ASL Perfusion fMRI to Image Psychomotor Vigilance Time-on-Task Effects in the Human Brain

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Introduction Performing a mentally-demanding task for a sustained period causes many individuals to show time-on-task (TOT) effects. TOT induces both objective performance decline (e.g., increased reaction times and propensity to commit errors) and subjective sensation of mental fatigue (MF). Although TOT is a common phenomenon in our everyday lives, the neural bases of subjective fatigue and objective performance decline are largely unclear. This may be partly due to the poor sensitivity of widely used BOLD fMRI to measure low frequency neural activity (1). Using magnetically labeled arterial blood water as an endogenous tracer, arterial spin labeling (ASL) perfusion fMRI can provide noninvasive quantification of absolute cerebral blood flow (CBF). With excellent temporal stability (1, 2), ASL offers a suitable tool for imaging neural activity associated with TOT occurring over long time-scales. Here we explored the neural correlates of TOT effects induced by a prolonged Psychomotor Vigilance Test (PVT) (3) using ASL perfusion fMRI. We were specifically interested in the role of brain attention, vigilance and executive control systems (thalamus-parietal-cingulate-prefrontal network) in mediating mental fatigue and performance decline.

Methods Written informed consent was obtained from all participants. Fifteen young subjects (8 male, age 21-31 years) were scanned in a Siemens 3T Trio scanner. A pseudo-continuous ASL sequence (4) (TR: 4s, label time: 1.5s, delay time: 1s) was used to measure CBF while subjects performed a continuous 20-minute PVT and during two 4-minute resting baseline periods before and after the task. Visual analog ratings of fatigue were obtained prior to and immediately after the PVT scan. Functional image processing and analyses were carried out with Voxbo and SPM2. One subject was excluded due to technical problems. Voxel-wise whole brain analyses were conducted to obtain the PVT induced activations. Quantitative global CBF (gCBF) and regional CBF (rCBF) analyses on the thalamus- parietal-cingulate-prefrontal network were conducted to examine the association between TOT effects and neural activity as manifested by CBF changes.

Results Behavioral data showed that 20-minute continuous PVT was able to induce moderate TOT effects, including significantly increased self-reported MF ratings ($p < 0.001$) and slower PVT reaction times (RT, $p = 0.002$). No correlation was found between these two effects ($p > 0.9$), suggesting that subjects might be largely unaware of their performance impairment due to a prolonged task. Compared to baseline, PVT induced significant activations in the left sensorimotor cortex, bilateral basal ganglia, and a predominantly right partial-cingulate-frontal network (Fig.1). During the PVT, absolute gCBF changes from the beginning to the end of the task predicted MF changes (r = 0.7, $p = 0.005$) but not RT changes ($p > 0.2$). RT changes were positively correlated with rCBF activity in thalamus and ACC (both $p < 0.05$, Fig.2 top). After the PVT, the right parietal-cingulate-frontal network was deactivated at post-task resting baseline (Rest2), and the deactivations correlated with RT changes (all $p < 0.05$, Fig.2 middle). In addition, after adjusting for global CBF differences, rCBF activity in thalamus and middle frontal cortex at pre-task resting baseline (Rest1) also predicted RT changes during task (both $p < 0.05$, Fig.2 bottom).

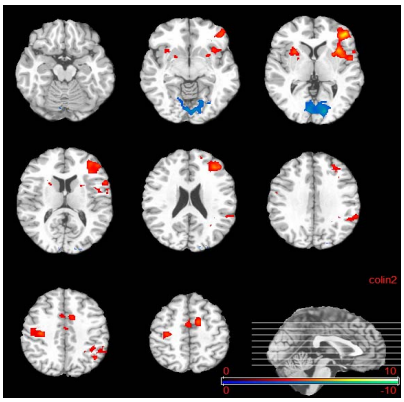

Fig1. PVT induced activations.

Conclusions Our findings suggest that reaction time performance changes are associated with regional brain activity in a right thalamus-parietal-cingulate-prefrontal network both at rest and during the task, while mental fatigue is associated with a global blood flow change from the beginning to the end of the task. These results demonstrate the feasibility and utility of ASL perfusion fMRI for imaging TOT effects, and support the key roles of brain attention, vigilance and executive control systems in mediating performance stability.

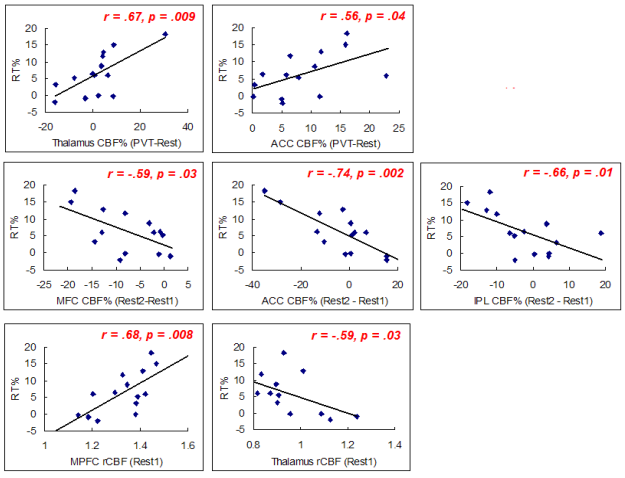

Fig2. Regional CBF activity correlated with reaction time (RT%) change both during PVT task and at resting baselines.

References

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