Visual attention for Brain-Computer Interface: towards using 7T fMRI to localize electrode implant sites

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Introduction: Recent developments in Brain-Computer Interface solutions for totally paralysed patients are moving towards implanting electrodes in specific parts of the brain in humans. A major caveat in this development is a lack of reliable indicators of where to position electrodes to get an optimal electrical signal for BCI. Moreover, localization of the best regions is more critical for minimally invasive surgery, where electrodes are placed in the cortex or on the surface of the cortex through a small hole in the skull. The accuracy of functional MRI in prelocalizing target regions is limited due to contribution of signal from draining veins. In the present study we investigated a new BCI solution where we use brain activity associated with visual attention for BCI control, and image brain activity with a 7T human MRI system. Visual attention is an attractive function to use for patients who cannot move their eyes due to neuromuscular disease or brainstem stroke. A 7T system was used to reduce contribution of draining veins (where signal is expected to be absent due to the very short T2*), with a high resolution to enhance spatial detail. Real-time feedback was tested in 7 healthy subjects to assess feasibility of using 7T fMRI for prelocalization of visual attention regions for implant of electrodes for BCI in paralysed patients.

Methods: Healthy subjects were scanned using a 7T Philips Achieva scanner equipped with a 16-channel headcoil. The functional data were recorded using an EPI sequence (TR/TE=1620/25ms; FA=90 ;35 coronal slices, acquisition matrix 96x96, slice thickness 2mm with no gap, 1.848 mm in-slice resolution). The FOV was selected so it covered the occipital lobe. The visual stimuli were constructed as two rectangular areas, one in the left peripheral visual field and one in the right, each containing a scrolling checkered pattern and both at a visual angle of 11 degrees (Fig 1). In the centre was a marker on which the subjects were instructed to fixate their gaze at all times. The centre marker was alternated between a right arrow, a left arrow and a circle indicating on which side to focus the attention and when to rest (attend centre). Each experiment consisted of 500 volumes where the first 200 volumes were statistically analyzed on the fly to locate the activated regions. During the remaining 300 volumes the subject got feedback based on the activity in these located regions (centre stimulus arrow turned green if attention-related brain activity matched the instruction, i.e. left, right or centre).

Data processing: Directly following reconstruction the data were sent to the computer doing the analysis (Dual-Core 2.5GHz notebook) via the local network. The stimulus was projected to the subject from a second computer. An update-trigger containing information about the direction and colour of the instruction marker was sent from the first computer via a serial cable. The first volume was used as the template for motion correction and all the subsequent volumes were rigidly aligned to it in real-time. To find the activated voxels in real-time without the need of interrupting the scan before starting the feedback we implemented the incremental GLM method described in [2]. Two regressors representing right and left sided attention as well as a linear confounder were included in the model. The contrasts "right minus left" and "left minus right" were used to identify voxels of interest for the feedback task. When the localization part was finished the final t-maps were used for making the ROIs representing right- versus left-sided attention. From each map's 500 highest t-values, clusters smaller that 5 voxels were removed. Both ROI's baseline were estimated by averaging the signal in the ROI in the data recorded during the rest condition. In the feedback part of the scan we gave the subjects real-time information on their performance based on the activity in the ROIs. A green instruction marker indicated a correct classification while red represented the opposite. During feedback, each new volume was registered in real-time and online detrending was applied to all voxels in the ROIs individually. The detrended values were averaged to give a single value per ROI. These numbers were in turn normalized (using the baseline estimation) and subtracted to give the value of the control signal.

Results: The control signal, derived from the contrast based on the ROIs obtained from the localizer task, was compared to the task (sequence of events where the centre stimulus indicated attend left, right or center in the feedback task). The BOLD control signal was shifted by three TR's to correct for the BOLD delay (4.8 s), and correlation with the task was computed (see fig 2). Average correlation was 0.71. Performance on the task (i.e. whether subjects managed to get arrows to turn green) was dependent on the threshold chosen for the control signal. Although feedback performance was mediocre during the actual experiment (32% hit rate, versus 4% false positive), selection of a less stringent threshold would have yielded dramatically better results (80% hit rate versus 20% false positives). In future, adjustment of the threshold can be done during feedback, resulting in these better results. Figure 3 illustrates for one subject the regions that were used for feedback and can be targeted with electrodes. In conclusion, 7T fMRI localization of visual attention regions yields excellent results in a feedback experiment in healthy controls. It carries great promise for presurgical localization of target foci for placement of electrodes for BCI in paralysed patients.

References:
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Figures:
Figure 1. Task used for localizing attention regions, and for feedback. Task involved three states: attend left, rght or centre
Figure 2. The blue curve shows the control signal during feedback for one subject. The dotted line represents the instructions (attend left, center and right)
Figure 3. Surface view of the interhemispheric surface in one subject. Red and Blue represent the ROI's for attention right and left respectively.