The neural network of mental calculation in child abacus experts and nonexperts

F. Chen[1], Z. Hu[2], X. Tang[1], P. Shi[2]

[1]Department of Physics, Zhejiang University, Hangzhou, Zhejiang, China, People's Republic of, [2]Department of Electrical and Electronic Engineering, Hong Kong University of Science and Technology, Hang Kong, China, People's Republic of

Introduction

Abacus mental calculation (AMC), or “zhuxinsuan” in Chinese, is a specific kind of mental calculation that relies on the basic principles of abacus calculation. AMC experts thus refer to those who have been trained and also demonstrated extraordinary capability of AMC. To date, great efforts have been devoted to clarify the neurophysiological mechanisms on adult abacus experts [1, 2] and non-experts [3, 4]. However, the cognitive mechanisms and underlying neural correlates of mental calculation remain unclear, especially for abacus experts. In this study, we attempt to characterize the joint interactions among several brain regions during mental calculation. We have found a substantially different functional connectivity networks for child AMC experts and non-experts during mental calculation experiments.

Methods

Subjects 16 right-handed healthy subjects aged between 10 and 15 years (8 AMC experts and 8 non-experts, 11.75±1.39 years) volunteered to participate in this study with informal written consents from their parents/guardians. Subjects were required to perform simple and complex mental calculations through visual stimuli during MRI scanning sessions.

Data acquisition Imaging data were collected with a 1.5 T MR scanner (Marconi, USA) with a standard circularly polarized head coil. Anatomical imaging included a transverse 3D gradient echo T1-weighted sequence (500/12 ms [TR/TE], flip angle 90^o, FOV 23×23 cm, matrix 192×256, slice thickness/gap 6/1 mm, number of slices 21). For fMRI, a whole brain T2*-weighted, echo-planar imaging (EPI) sequence (2000/40 ms [TR/TE], flip angle 90^o, FOV 23×23 cm, matrix 64×64, slice thickness/gap 6/1 mm, number of slices 21) was used. A total of 216 images were acquired for every subject.

Data analysis Data analysis was performed using SPM2. After realignment, the images were normalized into standardize coordinate space approximated to the Talairach and Tournoux space and then smoothed spatially using a Gaussian kernel of 8 mm FWHM. The statistical analysis was performed for finding significant activations for the AMC expert and non-expert groups. Based on group t-test, we chose six anatomically defined regions. Then, based on individual t-map, the voxel with the largest t-value within two regions was taken as the subject-specific peak voxel. We defined clusters based on faces and edges, but not corners, so each voxel had 18 neighbors. Subject-specific averaged time series were extracted by averaging the time series of 19 voxels. The connectivity degree $\eta_{ij}=e^{-\xi d(i,j)}$ between node i and node j was used to identify the change of functional connectivity associated with differential tasks, and we had defined the total connectivity degrees between node i and all other nodes as $\Gamma_i=\Sigma_{j=1}^{n}\eta_{ij}$. Finally, we normalized Γ_{ij} of a node i, namely, $\Gamma= \Gamma_j/\sum \Gamma_j$. In details, measuring the strength of the relationship between the two nodes, η_{ij} was calculated as a hyperbolic correlation measure [5], with ξ a real positive constant (ξ was a subjective selection and was set to $\xi=2$ in our study) and $d(i,j)=(1-Coh_{ij})(1+Coh_{ij})$, where $Coh_{ij}(\lambda)=|f_{ij}(\lambda)/f_{ii}(\lambda)f_{jj}(\lambda)|\ )|$, where $f_{xy}(\lambda)$ is the cross-spectrum of x and y at frequency λ, and $f_{xx}(\lambda)$ and $f_{yy}(\lambda)$ are the respective power-spectra of x and y, the normalized cross-covariance function in the spectral domain, represented the coherence between the two nodes [6]. In this study, we had only considered coherence in low-frequency (0-0.15 Hz).

Results and Discussion

Figure 1 shows the brain activities observed during complex vs. simple mental calculation for the child AMC expert and non-expert groups. Figure 2 shows the functional connectivity degree (Γ) of each brain region across all subjects for each group. A larger Γ suggests that there are significant functional connectivity between this brain region and others, and it is thus considered as a crucial node in the network. In this study, we have found that the neural network of cerebral activities in AMC experts was substantially different from those in the non-experts (Figure 1) and from those in previous imaging studies of mental calculation [3, 4]. Significant activity was observed in GFi (inferior frontal gyrus, Broca’s area) among non-experts, while more important activities were found in GL (lingual gyrus) and bilateral PLs (superior parietal lobule) among AMC experts. One probable explanation of the discrepancy is that the influence of cognitive strategies impacted on two groups. In non-experts, mainly verbal-based strategy was employed, while in AMC experts, visual-based strategy rather than numbers and/or language played a crucial role. Furthermore, in the results of functional connectivity, a larger Γ was observed in the left PLs of both groups, while the right PLs showed a greater Γ in AMC experts but the GFi showed a greater Γ in non-experts. These results also support the above-mentioned notion - cognitive strategies affect the cerebral activities. In conclusion, our findings have demonstrated that the different neural networks and functional connectivity degree of mental calculation between child AMC experts and non-experts are related to the cognitive strategies implied in the processing of mental calculation. The findings reported here are preliminary and clearly more data samples and stratification are required.

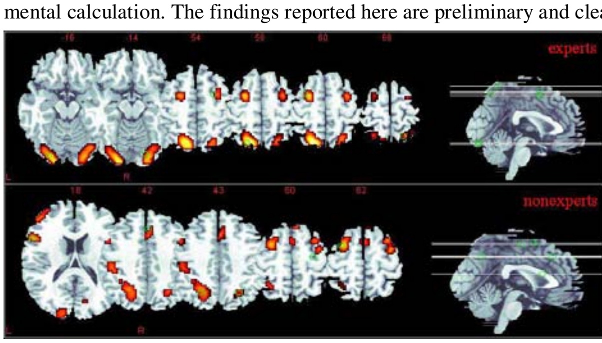

Figure.1

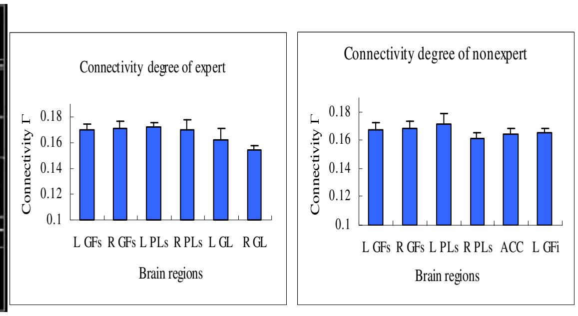

Figure. 2

Reference

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