1-B-8 Augmenting intracortical brain-computer interfaces in monkeys and humans with neurally driven error detectors

Nir Even-Chen[1], Sergey Stavisky[1], Jonathan Kao[2], Chethan Pandarinath[3], Paul Nuyujukian[1], Stephen Ryu[1], Leigh Hochberg[4], Jaimie Henderson[1], Krishna Shenoy[1]

[1]Stanford University, [2]UCLA, [3]Emory University, [4]Brown University

Introduction: Intracortical brain-computer interfaces (iBCI) recording from motor cortex have shown promising results in pilot clinical trials. While much work continues to be done to reduce iBCI 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 undo 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. Here, we asked two primary questions: (1) does an outcome error signal exist in the motor cortex used for iBCI?, and (2) can decoding this signal benefit BCI performance?. To answer those questions we first investigated them in preclinical monkey experiments and then extended our results to the case of human participants in the BrainGate2 clinical trial. Material, Methods and Results: In both monkey and human experiments, the user controlled a 2D cursor through an iBCI system and performed a random grid task, in which they needed to select a cued target among a grid (e.g., 6 x 6) of selectable targets. During the task, the neural activity was recorded using 96-channel intracortical silicon microelectrode arrays (Blackrock Microsystems) implanted in the hand area of the motor cortex, and was decoded into a velocity control signal using previously described methods [Gilja et al 2012, Pandarinath et al 2017]. First, we investigated our questions with two monkeys. Surprisingly, we found task outcome neural correlates, and we were able to decode trial outcomes shortly after and even before a trial ended with 96% and 84% accuracy, respectively. This led us to develop and implement in real-time a first-of-its-kind intracortical iBCI error 'detect-and-act' system that attempts to automatically 'undo' or 'prevent' mistakes. The detect-and-act system works independently and in parallel to a kinematic iBCI decoder. In a challenging task that resulted in substantial errors, this approach improved the iBCI performance by up to 18%. After the encouraging results with monkeys, we investigated whether this task outcome-related neural signal was present in two human participants (T5 and T6). 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. T6 was a 51 years old at the time of these experiments and was diagnosed with ALS and had a resultant motor impairment (functional rating scale (ALSFRS-R) measurement of 16). We found that human motor cortex was also modulated by task outcome, and in offline analysis of previously collected data, we were able to decode errors with high accuracy (70-85%) with minimal (0-3%) misclassifications of successful trials. We also found that decoders trained on a random grid task could be generalized to a virtual typing task in which the targets are not cued for the participants. This suggests that these task outcome neural correlates were at least to some degree task-independent. Discussion: After showing the benefit of an automatic error detect-and-undo strategy in real-time in monkeys and subsequently showing similar error-related neural modulation in humans, our next step will be to augment a human clinical trial iBCI with real-time detect-and-undo capability . A detect-and-undo system could be used for various BCI applications. During typing this could be used for immediate character auto-deletion or for error tracking to improve upon word prediction algorithms. Detect-and-undo systems can also be utilized for returning to the previous menu during application use, and returning to a previous position when using a robotic arm. Though encouraging, whether or not similar task outcome error signals exist in more complex tasks such as prosthetic limb control remains an open question for future research. Significance: Detecting and undoing errors in real-time should make hard tasks feel easier, increase iBCI performance, and improve the user experience.

1-B-9 Retrospective analysis of the effects of nonstationarities on decoding performance in people using an intracortical brain computer interface

David Brandman[1], Thomas Hosman[1], Jad Saab[1], Jessica Kelemen[2], Brian Franco[2], Leigh Hochberg[1], John Simeral[3]

[1]Brown University, [2]Massachusetts General Hospital, [3]Rehabilitation R&D Service

Background: Intracortical brain computer interfaces (iBCIs) use information recorded from the cortex to provide people with paralysis the ability to control devices in their environment, such as computer cursors for communication. An ongoing area of research in iBCI systems is to ensure long-term robust and reliable control for the user. Degradation in neural control is often attributed to short-term nonstationarities in the recorded signals (Perge et al., 2013). The most common approach to addressing these nonstationarities involves recalibrating the decoder coefficients by incorporating recent neural data (Orsborn et al., 2014, Jarosiewicz et al., 2015). While recalibration has been shown to provide users with long-term control, the underlying nonstationarities have not been fully characterized. Gains in decoding performance could be made by understanding the frequency of nonstationarities and quantifying their effects on modern decoding algorithms. Material, Methods and Results: Participants T9 (52 year-old man right-handed man with ALS, ALSRFS-R=7) and T10 (35 year-old man with C4-AIS Grade A spinal cord injury) were enrolled in the ongoing BrainGate2 clinical trial. We retrospectively analyzed all closed-loop cursor control research sessions spanning 731 and 365 days, respectively. Channel spike counts and broad-band signal power were used as neural features (Brandman et al., 2017), recorded in non-overlapping 20ms bins. For each research session, a Kalman decoder was trained using a random subsample of data (without replacement), and then used to predict the decoded velocity vector of each time-step in the testing dataset. We quantified decoder performance for each session by computing the angular error between the kinematic cursor's decoded velocity and the assumed intended vector to target (Willet et al., 2017). We retrospectively analyzed 137 and 96 sessions for T9 and T10, respectively, where the participant performed closed-loop neural control of a computer cursor. Across all research sessions, we did not observe a linear trend in overall decoder performance for either participant (T9 R2 = 0.001, T10 R2 = 0.071). For individual research sessions, we found a linear relationship between decoding performance and z-score offsets in the observed neural features. To mitigate the effect of nonstationarities, we swept a variety of z-score threshold values and found that saturation above 2-zscores did not impact decoding performance (saturation below this level degraded decoding performance). We found that features with z-scores greater than 2 accounted for 5% of all observed