Standards needed for bidirectional brain–computer interfaces

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Develop *bi-directional brain-computer interfaces* (BBCIs) to help people heal, feel, and move again.
Engineered Systems Vision

BBCI Engineered System

Implanted Components

- Onboard Computing
  - Decode Brain State
  - Sense Electronics
  - Sense Electrodes
  - Encode Stimulation
  - Stimulation Electronics
  - Stimulation Electrodes

External Components

- External Computing
  - Encode Sensory feedback
  - Optimal control of hand

Power

Data

Brain or spinal cord

Center for Sensorimotor Neural Engineering
Testbed 1: Cortical and Spinal Plasticity

Jackson et al... Fetz  Nature 2006
Testbed 2: ECoG BBCI Testbed

Goals: Develop co-adaptive ECoG decoding algorithms for control and stimulation protocols for artificial sensory feedback.
ECoG recording for intention decoding


ECoG stimulation for sensory feedback

- Cronin, Olson, Rao, Ojemann, et al., in review, 2016

![Graph showing aperture trace and target range.](image)
Testbed 3: Cortico-Spinal Reanimation

Goal: Restore paralyzed hand and arm function via brain-controlled spinal stimulation
Brain-controlled spinal stimulation via existing technology?

- First 2 subjects implanted with chronic ECoG for BCI testing and closed-loop DBS control

- Goal to combine studies and use brain recording to control spinal stimulation via approved platform

Herron, Ko, Ojemann, Chizeck; Inanici, Hoffstetter, Moritz
Epidural stimulation most promising & early studies used Medtronic devices

Voluntary movements (leg, ankle, and toe) with epidural stimulation (4 V, 30 Hz)

Harkema et al., Lancet 2011, and Angeli et al., Brain 2014
Cervical epidural stimulation improves hand function after SCI

Participant with ASIA B cervical injury improves volitional hand grasp function during epidural stimulation

Lu et al… Edgerton *Neurorehabil Neural Repair* 2016
Leverage independent advances for complete system

Extract control signals from penetrating array or ECoG

Reanimate limbs using muscle stimulation (FES)

Anderson, J Neurotrauma 2004

"FreeHand" Peckham et al. J Hand Surgery 2002
BCI to control surface muscle FES

- 23 y/o tetraplegic man with SCI
- Utah/Blackrock Array in M1
- Surface FES array on forearm chosen to reduce regulatory/risk

Moritz, Perlmutter & Fetz *Nature* 2008
Ethier, Oby, Bauman & Miller *Nature* 2012
Challenges in translation: the case for hardware standards

• Brain recording and spinal stimulation systems must continue to be tested in isolation to permit eventual combination into a complete Brain-Controlled Spinal Interface (BCSI)

• Cannot predict which systems will emerge as optimal

• Therefore, recording electrodes, implanted amplifiers, logic and stimulators must be compatible (e.g., Blackrock, Medtronic, Neuropace, Neurorecovery technologies)

• Individual nodes may communicate wirelessly if an IEEE-like standard is adopted

Moritz, Hoffstetter, Ko, Ojemann, Williams, Inanici, Chizeck, Lang
Standards needed for BCI performance

ISO HCI standard

Fitts’s law

Shannon-Welford model

(a) ISO 9241-9 2D Task

(b) 1D BCI Task

ISO. Ergonomic requirements for oce work with visual display terminals (VDTs) Part 9
Requirements for non-keyboard input devices (ISO 9241-9), 2002.


Matlack, Moritz & Chizeck. Performance Consequences of Control-Display Gain In Pointing Devices, In Preparation, *Human-Computer Interaction*