Evaluation of hypercapnic tasks to hemodynamically scale activation-induced fMRI-BOLD signals

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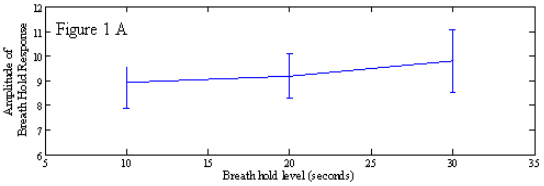
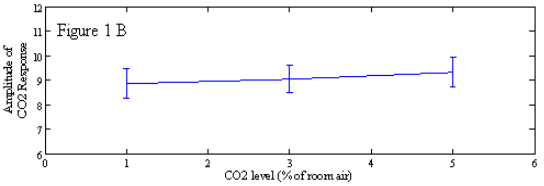
Introduction: Hemodynamic scaling of fMRI responses reduces BOLD signal variation due to vascular sensitivity. Scaling of fMRI-BOLD response to a neural task is currently carried out using vascular reactivity information usually determined by a hypercapnic task such as breath hold (BH), breathing CO_2 or hyperoxia [1,2,3,4,5,6]. Hemodynamic scaling is accomplished by simply dividing the task induced response signal with the response obtained during a hypercapnic task. However, the optimal level of hypercapnia obtained either during the BH task or breathing CO_2 for hemodynamic scaling is not yet estimated. If the hypercapnic response in a corresponding voxel is greater than the neural-task response in the same voxel, then it has a greater chance to get scaled out (loses significance as a result of scaling). To optimize hemodynamic scaling using hypercapnia tasks such as BH or CO_2, we have studied different durations of inspirational BH and breathing various levels of CO_2 in healthy young individuals. We have estimated the extent of scaling during each condition on the neural task-induced fMRI-BOLD response.

Methods: Five healthy volunteers (2 females; 3 males) aged between 22-39 years were scanned on a 3Tesla MR-scanner. In each volunteer, echo-planar images were obtained across the whole brain in the axial plane (64x64 matrix, TR/TE=2 sec/30 msec, FOV=22 cm, 32 slices, slice thickness=4 mm and bandwidth 125 kHz). Images were obtained under different conditions namely (a) rest while breathing room air, (b) bilateral finger-tapping (c) inspirational BH for 10, 20 and 30 sec (d) breathing a mixture of 1%, 3% or 5%CO_2 in air. For the finger-tapping task, subjects were instructed to successively touch each finger with the thumb in a self-paced manner. For the BH task, subjects practiced the inspirational BH several times prior to performing in the scanner. A high-resolution T1-weighted anatomical image was finally acquired using a magnetization prepared gradient echo sequence (MPRAGE, TR = 2500 ms; TE = 4 ms; TI = 900 ms; flip angle = 8; 144 slices and FOV = 22 cm).

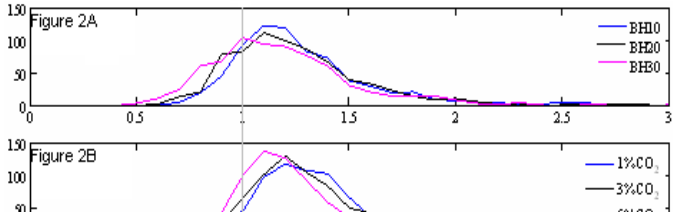
EPI images were corrected for motion using a rigid-body volume registration algorithm in AFNI. Analysis was done only on the voxels that represented the brain tissue. All the data sets were corrected for quadratic trends. Percent change in BOLD signal due to hypercapnia task (estimated as the temporal standard deviation (SD)) was obtained in each voxel throughout the brain for all subjects.

Results: The amplitude of the hypercapnia-induced BOLD signal response increased linearly with increasing duration of BH or increasing percentage of CO_2. As shown in Fig 1A, increasing the duration of BH from 10 sec to 30 sec increased the BOLD signal response linearly in all subjects. A similar trend was observed when CO_2 percent in the breathing gas was increased from 1% to 5% (Fig 1B).





Hemodynamic scaling was performed by dividing the BOLD signal response during the fingertapping task with the BOLD signal response during BH or CO_2 on a voxel-wise basis [Bandettini and Wong, 1997; Thomason et al., 2007; Handwerker et al., 2007]. The distributions after hemodynamic scaling (shown in Fig 2) was obtained from the ROI determined by cross-correlating the fingertapping signal time series with a task reference function. All pixels having a correlation coefficient greater than 0.5 ($p<0.0001$) was considered significant. Fig 2 shows the typical distributions of the BOLD signal response to the fingertapping task after scaling with different durations of BH (Fig 2A) and CO_2 (Fig 2B). Scaling with BH or CO_2 led to a significant number of voxels with value below 1. (i.e., the signal change due to the fingertapping task was less than that obtained during BH or CO_2 in those voxels). The number of voxels with value below 1 decreased with decreasing durations of BH or decreasing percentage of CO_2 over all subjects (Fig 2A,B Table-1). Hemodynamic scaling with the highest BH level (Fig 3B) greatly minimized the activation volume in comparison to scaling with the lowest BH duration (Fig 3A). Similar results were obtained for all other subjects for different durations of BH and different levels of CO_2 (Table-1).



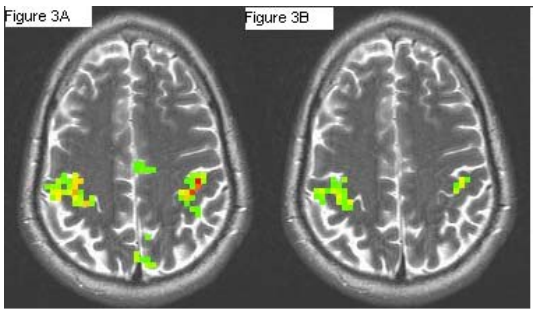


Table 1. Percentage of voxels with value below 1 after scaling with BH and CO_2

	BH duration (5 subjects)			CO_2 level (3 subjects)		
	10 sec	20 sec	30 sec	1%	3%	5%
Mean	13.3	22.1	32.8	8.06	8.9	20.34
SD	7.3	5.5	13.7	3.5	1.3	5.9

Conclusions: As the duration of BH or percent of CO_2 increases, the percent change in BOLD signal response increases. This leads to the number of voxels below 1 to increase gradually with increase in duration of BH or percentage of CO_2. It is suggested that when BH is used as a hemodynamic scaling factor, the duration of the inspirational BH should be very minimal up to 10 sec or less. On the other hand if CO_2 response is used as a hemodynamic scaling factor, 1%CO_2 in air is a suitable hypercapnic stimulus. This would significantly reduce the loss of spatial extent after hemodynamic scaling using BH or CO_2. A minimal BH duration can be easily performed by all subject population including the elderly and patients.

References:

1) Bandettini PA, Wong EC. NMR Biomed. 1997, 10(4-5):197-203. 2) Biswal BB, Kannurpatti SS, Rypma B. Magn Reson Imaging. 2007 May 3. [Epub ahead of print]. 3) Chiarelli PA, Bulte DP, Wise R, Gallichan D, Jezzard P Neuroimage. 37(3):808-20. [Epub 2007 May 31]. 4) Handwerker DA, Gazzaley A, Inglis BA, D'Esposito M. Hum Brain Mapp. 2006 Nov 8;28(9):846-859. 5) Kannurpatti SS, Biswal BB. *Neuroimage* (2007) *in press*. 6) Thomason ME, Foland LC, Glover GH. Hum Brain Mapp. 2007 Jan;28(1):59-68.