Applying MRI for Investigating Brain Plasticity Resulting from Attention Training on Healthy Highly Educated Subjects

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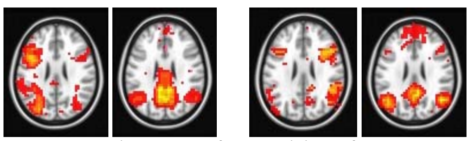
Introduction: Attention training (AT) results in changes in brain structure, grey matter and the connections of the structures (i.e., brain plasticity) (1-2). Here we present our study on applying MRI modalities including resting state functional MRI (rfMRI), DTI, and high resolution structural images to examine the impact of AT on brain plasticity of healthy highly educated subjects. Our hypothesis was that brain plasticity including functional and structural connectivity and grey matter volumes results from AT within 2 weeks. Our results of rfMRI, DTI, and tensor based morphometry (TBM) on the AT of the healthy highly educated subjects demonstrated the brain plasticity indeed happened within 2 weeks. **Materials and Methods:**12 normal subjects (6 females and 6 males; age:23.3±1.8 years, IQ:116.1±7.2 and mean years of education:16.6±1.4) were recruited for AT in which they were asked to practice N-back tasks for 20 minutes a day for two weeks. Among them 9 showed improvement on the training and are reported here as the training group. Six age and IQ matched normal subjects who did not receive the AT were also recruited as the control group. The subjects in the two groups were scanned twice: one was prior to the training (i.e., the 1st day), and the second at the completion of training (i.e., the 14th day). The MRI scans were performed on a 3.0 T MRI scanner with a standard birdcage head coil. After a T1-weighted high spatial resolution imaging using a MPRAGE pulse sequence (TR/TE: 450/3.81ms, slice thickness: 1.5 mm and 124 axial slices for covering whole brains), rfMRI imaging was performed by using a multi slice 2D EPI (TR/TE: 4000/30ms, field of view (FOV): 240 mm, image matrix:128*128, slice thickness: 4 mm, 32slices) for total 64 volumes. The subjects were asked to close their eyes, and "rest" during the rfMRI scans. Then, a DTI data with 25 directions and 38 axial slices was acquired. rfMRI analyses were performed by using FSL (3) and AFNI (4). Individual and group independent component analyses (ICA) were performed by FSL, and the "attention" component (i.e., dorsal attention network (DAN)) and "default mode network (DMN)" were found from the ICs, then the DAN and DMN maps for each individual subject was exported to AFNI to get the mean Z values of the networks . Fractional anisotropy (FA) was calculated within DTIStudio (5). ROIs were drawn in the genu and splenium of the corpus callosum (CC). The mean and standard deviation for N back score, FAs and Zscores in the 1st day and the 14th day were calculated, and a two tail, equal variance, t-test was applied to the data before and after AT in order to get P values. P < 0.05 was set as significant. The TBM analyses for longitudinal volume changes was done with SPM8(6).**Results:**The DAN and DMN maps form the rfMRI data of the control group from two rfMRI scans in the first day and the last day (i.e., the 14th day) are presented in Figure 1. Even though the images from the two days look different, the Z scores for the DAN and DMN are the same (see Table 1, DAN: 4.16±0.91 and 4.55±0.46 with a P =0.22; DMN: 4.50±0.14 and 4.80±0.29 with a P=0.111 for the 1st and 14th day, respectively). The N- back scores for the controls (Table 1) also suggested no change (P=0.402) in the 2 weeks. For the training group the changes of GM volumes in the ROIs of the left occipital, frontal, and parahippocampal gyrus (the coordinates of the ROIs are (-20 -54 -2), (-46 34 -2), (-18 -38 -4); respectively) were demonstrated in the Figure 2. The DAN and DMN of the 9 subjects before and after attention training were presented in Figure 3. For the controls and trainings in the 1st and 14th days, the mean values and standard deviations of the N-back scores, FAs in the two ROIs and Z scores and the P values for the data in the 1st day verse the data in the 14th day or the changes of GM volume in the three ROIs, were listed in the Table 1.

Fig.1. Images for the controls of DAN and DMN in 1st day (left) and 14th day (right).



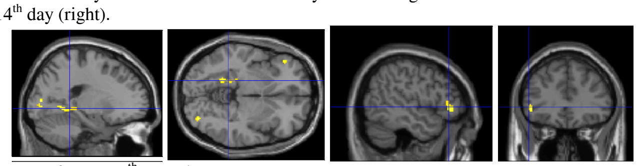


Fig. 2. For the training group the changes of GM volumes in (shown by yellow) the left occipital, frontal, and parahippocampal gyrus following the AT.

Fig.3. Images for the trainings of DAN and DMN in 1st day (left) and 14th day (right).

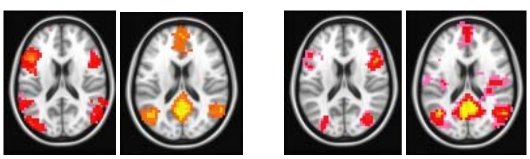


Table 1: Mean N back, FAs and Z scores before (B, i.e., the 1st day) and after (A, i.e., the 14th day) the AT and the changes of GM volumes in the ROIs for the controls (the 1st B, A and P rows) and trainings (the 2nd B, A and P rows).

	N-back score	FA(G)	FA(S)	Z(DAN)	Z(DMN)	ΔV(o)	ΔV(f)	ΔV(h)
B	**39.50±4.59**	**0.80±0.03**	**0.80±0.02**	**4.16±0.91**	**4.50±0.14**	**N/A**	**N/A**	**N/A**
A	**41.17±6.30**	**0.78±0.03**	**0.79±0.02**	**4.55±0.46**	**4.80±0.29**			
P	**0.402**	**0.071**	**0.420**	**0.220**	**0.111**	**>0.05**		
B	**47.11±7.98**	**0.79±0.03**	**0.82±0.03**	**3.45±0.72**	**4.26±1.26**	**0.42**	**0.39**	**0.36**
A	**73.33±16.5**	**0.81±0.03**	**0.82±0.03**	**4.24±0.58**	**5.5±0.90**			
P	**0.0002**	**0.0161**	**0.611**	**0.004**	**0.027**	**<0.05**		

Discussion: No significant changes were observed for the pre (the 1st day) versus post (the 14th day) scans in the control participants (see Table 1: for N Back score, FA(G), FA(S), Z(DAN) and Z(DMN), P>0.05). For the training group, Figure (2) shows the AT increases the volumes (shown in yellow) in the three gray matter cortices: left occipital, frontal, and parahippocampal gyrus, for which are known to be related to memory, attention, vision, and executive functions. The images (Figure 3) obtained from the rfMRI group analyses of the training group demonstrate a bilateral dorsal attention system and a triangular shape default mode network. The P values and the parameters for the training subjects (Table 1) suggested the increase in the N back scores, Z(DAN), Z(DMN), FA(Genu) and GM volumes in the ROIs after the AT. These brain changes in the training group were coupled with increased attention ability (in Table 1, N-back scores increase with a P=0.0002). This implies that the training effect enhances the intrinsic, dynamical linkage among the eloquent cortices (Table 1) in DAN and DMN, i.e., significantly increased Z scores: the strength of the DAN (P=0.004) and DMN (P=0.027). FA(S) did not change after the AT (P=0.611) and FA (genu) does (P=0.0161, Table 1). After the training, the N-back score, FA (G), Z (DAN) and Z (DMN) and GM volumes in the ROIs were significantly higher (Table 1). The results suggested that the AT effects enhanced the intrinsic, dynamical linkage among all attention eloquent cortices and the cortices in DMN and also increase the GM volumes in the three ROIs, but increased structural anisotropy only in genu (G) of the CC. **Conclusion:** The multi regional enhancements in the GM and the increment of the anisotropy for the WM in the genu, may lead to the improvement of working memory and attention functions indicated by increasing N-back scores. **References:**[1] Wager, T., Neuroimage, 2004, 1679-93. [2]. Draganski, B., Nature, 2004, 311-312. [3]Cox, RW., Comput. Biomed. Res., 1996, 162–173. [4] Smith, SM., et al., NeuroImage, 2004, 208-219. [5] Jiang, H., et al.,Computer Methods and Programs in Biomedicine, 2006, 106-116. [6] Friston, K., Introduction: experimental design and statistical parametric mapping. In Frackowiak et al. (Eds.), 2003, Human brain functions.