Minimization of Post-Stimulus Undershoot in Heavily Diffusion-Weighted Functional Magnetic Resonance Imaging

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INTRODUCTION

Darquie et al. reported a new fMRI method using apparent diffusion coefficient (ADC) showing a different transient feature from other fMRI methods at visual cortex activation, which had a slow return to baseline after stimulation [1]. They suggested that the ADC change may reflect cortical cell swelling due to neuron activation. However, further study to confirm this hypothesis has not been performed. The timing of the slow return to baseline in the ADC time course is mostly consistent with undershoot in the blood-oxygen-level-dependent (BOLD) response, suggesting a relationship between the slow return in ADC and undershoot in BOLD transients. Therefore, we analyzed post-stimulus undershoot in heavily diffusion-weighted MRI (DWI) (b=1400 s/mm^2), and compared it with those in weakly DWI (b=200 s/mm^2) and BOLD image. The 1400 s/mm^2 and 200 s/mm^2 values of b-factor are the same as those used for calculation of ADC in the above report [1].

MATERIALS AND METHODS

A visual stimulation study was conducted on six healthy volunteers (4 males and 2 females, ages 21 to 29 years). All participants gave their informed written consent. The study was approved by an Institutional Ethics Committee.

DWI and BOLD imaging were performed on a whole-body 3-T MRI system (Excite, GE Medical Systems, Milwaukee, WI). An echo planar imaging sequence, sensitized to diffusion by application of additional gradient pulses on either side of the refocusing radiofrequency (RF) pulse, was used to provide images with diffusion weighting (echo time (TE) as short as possible: 71.2 ms). This sequence was run by alternating two *b* values (*b*=200 s/mm^2 and 1400 s/mm^2) to minimize effects of motion, at a rate of repetition time (TR) 2 s for a total of 250 repetitions. BOLD data were obtained using a T2*-weighted gradient echo planar imaging (EPI) sequence (TE = 72 ms, TR = 2 s). The field of view (FOV) was 240 mm, slice thickness was 4 mm, and matrix was 64x64 in both diffusion and FID EPI sequences.

The task for each subject consisted of 2 sets of 4 cycles of 40 s of an alternating black-and-white flickering checkerboard (8 Hz) followed by 80 s of rest (total of 16 activation blocks) for DWI and BOLD image. A cross-correlation analysis was used for activated pixels identification. The pixels where correlation coefficients of both b=1400s/mm^2 and b=200 s/mm^2 were more than 0.4 were selected as activated ones. The ADC transient feature was calculated using selected DWI (b=200 s/mm^2 and 1400 s/mm^2) signals. For estimation of post-stimulus undershoot, mean values were calculated for three intervals after the onset of stimulation, defined as activation (18-30 s), undershoot (54-66 s), and baseline (102-120 s).

RESULTS

Across the 6 subjects, 224 pixels in the visual cortex passed the criteria for activation, and the average curves for DWI (b=200 s/mm^2 and 1400 s/mm^2), BOLD response, and calculated ADC are shown in Fig 1. The qualitative result was that the DWI (b=200 s/mm2) and BOLD curves were rather similar, but the DWI (b=1400 s/mm^2) curve was distinctly different, with the DWI (b=1400 s/mm^2) signal exhibiting a smaller post-stimulus undershoot than those observed in DWI (b=200 s/mm^2) and BOLD images. The ratio of undershoot (baseline - undershoot) with activation (activation – baseline) in DWI (b=1400 s/mm^2) was 22.9 ± 16.4%, which is significantly smaller than 64.4 ± 20.8% in DWI (b=200 s/mm^2, n=6, paired-t test, p<0.01). The ADC curve shows gradual decreasing slope during the stimulus and slow return to baseline after stimulus. These results did not conflict those reported by Darquie et al. [1].

CONCLUSION

The fact that the calculated ADC time course in this study was similar to that of Darquie et al. [1] indicates that our method reflected the same phenomenon as theirs. The DWI (b=1400 s/mm^2) curve showed minimization of the post-stimulus undershoot, significantly different from that in DWI (b=200 s/mm^2). The same physiological mechanism might cause undershoot minimization in DWI (b=1400 s/mm^2) response and a slow return in the ADC transient feature after stimulation. However, the mechanism involved is still unclear, and further study will be required.

REFERENCE

1. Anne Darquie et al. (2001) PNAS 98, p9391-9395

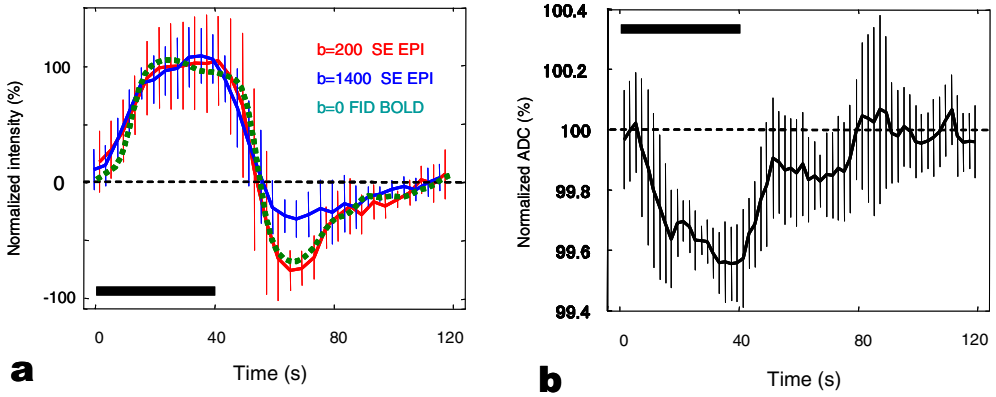

Fig. 1 (a) DWI (b=200 s/mm^2, red; b=1400 s/mm^2, blue) and BOLD (green dots) transient features. (b) ADC changes calculated from DWIs. Error bars indicate standard deviations.