Reliability of Resting Brain Networks in BOLD and ASL fMRI across Time and Platforms

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Background: Since the seminal work by Biswal[1], the study of resting brain networks (RBN) based on functional connectivity (FC) in resting state fMRI (rs-fMRI) has experienced an upsurge from basic to clinical neuroscience. In addition to the widely used blood oxygen level dependent (BOLD) contrast, RBNs can be detected using arterial spin labeled (ASL) perfusion MRI which measures cerebral blood flow (CBF) and, compared to BOLD, provides quantitative and more direct measures of the physiology and metabolism of specific networks. The purpose of the present study was to systematically test the similarity and reliability of RBNs between and within BOLD and CBF. A 2x2x2 factorial design was applied where each subject underwent repeated BOLD and ASL rs-fMRI scans (2 modalities) on two occasions on two separate MRI scanners respectively.

Method: 10 healthy young subjects (6F/4M; Age [mean±SD] = 22±3 years) repeated rs-fMRI scans with 2D-EPI BOLD (Volumes=240, Matrix=64x64, Slice Thickness=4mm with 1mm gap, TR/TE=2000/30ms, Flip Angle=77°, Pixel Bandwidth=2298Hz, FOV=220mm) and background suppressed 3D GRASE pCASL[2] (60 label/control pairs, Matrix=64x64, Slice Thickness = 5mm, TR/TE/τ/PLD = 4000/22.62/1200/1000ms, Pixel Bandwidth=2003Hz, FoV = 220 mm, labeling offset=9cm, 2 global inversion pulses were applied during the PLD for background suppression)– 2 times on each of the 2 MR scanners – to evaluate the reliability of RBNs detected using each technique. After preprocessing, functional connectivity was assessed by means of a temporally concatenated group Independent Component Analysis (ICA)[3] approach. Statistical analyses were performed on the network as well as on a voxel-wise level. Repeated-measures ANOVAs with within subject factors modality (BOLD/ASL), scanner (1/2) and session (1/2) and post-hoc t-tests were computed to identify differences between all factors. Test-Retest (TRT) reliability of ASL and BOLD based RBNs was estimated using Intraclass Correlation Coefficients (ICCs)[4].

Results: We found that CBF based FC is feasible and yields group RBNs similar to the BOLD-RBNs (Fig1), Group ICA identified 5 common RBNs (Default Mode Network DMN, left/right Executive Control Networks L/R-ECN, Occipital Visual Network OVN and AUditory Network AUN). Significant differences in specific areas were also observed depending on the modality. In particular, the DMN showed higher FC for BOLD in precuneus and bilateral angular gyrus but higher FC in orbital medial frontal cortex in ASL. The ECNs had higher FC in BOLD within network areas on the ipsilateral hemisphere, but increased FC to the contralateral homotopic areas in ASL. TRT analyses indicated more reliable networks in BOLD (average ICC across networks: 0.905±0.033 between-sessions; 0.885±0.052 between-scanners) than ASL (0.545±0.048 / 0.575±0.059) in terms of associated spatial patterns (Fig2; Table1). However, ASL provided highly reproducible (0.956±0.010; 0.939±0.026), network-specific CBF measurements (Table1). RBN-CBF [in ml/100g/min ± SD] were for DMN 71.1±3.0, LECN 62.2±2.83, RECN 61.7±3.6, OVN 61.7±4.4 and AUN 71.6±5.9 (Fig3).

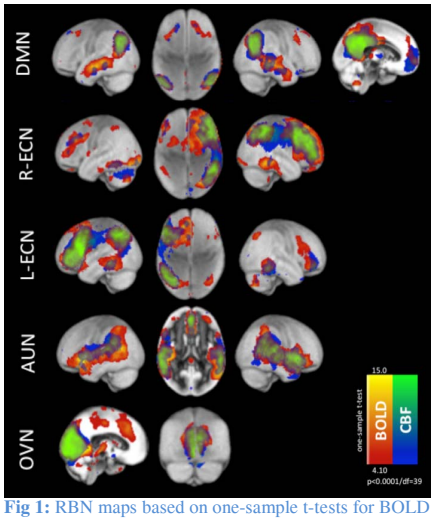

Fig 1: RBN maps based on one-sample t-tests for BOLD (red-yellow) and ASL (blue-green) overlaid on a 3D rendered brain

Discussion: While BOLD RBNs showed excellent test-retest reliability across sessions and scanners in their spatial pattern, ASL RBNs showed reduced yet still adequate repeatability. But ASL rs-fMRI provided the unique feature of absolute quantification of CBF as an index of the metabolic activity of specific networks with high repeatability. Our findings suggest that the combination of ASL and BOLD rs-fMRI provides a powerful tool to fully characterize the spatiotemporal and quantitative properties of resting brain networks, an especially desirable possibility for longitudinal rs-fMRI studies, pharmacological MRI studies as well as for the comparison of networks across different subject groups.

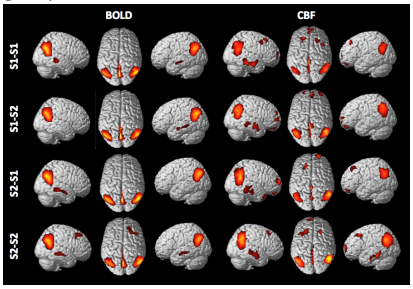

Fig 2: Spatial pattern of the DMN in all sessions, scanners and both modalities

	modality	modal ICC within site	modal ICC between site	CBF ICC within	CBF ICC between
DMN	BOLD	0.925	0.900	0.941	0.948
	ASL	0.550	0.625		
LECN	BOLD	0.900	0.925	0.957	0.937
	ASL	0.625	0.650		
RECN	BOLD	0.875	0.875	0.952	0.942
	ASL	0.525	0.525		
OVN	BOLD	0.950	0.925	0.959	0.969
	ASL	0.500	0.525		
AUN	BOLD	0.875	0.800	0.969	0.897
	ASL	0.525	0.550		
				GM_{CBF}	
				0.964	0.952

Table 1: Within and between scanner modal-ICC results for BOLD and CBF RBNs spatial pattern as well as the their specific CBF.

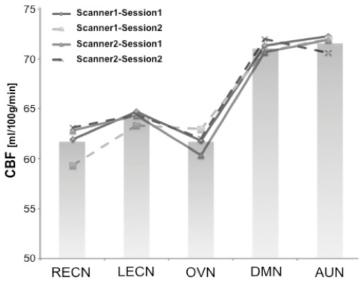

Fig 3: RBN_{CBF} for all sessions (lines) and across session average (bars).

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