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Detecting and utilizing the idle state in an intracortical brain-computer interface

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Introduction: Much attention in the field of brain-computer interfaces (BCIs) has been devoted to decoding the intended motor output of a neural prosthetic. However, detecting when the user actually desires to utilize the device remains an important yet relatively understudied problem. Our lab has previously demonstrated the differences in intracortical activity that differentiate periods of active physical reaching or holding an arm posture vs. resting one's arm [1]. Similarly, other studies have examined differences in cortical modulation patterns between active task and rest periods in the context of a BCI paradigm [2]. However, these differences have yet to be exploited for the purposes of enabling or disabling a prosthetic device. In this study, we first examine post-hoc analyses of differences between active and resting periods in a BCI task. Utilizing these results, we demonstrate the online implementation of a BCI idle state detection scheme for gating movements of a cortically controlled prosthetic arm. Finally, we examine the differences in idle/active states that arise when monitoring a physical reaching task or a similarly structured BCI task.

Material, Methods and Results: Two rhesus macaques (Macaca mulatta) were implanted with one or two 96-channel intracortical microelectrode arrays. Threshold crossing or sorted unit firing rates from these arrays were used to control the end-point velocity of a robotic arm (WAM Arm, Barrett Technology) to perform 1D, 2D, and 3D reaching tasks. Blocks of “rest” trials, in which the WAM arm and target presentation robot were locked in their home position for ~30-60 seconds, were interspersed between active BCI task blocks.

To investigate the neural changes between active and idle states during BCI operation, we first calculated a discriminability index, d’, on individual channels. These analyses showed significant active/idle distribution differences using firing rates as well as LFP power in several discrete frequency bands (8-15 Hz, 15-24 Hz, 30-50 Hz, 70-150 Hz). We extended these offline analyses to a population level by training an idle state classifier using several approaches. For one model, we trained the classifier using labeled periods of arm resting and reaching during a physical reaching task performed just prior to a BCI session. A second approach utilized the rest blocks described above and the reach portion of BCI trials to label rest and active training samples. When applied to test neural data from each task (hand control – HC, brain control – BC), the BC derived model accurately classified idle and active periods with a high degree of accuracy in both HC and BC test sets. When the HC derived model was applied, it did classify BC task and idle states at a rate much better than chance performance, although the overlap of these distributions was much greater than was observed for the BC model.

Finally, we implemented this classification scheme in real-time during a BCI task. When an idle state was detected, brain control of the WAM arm was suspended, and the robot was moved toward its home position. When put into practice, we observed that the idle detector accurately permitted prosthetic movement during BCI task periods and correctly gated movements during rest blocks. In addition, movement was also intermittently gated when a monkey was externally distracted or when his motivation declined toward the end of a session.

Discussion: These results demonstrate the potential utility of several intracortical signal modalities in detecting the intent of a subject to use a BCI device. Not only may classifiers built with these signals be used in real-time to gate the movement of a prosthetic device as demonstrated in this study, they may also be used to identify periods of inattention or low motivation that may be used to exclude data from movement decoder calibration or other analyses. Finally, the differences observed between using HC or BC derived models suggest that these processes likely operate in similar but non-identical neural state spaces.

Significance: We demonstrate a novel implementation of idle state detection to gate the movement of a BCI prosthetic device in real-time. This feature would grant BCI users an additional layer of safety and autonomy over when to enable a prosthetic device as well as the potential to serve as a state classifier for multi-tasking between BCI and other activities sharing similar neural resources.

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References

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