Partial volume effects in VASO-fMRI

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INTRODUCTION: BOLD fMRI has become a standard technique for studies of human brain function. However, the interplay between local hyperemia and oxygenation changes as measured by BOLD and their relationship with electrical activity remains unclear. Recently introduced, the Vascular Space Occupancy (VASO)-fMRI technique [1] allows the measurement of blood volume related changes upon activation and has therefore a great potential to help elucidating the origin of the BOLD signal [2]. However, different percentage of signal changes in VASO have been reported in the original papers (from 0.7% to more than 4% [1,2]), which seemed to be directly related to the resolution used in each experiment As VASO signal is thought to come primarily from the parenchyma, and due to the fact that the inversion-recovery sequence used to obtain a VASO signal induce a very strong T1-weighting, such partial volume effects are naturally expected. On the other hand, such partial volume effects might be directly reflected in calculated absolute cerebral blood volume (CBV) changes derived from VASO signal changes. In this work, we therefore present a small study on the effects of partial volume averaging on both BOLD and VASO in a simple visual stimulation paradigm, and the calculated physiological parameters related.

METHODS: Data from BOLD/VASO fMRI experiment performed on a Philips Intera 3.0T system in six normal volunteers was used in this study. Visual stimulation using BW radial checkerboard (8Hz) with 3 different contrast levels (25%, 50% and 100%) relative to an iso-luminance resting condition was performed as a block paradigm (30 sec ON, 45 sec OFF, 2 repetitions for each contrast level for BOLD, 3 for VASO). Single-shot GRE EPI (matrix=112x110 recon=128x128, FOV=224mm, single 5mm slice) was used for BOLD (TE=35ms, TR=3s, FA=90) and for the dual-echo VASO (TI=889ms, TE_1=12ms, TE_2=60ms, TR=3s, FA=90) acquisitions.

Data processing: Activation maps from BOLD and 1st echo VASO acquisitions were obtained by means of t-test between activation and rest conditions, ignoring one image after activation onset and five images after the activation period ($p<0.001$ uncorrected, $T_{bold} > 3.3$, $T_{vaso} < -3.4$, cluster >3). Additional criteria for VASO was SNR >10. The intersection of the two activation maps was used to create a ROI from which averaged BOLD and VASO time-series were obtained. Only the 100% contrast activation condition was considered in this study. In order to simulate partial volume effects, we applied Gaussian filtering (FWHM=3, 4, 5, 6mm) to the original BOLD and VASO data and re-extracted the time-series using the original ROI. Mean BOLD and VASO signal changes were computed on the time-series averaged across all the subjects and the estimates of CBV and CBF signal changes were obtained using $\Delta CBV/CBV = -\Delta S_{vaso}/S_{vaso}[(1-\xi^{rest})/\xi^{rest}]$ and the Grubb's equation (ξ^{rest} =4.59%, α=0.5, β=0.5) [3].

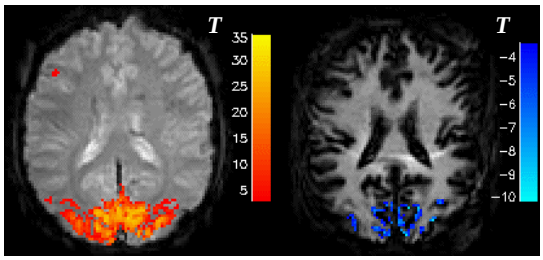

Figure 1: BOLD and VASO activation T-maps overlaid on the corresponding EPI images

RESULTS and DISCUSSION: Robust activation of the primary visual cortex was detected in all six subjects in both BOLD and VASO experiments. Typically, BOLD activation areas were much larger and less specific in terms of localization compared to VASO as shown in Fig. 1. The VASO activation was generally contained within the BOLD activation map. The mean size of the intersection ROI was 134 (range: 57 -183) pixels. Figure 2 shows the averaged VASO and BOLD time-series at the original image resolution and for different Gaussian filters. The VASO signal has been inverted to facilitate comparison with BOLD. Smoothing produces a drastic VASO signal change even for the smallest filter size, while it has only a minor effect on the BOLD signal. The percent signal changes are summarized in Table 1. The change of the VASO signal has important consequences for the CBV and CBF changes estimation and consequent estimation of parameters such as oxygen extraction fraction and $CMRO_2$. Our estimates for CBV and CBF are higher than expected from the physiology, albeit in agreement with similar measurements performed at 1.5T at the same resolution [1], if no smoothing is applied. Such large VASO changes would mean either that: 1) the physiological changes encountered at very high resolution are much more important than what was expected from conventional imaging capabilities (e.g. PET) [4,5]; or that 2) the changes in the VASO signal are not only related to CBV increase, but also to other effects such as T1-lenghtening, which may for example come from increase in water proton exchange between blood and parenchyma [1]. On the other hand, the relative small effects of such smoothing on the BOLD signal was expected considering our initial resolution, the relative low contrast between gray and white matter and the fact that it is less specific in terms of localization.

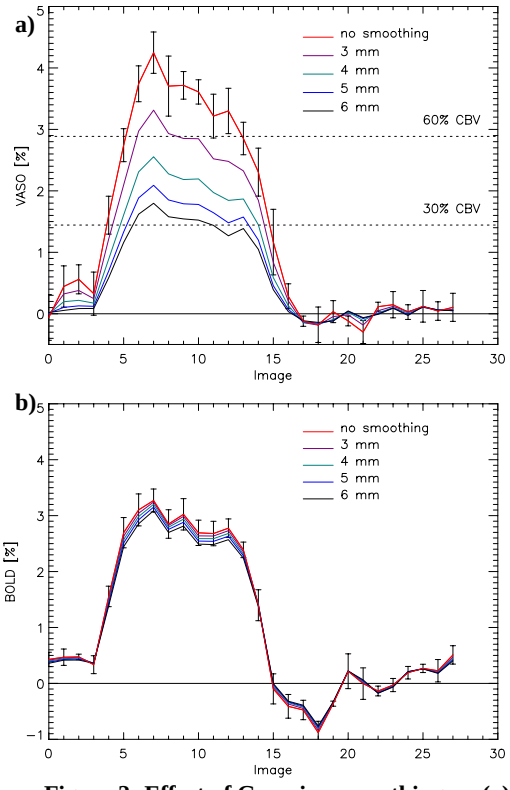

Figure 2: Effect of Gaussian smoothing on (a) VASO and (b) BOLD signals (bars= s.e.m.)

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	BOLD %	VASO %	CBV %	CBF %
ns	2.7	3.3	69.0	185.7
3mm	2.7	2.6	53.7	136.1
4mm	2.6	2.0	41.2	99.3
5mm	2.6	1.6	33.6	78.5
6mm	2.5	1.4	28.9	66.2

Table 1: Relative signal changes