Real-time single-trial BOLD response detection for visual attention at 7T

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Introduction:

With the long term goal of developing Brain-Computer-Interface (BCI) implants we need to assess different mental tasks and strategies for self-regulation of brain activity. fMRI has previously been used to measure the cortical response of visuospatial attention [1]. We here investigate the possibility of using visual attention-related brain activity as a control-signal for BCI. The ultimate goal is to allow paralysed patients to navigate around a computer screen by attending to one of the four edges of the screen which then moves that part of the screen to the middle (fixation point of the eyes). High-field fMRI was used to determine cortical regions that respond to visual attention, for subsequent implantation of intracranial surface electrodes from which neural activity is recorded for BCI. A visual attention localizer task was used for identifying visual attention regions. Activation in these regions was subsequently used as control signal for BCI by means of real-time decoding of BOLD signal change.

Method:

The data were collected from two healthy volunteers on a 7T Philips Achieva system with a 16-channel headcoil. The functional data were recorded using an EPI sequence (TR/TE=1600/25ms;FA=60°;35 oblique slices, acquisition matrix 112x112, slice thickness 2mm, no gap, 2 mm isotropic resolution). The visual stimuli were constructed as two square areas, one in the left peripheral visual field and one in the right, each containing a checkered pattern (Figure 1). To facilitate peripheral visual attention, we made the checkered patterns move upwards on the left side and downwards on the right. In the centre was a marker on which the subjects were instructed to fixate their gaze at all times. Both checkerboards were constantly on and in the centre, either a right arrow, a left arrow or a circle was shown, indicating which checkerboard to attend to (or keep attention in the centre, indicated by the circle). This instruction alternated every 8 scans (12.8 seconds per epoch). The localizer data were saved to disk in real-time as they were reconstructed to be available for analysis as soon as the scan (240 volumes) finished. The BCI scan was done in the same way as the attention localizer task with the difference that the subjects were given real-time feedback on brain activity in selected visual cortex ROI's, and volumes were analysed on the fly. The colour of the central arrow reflected the strength of the control signal (i.e. the decoded BOLD response), see Figure 1. The epochs were 10 volumes (16s) long and the whole scan consisted of 300 volumes.

Data processing:

Analysis of the localizer data was performed using in house built software (Matlab). The difference between attend right and attend left was used as contrast. The resulting functional map was used to define two ROIs, ROI_R and ROI_L, in V1-V3 representing the attention to the right and left visual field respectively. During the feedback experiment the data were processed in real time. Every volume was registered to the first volume of the visual attention to make sure the ROIs represented the correct regions. The first 15 dynamics were used to compute the mean BOLD amplitude inside the two ROIs, m_R and m_L. The control signal s_c was then for each new volume k computed as $s_{c,k} = 100*[(s_{R,k}-m_R)/m_R - (s_{L,k}-m_L)/m_L]$, where s_R and s_L are the average signal strengths within the ROIs. The control signal was classified as 'weak right' ($2<s_c<4$), 'strong right' ($s_c>4$), 'weak left' ($-4< s_c<-2$), 'strong left' ($s_c<-4$) or off ($-2< s_c<2$). Two tones of green of the central instruction marker (arrows) represented weak and strong signal in the correct direction while two tones of red represented a control signal in the wrong direction. A signal classified as "off" gave a gray colour. This was also the colour of the circle shown during the rest periods.

Results:

ROI's were found in visual cortex during visual attention, corresponding to expected visual perception regions (V1-V3) in contralateral hemispheres. The control signal for one subject is plotted in Figure 2 together with the expected response representing the experiment's design. The correlation between instruction (sequence of left/right/centre attention) and the control signal (differential MRI signal between left and right visual ROI) was 0.60 (0.39 for the other subject). Off-line analysis showed that the areas chosen during fMRI sessions as ROIs were not optimal, and that a correlation of 0.7 could be achieved for both subjects after re-computing the control signal based on these better ROIs.

Conclusions:

Both subjects were able to control their visual attention and at 7T the effect is strong enough to be used on a single-trial basis. Both subjects also reported after the experiments that the feedback helped in keeping their attention focused. These preliminary results indicate that brain activity evoked by spatial visual attention carries great promise for BCI. Further experiments will be done to improve the strength of the control and the on-the-spot selection of optimal ROIs.

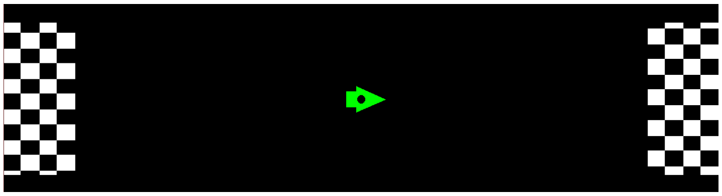

Figure 1. The visual stimuli given during the feedback experiment. The checkered patterns moved up and down respectively on the two sides. The arrow changed colour according to the subject's performance.

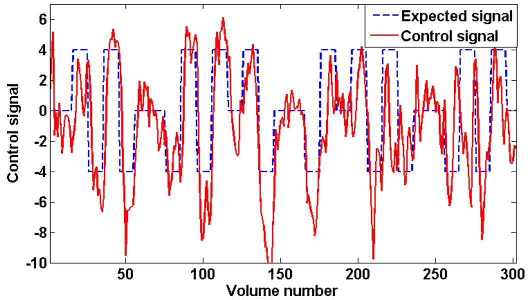

Figure 2. The red curve shows the control signal for one of the subjects. The dotted line represents the expected control signal with value 4 for 'right blocks', -4 for 'left blocks' and zero during rest. The expected signal has been shifted 3 TRs (4.8s) to compensate for the hemodynamic delay.

References:

[1] Brefczynski, J. A. et al. "A physiological correlate of the 'spotlight' of visual attention", Nat Neurosci 2: 370-374 (1999).