CBF-CMRO2 Coupling in the Default Mode Network

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Introduction: The Default Mode Network (DMN) has recently attracted attention in the neuroscience community [1]. The DMN is characterized by task independent deactivation a decrease in regional brain activity as measured by cerebral blood flow (CBF) [2,11] or the blood oxygen level dependent (BOLD) signal [3,4], during an arbitrary cognitive task relative to baseline. It is still unclear whether the observed deactivation is specific to reduced metabolic needs or corresponds, in whole or in part, to respiration rate variations [5] or vascular steal [6]. The aim of the present work was to calculate and compare the coupling ratios between CBF and cerebral metabolic rate of oxygen consumption ($CMRO_2$) in a region involved in the DMN and in areas of normal activation in order to characterize the processes underlying the DM.

Methods: Five healthy subjects (4 Male and 1 Female, aged 24±5 years) were posed arithmetic series problems to induce task independent deactivation (TID) of the DMN, in a self-paced block design with 4 off periods of 60 s and 3 task blocks of 60-70 s, with 3 runs per subject. A 4.0 T Bruker Medspec scanner equipped with an eight-channel multi receive system was used. Structural images were acquired with optimized 3D MPRAGE (1x1x1 mm^3, GRAPPA IPAT = 2) [7]. Functional images were acquired with a Q2TIPS pulse arterial spin labeling (PASL) sequence [8] with the following parameters: FOV = 192 mm, matrix size = 64x64, TR=2 s, TE=17 ms, TI1 =700 ms, TI2=1400 ms, T1s =1050 ms, 226 volumes, 7 min 32 sec per run.

Data analysis: All fMRI image processing and analysis was performed with AFNI and in-house developed software written in MATLAB. For each subject, images were motion corrected and spatially smoothed using a Gaussian kernel of FWHM 6mm. The perfusion image series was generated by sinc subtraction of the label and control images, followed by conversion to absolute CBF image series using the kinetic model [9].The BOLD time series was constructed by averaging adjacent tag images and control images. Functional activation and deactivation maps from the CBF and BOLD time series were estimated with AFNI using the General Linear Model with number processing periods convolved with a gamma hemodynamic response function (HRF). Multi-session activation contrast maps were then analyzed with one-sided t-tests across subjects fixed effects analysis. Statistical maps were corrected for multiple comparisons at $p<0.02$ using Monte Carlo simulations (AlphaSim program in AFNI). For each subject, CBF and BOLD time courses were extracted from bilateral ROI in the left middle occipital gyri (MOG) and deactivation from an ROI in the posterior cingulate cortex (PCC). Percent signal changes in CBF and BOLD were calculated relative to baseline. ΔBOLD and ΔCBF signal change from activation and deactivation ROIs were used to calculate $CMRO_2$ using the approach described by Davis et al [10]. The value of M of 0.072 was taken from the literature [11]. The α parameter value was assumed to 0.38 and β was taken to be 1.5 [12,13]. $CMRO_2$-CBF coupling was characterized by the percent change in oxygen metabolism ($\Delta CMRO_2$) to the percent blood flow change (ΔCBF).

Results and Discussion: Fig.1 shows areas of significant activation and deactivation during the arithmetic series task, calculated from perfusion data, overlaid onto the average anatomical image for the group. Activated voxels are t-statistics, corrected for multiple comparisons ($p < 0.02$). Consistent with previous reports on processing in similar mathematical tasks we found deactivation in the PCC (green arrow) and activation in the left MOG bilaterally (pink arrow). Fig.2 shows the coupling relationship between $CMRO_2$ and CBF for all runs and subjects (15 measurements) as estimated from the PCC (DMN) and left MOG (activation network). Fractional changes in $CMRO_2$ and CBF were linear for all subjects and sessions during activation and deactivation. The $CMRO_2$/CBF coupling ratios were 0.68±0.02 (activation) and 0.66±0.03 (deactivation); not significantly different. In recent studies Stefanovic et al [11] estimated a lower $CMRO_2$/CBF coupling ratio of 0.44±0.04 in the motor cortex, although Chiarelli et al have shown [14] showed that there are regional differences of the neurovascular coupling in visual, motor and supplementary motor areas. The neurovascular coupling ratio calculated here is very similar to that for activation, and is consistent with a neuronal origin for task-independent deactivation of the DM.

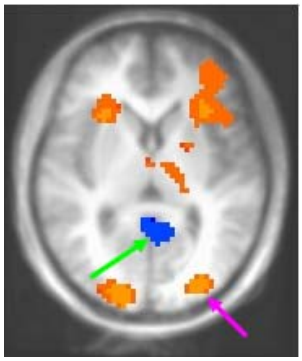

Fig. 1. Functional perfusion maps of activation (red) and deactivations (blue) during the arithmetic task ($p<0.02$).

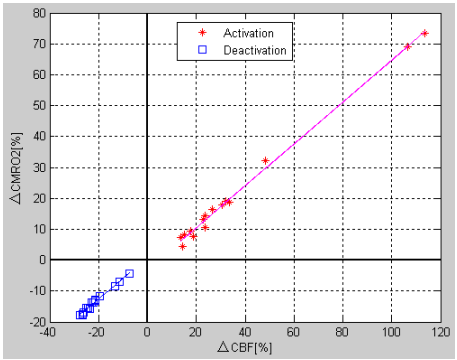

Fig. 2. Coupling relationship between CMRO2 and CBF

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