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Mouth Motor Movement Based BCI

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Abstract. While several EEG and Electrocorticography (ECoG) based augmentative and alternative communication (AAC) devices have been developed, they have thus far been restricted making creative use of binary on-off brain signals using non speech related cognitive tasks. In this study we investigate whether we can decode elements of actual speech from sensorimotor cortex. To assess decodability we collected data from subjects performing phoneme pronunciation using both high-field fMRI in healthy volunteers, and high-density ECoG in epilepsy patients. Our results demonstrate that four classes of spoken phonemes produce unique activity patterns in sensorimotor cortex that can be used to discriminate complex mouth motor movements well above chance. These results provide strong evidence that a small high-density ECoG grid, anatomically specific to sensorimotor cortex can provide a robust platform for a BCI AAC device.
Keywords: ECoG, fMRI, Mouth Motor Movements, AAC

1. Introduction

Electrocorticography (ECoG) has been shown to be an important platform for Brain-Computer Interfaces (BCIs) for application in providing an improved communication channel for profoundly paralyzed individuals. While several EEG and ECoG based augmentative and alternative communication (AAC) devices have been developed [Allison et al., 2007] they have been restricted making creative use of binary on-off brain signals using non speech related cognitive tasks. In this study we explore the use of a high-density (3 mm spacing inter-electrode spacing) ECoG grid implant over the mouth motor cortex as the platform for multi-dimensional BCI control.

A BCI device based on complex mouth motor movements would provide an intuitive and robust platform for a communication AAC. Overt and covert motor movements have been shown to produce robust BCI control signals in the gamma range (65-95 Hz) in ECoG signal [Miller et al., 2007]. In addition resent results demonstrate that attempted movements in a paralyzed subject could be used for BCI [Wang et al., 2013]. However, much of the previous work has focused on hand movements. Given the primary role of mouth movements in human communication we believe that a mouth motor based BCI can provide a robust and cognitively intuitive AAC. We are inspired by work of Guenther and Kennedy [Guenther et al., 2009], who were able to show that a Neurotrophic Electrode placed in motor cortex can be used to produce two distinct BCI control channels from attempted pronunciation of two distinct phonemes.

The main goal of this work was to show that multiple complex mouth movements produced through phoneme pronunciation can be discriminated from sensory motor cortical activity. We collected data from subjects performing overt phoneme pronunciation using High-filed Functional Magnetic Resonance Imaging (7 T fMRI) in addition to high-density ECoG. fMRI has the advantage that there is consistency in complete coverage of sensory motor cortex, while high-density ECoG has the advantage of better signal fidelity and temporal resolution. By combining both modalities, the optimal location and size of the implant for the target AAC can be explored.

2. Material and Methods

2.1. High-field fMRI

Data Acquisition: Five healthy volunteers participated in the fMRI study. They performed two event related sessions consisting of 10 trial of each of four (/j/, /l/, /ɔ/, and /eː/) visually cued and overtly pronounced phonemes. Each stimulus was presented for 750 ms with a fixed inter stimulus interval of 13 seconds that assured that the effects of the previous trial was washed out. The fMRI measurements were implemented using a 7 Tesla Philips Achieva MRI system with a 32-channel head-coil. The functional data was recorded using an EPI sequence. The field of view covered the left pre- and postcentral gyrus. A high-resolution image was acquired for anatomical reference using a T1 weighted 3D TFE sequence.

Data processing: First, the data was slice time corrected, realigned, and detrended, Next feature voxels were selected that that showed little variability within the condition and large differences between conditions using an

ANOVA analysis. Finally, the fMRI response for each trial was formed by concatenating the summed FIR analysis response from the 4th 5th and 6th scan after stimulus for each feature voxel.

2.2. High-density ECoG

Data Acquisition: ECoG signal was collected from three intractable epilepsy patients who had research grids implanted on their cortical surface under the dura alongside clinical scale ECoG electrodes. We refer to these grids has high density ECoG grids due to their small size, relative dense 3 mm inter-electrode spacing, and small 1.3 mm exposed surface as compared to clinical ECoG implants. The placement of the grids was targeted at the estimated mouth motor area, but coverage varied across subjects. The subjects were visually cued to pronounce the phonemes /p/, /k/, /u/, and /aː/ or rest and fixate on an ‘*’ on the screen. A microphone recording of their voice was synchronously recorded with the ECoG signal to evaluated task performance. Subjects 1, 2, and 3 performed a total of 246, 85, and 190 correctly performed spoken phonemes or rest conditions over several runs respectively.

Data processing: First, the high-density ECoG signal was re-referenced to a clinical scale electrode that was located on top of the grid and the spectral response was computed using a Gabor Wavelet Dictionary in 1 Hz increments. Next the spectral power for frequencies 65 to 95 Hz was summed to obtain the gamma response for each grid electrode. Finally the ECoG response for each trial was formed by concatenating the gamma response for each electrode from the time period of 0.5 s before and 1 s after voice onset time (determined from the microphone signal).

2.3. Classification

For classification of the phonemes, a nearest-neighbor (template matching) classification procedure was applied for fMRI and ECoG. Individual trials were classified using a leave-one-out procedure. First a template was computed for each class by computing the mean response from all but one trial. Next, the Pearson correlation between the ‘left out’ trial and the templates was used to classify the trial as the phoneme it had the highest correlation with in a winner-takes-all manner. This was done for each trial in the set of all trials.

3. Results

Using high-field fMRI, we achieved classification scores ranging from 50 to 60% (25% chance) accuracy. The fMRI template maps showed activity across sensorimotor cortex that was consistently focused on mouth motor cortex. Confusion matrices demonstrated that there was no consistent trend towards one phoneme being better represented on the motor cortex than another.

Using high-density ECoG classification rates of 81, 72, and 61% (20% chance) where achieved. While the classification scores were generally better for the ECoG subjects, there was more variability in performance across subjects despite the fact that the detection of speech (ie: the rest condition vs. any spoken phoneme) was above 90% for all subjects. Also unlike the fMRI results, there was a pattern of phoneme preference visible in the confusion matrices. Both subjects 1 and 2 more often confused the voiced (/u/ and /aː/) with each other than with the unvoiced (/p/ and /k/) phonemes. Subject 2, however, showed the strongest ECoG responses for the /p/ and /u/ phonemes and more often confused /k/ and /aː/ with the rest condition.

4. Discussion

In this work we demonstrated that high-filed fMRI can accurately identify good target locations for high-density ECoG implants that were able to discriminate 4 phoneme classes from rest with 81% proficiency when accurately located over the mouth motor area. These results point towards high-density ECoG grids that can be implanted without a full craniotomy when target locations are accurately predicted, as a promising platform for a fully implantable cognitively intuitive AAC.

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