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Hemicraniectomy-based EEG as a platform for low-risk investigations of BCIs in subjects with brain injuries

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Introduction: Brain-computer interface (BCI) devices sample brain signals to discern intent, often the intent to move the limbs. Much BCI research is performed in motor-intact subjects, limiting the conclusions we can draw about BCI efficacy in a motor-impaired population. An alternative use for BCI is to rehabilitate function, rather than replace it, following a stroke or other brain injury[1]. This would greatly expand the potential end-user population. Here, we explore the feasibility of decoding motor intent from human patients recovering from traumatic brain injury who have undergone a decompressive hemicraniectomy as part of the treatment of their condition. Working with this subject pool provides the opportunity to noninvasively record brain signals in the absence of attenuation by the skull. Previous studies have shown that EEG signals recorded over a skull defect left by a hemicraniectomy (hEEG) have higher spectral bandwidth than signals recorded over intact skull, and are more informative about movement than homologous skull sites[2]. Here, we used hEEG signals to decode continuous, isometric force produced by the thumb and index finger, as subjects performed a random-target pursuit, force-based behavioral task.

Materials, Methods and Results:

All experimental procedures were approved by Institutional Review Board at Northwestern University. All subjects gave written informed consent prior to study participation. The subjects used their hand contralateral to the hemicraniectomy to perform the random-target pursuit task. We recorded hEEG from frontal, central, and parietal regions (10-20 electrode locations). We decomposed the neural data into the local motor potential (LMP)[3], and five spectral features (0-4 Hz, 7-20 Hz, 70-115 Hz, 130-200 Hz, 200-300 Hz). We trained decoders on the hEEG features using a Wiener cascade filter, and implemented a real-time BCI using techniques developed in our lab for BCI control with continuous neural data[4]. We postulated that the absence of skull between the recording sites and underlying cortex would enable us to capture more of the spectral content of the signals. We then hypothesized that the increased ability to extract high frequency content, such as high-gamma band activity, would lead to more accurate decoding of force than with standard EEG, perhaps close to that achieved with epidural or subdural signals[5]. Further, the subjects should be able to exert continuous BCI control over a computer cursor, using these high frequency signals.

We performed this experiment with five human subjects. We used Fraction of Variance Accounted For (FVAF) as a measure of performance in the offline decoding of force. Substantial information was present in the high gamma band for all subjects. The mean cross-validated FVAF values for the subjects were as high as 0.5, with smaller segments of the data accounting for as much as 72% of the variance in force. The overall mean (±SE) across subjects was 0.32 ± 0.05. Two of the subjects achieved real-time BCI control, successfully acquiring 50% and 75% of targets, respectively.

Discussion: This proof-of-concept study demonstrates that 1) hEEG signals can provide nearly as much information about force as those directly on the dura, and 2) this information can enable patients with brain injuries to control a BCI. This paradigm provides an important way to study high-gamma based BCIs in brain-injured patients without incurring additional risk. We have begun to use this paradigm to study BCI-based rehabilitation in brain-injured patients.

Significance: Hemicraniectomy-based BCIs offer a noninvasive way to study high-frequency brain signals in end-user populations.

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