Spatial variation of BOLD contrast in the activated ROI is correlated with voxel-wise gray matter volume fraction

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Introduction

Blood oxygenation level dependent (BOLD) contrast has been widely used in fMRI study to investigate neuronal functionality. Since BOLD contrast is a complex interplay of blood flow, blood volume, and oxygen consumption [1], the amplitude of BOLD contrast (commonly called β) varies over subjects. These inter-subject β variations have been investigated using various approaches [2-4]. However, spatial β variations within individual subjects have not been well examined. In this study, we investigate spatial β variations in BOLD contrast within individual subject, by correlating the β with fractional volume (f_v) of brain tissue and T_1 in the activated voxels. Maps of f_v and T_1 are obtained using a new brain segmentation technique, FRASIER [5]. The spatial β variations are also compared with Resting State physiological Fluctuation in Amplitude (RSFA) [3].

Methods

FRActional Signal mapping from InvErsion Recovery (FRASIER): FRASIER provides volume fractions of gray matter (GM), white matter (WM), and cerebral-spinal fluid (CSF), based on a recently developed fast T_1 mapping method using inversion recovery Look-Locker echo-planar-imaging at a steady state (IR LL-EPI SS) [6]. Using a single-shot IR LL-EPI SS, the effective relaxation time constant (T_1^*) can be expressed as $1/T_1^*=1/T_1-\ln(\cos\alpha)/TR$, where α is a flip angle, and TR is a time gap between two consecutive EPI acquisitions of the same slice. The signal recovery during the time of duration (TD) is described as $S(t) = M_{SS}|1-2exp(-t/T_1^*)|$. The measured voxel-wise signal during IR procedure is fitted into a three-compartment (WM, GM, and CSF) exponential recovery model

MR imaging and data analysis: Eight healthy subjects were scanned using a single-shot IR LL-EPI SS sequence for FRASIER: T_1 and f_v mapping (non-selective IR, TR/TE=400/13 ms, α=16°, matrix=64x64, 15 slices, and TD=10s). Five FRASIER measurements were acquired in 1 min including the preparation time of 10 s. A visual stimulation paradigm with 8 Hz flashing checkerboard (30s on and off) was used in a BOLD experiment acquired with TR/TE=3s/27ms, matrix=64x64, 39 slices, and total running time = 5:32. The center slice locations of IR LL-EPI SS and fMRI images were aligned so that the direct voxel-wise comparison between the two scans was feasible because the FRASIER used the same gradient-echo EPI kernel as the fMRI acquisition (similar geometric distortions). Activated region-of-interest (ROI) was defined by 200 voxels with the highest t-values from statistic analysis. In addition, resting state BOLD scanning was performed to calculate RSFA [3] (TR/TE = 2s/27ms, 39slices, and 8:02).

Results and Discussion

Fig.1 shows the representative result of β, $f_{v,GM}$, T_1 and RSFA in the activated ROIs, defined by 200 voxels with the highest t-values. The amplitude of BOLD contrast, β shows positive correlations with $f_{v,GM}$ and T_1. This might be interpreted as that the voxels containing larger fractional volume of GM could produce higher activation. Alternatively, this might be explained as that the voxels including more cerebral blood volume could provide higher β values, since the T_1 of blood is higher than that of GM. In addition, it is observed that voxels with larger RSFA values produce the higher β, consistent with the previous literatures [4].

Dependence of β on the biophysical/physiological parameters (T_1, $f_{v,GM}$ and RSFA) of individual subjects (N = 8) in the activated ROI defined by 50 voxels with the highest t-values is shown in Fig. 2 (presented as different color dots). The results of linear regression between β and these parameters are listed in Tab.1. Strong correlations between β and $f_{v,GM}$ and between β and T_1 are observed. Interestingly, there are individual variations of the slope between β and these parameters (A's in Tab 1).

In summary, we found that voxel-wise BOLD contrast in the activated ROI of individual subjects is highly correlated with fractional volume of GM, T_1, as well as RSFA, and the dependence varies over subjects. These findings may help to understand and interpret the functional signals, and may be used to calibrate BOLD signals for improving sensitivity and specificity in detecting brain activity.

Acknowledgements

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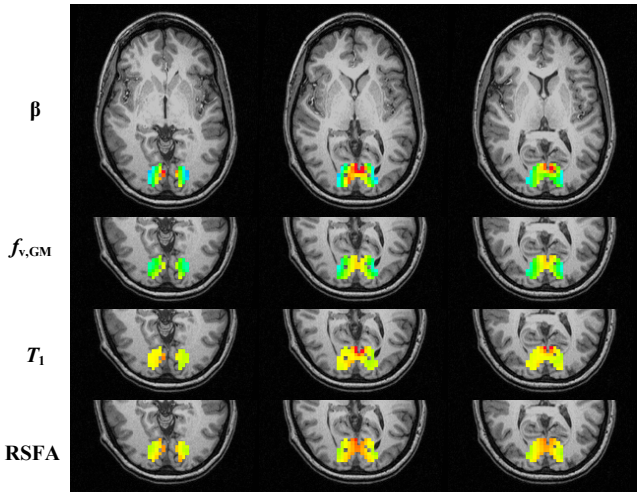

Fig 1. Demonstration of β, $f_{v,GM}$, T_1 and RSFA in the activated ROIs (cool < warm)

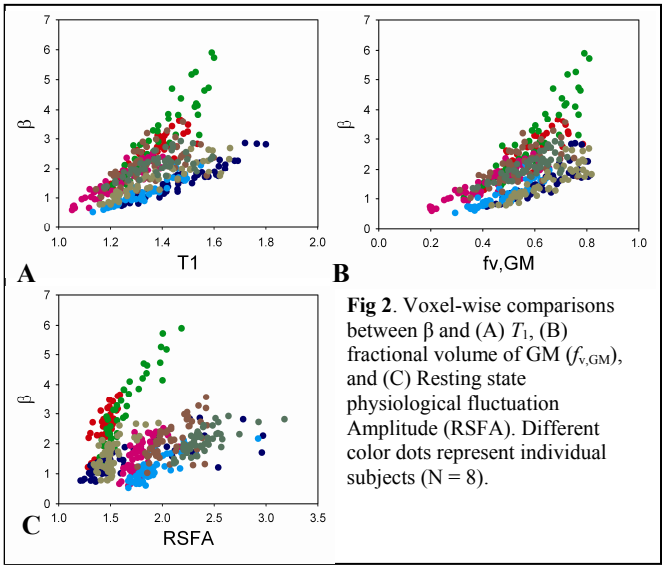

Fig 2. Voxel-wise comparisons between β and (A) T_1, (B) fractional volume of GM ($f_{v,GM}$), and (C) Resting state physiological fluctuation Amplitude (RSFA). Different color dots represent individual subjects (N = 8).

sub	β(%) vs T_1(s)			β(%) vs $f_{v,GM}$(%)			β(%) vs RSFA(%)		
	A	B	r^2	A	B	r^2	A	B	r^2
1	6.4	-6.2	0.79	5.2	-0.5	0.76	5.0	-4.9	0.32
2	10.0	-10.8	0.85	9.2	-2.5	0.83	5.9	-6.5	0.85
3	3.6	-3.7	0.91	4.0	-1.0	0.74	0.8	0.1	0.50
4	4.9	-4.5	0.83	3.9	-0.1	0.85	3.3	-4.4	0.49
5	3.6	-3.6	0.87	3.8	-0.7	0.80	1.5	-1.8	0.62
6	2.8	-1.7	0.28	3.5	0.3	0.39	1.9	-1.8	0.37
7	3.3	-3.0	0.80	4.3	-1.2	0.76	2.8	-2.6	0.43
8	2.6	-1.5	0.48	3.5	0.1	0.62	1.4	-1.2	0.49

Tab 1. Regreesions between β and the biophysical/physiological parameters (T_1, $f_{v,GM}$, and RSFA) in the activated ROIs. Voxel-wise β was fitted into A × (T_1, $f_{v,GM}$, or RSFA) + B