Quantitative Evaluation of the Dynamic BOLD and CBF Responses to Breath Hold in Different Brain Territories

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Introduction

Blood oxygen level-dependent (BOLD) signal and cerebral blood flow (CBF) increases induced by hypercapnia stress have been investigated in human brain, which reflects the cerebral hemodynamic response to vasodilatation. The difference of signal response in different regions, such as cerebellum, visual cortex and frontal cortex, has been demonstrated by Kastrup *et al*. [1]. Recently, Leoni *et al*. has quantitatively investigated the varied dynamics of the BOLD response to hypercapnia in the different brain regions supplied by the main cerebral arteries [2]. However, BOLD signal reflects a complex combination of CBF, cerebral blood volume (CBV), and oxygen consumption changes [3]. Therefore, this study aimed to quantitatively evaluate the dynamics of the CBF changes in those territories following a hypercapnia stress using the arterial spin labeling (ASL) technique and compare with BOLD.

Methods

Three healthy male subjects aged from 26 to 27 years old were recruited in this study. Each subject performed four separate functional scans including two BOLD and two ASL scans on a 3T HDx scanner (GE Healthcare, Milwaukee, WI, USA). Each scan had four repetitive cycles, involving 20 s breath-holding condition followed by 40 s natural breathing and initial 30s natural breathing. The BOLD experiment was performed by using a single-shot gradient-echo EPI with TR/TE/FA = 2000 ms/ 35 ms/ 90°, matrix size = 64×64, field of view = 220 mm, and 29 slices with thickness = 3 mm. The CBF experiment was performed using a FAIR-ASL sequence with EPI readout and the following parameters: TR/TI/TE = 2000 ms/ 1400 ms/ 22.7 ms, matrix size = 64 × 64, field of view = 220 mm and two slices with thickness = 5 mm. The estimated ASL signal time courses were processed by the strategy provided from Lu *et al*. [4] and applied a tSNR threshold due to the less SNR in the images. Subject motion was checked from the images and confirmed to be less than 0.5 mm translation. Images were spatially smoothed using a Gaussian kernel (FWHM = 5mm) and corrected for signal baseline drift. Regions-of-interest (ROIs) were drawn in each subject to cover of territories supplied by anterior cerebral artery (ACA), middle cerebral artery (MCA), and posterior cerebral artery (PCA). Mean BOLD and CBF time courses obtained from those ROIs were averaged across repeated cycles and sessions after carefully aligning the starting points of each breath-holding by referencing the data recorded from the respiratory belt.

Results and Discussion

The percentages signal change averaged across two times and between subjects are shown in Fig. 1a and 1b which denote the BOLD scans and the ASL scans, respectively. In BOLD time courses, MCA and PCA territories had greater signal changes than the ACA, whereas in ASL time courses the PCA had greater signal changes than the other two. Table 1 summarizes the onset time, full width at half maximum (FWHM), and maximum signal change obtained from fitting the measured time courses with a gamma-variate function. Both the figure and the table show that PCA territory had delayed response than the ACA and MCA, which was consistent between BOLD and ASL. In summary, this study demonstrated substantial differences between the BOLD and ASL responses to the breath-holding task. Further investigation is needed to understand the implications of the territory-dependent responses to vasodilatation for both task-induced and resting-state fMRI.

References

[1] Kastrup A, *et al*., Neuroimage 1999;10:675-81. [2] Leoni RF, *er al*., Neuroimage 2008;41:1192-98. [3] Ogawa S, *et al*., Biophys J 1993;64:803-12. [4] Lu H, *et al*., Magn Reson Med 2006;56:546-52.

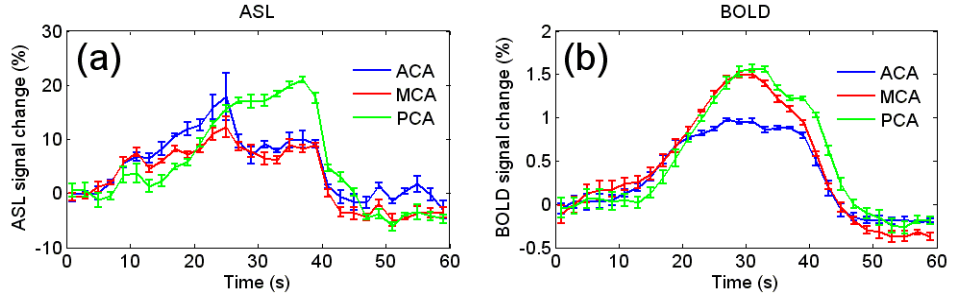

Fig 1. Averaged signal changes with breath holding of 20 s on the territories supplied by ACA (blue), MCA (red) and PCA (green). The data are shown as mean ± SEM over three subjects. **(a)** ASL signal change. **(b)** BOLD signal change.

Table 1. The results of gamma-variate fitting.

	ASL			BOLD		
	Onset Time (s)	**FWHM (s)**	**Max. Signal (%)**	**Onset Time (s)**	**FWHM (s)**	**Max. Signal (%)**
ACA	17.57 ± 1.31	31.89 ± 2.34	15.90 ± 1.85	24.59 ± 0.45	36.06 ± 0.85	0.97 ± 0.05
MCA	18.54 ± 1.19	31.82 ± 1.18	11.10 ± 0.77	27.58 ± 0.36	28.87 ± 0.77	1.54 ± 0.04
PCA	28.44 ± 1.27	29.73 ± 0.89	20.29 ± 1.81	30.27 ± 0.55	29.55 ± 0.58	1.58 ± 0.04