results

Significant activation by each of the task condition is shown in Figure 1. During the mental calculation of 1-digit-addition problems, activation was present in the prefrontal cortex (PFC) in five of 10 subjects (two bilateral and three left only). BOLD effect was present in the left posterior parietal cortex (PPC) near the supramarginal gyrus (SMG) in three subjects, seven subjects showed no parietal activity. During the calculation of 2-digit-addition problems, bilateral activation was observed in seven subjects in the inferior frontal gyrus (IFG), medial aspect of the middle frontal gyrus and superior frontal gyrus and the anterior cingulate gyrus. Two subjects had only left IFG activation and one had no frontal activation. Parietal activation was also observed in right precuneus, left SMG, angular gyrus in nine subjects. One subject had parietal activation only in the right precuneus region. For the 3-digit-addition task, bilateral activation was observed in the PFC of all subjects similar to the 2-digit-addition task. Three subjects also had additional activity in left caudate nucleus. All subjects showed profound activation in the PPC in the precuneus and SMG region around the inferior and superior parietal cortices and partially extended into the post-central cortices (Figure 2).

Discussion

Our results confirmed the importance of the PFC and the PPC in mental calculation [2,3]. Greater activation is observed with increasing task difficulty, particular in PPC (Figure 1). The angular gyrus was found to be closely linked to arithmetic complexity [4]. Our preliminary results further indicate that the precuneus and SMG are critically involved in complex mental calculation. Future studies should investigate the precise functions of these regions in the context of arithmetic processing.

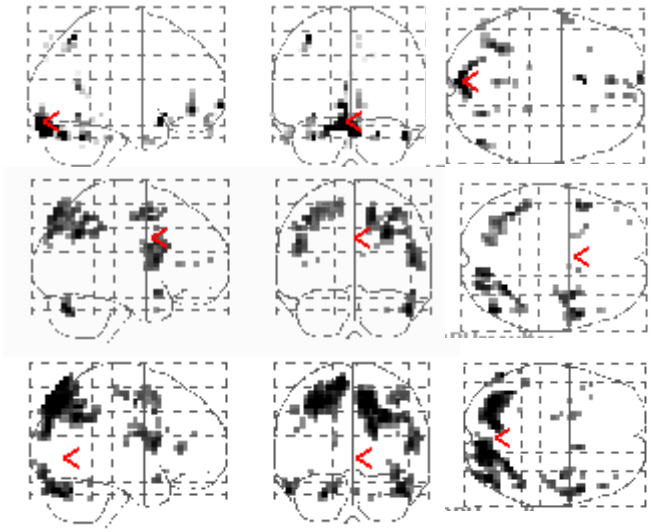

Figure 1. Areas activated by each of the mental addition task .

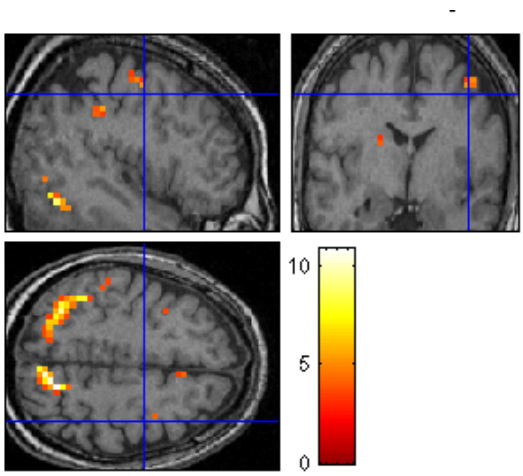

Figure 2. Activation maps of the 3-digit-addition task .

References

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