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A brain-computer interface simulator for closed-loop cursor control

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***Abstract*— Brain-computer interfaces (BCIs) aim to improve the lives of patients suffering from paralysis. Here we present a closed-loop BCI simulator that generates synthetic motor imagery (MI) electroencephalography (EEG) activity in real-time according to computer mouse movement, allowing human subjects to engage in a 2D continuous cursor pursuit MI BCI task without requiring EEG acquisition. In 5 participants, we observed no effect of maximum target and cursor velocity on performance during control, removing design constraints in continuous pursuit BCI tasks.**

***Clinical Relevance*— The proposed method allows for rapid prototyping of MI EEG BCI decoders, decreasing the costs needed to develop clinically translatable BCI methods.**

I. INTRODUCTION

Brain-computer interfaces (BCIs) can restore function in motor-impaired patients by decoding their brain activity and converting it into commands for device control e.g., robotic arm [1]. Due to various costs associated with human trials, many BCI decoders, tasks and their parameters are tested offline, ignoring the crucial role of user feedback which is always present in real-world BCI cases. To allow inexpensive closed-loop experiments, BCI simulators have previously been developed for neural spiking activity [2-3].

Our system, instead simulates motor imagery (MI) electroencephalography (EEG) data, allowing EEG BCI decoders to be tested pseudo-online. Mouse movements are continuously converted to MI EEG by a well-defined encoding model, eliminating the behavioral dynamics present in EEG recordings and allowing for the assessment of an algorithm's performance ceiling.

II. METHODS

Motor imagery signals in the form of alpha-power modulations were encoded through the use of instantaneous mouse velocity. Said velocity was passed through sigmoid functions embodying task specific desynchronization, with the corresponding alpha power (8-12 Hz) being assigned to a subset of fixed orientation dipoles located at the hand-knobs. These signals, along with source-level background activity modelled as uniform colored noise from random locations, were linearly projected via a leadfield to generate EEG activity. Here, online cursor control was produced through the linear classification of autoregressively estimated (AR) alpha power of the small Laplacian filtered C3 and C4 electrodes.

The proposed system was evaluated in 5 human subjects performing a 2D continuous pursuit (CP) task. We hypothesized that mismatches between maximal cursor and target velocities (CV and TV) would affect tracking performance. To test this, in a series of 27, 60 second trials, TV and CV were randomly drawn from 3 values. While both the cursor and target utilized a momentum-based kinematic model [4], TV was limited by varying the drag coefficient and CV was limited using online thresholding. All subjects provided written consent to a protocol approved by the Institutional Review Board at Carnegie Mellon University.

III. RESULTS

The ratio of maximal target to cursor velocity (TV/CV) showed no significant effect on behavioral performance during CP (Fig. 1).

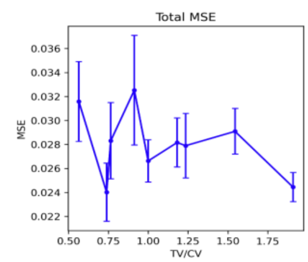

Figure 1. Five-subject average total mean-squared error (MSE) between cursor and target position. Error bars represent standard error of the mean.

IV. DISCUSION & CONCLUSION

In developing the simulator, we found that the AR decoder entered long periods of bias against the dominant behavioral direction, if non-uniform movement was present early on in a trial. This was alleviated by adding a discrete uniform center-out task to calibrate a statistical buffer for output temporal normalization, which we suggest be added for future attempts at CP BCI. Our results do not indicate an effect of TV/CV ratio on performance, suggesting that interface movement velocity can be tuned to increase task efficiency. In sum, the present EEG BCI simulator offers a unique platform for the evaluation of motor imagery BCI paradigms, and demonstrates the necessity of calibration steps when using decoding techniques that assume control distributions.

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