Spatio-Temporal Characteristics of the BOLD Signal: Spin-Echo and Gradient-Echo fMRI at 3 T

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Introduction

In response to neural activity, local blood flow increases and causes a decrease in deoxyhemoglobin in the microvessels and veins perfusing the activated neurons. This decrease in deoxyhemoglobin improves the local field homogeneity, and consequently increases the signal in T_2 and T_2* weighted images[1]. It has been well demonstrated that the hemodynamic response to neuronal activation is delayed by 1-2 seconds, and peaks in 4-6 seconds[2]. It has been suggested that there is an "initial dip" component of the signal that occurs only in the immediate vicinity of activated neurons, but many groups have failed to reproduce these findings and it remains controversial[3]. Blood flow and saturation changes occur first in capillaries and small vessels near the activation site, and gradually extend to larger draining veins. The temporal delay between the capillary and venous hemodynamic response is on the order of 10 to 100 milliseconds[4]. Using GE-EPI and SE-EPI with multiple echo times, we measured the time-to-peak (**TTP**) BOLD signal change in response to visual stimulus. We hypothesize that at 3 tesla longer echo times (TE) will suppress BOLD signal from large draining veins, where the T2 of blood is shorter than the T2 of tissue, and therefore better localize neural activity.

Materials and Methods

Ten fMRI sessions were performed on four subjects at 3T. A black and white checkerboard, alternating at 8Hz, was pseudo-randomly presented 32 times with 2 second durations, during the acquisition of 144 EPI volumes. Each session repeated this visual paradigm 6 times: 5 SE-EPI were acquired with TR=2s, TE= 30, 40, 50, 70, 90 ms, 3.75x3.75x4 mm voxel size, 14 slices; and 1 GE-EPI with TE=30ms. Statistical activation maps were created using SPM99, after smoothing (10mm) and slice timing correction. The maps were thresholded for significance ($p<0.05$ corrected), and empirical hemodynamic response functions (HRF) were derived from a linear regression of the mean activated voxel time-course signal to an unbiased basis set modeling the response for 9 TRs.

Results

Figure 1 shows the derived HRFs from the GE-EPI and SE-EPI results of a single session. The TTP of the SE (4.8ms) was significantly shorter than that of the GE (5.8 ms). The GE had a larger signal change (0.86%) than the SE (0.60%) in response to activation, although the SE had less intertrial variability (data not shown). The TTP for the different SE echo times averaged across all trials showed a significant decrease from GE (Fig. 2), and the TTP decreased with increasing echo time, as expected.

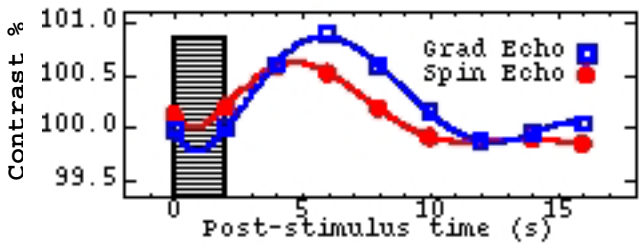


Figure 1. Typical BOLD HRF from a GE-EPI and SE-EPI (TE=70ms) session. The stimulus was presented during the first two seconds. The time-to-peak activation was shorter for SE (4.6 ms) than GE (6.0 ms).

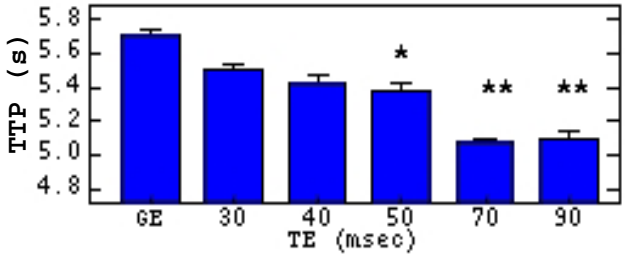
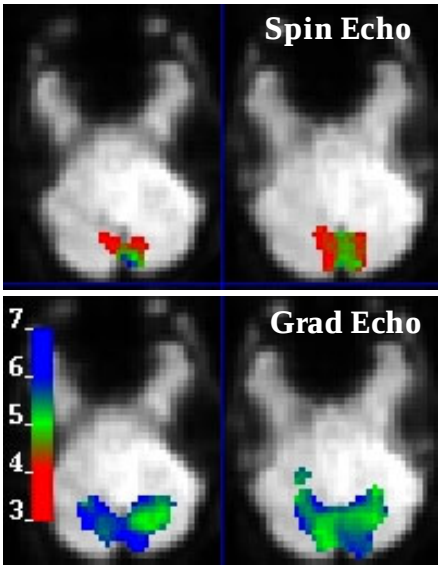


Figure 2. Average TTP of the HRF from all sessions, with error bars expressed as standard error. Y-axis is in units of seconds. At echo times greater then 40ms, the TTP for SE-EPI was significantly ($p<0.05$*, $p<0.001$**) less than the TTP for the GE-EPI.



A TTP map of activated voxels is shown in **Figure 3** at left, with barscale in seconds. Equivalent contiguous slices from the SE-EPI (TE=70ms) (**top**) and GE-EPI (**bottom**) images of a single session are depicted. Shortest peak times are displayed in red, followed by green and then blue. In the SE-EPI results, the shortest activation times are seen bilaterally in primary visual cortex (V1), and are surrounded by areas with longer TTP, shown in green. The sagittal sinus appears blue and is barely discernible in the posterior midline of the left image. The GE map shows longer TTP values globally, and a more uniform spatial distribution.

Conclusion

The time-to-peak BOLD signal contrast in SE-EPI of the visual cortex is significantly shorter than that of the GE-EPI, and decreases with increasing TE. TTP activation maps show that shorter peak activation times more closely localize to the center of primary visual cortex. These results imply that SE-EPI has improved sensitivity to tissue and microvessels close to sites of neural activation, as demonstrated by others[5]. Our results suggest that TTP maps may provide insight into the temporal ordering of neuronal pathways.

References

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