Improved sensitivity to BOLD contrast with multi-echo gradient echo imaging.

A. S. Lowe[1], H. L. Sloan[1], N. R. Sibson[1], and G. J. Barker[2]

[1]Department of Physiology, Anatomy and Genetics, University of Oxford, Oxford, Oxfordshire, United Kingdom, [2]Centre for Neuroimaging Sciences, Kings College London, London, United Kingdom

Introduction

Small animal functional magnetic resonance imaging under certain experimental conditions is limited to gradient echo (GE) imaging, which while devoid of spatial distortions is liable to relatively poor sensitivity to blood oxygen level dependent (BOLD) contrast. We present a relatively simple technique to substantially improve the sensitivity to BOLD contrast – multi-echo gradient GE imaging. The utility of the method is demonstrated via a direct cortical stimulation model in the rat [1], with the individual echoes providing a reference for conventional acquisition protocols [1].

Methods

Subject: male Sprague-Dawley rat (220g). **Pre-imaging:** anaesthetised under halothane and nitrous oxide: femoral artery cannulation; tracheotomy and subsequent ventilation; two bore holes drilled (2mm apart and 1.5 and 3.5mm from the mid-line) and subdural carbon fibre electrodes were rostrally advanced over the brain surface to approximately Bregma – concomitant with primary sensorimotor cortex for the hindpaw. The electrodes were sealed in situ and test electrical stimulations confirmed unique responses in the hind limb muscles. **MRI system:** 7T (Magnex Scientific, Abingdon, UK) super-conducting, horizontal bore magnet; SGRAD 156/100/S (Magnex Scientific) combined gradients and shims (max 2.5 mT/m/A); 34mm I.D. Aldermann-Grant resonator; and VNMR 6.1C Inova scanning software (Varian Associates, Palo Alto, CA). **Multi-echo GE imaging protocol:** TR=27.3ms; TE=7, 14, 21ms (acquired within one TR); acquisition matrix = 192x64 (zero filled to 192x96); 1 slice, voxel size 0.47x0.47x1.5mm; α=20º; nex=1 (dc offset corrected offline); 1.75s per acquisition. **Paradigm:** 10 repetitions of 7s pre-stimulation, 2.5s electrical stimulation and 98s post-stimulation. Electrical stimulation was 0.3ms pulses applied at 300Hz in 50ms trains (5 per second). **Post-processing:** mean echo images were calculated from the arithmetic mean of the individual echo images; the brain was manually masked; a cubic spline with 80 time-points per knot detrended low frequency drifts at each individual voxel [2]; and images were Gaussian smoothed with a kernel 2 times the in-plane resolution. **Analysis:** A semi-model free approach IRVA (Inter-Repetition Variance Analysis) determined repeated epoch specific variances [3]. A region of interest (the ipsi-lateral striatum) delineated from the mean echo Z-map was used to illustrate the relative sensitivities to the underlying BOLD contrast changes within the individual and mean echo data.

Results

Figure 1 illustrates the regional changes (z-maps) in BOLD contrast concomitant with 10 direct cortical electrical stimulations (graphs: mean ± sem). There are quantitative improvements demonstrable between the mean echo Z-map and the individual echoes. Mean (and peak) Z scores for the ROI within the ipsi-lateral striatum were: 11.1 (17.7), 9.4 (20.5), 9.3 (16.7) for the individual 7, 14 and 21ms echo data respectively and; 14.2 (23.4) for the mean echo data.

Discussion

Differential degrees of sensitivity to BOLD contrast changes concomitant with a direct stimulation model have been demonstrated for a multi-echo GE imaging sequence. While the scope for variant analytical approaches is possible, our semi-model free IRVA derived Z-maps demonstrates that the arithmetic mean echo data provides a greater degree of sensitivity to BOLD contrast changes than any single echo. For experimental designs that warrant a GE approach, this method may afford substantial improvements in statistical power without compromising the inherent characteristics of the BOLD response. Further, with the rise of parallel imaging this technique may find some utility in echo-planar imaging (EPI) applications.

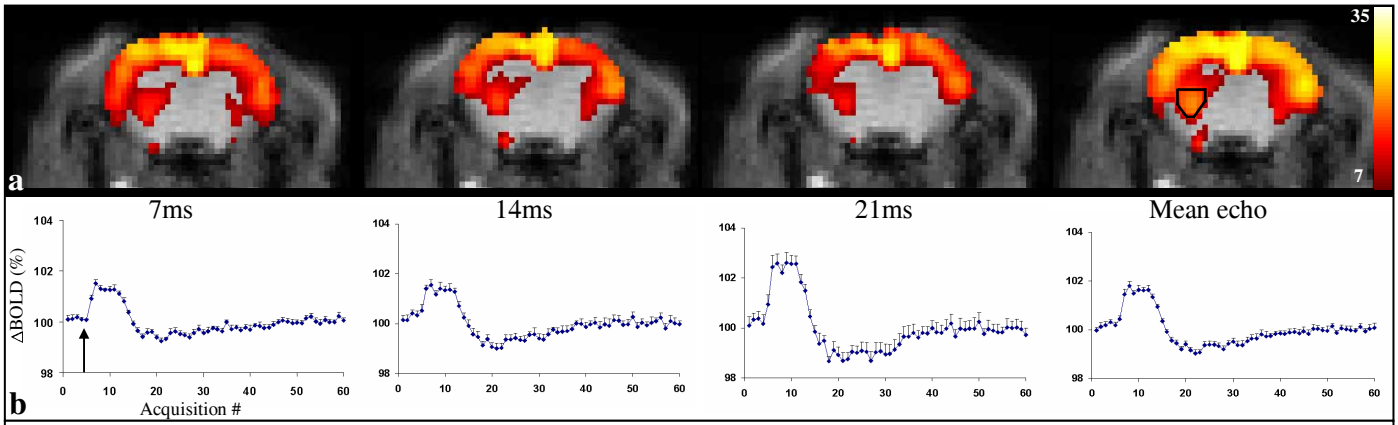

Figure 1: (a) Z-maps representing a semi-model free analysis of variance between epochs of electrical stimulation and the whole time course for the individual echo and mean echo data. The region outlined in black within the mean echo Z-map was used in all data sets to determine (b) the average BOLD contrast responses in arbitrary units against acquisition number. Arrow indicates stimulus onset. Colour overlay represents z-scores above a threshold of 7 (corrected p<0.001).

References

[1] Austin VC *et al* (2003). Magn. Reson. Med. **49(5)**:838-47. [2] Lowe AS *et al* (In submission). NMR Biomed. [3] Clare S *et al* (1999) Magn. Reson. Med. **42(6)**:1117-22.