Field Strength Dependence of BOLD Contrast in Motor Cortex

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INTRODUCTION

Blood oxygenation level dependent (BOLD) signal changes occurring during the execution of a simple motor task have been measured at field strengths of 1.5, 3 and 7 T, so as to quantify the benefits offered by ultra-high magnetic field for functional MRI (fMRI).

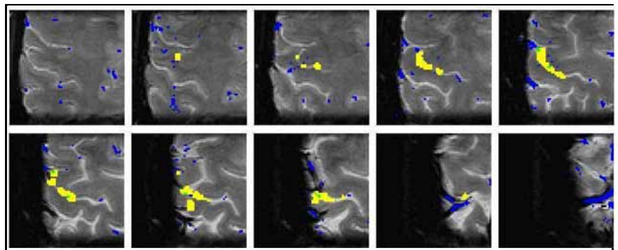

Figure 1: ROI's of a representative subject, shown overlaid on EPI data. Yellow: composite ROI, blue: veins, green: overlap.

METHODS

fMRI acquisition: Six subjects were scanned on 1.5, 3 and 7 T Philips Achieva scanners. FMRI data were acquired using single-shot, GE-EPI with outer volume suppression on a 64 x 64 matrix and an in-plane spatial resolution of 1 x 1 mm^2. Twelve, contiguous axial slices (3 mm slice thickness) covering right MI were acquired every two seconds. FMRI experiments were performed at four different echo times at each field (30, 50, 70 and 80 ms at 1.5 T; 22, 35, 50 and 65 ms at 3 T; 18, 25, 34 and 43 ms at 7 T). The block paradigm employed an 8s ON-period followed by an OFF-period of 20.25s. During the ON-period, subjects pressed a button at approximately 3 Hz using their left thumb. High resolution 3D, T_2^*-weighted image data (FOV = 230 x 230 x 76.8 mm^3; 384 x 384 x 96 matrix) were acquired for each subject at 7 T using a spoiled-FLASH sequence (α=11^o; TR=27 ms; TE=15 ms) and used to identify the location of large veins.

Analysis: Initial processing steps were carried out using SPM2 (FIL, UK). FMRI data were corrected for slice timing, realigned, co-registered and spatially and temporally smoothed. SPM's were formed for each fMRI data set (thresholded at p_{corr} = 0.05). Data acquired at each field strength and echo time were co-registered to allow generation of ROI's representing areas of significant activation. Two types of ROI were formed: (i) a 'composite' ROI comprising voxels that were classified as active at all echo times at at least one field strength; (ii) a larger 'inclusion' ROI made up of voxels that were classified as active at any echo time/field strength. ROI's were also divided into venous and tissue regions using the high resolution T_2^*-weighted images, as shown in Fig. 1. Values of the change in relaxation rate, ΔR_2^*, were found by linear regression of the fractional BOLD signal change in the ROI, $\Delta S_{BOLD}/S$, to TE [1]. Values of R_2^* and mean t-scores within the ROI's were also calculated, the latter providing a measure of the BOLD contrast to noise ratio. Variation of the number of active voxels as a function of TE and field strength was also analysed.

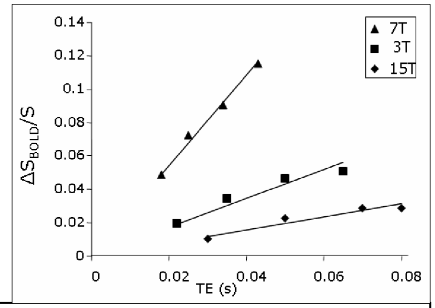

Figure 2: Linear regression of $\Delta S_{BOLD}/S$ to TE for a composite ROI in one subject. ΔR_2^* values are: 0.39 ± 0.02, 0.86 ± 0.05 and 2.81 ± 0.05 s^{-1} for 1.5, 3 and 7 T, respectively.

RESULTS AND DISCUSSION

Figure 2 shows plots of fractional BOLD signal change as a function of TE for the composite ROI in one representative subject. A linear variation with TE is evident with the slope increasing with field strength as expected. Figure 3 shows the variation of ΔR_2^* with field strength averaged over the 6 subjects for the two different ROI types. Both show a supra-linear increase with B_0 with greater values of ΔR_2^*occurring for the smaller, composite ROI, which comprises the more consistent areas of activation. Values found in a previous study using a visual stimulus at 4 and 7 T [2] based on analysis of anatomically defined ROI's are also shown on Fig. 3 and are consistent with the results from the composite ROI's used here. Table 1 details the values of $\Delta R_2^*/R_2^*$, which dictate the achievable BOLD contrast. Both ROI types show a significant increase with field strength, confirming the advantages of high field for fMRI experiments [1,2]. This was also evident from analysis of the average number of voxels classified as active, N, for the different field strengths. N was found to vary with echo time and the maximum value, N_{max}, was larger and occurred at shorter echo times at higher field (N_{max}/TE: 74/80ms at 1.5T; 165/50 ms at 3T and 460/34ms at 7 T). A similar echo time dependence and increase with field strength was manifested by the mean t-scores within the ROI's. These data show that the maximum sensitivity to BOLD signal changes occurs at TE-values close to T_2^* and increases significantly with field strength.

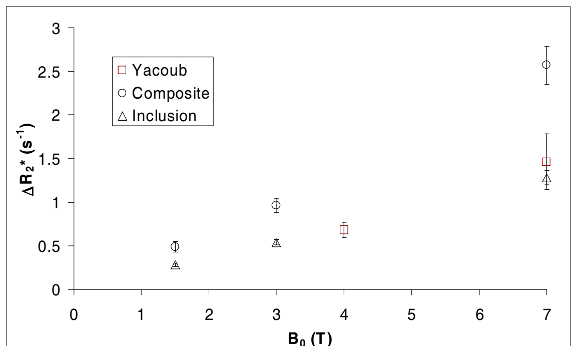

Figure 3: Variation of ΔR_2^* with B_0 taken from the composite and inclusion ROI's and data from Reference [2].

Focussing on the composite ROI, on average only 10% of voxels were classified as overlapping with veins identified on the high resolution T_2^*-weighted data. ΔR_2^* values in these voxels were only found to be significantly elevated relative to the tissue compartment in the 1.5 T data. This may reflect the fact that at 3 and 7 T venous blood T_2^* is short compared with the echo times employed in this study [2] or could be a result of partial volume effects in the EPI data. Haemodynamic responses formed by combining the data acquired across all cycles of the paradigm and averaging over subjects are shown in Fig. 4., along with a linear fit to the leading edge of each of the responses. The intercept of this line with the baseline was used as a measure of the onset of the haemodynamic response [3] yielding times of 3.2 ± 0.3, 2.7 ± 0.3 and 1.9 ± 0.3 s after the start of the stimulus at 1.5, 3 and 7 T, respectively. The earlier onset at higher field is consistent with a lower venous contribution to the signal change, since BOLD effects occur first in the microvasculature and then propagate into the venous compartment [4].

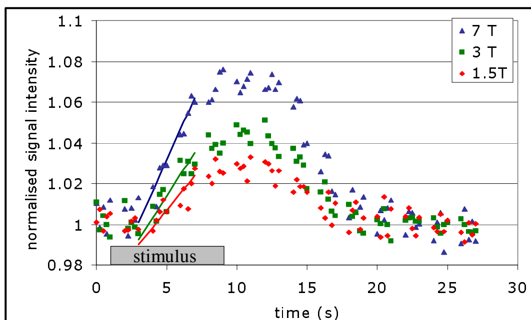

Figure 4: Average, reordered time-courses of relative signal change (TE= 50, 35 and 25 ms at 1.5, 3 and 7T).

ROI	1.5 T	3 T	7 T
Composite	0.043±0.006	0.053±0.006	0.083±0.010
Inclusion	0.022±0.002	0.028±0.002	0.035±0.003

Table 1: $\Delta R_2^*/ R_2^*$ values averaged over subjects.

CONCLUSIONS

Previous studies of the dependence of BOLD contrast on field strength [1,2] have been extended to motor cortex, with the use of single rather than multi-shot EPI and the definition of areas of activation from co-registered activation maps. Results show significant increases in ΔR_2^*, $\Delta R_2^*/R_2^*$ and average t-score with field strength, and provide some evidence of reduced venous contribution at high B_0.

REFERENCES

[1] Gati, J. et al. Magn Reson Med. 38 296-302, 1997, [2] Yacoub E. et al. Magn Reson Med. 45 588-594, 2001 [3] Gibson, A. M. et al. S S Nucl Magn Reson 28 258-65, 2005. [4] Hulvershorn, J. et al. Neuroimage 24 216-23, 2005.