A Comparison of the BOLD Response between two High Magnetic Field Strengths: 7.0 and 11.7 Tesla

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Introduction: It is generally accepted that the BOLD effect increases with higher field strengths [1]. We present here a comparison of the BOLD effect in the somatosensory cortex of the rat brain following forepaw stimulation at 7.0 and 11.7 Tesla within a single experimental session. On both systems the same protocol was used to compare directly the calculated BOLD signal intensity changes. Additionally, high resolution BOLD scans at 11.7 Tesla were performed to profit from both the higher magnetic field strength and the stronger gradient and spectrometer strength. Here we show that during transition from 7.0 to 11.7 Tesla, the dominant effect is not further increase in BOLD amplitude, but increased sensitivity leading to larger activated area.

Methods: MRI Comparison: Experiments were conducted on (Bruker BioSpin) horizontal small animal MRI scanners of 7.0 Tesla equipped with a gradient of 200 mT/m using custom-build coils (14 cm Helmholtz coil for transmission, 2.8 cm surface coil for reception) and 11.7 Tesla with a gradient of 750 mT/m using standard Bruker coils (72 mm quadrature resonator, quadrature surface coil). Each experimental session consisted of four fMRI scans per study and field strength. The same MRI protocol (multi-slice single-shot SE-EPI, Matrix 64 x 64, FOV 2.56 x 2.56 cm², in-plane resolution 400 x 400 µm², 2 cm slice thickness, TR/TE 3000/25 ms) was used for both field strengths. T2* values of the cortex were determined: at 7.0 Tesla, T2* = 27 ± 5 ms, and 11.7 Tesla, T2* = 23 ± 5 ms were found.
High–Resolution MRI: At 11.7 Tesla additional high-resolution EPI protocols with in-plane resolution of 300 x 300 µm², 200 x 200 µm² and 150 x 150 µm² were performed (which are not possible at 7.0 Tesla because of lower available gradient strength) to visualize detailed structure of the activated S1 area and to detect activation in S2 and thalamus.
Animals + Physiology: Male Wistar rats (n=8) were scanned three times under medetomidine anesthesia. BOLD–fMRI was achieved during electrical forepaw stimulation (I=1.5 mA, f=6 Hz) with a block paradigm (45s rest + 15s stimulation periods, 5 times) [2].
Exclusion criteria: Mortality (1/8 animals), insufficient sedation (1/22 studies) as well as technical problems (9/172 scans), resulted in 69 (7.0 Tesla) and 70 (11.7 Tesla) of original 96 scans per field strength.
Analysis: Images were analyzed with *stimulate* software using t–test analysis with a 99 % confidence level. For the analysis the largest cluster within the S1 area was taken. The number of activated pixels contributing to the cluster as well as the average and the maximum BOLD signal intensity change [in %] of the cluster were calculated.

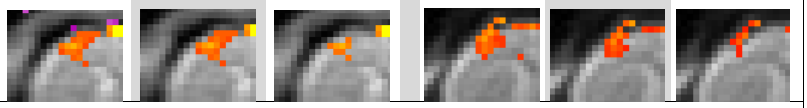
Cluster parameters	7.0 Tesla			11.7 Tesla		
minimum BOLD limit	0.0001%	1%	2%	0.0001%	1%	2%
number of scans	69	66	43	70	70	41
average BOLD in %	1.68 ± 0.48	1.79 ± 0.44	2.62 ± 0.44	**1.48 ± 0.59**	1.68 ± 0.55	2.77 ± 0.65
maximum BOLD in %	2.73 ± 1.48	2.81 ± 1.44	3.45 ± 1.41	2.71 ± 1.60	2.71 ± 1.60	3.60 ± 1.55
activated pixels	13.7 ± 12.2	12.9 ± 11.4	7.56 ± 8.00	**18.1 ± 13.4**	12.8 ± 12.2	7.83 ± 9.14
Example image of S1 activation in left cortex (red to yellow: 0-5 %)						

Table 1: Average and maximum BOLD signal intensity changes [in %] as well as activated pixels of the cluster of activation. BOLD cluster parameters and image of activation are shown in dependence on field strength and minimum BOLD limit of the calculated BOLD values.

Results: BOLD response was observed in all fMRI scans. No significant differences between field strengths could be found for calculated BOLD increases > 1 % (Tab. 1). At 11.7 Tesla the SNR in-vivo is increased by a factor 1.5 – 2 showing more activated pixels with BOLD signal changes between 0.0001 – 1 %, resulting in a decreased average BOLD value of the cluster (highlighted in Tab. 1). Thalamus activation or structural details of the activated cortex could not be seen, because the achieved in-plane resolution of 400 µm is too low. However, when optimized protocols were performed at 11.7 Tesla, with a resolution of 300 x 300 µm², activation in S1, S2 and thalamus was detected (Fig. 1 a-c). With an in-plane resolution of 150 x 150 µm² also cortical layer structures in the S1 area are visible, in full agreement with earlier reports [3].

Conclusion: Higher magnetic field strength improves the detectability of the BOLD response. This is mainly due to an increase in the number of detectable activated pixels rather than an increase in the maximum BOLD signal intensity change. An increase of BOLD signal intensity change within the activation area was not seen in this study. The increase of SNR due to higher field strength was utilized for high spatial resolution scans which show layer structure of the activated S1 areas in more details as well as activation in the thalamus. Such a protocol optimization in conjunction with new phased-array coils will show more details of activation with higher three-dimensional and temporal resolution.

References:
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[2] Weber, *et al.*, 2006. NeuroImage. 29: 1303–1310.
[3] Silva, *et al.*, 2002. PNAS. 99: 15182–15187.

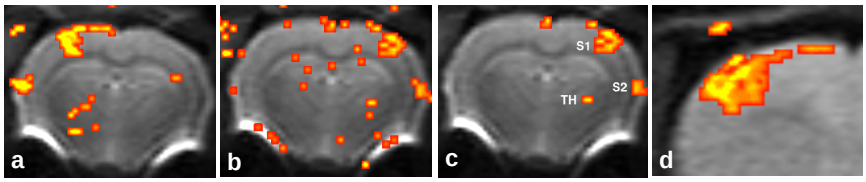

Figure 1: High in-plane resolution BOLD-EPI at 11.7 Tesla shows activation in (**a**)-(**c**) thalamus, S1 and S2 areas, and (**d**) cortical layer structures in S1 area.

Acknowledgements: Financial support by the BMBF network "Stem-Cell based regeneration" as well as by the EU funded Networks of Excellence EMIL (LSHC-CT-2004-503569) and DiMI (LSHB-CT-2005-512146) and is gratefully acknowledged.