Comparing the microvascular specificity of the 3 T and 7 T BOLD response

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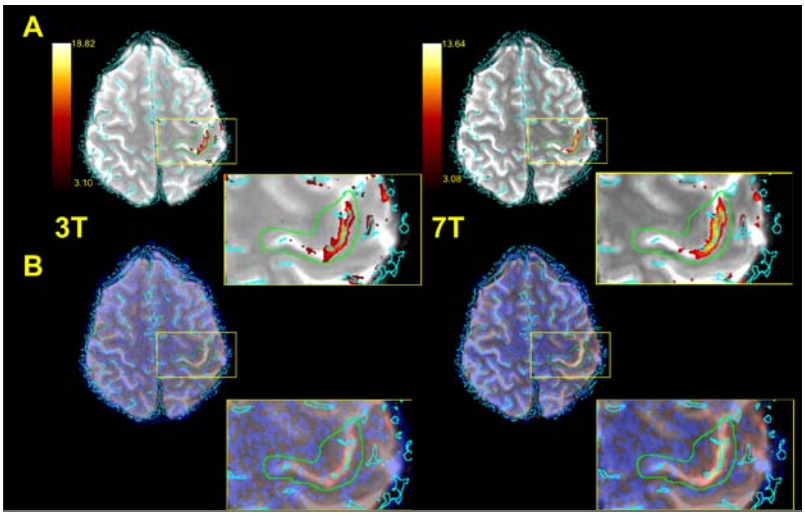
Introduction: In functional MRI it is desirable for the BOLD signal to be localized to the tissue containing activated neurons rather than the veins draining it. There is broad consensus in the literature that the specificity of the BOLD response – the relative contribution to the total BOLD signal that comes from tissue compared to that from venous vessels – increases with field strength[1,2,3,4]. Those studies assessed image signal to noise ratio (SNR) and transverse relaxation rates in isolated vein and tissue voxels, and found a greater than linear increases in tissue, and a less than linear increase in veins. In the light of multiple recent studies showing less than linear increases with field strength of more functionally relevant quantities - time-series SNR[5] and activation statistics[6,7] - this study revisits the question of how the specificity of the BOLD response depends on magnetic field strength in the high and ultra-high field regime.

Materials and Methods: Twelve right handed volunteers (4 female, mean age 31.6 years) performed 2 runs of a hand clench motor task on both 3 T Siemens TRIO and 7 T Siemens MAGNETOM scanners, both with 32 channel head coils. High resolution EPI (1x1x2.4 mm voxels) was acquired with T_R= 3 s and GRAPPA 4, with T_E = 35 ms and 37 slices at 3 T and T_E = 22 ms and 44 slices at 7 T. Additional measurements were carried out at matching echo times to examine echo time dependence of specificity findings. High resolution SWI (0.3x0.3x1.2 mm voxels) was acquired at 7 T.

Analysis: fMRI analysis was performed in the native EPI space with Independent Component Analysis (ICA) using FSL's MELODIC[8]. ICA effectively separates activation from physiological noise and is insensitive to possible latency differences between tissue and vein signals. Activation results were coregistered to SWIs in a number of linear and non-linear registration steps using FSL's FLIRT[9] and FNIRT. Vein and tissue masks were generated from SWI, and used to identify which activated voxels corresponded to veins and which to tissue. The number of voxels above threshold and mean z-values of all voxels in anatomical ROIs were assessed.

Results: Figure 1 illustrates typical functional results within an anatomical ROI (green) for a single subject. Row A shows voxels above the ICA Gaussian mixture modeling threshold of $p > 0.5$ threshold, row B all functional voxels. Veins identified in SWI are outlined in cyan. The zoomed depiction clarifies the situation inside the ROI.



7/3T SENSITIVITY	
N vessels	1.21 (0.31)
N μvasc	1.42 (0.44)
Z vessels	1.41 (0.35)
Z μvasc	1.48 (0.32)
7/3T SPECIFICITY	
% ln μvasc	1.01 (0.13)
Z μv/*Z* vessel	1.07 (0.17)

Values in brackets are standard deviations on the mean.

Table 1: summary statistics for sensitivity and specificity

Figure 1: Example results for a single subject. (A) Functional image with vessel outlines (cyan), overlaid with thresholded IC results and anatomical VOI (green). (B) As in (A), but with no thresholding applied to the IC map. A zoomed representation of the target area is also illustrated.

On average, 21 % more voxels were above threshold in veins at 7 T than at 3 T and 42 % more voxels in the microvasculature. These increases in BOLD sensitivity with field strength in both veins and the microvasculature were statistically significant in t-tests at $p < 0.05$. The proportion of activated voxels in the microvasculature did not differ significantly between the two field strengths, however, indicating no increase in specificity. Likewise, mean Z values were significantly higher in the 7 T results in both the vessels and the microvasculature. In veins, the increase was 41 %, in the microvasculature it was 48 %. There was an increase in the ratio of mean Z values in the microvasculature to veins with field strength but this was small and not significant, also indicating no increase in specificity. The same finding, of no significant increase in specificity, held when the assessment was carried out for measurements made at the same echo time at each field strength.

Discussion and Conclusion: There was a significant increase in the number of activated voxels at 7 T in both the veins and the microvasculature – a BOLD sensitivity increase. The small increase in specificity measured at 7 T was not significant, however. For the motor region and the acquisition methods used, our findings do not support the hypothesis of an increase in the specificity of the BOLD response at ultra-high field. This is consistent with reports of modest increases in tSNR and activation statistics from 3 T to 7 T due to physiological noise[5].

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