Slower DMN, faster reaction: coupling of resting-state CBF and BOLD oscillations in specific frequency bands predicts vigilance task performance

Xiaopeng Song[1], Shaowen Qian[2], Kai Liu[2], Zhenyu Zhou[3], Gang Sun[2], and Yijun Liu[1]

[1]Department of Biomedical Engineering, Peking University, Beijing, Beijing, China, [2]Department of Medical Imaging, Jinan Military General Hospital, Shandong, China, [3]GE Health Care, Beijing, China

INTORDUCTION AND PURPOSE. People usually say “smarter brain works faster and reacts faster”. Can we observe this phenomenon by neuroimaging techniques? Is it true that faster brain rhythms are always associated with faster behavioral reaction? To answer these questions we used BOLD-fMRI to evaluate how fast the resting-state brain activities are and explore in what brain areas the resting-state BOLD oscillation frequency is correlated with psychomotor vigilance test (PVT) performance. On the other hand, previous studies have reported significantly slower attentional reaction and altered regional cerebral blood flow (rCBF) during passive hyperthermia (HT) [1]. The changes of BOLD rhythms in some brain areas might be associated with the increased reaction time (RT) under HT. Previous researches also indicated that BOLD activities in different frequency bands might be related to different neuronal or physiological processes. Since heart beat and breath have been found to contribute to BOLD oscillations in the higher frequency band (>0.1), we hypothesize that CBF, as a measure of brain physiology, may mainly contribute to BOLD oscillations in certain lower frequency band. We also hypothesized that the coupling of CBF and BOLD oscillations in specific frequency bands would be altered during HT, and the rhythmic-specific coupling of CBF and BOLD oscillations might predict vigilance task performance under either normothermic (NT) or HT conditions. The purpose of this study is to explore the brain network whose BOLD frequency is significantly correlated with RT under NT or HT conditions, and to examine how NT and HT conditions modulate the coupling of CBF and BOLD oscillations of different frequency bands in this network.

METHODS. *MRI Data Acquisition.* 15 participants (22.5 ± 1.75 y) underwent two simulated environmental thermal conditions (50 °C/25 °C, 1 h) 40 min before and during MRI scanning in a random order with 3–7 days apart in an environmental chamber. The CBF images were acquired with a 3D pseudo-continuous ASL sequence using a GE MR750 3.0 T scanner (TR/TE = 4632/10.5 ms, slice thickness = 4 mm, FOV = 24 × 24 cm2, PLD = 1525 ms). BOLD images consisted of 200 volumes were acquired with a gradient echo T2*-weighted EPI sequence (TR/TE = 2000/40 ms, FA = 90, number of slices = 29, matrix = 64 x 64, FOV = 24 x 24 cm2, thickness/gap = 4/0 mm). After scanning, a highly-demanding attentional task, PVT, was performed, in which participants are asked to respond as rapidly as possible to a red block presented at short, random intervals. The PVT is free of aptitude and leaning effects, thus it can be repeatedly performed on one participant during both conditions. *Data Processing.* CBF and BOLD images were preprocessed with SPM8. For BOLD images, a data-driven method, Frequency clustering analysis (FCA)[2], was applied in a voxel-wise fashion to assign each voxel a single value to represent its mean BOLD oscillation frequency. FCA method also adaptively decomposes the time course of each voxel into five time series termed intrinsic mode functions (IMFs). Each IMF occupies a unique frequency range: IMF1 0.1-0.25Hz, IMF2 0.04-0.1Hz, IMF3 0.02-0.04Hz, IMF4 0.01-0.02Hz, IMF5 0-0.01Hz. The energy of each IMF was calculated. A group-level voxel-wise multivariate linear regression analysis was employed to detect the brain areas in which the BOLD oscillation frequencies were correlated with RT under either NT or HT conditions. These areas were combined to create a mask. The cross-voxel spatial correlations between CBF and BOLD oscillation energy of the five IMFs in this network were calculated for each subject under NT and HT conditions.

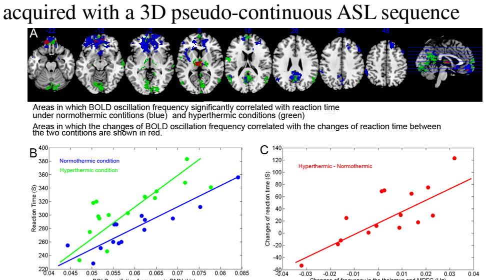

Fig.1

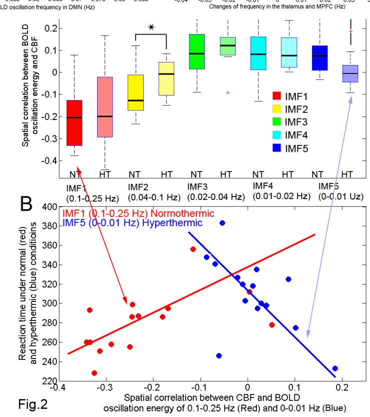

Fig.2

RESULTS. Paired t-test showed significant slower reaction during HT condition (p=0.022). As shown in Fig.1, the BOLD frequencies in the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), bilateral angular gyrus, and thalamus are positively correlated with RT under both NT and HT conditions (FDR corrected, p<0.05). These areas constitute the default mode network (DMN). While the ventral MPFC (vMPFC) and inferior frontal gyrus are more significant with NT, the dorsal MPFC, occipital areas, and ventral lateral thalamus are more significant with HT. The changes of BOLD frequency in the medial thalamus and vMPFC are also correlated with the changes of RT between HT and NT. As shown in Fig.2, the spatial correlation between CBF and BOLD oscillations in IMF3 and 4 are the highest, i.e. the spatial distribution pattern of CBF resembles the spatial distribution of BOLD oscillation energy in 0.01-0.04 Hz the most. On the contrary, the spatial distribution of BOLD oscillation energy in 0.1-0.25 Hz shows an inverse pattern of CBF distribution. ANOVA revealed significant interactions between different frequency bands (IMFs) and HT-NT conditions (p<0.05). Post-hoc analysis showed that the coupling between CBF and BOLD oscillation energy decreased significantly in IMF2 and IMF5 during HT (spatial correlation coefficients are more close to 0 during HT compared with NT, p<0.05). The coupling strength between CBF and BOLD oscillation energy in IMF1 is significantly correlated with RT during NT but not HT, whereas the coupling of CBF and BOLD oscillation in IMF5 is significantly correlated with RT during HT but not NT. **DISCUSSION.** Those who had slower resting-state BOLD activities in DMN reacted faster in PVT task. The DMN is involved in “mind wandering”, sleep and self-referential thoughts. It maintains the brain in an idle and “ready” or “default” mode. It is usually deactivated during task states. Slower resting-state BOLD activities in DMN may indicate more plasticity of the DMN functions during task-state, and task-irrelevant thoughts can be more easily suppressed hence improve task performance. CBF mainly contributes to BOLD oscillations of 0.01-0.04 Hz with both NT hand HT. The negative correlation between CBF and high frequency BOLD fluctuations suggests that high frequency BOLD activities may contain less neuronal processes. A stronger coupling of CBF and low frequency BOLD activities predicted better task performance during HT, emphasizing the importance of low frequency BOLD activities in DMN during HT. **CONCLUSION.** Our study linked resting-state brain rhythms to task performance, and for the first time revealed the frequency-specific coupling between blood supply and BOLD oscillation topology during rest and its modulation in response to HT, which may shed light on the physiological basis of resting-state BOLD activities and its relevance to task performance.

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