Brain Performance Correlations with Oxygenation Levels and Neuronal Activity in Resting State fMRI

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Introduction

Resting state network BOLD fluctuations are now included in investigations of a variety of diseases and psychological disorders. The default mode network has been shown to deactivate during cognitively engaging tasks and task positive networks correlate with a deactivation of the default mode during effective brain function. Here we used the random fluctuations of the resting state brain and capitalized on the hemodynamic delay of BOLD fMRI to investigate what *prepares* the brain for best performance: blood oxygenation or the neuronal activity.

Based on previous literature we hypothesized that a subject's reaction time to a button press cue correlates with BOLD signal levels. In addition, we wanted to see which was a stronger predictor of brain performance: the network specific blood oxygen level immediately prior to the button press (T_0); or the network's neuronal activity immediately prior to the button press. We used the hemodynamic delay between neuronal activity and the BOLD response as a temporal separation of the oxygen reserve at T_0 versus the BOLD response due to the neuronal activity at T_0. The neuronal activity immediately prior to the button press is reflected in the BOLD signal level at 1 TR after T_0 (T_{0+1}).

Methods

Subjects: The subjects included 6 healthy volunteers : 3 males and 3 females, aged 23-28 years (mean age = 24.7, SD = 2.25). There were no significant performance differences in response times between males and females.

Image Acquisition: Imaging was performed using a Siemens 3T Allegra MRI. Imaging protocols: Axial 3D-MPRage (TR = 2500 ms, TE = 4.4 ms, FOV = 23 cm, matrix size = 256x256, 208 slices with thickness = 0.9 mm). EPI BOLD scans were acquired using a GE-EPI sequence with the parameters: TR=2s, TE=27ms, FOV=21cm, 3mm thick, skip = 1mm, Matrix size=64x64, 32 slices. The resting state protocol acquired 532 measurements (~18 minutes). Subjects were told to lie quietly and press any button when prompted. Subjects were prompted a button press every 2.5 minutes for a total of 6 response time probes per session.

Image Analysis: Preprocessing of the functional images was performed in FSL and included motion correction (MCFLIRT), coregistration to the high resolution T1 images (FLIRT) and non-linearly registration to the standard MNI T1 template (FNIRT). Independent component analysis (ICA) was used to identify 18 unique networks of resting state activity using MELODIC (Beckmann and Smith 2004) as implemented in FSL. The default mode network (DMN) consisting of the anterior and posterior cingulate cortex and the bilateral parietal cortices (PC) has been consistently reported before by other studies (1,2, 3). The z-transformed BOLD levels of the DMN were extracted for each instance where the response time was probed (T_0) and 2 seconds after each probe (T_{0+1}).

Response times for each subject were z-transformed to run a group level analysis. A Pearson's Correlation Coefficient (r) was then calculated between z-transformed response times and BOLD signal level at T_0 and T_{0+1}.

Results

The MELODIC group analysis produced 80 components using automatic dimensionality estimation. Figure 1 shows the network that was identified as the default mode.
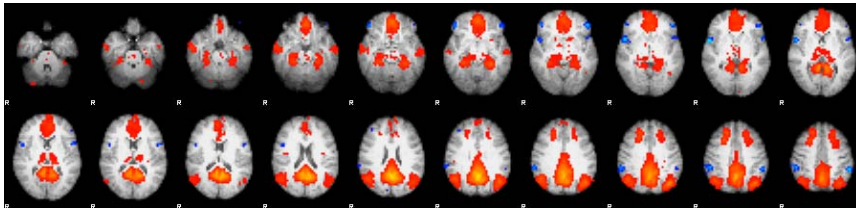

Figure 1. The resting state network that was identified as the default mode.

BOLD levels were extracted and z-transformed for each subject at T_0 and T_{0+1}. Reaction times were correlated with BOLD levels at both T_0 and T_{0+1} timepoints and are displayed in figure 2. Reaction time was correlated with BOLD levels at T_0 (r = 0.5; p < 0.003) but not with the BOLD levels at T_{0+1} (r = 0.05; ns).
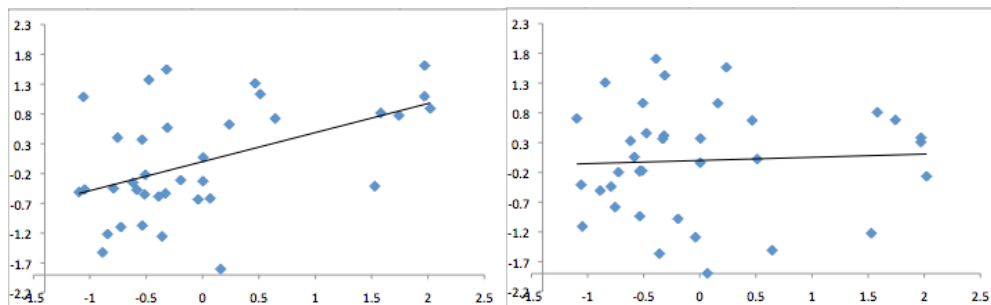

Figure 2. Reaction time (horizontal) vs. default mode network BOLD level at T_0 (left, vertical) and T_{0+1} (right, vertical). Correlation coefficients are r = 0.5 at T_0 (p < 0.003); and r = 0.05 at T_{0+1} (ns). Values are z-transformed.

Discussion

We confirmed our initial hypothesis that the BOLD levels of resting state networks correlate with performance. Specifically, we showed that the BOLD level of the default mode network positively correlate with subjects' response time. Far more interesting was the differences in the relationships of response time with oxygen levels versus neuronal activity: The response time was correlated with the BOLD levels at T_0 but not at T_{0+1} in the default mode network.

We interpret these results to suggest that the performance of the brain is highly dependent on the oxygen reserve but not with the imminent state of neuronal firing. We offer the analogy of an athlete that is warmed up and ready to perform: the organ's ability to perform is related to the oxygen reserve more so than the immediately preceding level of activity.

Further investigations should include experiments with very fast TR to gain a better temporal resolution and more clearly resolve the relationship between brain performance and oxygen levels.

References

1. Greicius, Krasnow et al. 2003
2. Damoiseaux, Rombouts et al. 2006
3. De Luca, Beckmann et al. 2006