High resolution SE-fMRI in humans at 3 and 7 T using a motor task

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Introduction

Blood oxygenation level dependent (BOLD) fMRI is a commonly used technique for noninvasive mapping of the human brain function. This contrast is based on the changes in transverse relaxation times T_2 and/or T_2^*. Usually a gradient echo (GE)–sequence is used, since this method provides the highest functional contrast. At low field strengths the GE – BOLD contrast arises from both intra- and extravascular compartments due to blood oxygenation changes in both small and large vessels but is dominated by the effects of large veins which can be distant from the actual site of neuronal activity. In contrast, the spin echo (SE)–sequence suppresses the extravascular contribution from larger veins because of static averaging [1]. However, the limiting factor of using SE – BOLD at lower fields is the reduced contrast-to-noise ratio (CNR). It has previously been shown that it is possible to produce robust, high resolution functional contrast at ultra high fields such as 7 T in response to a visual stimulation task by using SE acquisition in conjunction with a surface RF coil [2]. Here we use a zoomed functional imaging method [3] with a volume T/R coil to compare SE-BOLD responses to a motor task at 3 and 7 T. Additionally a venogram was acquired to determine the spatial correlation between the focus of observed activation and large veins.

Methods

All experiments were performed on Philips Achieva whole body scanners at field strengths of 3 and 7 T. Six healthy subjects (four female) were investigated in this study. For the motor task the subjects pressed an optical button with the left hand for 8 seconds, followed by a rest period of 20 seconds, repeated 15 and 10 times at 3 and 7 Tesla, respectively. To select the best six slices for the SE – BOLD fMRI, a GE-BOLD experiment with 12 slices and half the number of trials of the SE–BOLD study was first run and analyzed during the scanning session. The repetition time, *TR,* was set to 2 s for both GE and SE studies. For SE–BOLD three experiments were performed in which the motor task was performed on each subject at 3 different echo-times (*TE* of 56, 75, 98 ms at 3T and 40, 55, 70 ms at 7T respectively). The order of experiments was randomized across subjects to correct for habituation effects. The resolution (at both field strengths) was 1x1x1mm^3. Functional data were acquired with a single shot partial-Fourier SE-EPI technique; half-Fourier factor 0.7. The fMRI data were analyzed using FEAT (FMRI Expert Analysis Tool) as part of FSL (FMRIB's Software Library) [4]. Data were realigned using MCFLIRT [4] and slice-timing correction performed using Fourier-space time-series phase-shifting, data were spatially smoothed using a Gaussian kernel of *FWHM* 1.5 mm. A high-pass temporal filter (Gaussian-weighted least-squares straight line fitting, with σ = 60.0 s) was applied to remove large scale signal drifts. Time-series statistical analysis was carried out using FILM [4]. *Z* statistic images were thresholded using clusters determined by *Z*>2 and a corrected cluster significance threshold of *P*=0.05. In an additional session, each subject was also scanned with a high resolution (0.6x0.6x0.4 mm³) spoiled-FLASH sequence (α=11°; *TR*=27 ms; *TE*=15 ms) to determine the locations of large veins. Veins that were evident in the venogram were masked by visual inspection. The venogram was then co-registered to the functional scans using FSL's FLIRT [4] algorithm and the registration transformation matrix applied to the venous mask.

Results and Discussion

In all subjects, significant activation was detected at all *TE*'s and at both field strengths. Figure 1 shows representative *z*-score maps for one subject for *TE* = 75 ms at 3 T and 55 ms at 7 T overlaid on the appropriate mean SE – EPI images. The average percentage signal changes (P<0.05) over all subjects for each *TE* and field strength are shown in Figure 2. To account for the haemodynamic delay the percentage signal change was calculated for the duration of the ON period shifted by 6 s. The data were fitted to a linear regression with *TE,* yielding ΔR_2 values of 0.29±0.01 s^{-1} and 0.37±0.002 s^{-1} for 3 and 7 T, respectively (Figure 2). Interestingly, the ratio of the percentage signal change for GE- to SE-BOLD is 1.57 and 1.12 for 3 and 7 T, respectively (the same slices in GE- and SE-BOLD data were analyzed, TE_{GE}/TE_{SE}=35/75 ms and 25/55 ms for for 3 and 7 T, respectively).

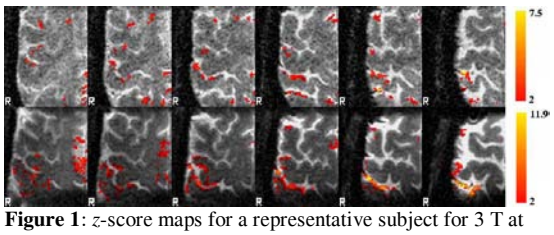

Figure 1: *z*-score maps for a representative subject for 3 T at *TE*= 75 ms (top) and 7 T at *TE* =55 ms (bottom) overlaid on appropriate mean SE-EPI data.

Table 1 shows the number of activated voxels and the maximum *z*-score values for each subject. For all subjects the number of activated voxels was higher at 7 T and a higher maximum *z*-score was found, suggesting increased sensitivity to BOLD changes at the 7 T in spite of the use of a larger number of functional trials at 3 T. The vein mask was compared with the activated voxels identified from the functional scans. None of the activated voxels correlated with macroscopic visible veins for any subjects at either field strength. This is to be expected because the echo times used in this study are longer than the T_2 of venous blood and thus the intravascular contribution is reduced.

Conclusion

A linear variation of average percentage signal change with echo time at 3 and 7T is shown, with significant increases in functional power (larger activated region, higher maximum *z*-scores and thus higher CNR) at 7T. At both field strengths functional areas identified using SE-BOLD are insensitive to large vein effects.

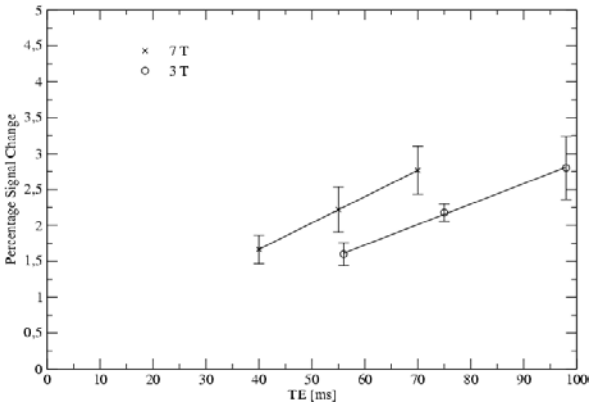

Figure 2: *TE* dependence of percentage signal change in motor cortex for 3 and 7 T yielding ΔR_2 values of 0.29±0.01 s^{-1} and 0.37±0.002 s^{-1} respectively.

Subject	3 T			7 T		
	TE = 56 ms	*TE* = 75 ms	*TE* = 98 ms	*TE* = 40 ms	*TE* = 55 ms	*TE* = 70 ms
# 1	378 / 4.36	386 / 4.37	133 / 4.32	292 / 4.72	721 / 7.26	576 / 6.31
# 2	195 / 3.82	90 / 4.51	42 / 3.13	662 / 8.24	871 / 8.93	716 / 6.21
# 3	286 / 5.02	518 / 7.49	418 / 8.04	1033 / 10.31	990 / 11.64	1015 / 12.66
# 4	63 / 4.02	59 / 3.56	243 / 4.34	614 / 10.43	603 / 8.37	504 / 8.56
# 5	30 / 4.33	50 / 4.72	101 / 4.40	218 / 4.47	578 / 5.01	632 / 7.36
# 6	172 / 5.14	33 / 3.17	145 / 4.07	489 / 6.81	222 / 7.09	329 / 8.07
act. voxel	187±131	189±208	197±148	551±293	664±268	628±230
zmax	4.45±0.53	4.64±1.52	4.72±1.7	7.50±2.6	8.05±2.2	8.20±2.38

Table 1: Number of activated voxels /maximum *z*-scores for the 6 subjects at 3 and 7 T. Bottom two rows show the average values.

References

(1) S.G. Kim et al., *Methods*, **30,** 28-41, 2003; **(2)** E. Yacoub et al., *Magn. Reson. Med.*, **49**, 655-664, 2003; **(3)** J. Pfeuffer et al., *NeuroImage,* **17**, 272-286, 2002 ; **(4)** S.M. Smith et al., *NeuroImage* , **23(S1)**:208-219, 2004