**Review\_ Human Intracortical Recording and Neural Decoding**

**for Brain–Computer Interfaces**

While there are many types of BCIs, all have three components: a sensor to record neural

activity or its proxy, a decoder that converts neural activity into a command signal, and an effector such as a computer cursor or robotic arm.

The BCI sensor choice determines the temporal and spatial resolution of the neural signal.

Cortical regions are demarcated at a centimeter scale and are identified by their location and function.

First,

neurons in a small area of primary motor cortex yield a richvariety of signals related to voluntary limb movement. Second, in humans, the hand area of motor cortex is an accessible surgical target. Third, neural modulation is present in motor cortex despite longstanding downstream injury of pyramidal neurons.

The interface between brain parenchyma and electrode recording device is complex, and the specific material considerations may dramatically impact recording characteristics . For instance, factors such as material pliability, shank / electrode alloy selection, electrode coating techniques, array insertion techniques, and other factors may impact recording quality

The process of actually converting the neural information (often high-dimensional)into the output signal (usually low-dimensional) is referred to as neural decoding.

To understand BCI decoding, it is important to distinguish between open - and closed- loop decoding.

Due to the characteristic appearance of band-pass filtered signals, action potentials are also known as spikes.

PVA(population vector algorithm)is a special case of solving a linear regression problem: if the preferred directions are uniformly distributed, then the surface mapping the binned firing rates to the kinematic variables can be solved by solving for the least-squares estimator.

An alternate way of approaching neural decoding is to model precise spike times as important.

Future decoding approaches will undoubtedly take advantage of ongoing developments in the machine learning literature.

Adapting the User to the Decoder vs. the Decoder to the User

The state-of-the-art approach to calibration of motorimagery BCI devices in humans is a three-step process. Users are first asked to attempt, or to imagine, performing an action – without feedback – in an open-loop step. Next, a trained technician uses the recorded data to compute decoder parameters. Finally, the user is provided closed-loop control. Decoders built solely from open-loop data yield suboptimal control in closed-loop decoding, due to context shifts of the neural tuning properties.

BCI technology is a viable approach to providing tools for communication for individuals with amyotrophic lateral sclerosis.

While the aforementioned demonstrations of robotic and native limb control are at a relatively primitive stage, they are proof of principle that neural information can be used for multi-dimensional limb control.

The original deep brain stimulators and cardiac pacemakers began as experimental devices with protruding wires, bulky electronic systems and limited efficacy.

the near future

First, much like deep-brain stimulators and cardiac pacemakers, the next generation of devices that will provide robust and reliable decoding of neural information should be fully implantable (i.e. without anything protruding through skin). Recent prototypes have been developed to wirelessly transmit real-time spike data through a hermetically sealed and fully implanted titanium system. This device has been successfully used in NHPs and is being transitioned towards human medical device manufacturing.

Second, the current devices used for closed-loop control of cursors and robotic limbs all require a dedicated technician to oversee their use. A major engineering achievement will be the development of robust and reliable closed-loop algorithms that works 24-hours a day with minimal outside intervention from trained technicians.

Third, while cursor control for communication has now been achieved in multiple individuals [15], [16], the ability to control complex robotic arm movements is still limited and has not yet reached the point of being a viable replacement for naturalistic control.

Algorithms may be developed to determine what parameters the brain will be able to adapt to use, and what features necessitate recalibration of the decoding parameters [6]. These innovations will also help to further the restoration of native limb movement, by iBCI-controlled

FES systems, with the goal of restoring arm/hand function and quality of life to individuals with cervical spinal cord injury or brainstem stroke.

Fourth, current cursors and robotic limbs do not provide somatosensory information back to the user. One approach would be to directly stimulate the cortex in order to mimic proprioceptive information. Early success with intracorticall stimulation in humans suggests this may be a viable approach in the future.

Finally, developing clinically viable tools is predicated on demonstrating efficacy. Without being able to demonstrate reproducible, clinically viable outcomes, it will be difficult to bring these devices to those who need them most. With the field of clinical BCI for communication and motor rehabilitation still in its infancy, consensus is required as to how to measure outcomes appropriately.