The Spatial Pattern of the Positive BOLD Response at High Magnetic Field is Approximately Stationary

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This study aimed at characterizing the spatio-temporal dynamics of BOLD response at high magnetic field (7T) in the human visual cortex. The spatial pattern of the BOLD response remained approximately stationary across the positive phase of the response. The onset of the response was relatively spatially coherent compared to previous reports from lower magnetic fields. The approximate stationarity of the positive phase of the response validates the usage of analysis methods that assume separability of time and space of the BOLD response.

Methods:

Subjects fixated on a point (0.4°) during both control and stimulation periods. The visual stimulus consisted of a thin ring composed of flickering checkers near eccentricity of 10°. The width of the ring was adjusted according to (1), such that the aggregate centers of activated receptive fields in V1 would form a strip 1.0 mm thick (assuming no scatter) parallel to the cortex. Gradient-echo planar imaging was performed at 7 Tesla, using a surface coil. Data was obtained from 2 sagittal slices in occipital cortex next to the midline (resolution 1x1x3 mm3, TR = 0.3 sec., TE = 20 msec.). Four subjects took part in this study, in 6 different scanning sessions.

Results:

To evaluate the temporal evolution of the pattern of the BOLD response, we used a voxel-wise t-test to compare the MR intensity at different temporal phases of the response against the baseline period preceding the stimulation (Fig. 1A). Using a constant threshold, the responding regions seem to extend wider during the peak of the response (4th image) than during the early (2nd image) and late (5^{th} image) phases. Is this due to different spatial specificity of the phases or due to the difference in CNR? To address this question, we obtained a mask, consisting of all the voxels that were significantly active, either positively or negatively, during 3 seconds of the whole cycle. Fig. 1B presents the time course as sampled using this mask. Fig. 1C demonstrates a similar time-course, that reflects the mean absolute MR intensity within the masked regions as a function of time. To evaluate the spatial evolution of the BOLD response, we repeated the t-test, but with thresholds scaled according to the contrast shown in Fig. 1C. During the first 2 seconds (Fig. 1D, 1st image), several voxels in V1 and other areas demonstrated an initial negative response. Note the similarity of response patterns that correspond to the different phases of the positive response (2nd – 5th image). The positively responding regions flip sign at the onset of the post-stimulus undershoot (6th image), while at the periphery of the response a post-stimulus positive response evolves.

To further evaluate the stationarity of the positive response, we computed the matrix of correlation values of percent change images, at a temporal resolution of 0.3 seconds (Fig. 2). Note the high-correlation values across the different phases of the positive response, starting 3 sec following the onset of the stimulus. Note also the negative correlation values between images obtained during the positive response and images obtained during the post-stimulus undershoot. These negative values indicate that the spatial pattern of the response during the undershoot is a mirror image of the pattern during the positive response.

The results from Fig. 1D and Fig. 2 indicate that the spatial patterns of the BOLD signal across the positive response are scaled versions of each other. Consistent with this finding, the variability of lags of the haemodynamic response was relatively small (~90% of values within ± 1 sec) across different voxels. To further evaluate the coherence of lags, we presented the same stimulus at high temporal frequencies (0.07 Hz, 0.14 Hz and 0.21 Hz; half the cycle on, half the cycle off), and applied a voxel-wise Fourier transform in the time domain. The phases corresponding to the voxels that demonstrated high magnitude at the stimulation frequency were relatively coherent (± 1 sec at 0.07 Hz; smaller variability at the two higher frequencies).

Conclusions and Discussion:

1) The spatial pattern of the BOLD response remains approximately unchanged across the positive phase of the response. 2) We attribute the difference between our findings and previous studies at lower fields (2, 3) to the smaller contribution of veins to the BOLD signal at 7T due to the suppression of blood related effects in BOLD, as the blood T2 gets extremely short with increasing magnetic field. 3) The approximate stationarity of the positive response at high field validates the usage of analysis methods (such as cross-correlation) that assume separability of time and space of the BOLD response.

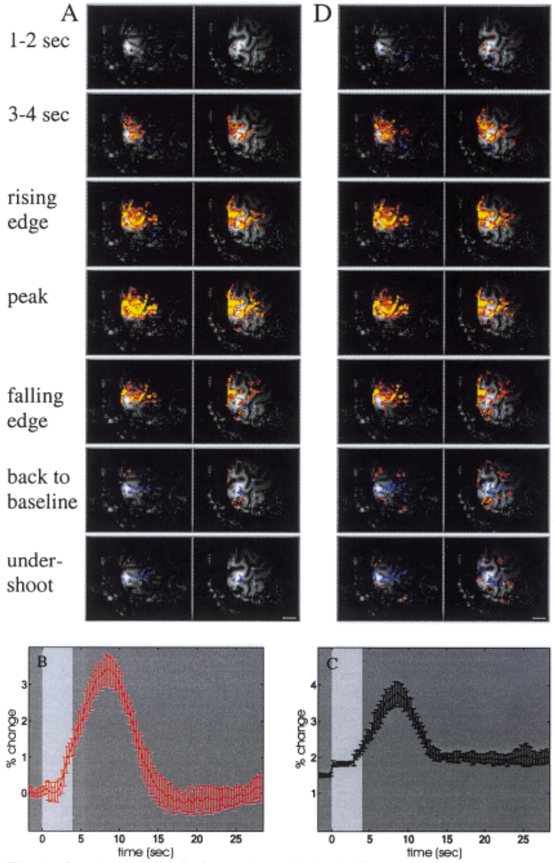
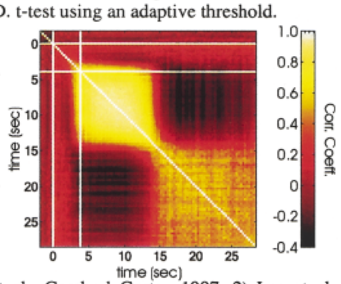


Fig.1: Spatio-temporal dynamics of the BOLD response. A. t-test using a constant threshold. B. Mean time-course sampled using a mask of significantly active voxels. C. Mean absolute time-course from the same voxels as in B, used for scaling the threshold to result in an adaptive threshold. D. t-test using an adaptive threshold.

Fig. 2: Similarity matrix of the spatial pattern of the BOLD response as a function of time. The entry (i,j) represents the correlation coefficient between the patterns of response at times i and j.



References: 1) Engel et al., Cerebral Cortex 1997. 2) Lee et al., MRM 1995. 3) Goodyear and Menon, Human Brain Mapping 2001.

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