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Modeling the Electroencephalogram Using Intracranial Signals

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Abstract. This study presents models of electroencephalographic (EEG) event-related potentials (ERPs) using intracranially recorded ERPs from electrocorticography (ECoG) and stereotactic depth electrodes in the hippocampus. The patients had medically-intractable epilepsy and underwent temporary placement of an intracranial electrode arrays to localize seizure foci. Six patients performed one experimental session using the P300 Speller paradigm controlled by scalp-recorded EEG prior to the ECoG grid implantation, and one identical session controlled by ECoG after the grid implantation. All patients were able to achieve excellent spelling accuracy using EEG, and four of the patients achieved roughly equivalent performance in the intracranial sessions. Each EEG-ERP was modeled from the intracranial ERPs. The results indicate that EEG-ERPs can be accurately estimated from the intracranial ERPs for the patients that exhibited stable ERPs over the respective sessions. The resulting models provide a better understanding of the EEG-ERPs and can potentially be used to improve noninvasive BCI methods.

Keywords: Electroencephalogram (EEG), Electrocorticogram (ECoG), Event Related Potential (ERP), P300 Speller

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1. Introduction

Event-related potentials (ERPs) have been proven to be reliable signals for controlling EEG and intracranial BCIs [Krusienski et al., 2008; Krusienski and Shih, 2011]. Because the tissue in the human head acts as a volume conductor for the brain's electrical activity, it is conceivable that scalp EEG can be mathematically modeled as a mixture of underlying intracranial signals [Krusienski and Shih, 2010]. It is believed that accurate models will better localize and enhance the desired brain activity of scalp EEG recordings, thus leading to more effective noninvasive BCI processing techniques. Since there are several major issues with simultaneous recording of scalp EEG and intracranial signals in temporarily implanted humans, such as the corruptive effects of the incision and implantation trauma on simultaneously monitored scalp EEG, the proposed approach relates scalp-EEG data recorded pre-intracranial electrode implantation to intracranial data recorded after implantation. Because both EEG and intracranial ERPs are represented using time-domain ensemble averages, their spatial and temporal characteristics are presumed to be well-defined and consistent. Thus, the resulting characteristic responses defined by ensemble averaging were used to create the models relating the scalp EEG and intracranial responses.

2. Material and Methods

2.1. Subjects and Data Acquisition

Six subjects with medically intractable epilepsy were implanted with intracranial grid or strip electrode arrays to localize seizure foci prior to surgical resection and were tested for the ability to control the P300 Speller paradigm using EEG and ECoG signals. Electrode placements and duration of ECoG monitoring were based solely on the requirement of the clinical evaluation without any consideration of this study. Table 1 shows the ECoG electrode locations and P300 Speller accuracy based on a linear classifier for each subject.

Table 1: *Subject Information.*

Subject	# Electrodes	Location	EEG Accuracy (%)	Intracranial Accuracy (%)
A	24	Left Frontal, Lateral Temporal	100	25
B	30	Left Frontal-Parietal	93	100
C	16	Bilateral Hippocampal Depth	100	100
D	30	Left Lateral Temporal, Inferior Frontal	100	44
E	24	Left Lateral Temporal	88	81
F	64	Left Frontal, Parietal, Lateral Temporal	100	88

Prior to electrode implantation, all the subjects performed a BCI session using 32-channel scalp-recorded EEG. The EEG was amplified, bandpass filtered 0.5–500 Hz and digitized at 1200 Hz (to match the typical intracranial rate) using g.USB amplifiers. Stimulus presentation and data recording was controlled by BCI2000. The intracranial sessions were performed between 24 to 48 hours after electrode implantation. All electrodes were referenced to a scalp vertex electrode and recorded using the identical hardware, software and protocols as the EEG data collection. The experimental protocol was based on the protocol used in EEG-based P300 Speller study [Krusienski et al., 2008].

2.2. Data Analysis

Both EEG and ECoG data were lowpass filtered to 20 Hz and decimated to 240 Hz, to smooth the data while retaining sufficient samples for modeling and ERP visualization. Only target stimulus ERPs were used for the construction of the model. For each EEG and ECoG channel, 800 ms of the data following each flash were extracted as the ERP. The average target ERP was computed for each channel. These ERPs were multiplied by a tapered cosine window to deemphasize the beginning and end of the ERPs in the regression models. The first half of the intracranial ERPs and EEG-ERPs were used to train a stepwise linear regression model. The remaining half of the intracranial ERPs were used to generate the predicted ERPs based on the trained model. The actual and predicted waveforms were compared by computing the mean absolute error (MAE), after excluding the highest 5 % of the absolute error values that are believed to be the result of artifacts in the test data. Prior to computing the MAE, the actual ERPs were scaled to unit variance and the corresponding predicted ERPs were scaled by the same factor to remove any amplitude dependencies when comparing MAE across channels.

3. Results

Low MAE models were observed over particular EEG channels for three of the six subjects (Subjects B, C, and F), and these channels were not always necessarily located over the intracranial electrodes. Fig. 1 shows the results for Subject C: (A) shows the relative axial locations of the EEG and hippocampal depth electrodes, with the color corresponding to the task classification accuracy obtained by using that electrode in isolation, (B) shows the MAE with two examples of actual and predicted ERPs.

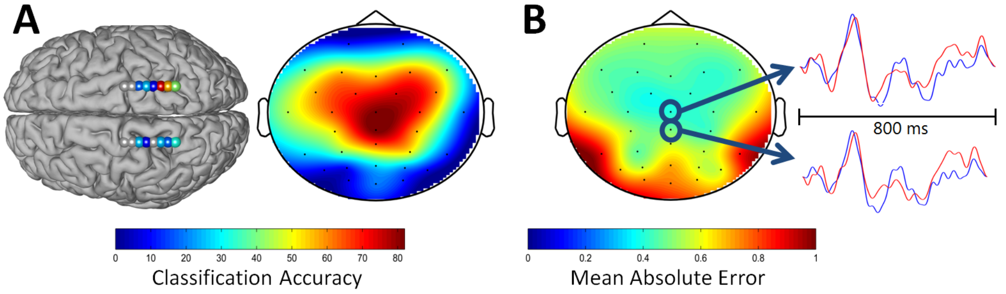

Figure 1: *The results for Subject C. (A) The relative axial locations of the EEG and hippocampal depth electrodes, with the color corresponding to the task classification accuracy obtained by using that electrode in isolation, (B) The mean absolute error topography of the prediction included with two examples of actual (blue) and predicted (red) ERPs.*

4. Discussion

The results indicate that the intracranial models can accurately predict the scalp ERPs when the intracranial electrodes are positioned to capture reliable ERPs. These favorable locations were found to be predominantly over the traditional parietal areas for the P300 as positioned in Subjects B, C, and F. More importantly, as illustrated in Fig. 1, accurate ERP predictions can be determined for the most task-relevant EEG electrodes. Further analysis of the signals and resulting models will provide new insights to the underlying sources of scalp ERPs and can potentially be used to improve noninvasive BCI methods.

References

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