Neural correlates of mathematics competence in children: a functional MRI study

John Y.S. Cheng[1,2], Wing P. Chan[3,4], Pei-Shan Ho[2,5], Ho-Ling Liu[5], and Chun-Yen Chang[2]

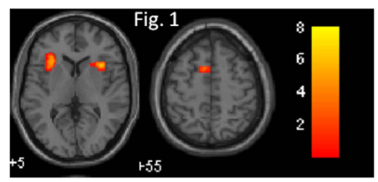
[1]*Division of Neurosurgery, Department of Surgery, Taipei Medical University Hospital, Taipei Medical University, Taipei, Taiwan, Taiwan,* [2]*Graduate Institue of Science Education, National Taiwan Normal University, Taipei, Taiwan, Taiwan,* [3]*Department of Radiology, Wan-Fang Hospital, Taipei Medical University, Taipei, Taiwan, Taiwan,* [4]*School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan, Taiwan,* [5]*Department of Medical Imaging and Radiological Sciences, Chang Gung University, Taipei, Taiwan, Taiwan*

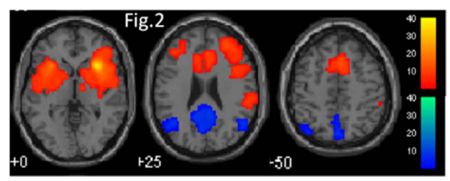
Introduction

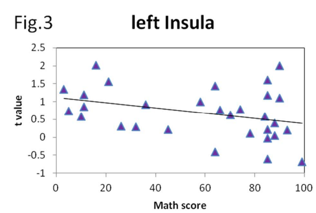
Simple arithmetic is one of essential mathematic cognition for our normal life. Arithmetic operation involved attention, verbal and spatial functions (1). By arithmetic related neuro-imaging studies for normally developing children and adults, the gain of arithmetic competence is reflected by a shift of activation from frontal brain areas to parietal areas, the shift activation is also observed within the parietal lobe from the intraparietal sulci to the left angular gyrus (2). And an inter-individual differences study showed the stronger angular gyrus activation is observed in higher mathematic competence subjects compare to lower competences in adults (3). However, rare is known the early developing activation of brain and its' individual differences related to mathematics competence in children. To investigate the neural activations, subjects most asked to perform a task during scan, the various arithmetic tasks resulted in different outcomes. In addition to task-related fMRI studies, recently functional connectivity (FC) detected by resting-state fMRI has emerged to give an insight into the baseline state of human brain (4). In this study, we focus on the brain activation during simple serial addition in children, and the relationship between the mathematic competence and functional neural images both in task-related and resting-state.

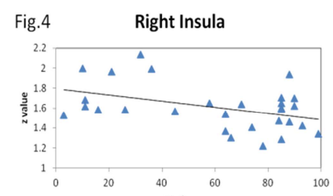
Methods

Twenty-nine right-handed healthy children (age: 10±1.4years) participated in this study. During the fMRI scan, subjects performed the single serial addition (SSA) task. Task began with the presentation of a stimulus of crisscross for 15s, followed by a control or a task period of 24s. The control block included 10 eight-digit random numbers presented in series with a frequency of 0.5Hz and subjects were required to keep gazing at numbers without calculation. During the task session, one-digit random numbers were presented with the same rate and subjects were instructed to sum them up. During the RS-fMRI scan, subjects were instructed to keep their eyes closed, not fall sleep, and to think of nothing in particular. fMRI images were acquired at a 1.5T clinical scanner using a T2*-weighted gradient-echo echo-planar imaging (EPI) sequence (TR/TE/FA = 3000ms/50ms/90°, in-plane matrix = 64×64, slice thickness = 6mm). For each subject, 20 axial slices per volume and a total of 104 volumes were obtained. RS-fMRI images were acquired using the same sequence but TR = 2000ms and total volume =180. After the scan, the Mathematics Development Ability Test for Elementary School Students (5) was employed to assess the children's mathematic competence. The data analysis was performed using SPM5 (http://www.fil.ion.ucl.ac.uk/spm/). The EPI data were realigned and spatial normalized into MNI template, and spatial smoothed with a Gaussian kernel of 6mm. Functional activations of SSA vs. control were obtained by modeling the data with GLM and group results were analyzed using one sample t-test ($p<0.001$, uncorrected, minimal cluster size = 5 voxels). For RS-fMRI, after data preprocessing, FC images were analyzed with seed-based correlation analysis using REST (http://resting-fmri.sourceforge.net). Seeds were selected from the results of task-related fMRI activation maps within bilateral anterior insula (AI) (6). The results of correlations were transformed to approximate Gaussian distribution using Fisher's z transformation, and group analysis was implemented by one sample t-test ($p<0.05$, FWE corrected). For regression analysis, the ROIs were selected from the activated clusters in AI which was determined by using anatomical automatic labeling (AAL) template within salience network.









Results

Figure 1 shows group results of the brain activation from the SSA task. SSA task induced activation in the bilateral AI and medial frontal gyrus (MFG). After using the left AI as a seed, the group result of FC map is shown in figure 2. It depicted that the right AI and anterior cingulated cortex (ACC) within salience network were positively correlated to left AI, and the default mode network (DMN), including posterior cingulated cortex (PCC) and bilateral inferior parietal cortex (IPC) (7), was negatively correlated to left AI. The regression analysis showed that SSA-induce activation strength (averaged t values) within left AI were negatively correlated with the mathematic scores ($r = 0.34$, $p = 0.034$) (figure 3). For the FC result, the correlation strength (averaged z values) in right AI were negatively related with the mathematic scores ($r = 0.42$, $p = 0.011$) (figure 4).

Conclusion This study found that the SSA task of fMRI activated bilateral AI and MFG in children, and the task-related fMRI activation in left AI was negatively correlated with mathematic competence. The RS-fMRI demonstrated negative correlation between the FC within the salience network and the mathematic competence.

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