Identification of Cortical Target Regions for Intracranial BCI Based on Covert Spatial Attention in 7T fMRI

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Abstract. For a good result in intracranial brain-computer interfaces (BCI), it is necessary to identify the best electrode placements before surgery. We have shown that non-invasive fMRI is suitable for this. We have also shown that covert visuospatial attention (COVISA) can be used for real-time fMRI BCI. In this study we show that these previous results also demonstrate proof of concept of an intracranial (ECoG) based BCI controlled by COVISA by restricting fMRI voxel selection based on limitations of ECoG electrodes.

Keywords: fMRI, ECoG, visuospatial attention

1. Introduction

Aim of our research program is to identify brain regions that provide a reliable control signal for ECoG-based intracranial BCI. We have shown that fMRI can be used to identify ECoG targets [Hermes et al., 2012; Vansteense, 2010]. We recently reported that covert visuospatial attention (without any eye movements; COVISA) can be used for BCI control using real-time fMRI [Andersson et al., 2012], and postulated that this suggests feasibility of COVISA for intracranial BCI. However, all regions in the occipital cortex were used for decoding visual attention, meaning that the results were based on activity that is not accessible with surface electrodes. In the current study, we investigate whether COVISA BCI with fMRI is feasible with only voxels from regions accessible with electrodes. We used fMRI data obtained in a previous study [Andersson et al., 2012], and re-analysed only the data from voxels located at the lateral surface of the cortex (i.e. which is accessible for ECoG), of a single hemisphere (aiming at minimal surgery with a single cranial entry point).

By analysing the fMRI data with the restrictions based on the limitations of ECoG, we could make the results more relevant to the latter modality, thereby making the case for feasibility of intracranial COVISA BCI stronger.

2. Material and Methods

Nine healthy volunteers (age 23–28, right-handed, 5 male) with normal or corrected-to-normal vision and naive to the task participated in the study. The study was approved by the ethics committee of the University Medical Center Utrecht in accordance with the declaration of Helsinki (2008) and all subjects had given their written informed consent.

The subjects were scanned with a 7T Philips Achieva system with a 16-channel SENSE head coil. The functional data were recorded using an EPI sequence (TR/TE = 1620/25 ms, voxel size 2×1.8×1.8 mm). Only the occipital lobe and the most posterior part of the parietal lobe were scanned. Each experiment consisted of 652 volumes from which the first 292 volumes were used as training data and the remaining part served as testing data. A high-resolution image was acquired for the anatomy using a T1 3D TFE sequence.

Subjects were presented with an image containing a central cue surrounded by four target areas located at the top, right, down, and bottom side of the screen respectively. For training the classifier, the first 292 scans were used, during which the central cue alternately indicated which direction (an arrow) to direct attention to, with 9 trials per direction. Subjects kept their gaze fixed to the center at all times. For the rest of the scans (test set), trials continued but now correct decoding of scans was indicated by changing the cue color from an initial red to green (per trial). Real-time decoding resulted in 80% correct, indicating good performance and motivation of subjects.

All brain volumes were blurred and registered to the first one by minimisation of the sum of squared differences using a stochastic gradient descent method [Klein et al., 2007]. After registration, the data were detrended [Tarvainen et al., 2002] and each voxel's signal was normalised to have zero mean and unit standard deviation. A surface mask containing only voxels on the cortical surface (to a depth of approximately 6 mm) was created by subtraction of a solid brain mask and an eroded version thereof and removing the medial surfaces, so that the remaining voxels meet the criteria described in the introduction.

A support vector machine (C-SVM from PyMVPA) consisting of six binary classifiers was used where each separated two of the four classes (directions). Each scan was assigned to the class with the majority vote among these binary classifiers. In order to avoid overfitting, the number of voxels was reduced by selecting the 250 voxels with the highest weight in the trained model for each hemisphere. Clusters consisting of less than 5 voxels were excluded, since only large clusters are suitable for electrode coverage. The classifier was trained on the first 292 volumes (9 trials per direction). In the test data, each trial was classified using only the 5th volume, giving enough time for the haemodynamic response to reach a detectable level.

3. Results

Based on the voxel selection by the classifier, the average performance over 10 trial sessions is 85.0% when using voxels from the left cortical surface and 78.9% with voxels from the right cortical surface, which is respectively 10% and 17% lower than if the whole brain were used (see Table 1). Performance is lower for ipsilateral attention due to contralateral hemifield processing in the visual cortex.

Table 1. *Average performance (in percent correctly classified) over 10 trial sessions.*

Voxels selected from …	*Attention (% correctly classified)*				
	Right	*Left*	*Up*	*Down*	*Average*
Whole brain	94.4	94.4	97.8	94.4	95.3
Left cortical surface	86.7	70.0	93.3	90.0	85.0
Right cortical surface	71.1	84.4	78.9	81.1	78.9

4. Conclusion

By performing the same classification analysis with different criteria on voxel inclusion, we have been able to estimate the implications of the anatomical limitations that have to be considered when planning to implant electrodes. In spite of significant anatomical constraints we could decode the directed attention with a high accuracy. Active voxels (166 on average) were distributed over an average of 8 clusters (2 per attention direction) with a total volume of 1.1 cm^3, which is sufficient for covering with ECoG electrodes. Since the BOLD signal has been shown to map well to changes in the gamma band of ECoG, the current results demonstrate proof of concept of an ECoG based BCI controlled by visuospatial attention. Because of the lack of anatomical consistency in the topography of the visual cortex, spatially restricted fMRI can be used to find the optimum electrode placements.

References

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