TRAINING CORTICAL CELLS TO PRODUCE BETTER DIRECTIONAL CONTROL SIGNALS WITH AND WITHOUT PHYSICAL LIMB MOVEMENTS

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We have recorded cortical units on implanted microwire electrode arrays in the motor and premotor cortical areas in macaques. Some channels have recorded units stably for over two years. The animals used these signals in real-time to move a virtual reality cursor to targets in 3D space. Two monkeys controlled the 3D cursor movements with their cortical activity while their arms were free to move, and two monkeys did this with both arms restrained.

In the arms-free experiments, a modified population vector was used to translate cortical activity into cursor movement in real-time. The animals used visual feedback of the cursor position to make on-line error corrections to their center-out trajectories. This allowed them to improve their target hit rate over that of trajectories created off-line from cortical signals recorded during similar hand-controlled center out movements. The animals showed significant improvement within each day and across days in both a slow and a ballistic 3D movement task

In the experiment where both arms were restrained, a co-adaptive algorithm was used to translate cortical activity into cursor movements. This algorithm does not rely on any *a priori* knowledge of the brain’s movement-related modulation patterns, and, therefore, could be implemented in immobile human patients. In the co-adaptation process, the movement prediction algorithm adapts to the brain activity while the subject attempts to make a sequence of brain-controlled calibration movements. The subject then uses visual feedback of these attempted brain-controlled movements to further modify its cortical activity and improve 3D cursor control.

In the arms-restrained animals, this co-adaptive process resulted in movement-related modulation patterns which were radically different from those seen during normal arm movements. Cortical tuning functions changed their preferred directions, became more cosine tuned, increased their modulation range, and decreased their movement-to-movement variability. This resulted in more accurate movements and a more uniform level of control throughout the workspace compared to the non-adaptive arms-free experiments. Off-line analysis using maximum likelihood estimation also showed these new cortical encoding patterns predicted the intended target better than the cortical activity recorded during regular center-out arm movements.

With regular practice, these beneficial changes significantly increased across days. Additionally, the subject’s muscle activity during brain-control declined with regular practice. This daily increase in beneficial tuning function changes and the reduction in muscle activity were matched by a significant improvement in brain-controlled movement accuracy and reliability across days.

The co-adaptive algorithm used in the arms-restrained experiment allowed the subjects to encode movement with new preferred directions that were unrelated to those used during physical arm movements. However, in these novel movement encoding schemes, units that were located close to each other in the cortex usually maintained correlation patterns between units which were similar to those seen during hand-controlled movements. This suggests a local modular organization which may have implications for the design and spacing of electrodes for neural prosthetic use. Wider spacing between electrodes may yield more signals which can be *independently* controlled by the subject.

The animals were also tested for their ability to transfer the center-out brain-control skills to more practical applications. The movement prediction algorithm was held constant in a non-adaptive state, and subjects were able to make long continuous sequences of movements to novel as well as trained target positions. Additionally, one subject was trained to reliably move a brain-controlled robot to different 3D target positions to get rewards.

MULTIMODAL NEUROELECTRIC HUMAN-COMPUTER INTERFACE DEVELOPMENT

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This project aims to improve performance of NASA missions by developing multimodal neuroelectric technologies for augmented human-system interaction. Neuroelectric technologies will add new modes of interaction that operate in parallel with keyboards, speech, or other manual controls, thereby increasing the bandwidth of human-system interaction. The research builds on recent feasibility demonstrations of electromyographic (EMG) and electroencephalographic (EEG) methods, which bypass muscle activity and draw control signals directly from the human nervous system. The broad objectives of the project are to: a) develop new modes of interaction that operate in parallel with existing modes such as keyboards or voice, b) augment human-system interaction in wearable, virtual, and immersive systems by increasing bandwidth and quickening the interface, c) enhance situational awareness by providing immediate and intimate connections between the human nervous system and the systems to be controlled or monitored. Our specific goals are also threefold: a) a signal acquisition and processing system for reliable EMG-based neurocontrol methods for data visualization and manipulation tasks, b) EMG-based automatic recognition and tracking of continuous human gestures, c) evaluation and feasibility testing of EEG-based neurocontrol methods suitable for use in parallel with other modes of communication and control using μ-rhythm signals recorded from motor cortex and other, nonlinear measures of EEG dynamics.

We have made progress in four areas. First we have developed real-time pattern recognition algorithms for decoding sequences of forearm muscle activity associated with control gestures. A real-time system successfully used these algorithms to control a flight simulator and a virtual numeric keyboard. Second, we have developed and compared signal processing strategies for open- and closed loop tasks involving EEG-based tracking of real and imaginary motion. The tasks involved either real or imaginary arm motion without feedback (open loop) or controlling a visual display of a needle gauge or a surface vehicle (Mars rover). EEG was recorded from three subjects with arrays of 4 to 128 channels, and spatially decomposed into orthogonal components. Time series analysis or frequency analysis of the component signals were tested and compared for efficacy of tracking motion and EEG desynchronization effects. We replicated known effects of mu-rhythm based control and compared this to several other methods, including spectral entropy, wavelet entropy, and a nonlinear dynamic analysis known as coarse entropy rate. In some cases, we found that nonlinear analysis was more sensitive to motion as compared with mu-rhythm power and other methods. Third, we have also developed a flexible computation framework for neuroelectric interface research, using the Linux operating system. The frameworks allow for modular construction of real-time systems for data processing and control, and for rapid prototyping of new algorithms. Fourth, we have partnered with a private company to develop non-contact E-field sensors, which measure EMG or EEG signals without resistive contact to the body. Preliminary data show that these sensors can faithfully record signals that track the surface EMG or EEG changes measured by traditional resistive electrodes.