Estimation of temporal onset variations in hemodynamic response by CBV-based ER-fMRI

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Synopsis

This study evaluated the temporal resolution of a CBV-based fMRI technique, vascular space occupancy (VASO) imaging, at different contrast-to-noise level from averaging different numbers of trials in an event-related (ER) design, and compares that with BOLD- and CBF-based techniques. Repeated short (1 s) visual stimulation was applied in this study. Our results revealed remarkably smaller onset time variations on the VASO data than those on BOLD data, which were comparable with those on the CBF-based data. From the results, we suggest that CBV-based techniques may lead to improvement of temporal resolution of ER-fMRI.

Introduction

Vascular space occupancy (VASO) dependent contrast, a novel noninvasive cerebral blood volume (CBV)-based fMRI imaging technique, has been proposed recently by Lu et al (1). Based on its good property of insusceptible to large blood oxygenation and flow, spatial indication of arteriolar and venular sites in the gray matter can be carried out by detecting their CBV changes due to brain activation. Better gray matter detection with large vascular space occupancy being as low as possible has been suggested having better temporal characteristics which may lead to closer reflection of the neuronal activity (1, 2). From this point, Lu et al have provided evidence that earlier onset of hemodynamic response (HDR) for VASO approach than for blood oxygenation level dependent (BOLD) technique, and also showed comparable results with CBF-based arterial spin labeling (ASL) approach. This is mainly due to high sensitivity to the smaller vessels for CBV-based and CBF-based fMRI techniques. Lu's promising results have inspired us to adopt VASO approach for the estimation of the temporal resolution of event-related (ER) fMRI. Based on similar temporal onset properties and comparable contrast-to-noise ratio (CNR) inherence with the CBF-based approach (1), we assume that VASO approach can also make stable estimation on the temporal onset times of HDR as the CBF-based technique (3). Therefore, in this study, we will apply VASO imaging to estimate the temporal onset variations in HDR, by using repeated-trial-averaging technique (2). All the experiments are conducted by the short visual stimulation ER designs. In addition to VASO, we will acquire BOLD images as well, and finally compare the results between each other. Besides, comparison will be also made with our previous published results by CBF-based and BOLD-based imaging (3).

Methods

Three healthy subjects were studied with both VASO and BOLD experiments. All were performed on a 1.5-T Magnetom Vision MRI Scanner. For VASO study, a flow-velocity-insensitive blood nulling for non-slice selective inversion pulse sequence was used. The paradigmatic design covered totally 30 repeated trials, with 1-s short visual stimulation plus 19-s resting per trial. 8-Hz-flashing annular checkerboards with a crosshair in the center were displayed as the visual stimuli. Six separate runs were designed to include three repeated runs for non-time-shift designs and three for 1-s-shift designs, with each run consisting of 10 trials. Prior to each runs, there were 20 s dummy scans for the imaging system and the subject reaching steady state. The imaging parameters were: TI/TR/TE/FA/NEX=1200ms/2000ms/9.3ms/90^0/110. In-plane spatial resolution of 3.3x3.3 mm^2 was derived from FOV of 211-square mm^2 and 64-square matrix with following interpolation to 1.65x1.65 mm^2. Single slice with slice thickness 8 mm was imaged along the calcarine fissure to cover the visual cortices. An inter-trial interleaf method was then applied in the data processing to obtain high sampling rate of 1 s for VASO images. For BOLD study, the images were acquired by using a single-shot T2*W GRE-EPI sequence, with the imaging parameters being: TR/TE/FA/NEX=1000ms/60ms/90^0/620. Identical in-plane spatial resolution was obtained as the VASO images. The imaging position as well as slice thickness was also the same as the VASO images. For the data processing, voxels with significant activation ($p<0.01$) were detected by inverse cross-correlation with a gamma reference function (4) for VASO images and positive cross-correlation with a summation function of two gamma functions (5) for BOLD images. After manually selecting the regions-of-interest (ROIs) within the visual cortices, VASO and BOLD time series were extracted pixel by pixel and averaged randomly across 30, 20, 10 and 1 repeated trials, respectively. By employing curve fitting method with usage of two separate gamma models which were identical with those for cross correlation, the onset times were determined at the time to half maximum of the fitted curves and the CNRs were determined as the percent signal changes of the fitted curves divided by the noise, which were measured as the standard deviation of the differences between the fitted curves and the raw time series (3).

Results

Fig. 1a demonstrated the relationship between CNR and standard deviation (SD, onset time variations) of the onset times measured from averages over three subjects for VASO and BOLD data, while fig. 1b showed our previous results of CBF-based (IR-SS) and BOLD-based data (3) for comparison. In fig. 1a, the four points from left to right for both VASO and BOLD data represented averaging across 1, 10, 20 and 30 trials, respectively, which were randomly measured by 10 times. For VASO, the CNR measured by averaging across 30 trials showed comparable results with that for IR-SS, but both were lower than that for BOLD by a factor of about 3. These results were in good agreement with Lu's finding (1). As the CNR increased, SD of the onset times significantly decreased. When comparing at comparable CNR level, we observed remarkably smaller SD of the onset times for both VASO and IR-SS than BOLD. This phenomenon was also demonstrated by BOLD and VASO onset time mapping (single subject's results) in fig. 2 with averages across 10 trials for BOLD and 30 trials for VASO. BOLD showed the scattered onset time distribution which would lead to higher SD of onset times, while VASO showed more focused onset time distribution. Fig. 3 drawed single subject's VASO and BOLD 30-trial averaged time curves, respectively, for demonstrating that earlier onset for VASO than for BOLD.

Discussion

The results provided good support that both CBV-based and CBF-based approach had better potentials than BOLD-based technique for probing the temporal resolution of ER-fMRI. This conclusion originated from the observations that the onset time distribution of the CBV-based and CBF-based HDR (3) showed a much smaller variance than that of BOLD-based HDR. Since CBV-based and CBF-based imaging techniques showed more sensitive to the microvascular responses, the faster onset responses and more accurate onset latencies within active voxel population could be detected. With this kind of stable onset behavior, assessment of temporal resolution of ER-fMRI would be carried out by using these approaches. Smaller onset variation is expected when CNR is further increased for CBV-based and CBF-based measurements. However, the intrinsic finite CNR would limit further exploration. Therefore, demands for higher CNR such as by higher magnetic field would be required for further investigation.

References

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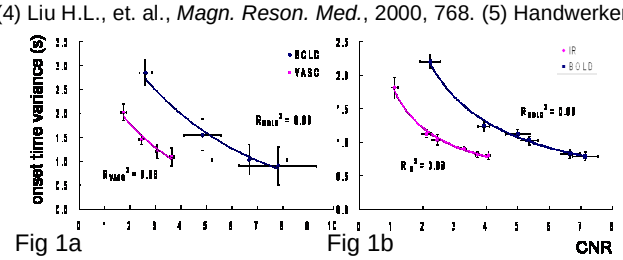

Fig 1a Fig 1b

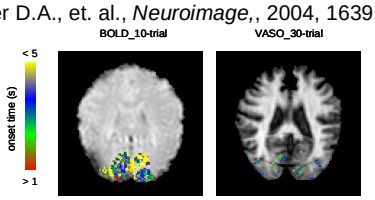

Fig 2

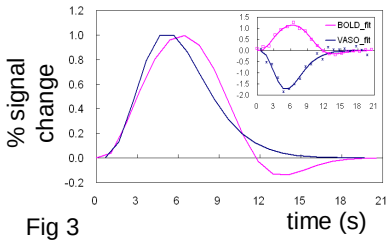

Fig 3