Task Outcome Error Signals in Human Primary Motor Cortex and Their Use in Brain-Computer Interfaces

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***Abstract*— Brain-computer interfaces (BCIs) aim to help people with impaired movement ability by translating their movement intentions into control signals for assistive technologies. Despite substantial performance improvements in recent years, BCIs still make errors that need to be corrected by the user. Here we show that such errors in a trial's outcome (i.e., selecting an undesired key on a virtual keyboard) can be decoded from the human primary motor cortex (M1) and can potentially be used to improve BCI performance by automatically detecting and undoing erroneous actions.**

I. Introduction

Intracortical BCIs recording from motor cortex have shown promising results in pilot clinical trials. This makes them prime candidates for serving as an assistive technology for people with paralysis [1]. While much work continues to be done to reduce BCI errors by improving the accuracy and reliability of movement intention decoders, here we explore a complementary and less explored approach: attempting to automatically identify, using neural activity, when an error occurs so that the BCI system can automatically correct the error. This 'automatic error detect-and-undo' strategy takes advantage of the closed-loop nature of a BCI; the user has constant visual feedback, and is aware of when the BCI performs an unintended action (i.e., an error). Somewhere in the brain, the user's neural activity will reflect this detection and recognition of an error. We recently reported that such outcome error related signals are present in rhesus monkey motor cortex [2]. Since the ultimate application of BCI error detection is for people with paralysis, it is crucial to test whether these signals also exist in human motor cortex.

II. Results

We analyzed the intracortical M1 neural activity of a BrainGate2 clinical trial participant (T5) neurally controlling a computer cursor to perform a target selection (grid) task and a virtual keyboard typing task. T5 was a 63 years old at the time of these experiments, and was diagnosed with a C2-3 ASIA C spinal cord injury prior to study enrollment.

Using principal components analysis (PCA) and linear discriminant analysis (LDA) we built a single-trial outcome classifier, which decodes whether a trial was a success or a failure. We could decode task outcome with high accuracy from a hybrid decoder of spikes and local field potential features (LFP). The classification accuracy for successful trials (true positive) was 99.7 ± 0.2% (mean ± s.e.), while for failures (true negative) it was 85 ± 1.4%.

We also investigated the decoder generalizability across tasks, which can aid in improving robustness across different BCI contexts. We trained a classifier using grid task trials and tested how well it could classify virtual-typing-task trials outcomes. The classification accuracy for successful trials was 91 ± 1.6%, and for failures it was 75 ± 2.4%.

These classification rates, which we believe to be quite encouraging and high, suggest that it should be possible to improve the performance of clinical intracortical BCIs by incorporating a real-time automatic detect-and-undo system alongside decoding of movement intentions. The system would detect errors with high accuracy while seldom misclassifying a successful selection as erroneous. Such a strategy could be used, e.g., for auto-deletion of mis-entered characters in a typing (communications) application, returning to the previous menu during tablet use, or returning to a previous position when neurally controlling a robotic arm.

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References

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