Verbal working memory in digital calculations: a functional MRI study

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Purpose

The neuropsychological and behavioral studying showed that calculation may be done based on the language processing (1). This study aimed to evaluate the relation of verbal working memory with digital calculations, and to assess the loading effect of the working memory in the digital calculation.

Methods

Twenty three right-handed healthy volunteers (Informed consent was obtained from every volunteer) received block-designed fMRI experiments included subvocal number reading, simple and complex calculation. Three task blocks and 3 control blocks ran alternatively. The task of subvocal number reading was reading silently a digit presented on the screen such as "12345", and the control was a "+" presented on the center of screen. The task of the simple and complex calculation included two parts (arithmetic and result selection, such as "24-18; 4, 6" in simple tasks and "(74-58) ×2; 42, 32" in complex tasks). The control was five "0" or five "1" and nine "0" or nine "1" in simple and complex experiment respectively. fMRI were acquired on GE1.5T Twinspeed Infinity with EXCITE II MR scanner with GRE-EPI sequence (TR=3000ms, TE=40ms, Matrix=128×128; thickness=7mm, slice gap=1mm). The data of the volunteers with correct calculation more than 27 of 30 tasks were processed by using SPM99. Significant threshold of t-test at voxel level for functional areas was $p<0.05$ (corrected).The regions including more than 10 consecutive activated voxels were regarded as functional areas. Conjunction analysis was performed to acquire average functional image. The results of three tasks were compared.

Results

The experimental data of twenty volunteers' satisfied standards were used for statistic analysis. The activated areas in subvocal number reading experiment included bilateral occipital lobes, the left Broca area, the left angular gyrus and bilateral medial frontal gyrus (figure 1). The left prefrontal cortex(LPC), bilateral premotor areas(PA), posterior part of the inferior frontal gyrus (pIFG), medial frontal gyrus (mFG), anterior part of the cingulated gyrus (ACG), posterior part of the inferior temporal gyrus (pITG), inferior parietal lobules (IPL), occipital lobes, and bilateral cerebellum were activated both in simple and complex calculation. But the right prefrontal cortex (RPC) was only activated in the complex calculation. Compared with simple calculation, the activated extent and magnitude in the left frontal cortex, posterior part of the left inferior frontal gyrus, bilateral premotor areas, and bilateral inferior parietal lobules increased obviously in complex calculation (figure 2, 3).

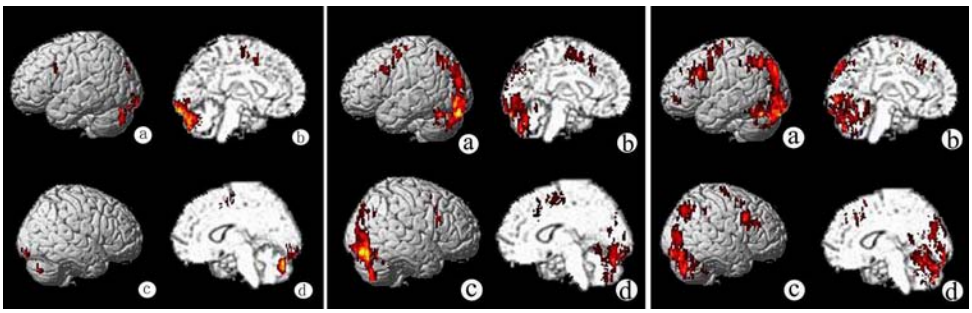

Figure 1 Subvocal number reading. Bilateral occipital lobes, the left Broca`s area, the left angular gyrus and bilateral medial frontal gyrus activated.

Figure 2, 3 Simple and Complex calculation. The LPC, bilateral PA, pIFG, mFG, ACG, pITG, IPL, occipital lobes, and bilateral cerebellum were activated both in simple and complex calculation experiments, and more obvious in the complex calculation experiment. The RPC was only activated in the complex experiment.

Discussion

Working memory was a comprehensive capability to process and store information temporarily and was necessary for many cognitive actions. Verbal working memory was responsible for storing and retrieving verbal information (2, 3). The results of subvocal number reading showed it was a simple kind of lingual action. Simple and complex calculations obviously activated the functional areas that activated in the subvocal number reading experiment, and furthermore, other functional areas were also activated. So the digital calculations must contain the lingual mechanism of the subvocal number reading, and may associate with other more complex cognitive actions. Calculations consisted of: recognizing number, understanding arithmetic symbol, retrieving arithmetic fact from long-term memory, selecting arithmetic methods, performing the arithmetic rules, storing and retrieving the median results, and presenting final result . During digital calculations, the verbal working memory was necessary for storing and retrieving the median results, and then performing the next calculation. Alternately storing and retrieving leaded to obvious activation of the posterior part of inferior frontal gyrus, prefrontal cortex, premotor areas, and inferior parietal lobule. The arithmetic skills were necessary even for very simple arithmetic problems to plan the procedures, to store the median results, and to acquire the final result (4), so the verbal working memory was more necessary. As an especial short-term memory, the working memory has physiological limitation of capacity, so the extent and intensity of activated areas were related to the work-loading. Our results demonstrated that more neurons in the functional areas related to the verbal working memory were needed to deal with the more difficult arithmetic problems, in another word, verbal working memory had the loading effect.

Conclusions

Verbal working memory was not necessary for subvocal number reading, but was even necessary in dealing with simple arithmetic problem, archiving and retrieving median results, controlling and modulating arithmetic process. Obvious loading effect of the working memory exists in the digital calculation.

References

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