Latency and Echo-Time Dependence of the GRE-BOLD Signal in High-Resolution fMRI

S. Hetzer[1], T. Mildner[1], T. H. Jochimsen[1], K. Müller[1], T. Schlumm[1], and H. E. Möller[1]
[1]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

Introduction

The measurement of the relaxation rate R2* provides a means to assess changes in blood oxygenation during brain activation (1). The activation-induced relative signal change is proportional to ΔR2* and increases not only with echo time (TE) but also with the average size of the venous vessels in the voxel (2). In a recent study, a two-compartment model suggesting nonlinear behavior of the BOLD signal at short TE was proposed (3). The experimental verification of this model requires, firstly, a high image resolution in order to exclude partial volume effects and, secondly, a wide range of echo times including ultra-short TE values. In the present work, an imaging sequence capable of high-resolution fMRI at very short TE was employed to investigate ΔR2*. In addition, data were evaluated by considering the BOLD latency which is related to the average vessel size (4).

Methods

Experiments were performed at 3T (Medspec 30/100, Bruker) using of a two-shot center-out EPI sequence optimized to enable high-resolution fMRI with minimal TE values around 2 ms. For stimulation, 10 s of presenting rotating red L-shapes were interleaved with 15 s of rest. 10 slices (thickness 3 mm, FOV 192×192 mm^2) were acquired with in-plane resolutions of 1×1 mm^2 or 1.5×1.5 mm^2. Each session consisted of several functional runs (TR 2.5 s, 150-200 repetitions) with TE varying between 2 and 25 ms.
A field-map scan acquired for each in-plane resolution was used for the reconstruction of the functional images (5) in order to correct susceptibility-induced geometrical image distortions. After preprocessing (baseline- and slicetime correction), functional time courses were evaluated by use of spectral analysis which provides measures of coherence and phase for each voxel with respect to a reference time course (4). The design function of the stimulus was chosen as the reference time course. In each voxel, coherence and phase are equivalent to the statistical significance and the latency, respectively. Relative signal changes were calculated only for voxels with a coherence level of >80% in the functional run with the longest TE.

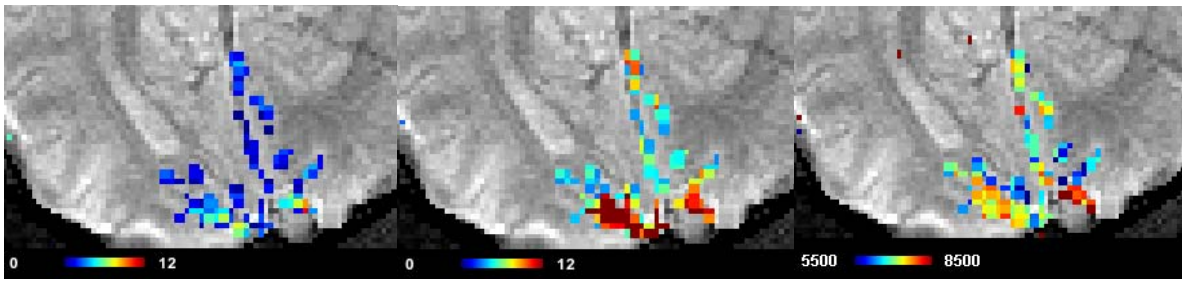

Fig. 1. *Percentage signal change during visual stimulation in a single subject for TE = 2 ms (left) and TE = 25 ms (center) and the BOLD latency in milliseconds relative to the stimulus onset (right).*

Results & Discussion

Figure 1 shows maps of the percentage signal change for TE of 2 ms and 25 ms obtained with a resolution of 1.5×1.5×3 mm^3 and a corresponding map of the BOLD latency. In regions with larger BOLD latency, signal chances increase more rapidly with TE corresponding to increased ΔR2* in these regions. The BOLD latencies varied between +5.5 and +8.5 s (total span of 3 s), which indicates that contributions from most sizes of vessels are detected by the two-shot, center-out EPI sequence.
Figure 2 shows the TE dependence of the signal change recorded in a different subject and results from linear fitting. Three masks containing equidistant sections of the BOLD latency were separately analyzed. ΔR2* increased from 1.3 s^{-1} (latency between 5.5 and 6.5s) to 1.6 s^{-1} (latency between 6.5 and 7.5 s) and 1.8 s^{-1} (latency between 7.5 and 8.5 s). While an almost perfect linear correlation was obtained for short BOLD latencies, deviations from linearity became evident for longer latencies. In addition, increasing non-zero, positive intercepts were observed with increasing latency. Experiments at higher resolution (1×1×3 mm^3) yielded even elevated ΔR2* values which could be explained by partial volume effects.

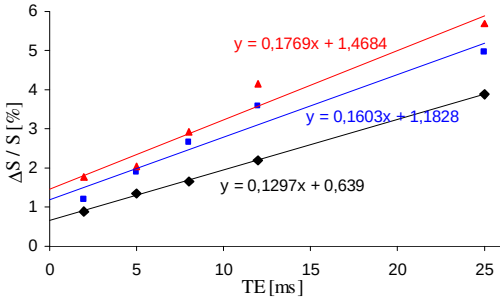

Fig. 2. *Percent signal change vs. TE for different intervals of the BOLD latency [5.5-6.5s] (diamonds), [6.5-7.5s] (squares), and [7.5-8.5s] (triangles). Solid lines show results from linear fitting.*

Interestingly, nonlinearities become apparent in our data which might be linked to the two-compartment model by Jin et al. (3) predicting nonlinearities for the intravascular BOLD signal at short TE (3). Previous experimental verification was limited to SE-BOLD data, whereas the shortest available TE did not allow a confirmation for GRE-BOLD (3). The experiments presented here significantly expand the range of available TE values for GRE-BOLD and are promising for a future reliable observation of such effects in the human brain.

References

(1) Ogawa et al., Proc Natl Acad Sci USA 1990; 87: 9868–9872.
(2) Jochimsen & Möller, NeuroImage 2008; 40: 228-236.
(3) Jin et al., MRM 2006; 55: 1281-1290.
(4) Müller et al., JMRI 2003; 17: 375-382.
(5) Noll et al., IEEE TMI 1991; 10: 629-637.