Repeatability of M, BOLD, CBF and $CMRO_2$ for cognitive tasks at 7 Tesla

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Target audience: Researchers and clinicians interested in brain physiology, cerebral oxygen metabolism, functional MRI and calibrated functional MRI

Purpose: Calibrated BOLD fMRI is a promising alternative to the classic BOLD contrast due to its reduced venous sensitivity and its greater physiological specificity [1,2]. The delayed adoption of this technique for cognitive studies, especially at ultra-high field, may stem partly from a lack of evidence for the reproducibility of these measures in the context of cognitive tasks. The purpose of this study is to explore the applicability and reproducibility of a state-of-the-art calibrated BOLD technique [3] using a complex functional task [4] at 7 Tesla. Variability of M, BOLD, CBF and $CMRO_2$ is compared and interpreted for two functional ROIs.

Methods: Experiments were performed with 13 subjects on a 7 Tesla whole-body MRI scanner using a 24 channel head coil. Three calibrated BOLD scanning sessions were performed within a period of 7 days. Each day consisted of one 10min acquisition with combined gas breathing challenge and functional task followed by three 10min acquisitions during the functional task only. Simultaneous acquisition of BOLD and CBF weighted images was performed via a pulsed arterial spin labelling (PASL) FAIR QUIPSSII sequence. Scanning parameters used in this study were: FOV=210x210mm, nominal isotropic resolution=3mm, TR=4s, GRAPPA factor 3, partial Fourier factor 6/8, TI_1=700ms, TI_2=1700ms. The functional stimulus used in this study was based on a well established visuo-motor task [4] where subjects were asked to counteract the intrinsic movement of a vertical bar displayed on a screen using a joystick. During the first ten-minute acquisition, a combined hypercapnic-hyperoxic gas-breathing challenge was used (7% CO_2, 93% O_2). The generalized calibration model (GCM) was used to estimate M [3]. Intra-subject and inter-subject variability was estimated using coefficients of variation (CV) for all measured quantities for two regions of interest (ROI) [5].

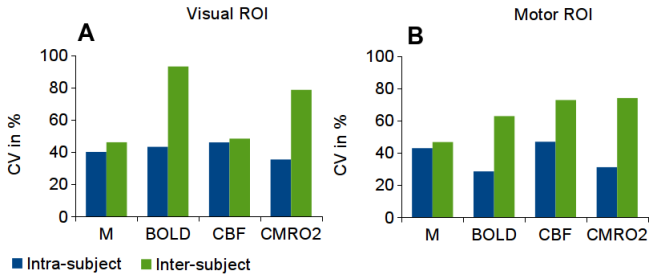

Fig 1: Coefficients of variation for M, BOLD, CBF and $CMRO_2$ estimates for a visual and motor ROI.

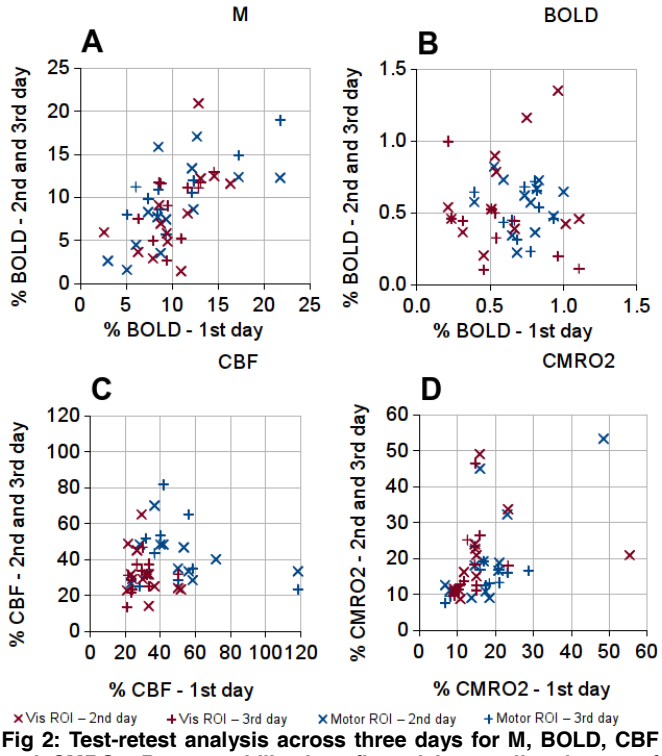

Fig 2: Test-retest analysis across three days for M, BOLD, CBF and $CMRO_2$. Better stability is reflected by smaller degree of scattering.

Results: CV across days (blue bars) and across subjects (green bars) for M, BOLD, CBF and $CMRO_2$ estimates can be found in Fig. 1 for both a functionally-defined visual ROI (left) and motor ROI (right). Fig. 2 shows a test-retest analysis of M, BOLD, CBF and $CMRO_2$ estimates. Signal changes from the second and third day of acquisition are plotted against those obtained on the first day. Higher degree of clustering reflects better repeatability.

Discussion: Our results confirm general trend observed at lower field strengths, and for simple motor or visual tasks [6,7]. Estimates of $CMRO_2$ obtained via the generalized calibration model showed similar (motor ROI) or better (visual ROI) intra-subject reproducibility compared to classic the BOLD signal (see Fig. 1). A greater degree of scattering from the unity line can be observed for BOLD as compared to CBF and especially $CMRO_2$ estimates (see Fig. 2). Therefore longitudinal and learning studies could benefit from using the calibrated BOLD technique, especially since $CMRO_2$ is a more direct surrogate of neuronal activity than the BOLD signal. These results further indicate that because calibration parameter M can change significantly across days for the same subject (see Fig. 2A) and it is therefore necessary to estimate M each time a calibrated BOLD scan is performed.

Conclusion: We have shown that a state-of-the-art calibrated BOLD technique shows reproducibility characteristics that are comparable or better than classical functional fMRI approaches. This study provides evidence that the calibrated BOLD approach can be reliably used in combination with more sophisticated cognitive study designs to obtain more physiologically meaningful estimates of neuronal activity. These results establish estimates of functionally-induced cerebral oxygen metabolism changes via calibrated BOLD fMRI as a powerful tool for longitudinal and learning studies.

References: [1] Davis et al. PNAS (1998), [2] Hoge et al. MRM (1999), [3] Gauthier et al. HBM (2013), [4] Grafton et al. Neuroimage (2008), [5] Tjandra et al. Neuroimage (2005), [6] Leontiev and Buxton Neuroimage (2007), [7] Stone et al. Proc ISMRM (2013)