Simultaneous acquisition of BOLD and VASO signals using Looker-Locker method

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Introduction

To date, blood oxygenation level dependent (BOLD) contrast (1,2), which is a function of blood flow, blood volume and oxygen consumption, is arguably the most commonly used signal source in fMRI studies. In the brain, it has recently been proposed that the local cerebral blood volume change (ΔCBV) accompanying neuronal activity can be measured by vascular space occupancy (VASO) imaging (3) in which images are obtained at the null point of blood signal after a magnetization preparation by global inversion. The association between ΔCBV and ΔVASO, however, has been reported as being confounded by spatial variations in resting CBV and inversion efficiency (4), as well as the existence of cerebral spinal fluid (CFS) (5). In this study, we use the Look-Locker (LL) (6) sequence to simultaneously measure BOLD and VASO signals during epochs of visual stimulation. The signal source of VASO and its interplay with BOLD contrast and flow are discussed.

Materials and Methods

Four healthy volunteers (age = 25-35, F = 2, M = 2) were scanned after having given written informed consent. All MR imaging was performed on a 3.0T whole-body system (Siemens Trio, Erlangen, Germany) with a standard setup of body coil transmission and array head coil reception. Foam pads were wedged bilaterally between the subject's head and the coil for stabilization. For visual stimulation, a whole-field, black-white, radial flashing checkerboard (ON) interleaved with a white square in the center of black background (OFF) was projected to a screen and viewed by the subject from a mirror attached to the head coil. The paradigm consisted of 4 cycles of 24 s ON and 36 s OFF, preceded by 24 s of baseline. The IRB approved protocol included a 3D T_1-weighted high resolution MPRAGE (TR = 1620 ms, TE = 3.87 ms, flip angle = 15^0, TI = 950 ms, voxel size = 1x1x1 mm^3, sagittal) and three functional scans (in-plane matrix size = 64x64, voxel size = 3.4x3.4x5 mm^3): LL with TE = 17 and 25ms, respectively (TR = 4 s, flip angle = 40^0, with TI stepped in increments of 200 ms from 200 ms to 2000 ms, three slices), and a pulsed ASL (PASL; TR = 4 s, TE = 17 ms, QUIPSS II (7) TI_1/TI_2 = 700/1700 ms, nine slices). For functional scans, oblique slices were prescribed with the center slice aligned with the calcarine sulcus and data were collected by single-shot gradient-echo echo-planar readout. Three scans were conducted in a pseudo random order. Off-line data processing was performed with SPM2 (8) and homemade program in Matlab (Mathwork, Natick, MA, USA). After 2D realignment and registration, running average and subtraction were applied to PASL images to generate BOLD and ASL signals, respectively. LL images were binned by TI and analyzed separately, which led to ten sets of time series data (L_1,L_2,...,L_{10}), each with a TR of 4 s. For L_k (k = 2-10), the time offset relative to L_1 was 200*(k-1) ms. Time delay between slices (~ 50ms) was taken into account in TI calculation. General linear model was applied to all time series to create t-score maps. Activated voxels were determined by following criteria: T≧4 (p<0.001) for BOLD, ASL and positive activation in LL signals, T≦-2 (p<0.05) for negative activation in LL signals, all with cluster size = 3.

Results and Conclusions

Fig 1 shows the activation maps obtained from a representative subject (center slice, TE = 17ms). In L_1, the activation map nicely matches that of BOLD (Fig 2) and ASL results (not shown). A few scattered negative activations are seen outside the primary visual cortex. The number of voxels with positive activation and the statistical significance are the largest at L_1, followed by a decrease as TI increases. At L_3 and L_4 where the TI's are close to the null point of blood, negative activation starts to occur in the voxels showing positive activation in BOLD and L_1 maps. After L_4, positive activation reappears with the t-scores increasing with TI. At L_{10} and L_9, activation maps are almost the same as those of BOLD and L_1 although the t-score is slightly smaller due to the smaller signal-to-noise ratio. Fig 3 depicts the temporal evolution of Mz for different tissues with the LL imaging parameters used in our experiment. One notices that L_1 can be used as conventional BOLD except for the inverted Mz which is expected to cause minor differences as long as the first TI is sufficiently short. On the other hand, signals reach a steady state at L9 and L10 with activation maps very similar to that in L_1 although the effect of inflowing blood (see the Mz difference between in-plane and inflowing blood in Fig 3) should be noted. When TE = 25 ms, more positive activation is found in intermediate TI's (L_5-L_8, data not shown), indicating the contribution of extravascular BOLD effect. This study demonstrates the feasibility of using LL method to simultaneously acquire BOLD and VASO signals. The varied weighting of BOLD and VASO signals at different TI's may help understanding of VASO signal source and extra- vs. intra-vascular BOLD. Flow information may be extracted by modeling the signals at L_{10} versus L_1. Detailed comparison of ΔBOLD and ΔVASO at different TI's is underway.

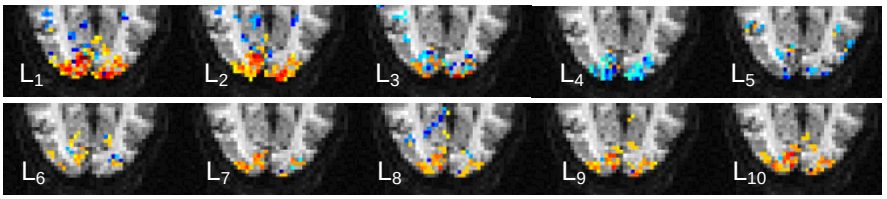
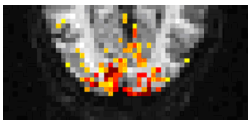


Fig 1. LL activation maps (↑).

Fig 2. BOLD activation map (↓)



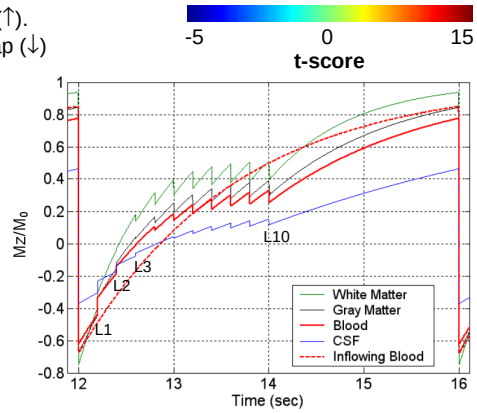


Fig 3. Mz evolution in LL imaging

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