NEUROPROSTHETICS FOR RESTORATION OF UPPER LIMB FUNCTION

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Motivation

- People with severe disabilities may have limited means to communicate or interact with their environment
- Traditional assistive technologies often require some amount of dexterity to operate
- A brain-computer interface (BCI) can establish a direct link between the brain and an external device
  - Potential for high degree-of-freedom, intuitive control
  - Rehabilitation

Outline

- Definition of BCI/ neuroprosthesis
- Multidisciplinary research approach
- BCI for neurorehabilitation
- BCI as assistive technology
  - User Priorities
  - Clinical research at Pittsburgh
- Barriers to clinical translation

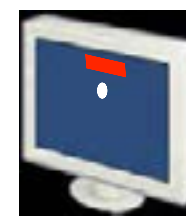
Brain-computer interfaces (BCI)

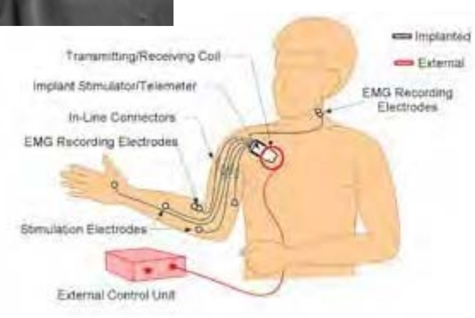
Multi-channel neural recording

Signal processing and feature extraction

Decoding movement or intention

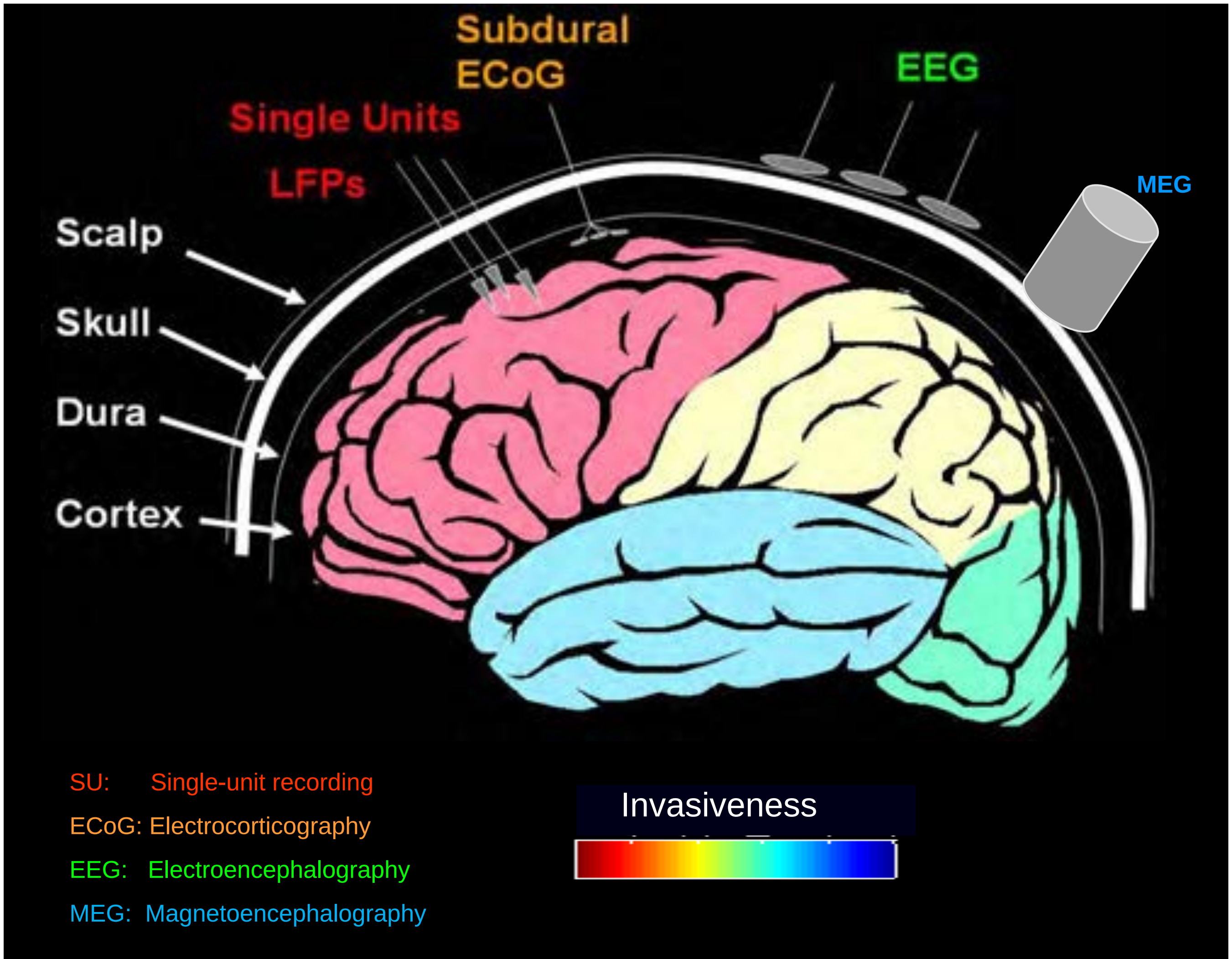
Control signal for an external device





Feedback

Neural Signal Acquisition Methods



Clinical BCI Research in Pittsburgh

Magnetoencephalography (MEG)

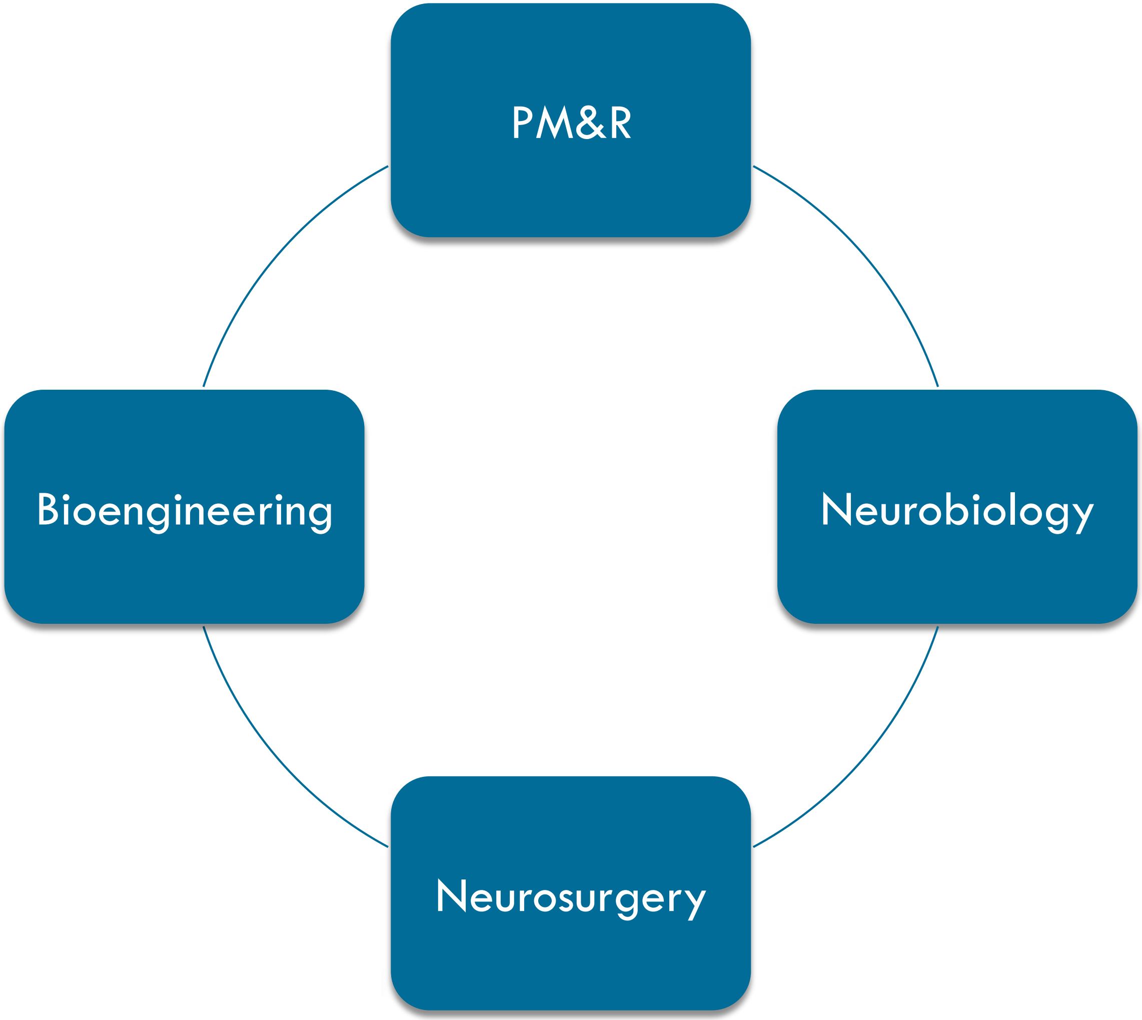
Electrocorticography (ECoG)

Intracortical microelectrodes

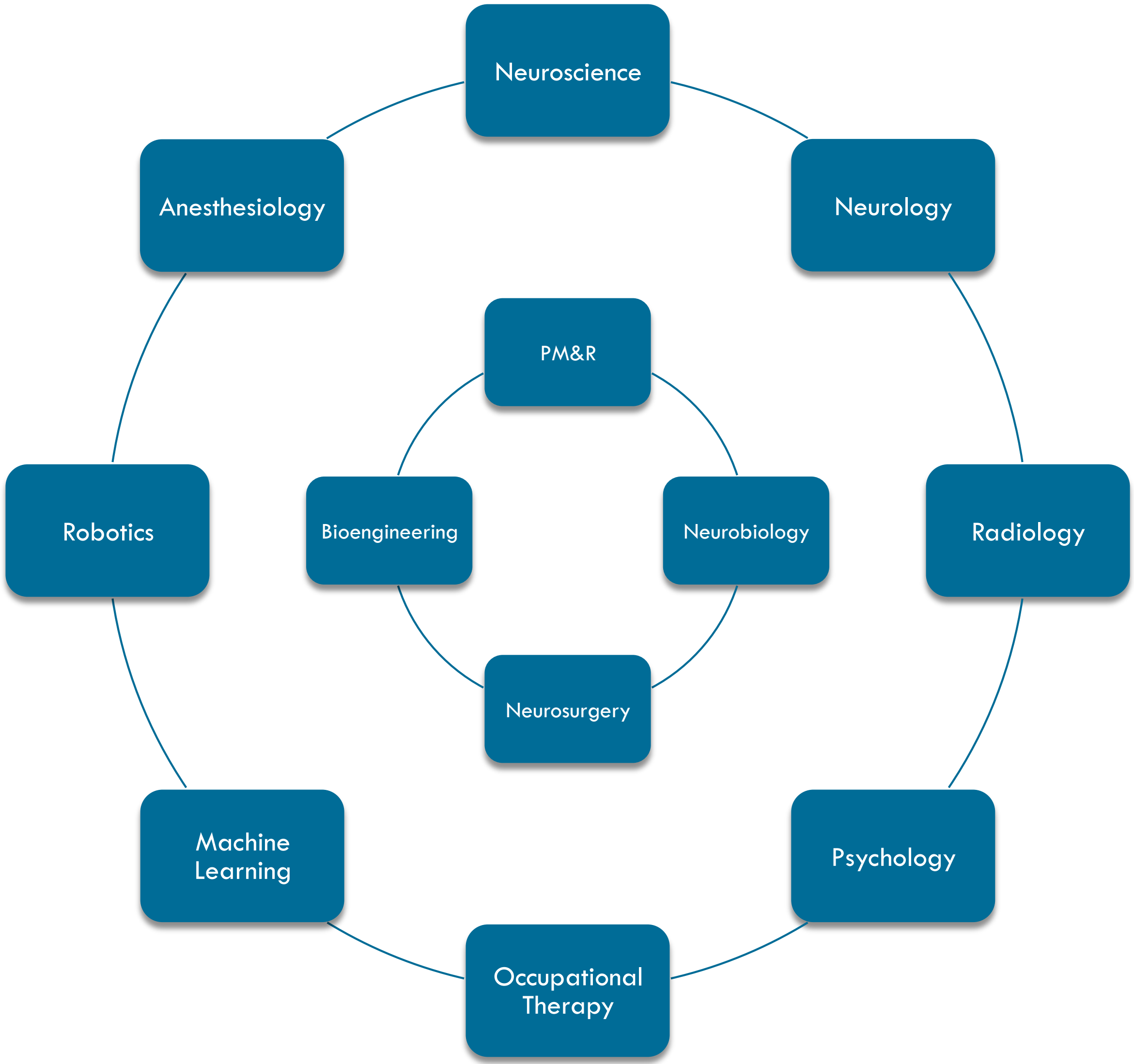
Motor command

Sensory feedback

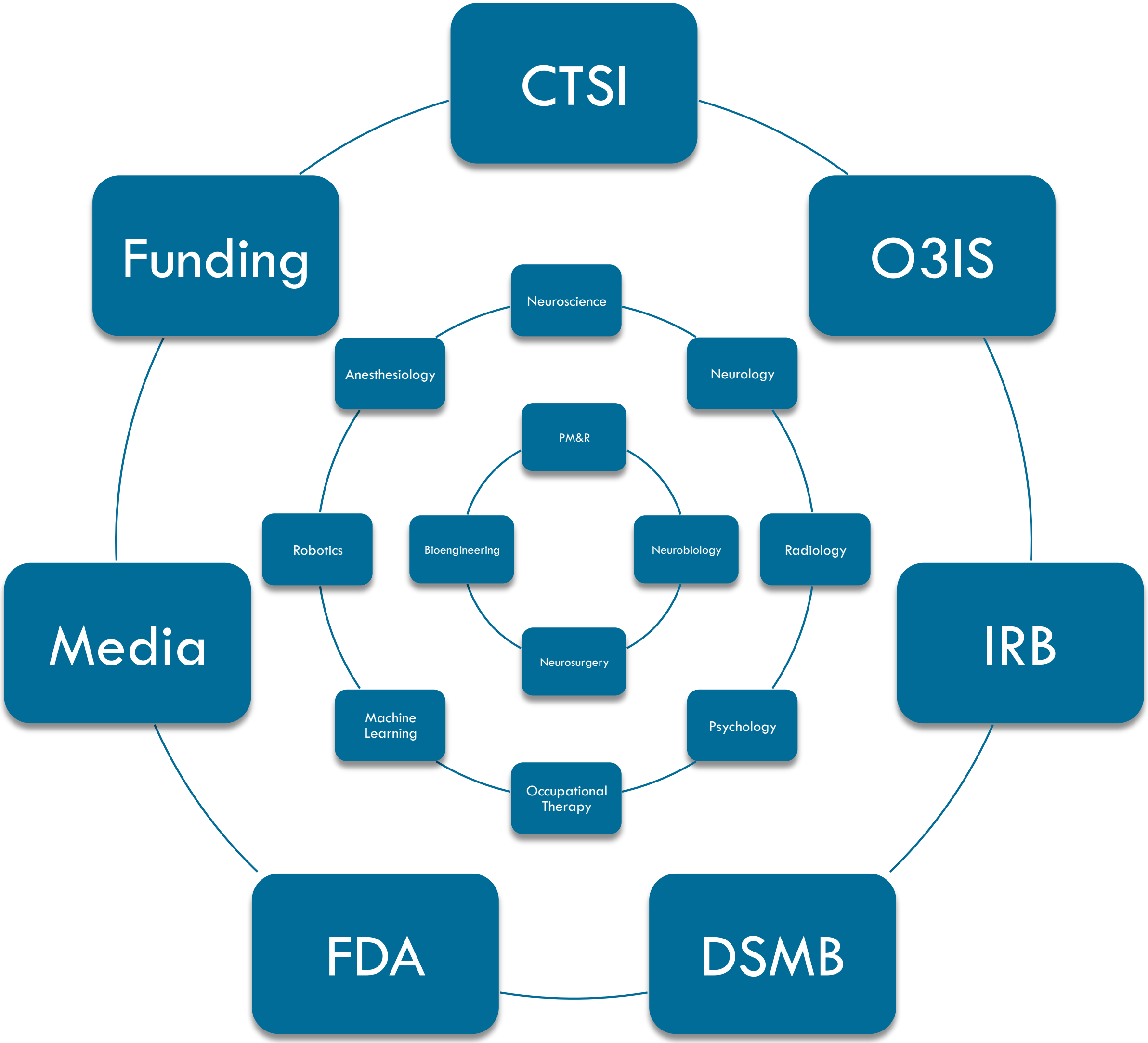
Multidisciplinary team



Multidisciplinary team



Multidisciplinary team



Collaborative Approach in the Development of High-Performance Brain–Computer Interfaces for a Neuroprosthetic Arm: Translation from Animal Models to Human Control

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Abstract

Our research group recently demonstrated that a person with tetraplegia could use a brain–computer interface (BCI) to control a sophisticated anthropomorphic robotic arm with skill and speed approaching that of an able-bodied person. This multiyear study exemplifies important principles in translating research from foundational theory and animal experiments into a clinical study. We present a roadmap that may serve as an example for other areas of clinical device research as well as an update on study results. Prior to conducting a multiyear clinical trial, years of animal research preceded BCI testing in an epilepsy monitoring unit, and then in a short-term (28 days) clinical investigation. Scientists and engineers developed the necessary robotic and surgical hardware, software environment, data analysis techniques, and training paradigms. Coordination among researchers, funding institutes, and regulatory bodies ensured that the study would provide valuable scientific information in a safe environment for the study participant. Finally, clinicians from neurosurgery, anesthesiology, physiatry, psychology, and occupational therapy all worked in a multidisciplinary team along with the other researchers to conduct a multiyear BCI clinical study. This teamwork and coordination can be used as a model for others attempting to translate basic science into real-world clinical situations. Clin Trans Sci 2013; Volume #: 1–8

Keywords: brain, clinical trials, methodology, translational research

MEG for Neurofeedback

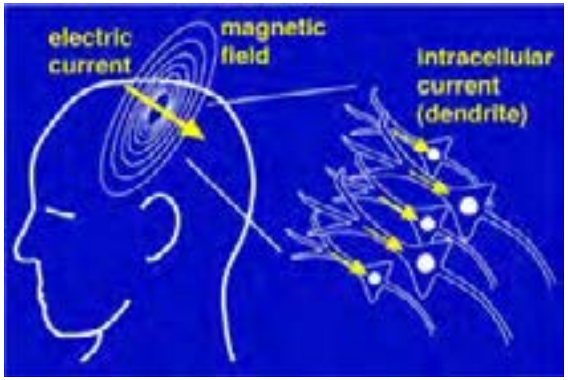
Motor Rehabilitation: SCI

- 225,000-296,000 people in the US with SCI
- Cervical level SCI impairs the ability to grasp and manipulate objects
  - Impacts independence and social participation
  - Improvement of hand function is a top priority for functional recovery
- Traditional rehab involves repetition of movements
  - What if patient cannot voluntarily activate muscles?
  - Limited improvement ~1 year after injury

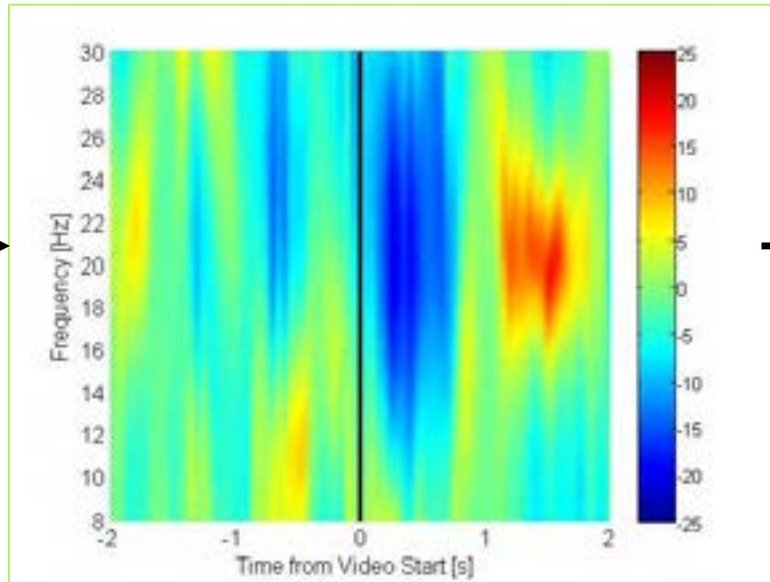
Definitions

- **Biofeedback:** The technique of monitoring physiological functions to provide information about these systems, with the goal of being able to manipulate these signals
- **Neurofeedback:** A type of biofeedback that uses real-time displays of brain activity, with the goal of controlling CNS activity. Typically, the goal is to "normalize" brain activity.

Technology: MEG



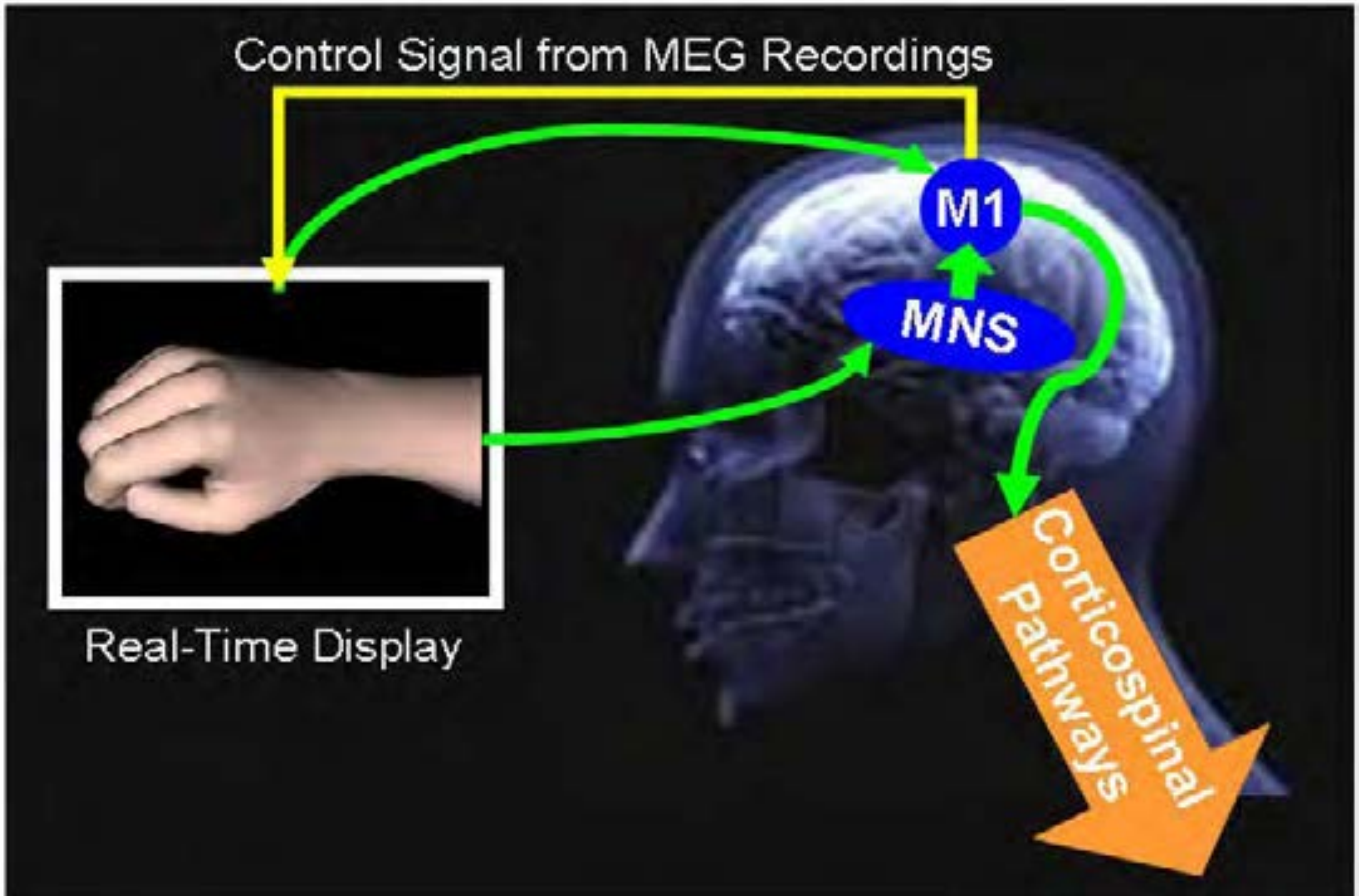
MEG Neurofeedback



Neural Decoding

Real-time Neurofeedback

Facilitation of Motor Cortex Activation

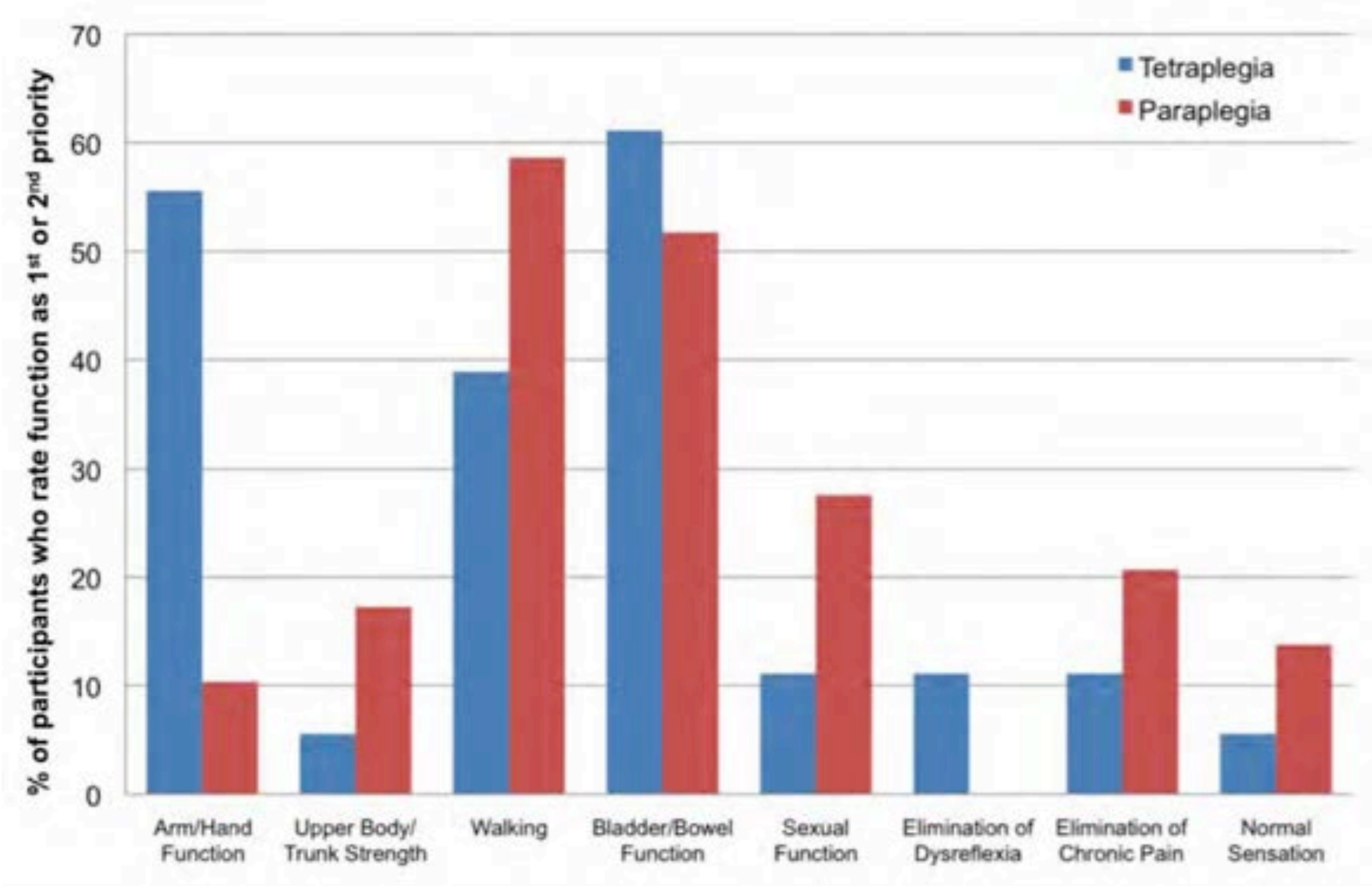


BCI as assistive technology

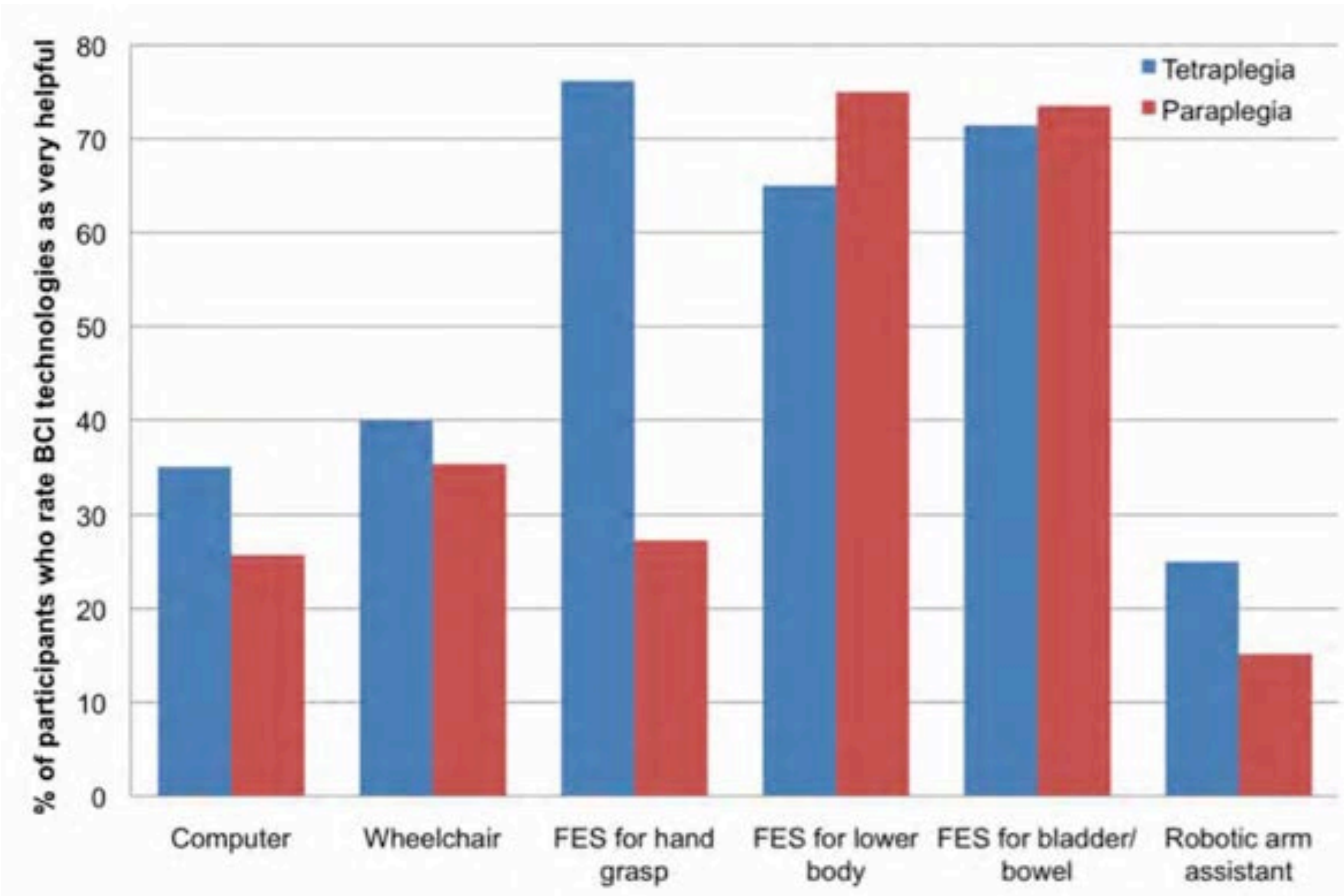
Who are our end users?

- People with mobility or communication-related impairments whose needs are not met by traditional assistive technology
- Each diagnosis group or specific impairment may desire different functionality
  - Recording modality
  - Risk/benefit tradeoffs
  - Type of terminal device(s)

What do they want?



BCI-controlled assistive technology



BCI design characteristics

- Independent operation was most important
- Training time was the least important
- 70% rated non-invasiveness as very important
- More than half would “definitely” or “very likely” consider having surgery to implant BCI electrodes

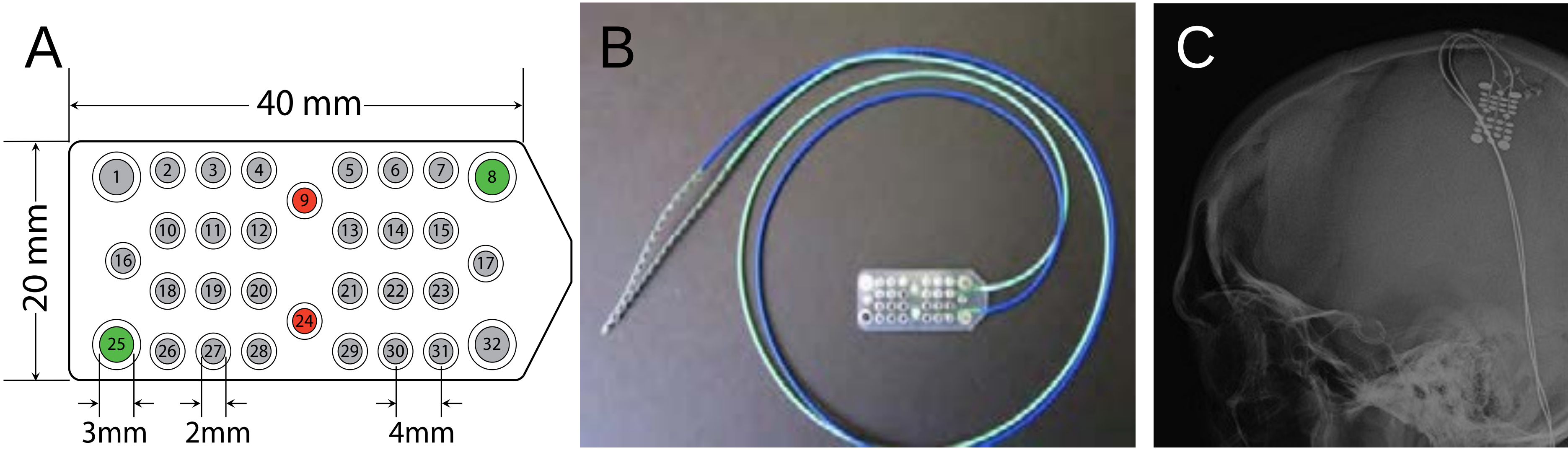
Priorities for users with ALS

- Most important features of a BCI
  - Accuracy, set-up simplicity, standby mode reliability, available functions
- EEG vs. implanted electrodes
  - 84% accept electrode cap
  - 72% accept surgical implant (outpatient)
  - 41% accept surgical implant (short hospital stay)
- BCI-controlled assistive technologies
  - Power wheelchair and robot arm control trended towards a more significant interest

Huggins et al. 2011

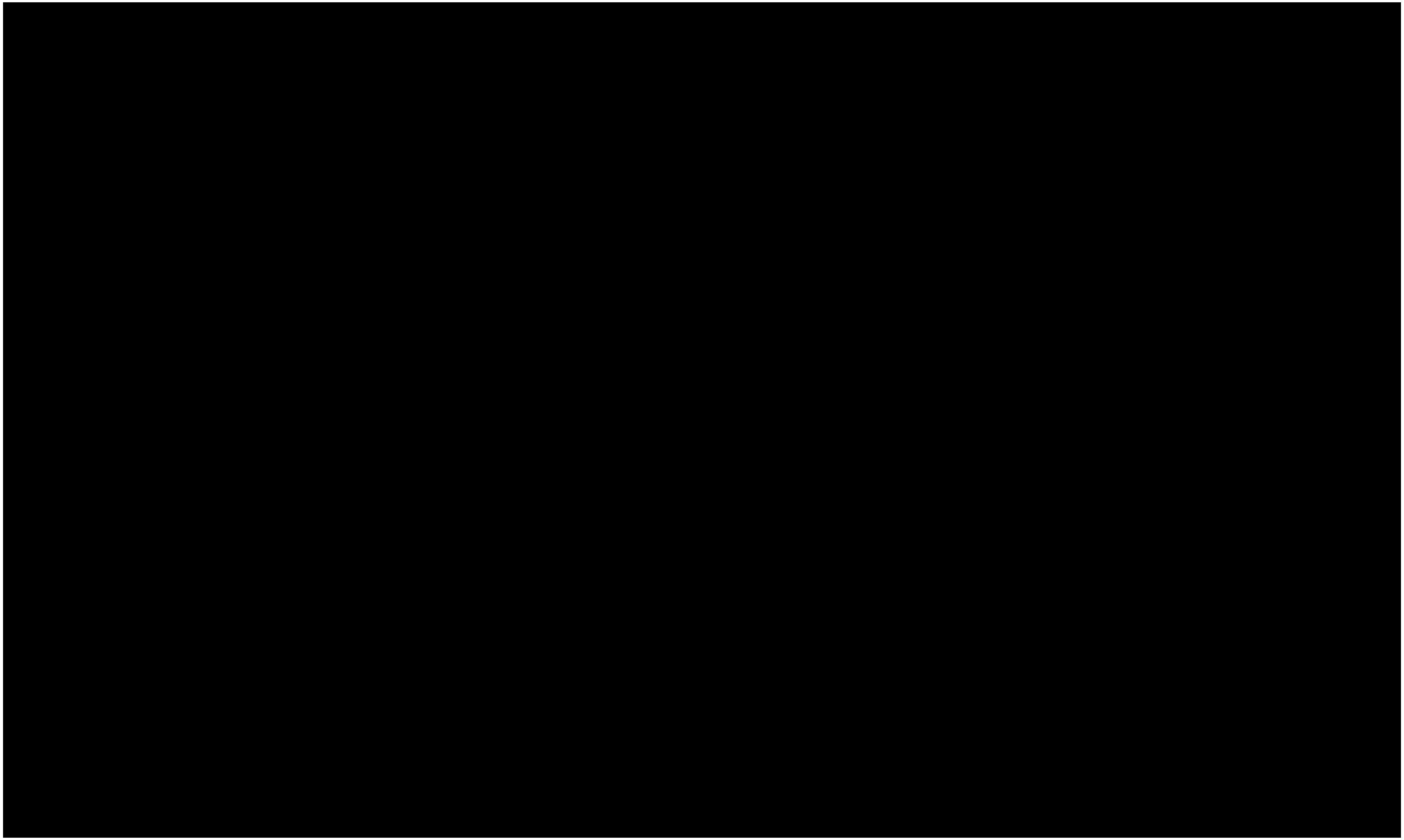
ECoG BCI

ECoG BCI: First Participant

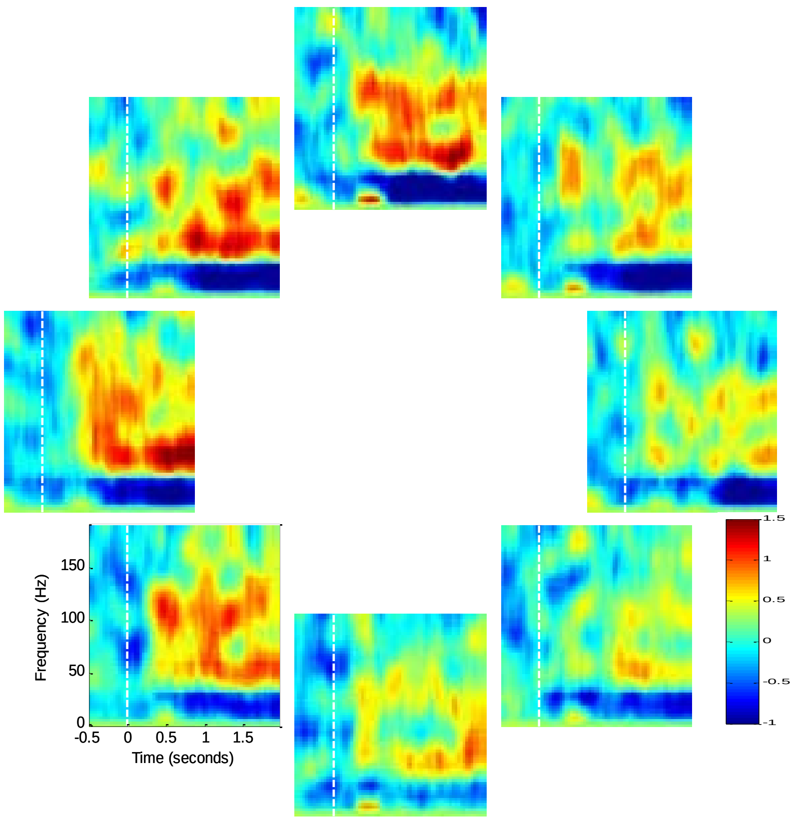


- A short-term study over 28 days (21 testing days)
- Subject: 30-year old male, C4-level spinal cord injury

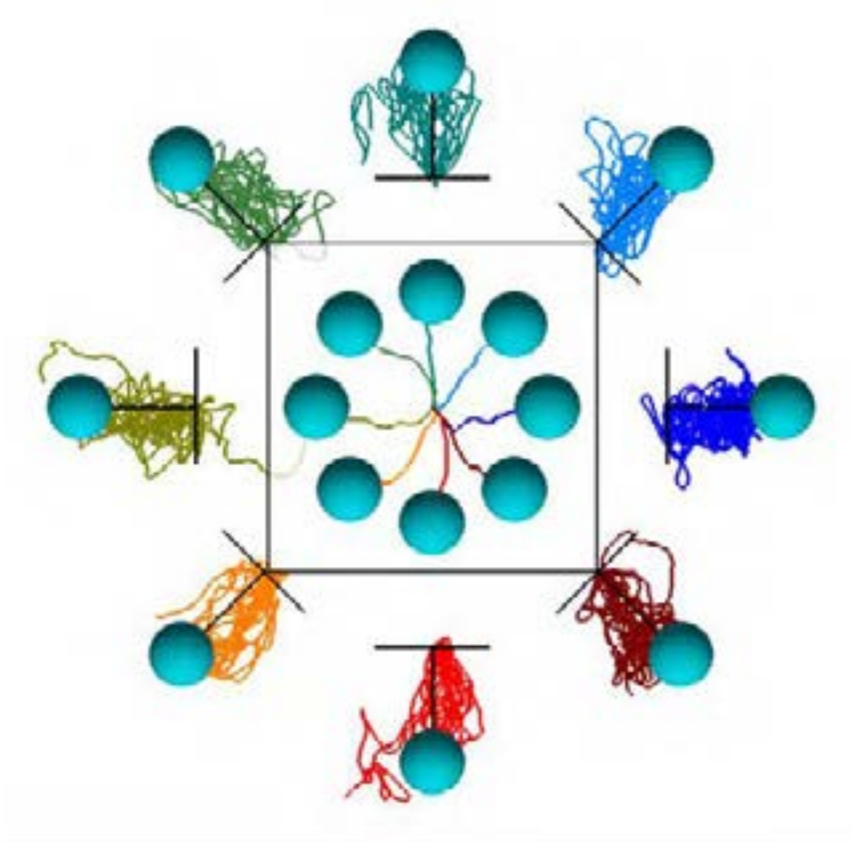
2D Cursor Control



ECoG signal modulation and 2D cursor trajectories

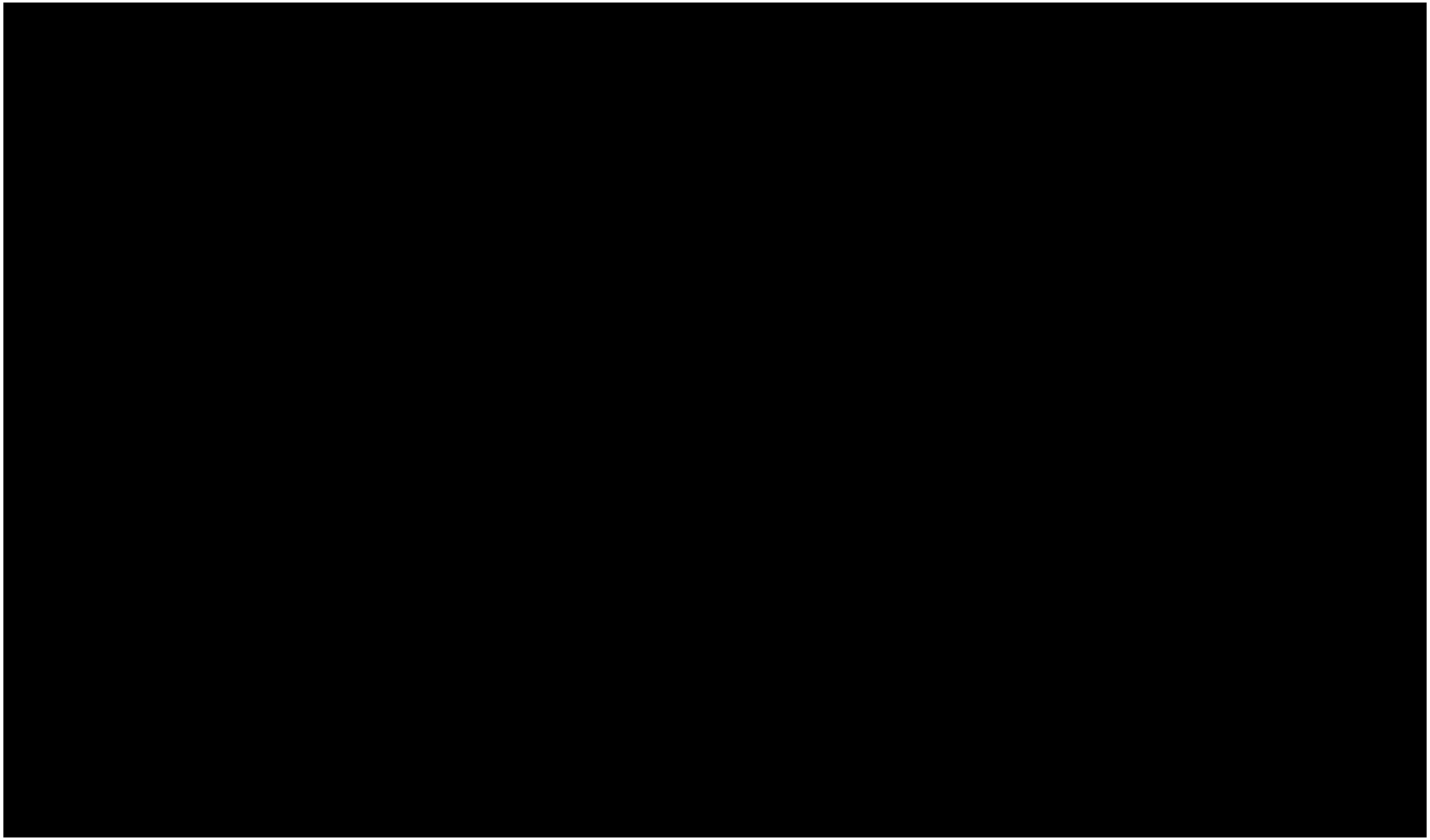


Channel 4



Average success rate: 87% over 176 trials

3D Cursor Control

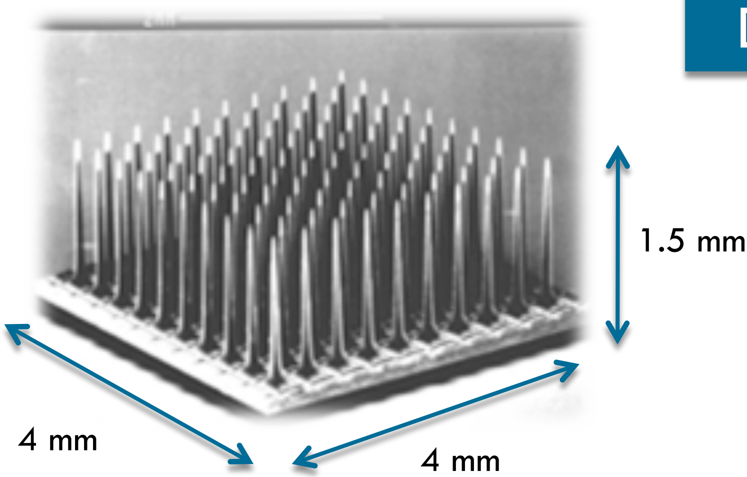


3D Control of the MPL

Meet our participant

Intracortical BCI

Intracortical BCI for robotic arm control



Neural Decoder

Conducted under an FDA Investigational Device Exemption

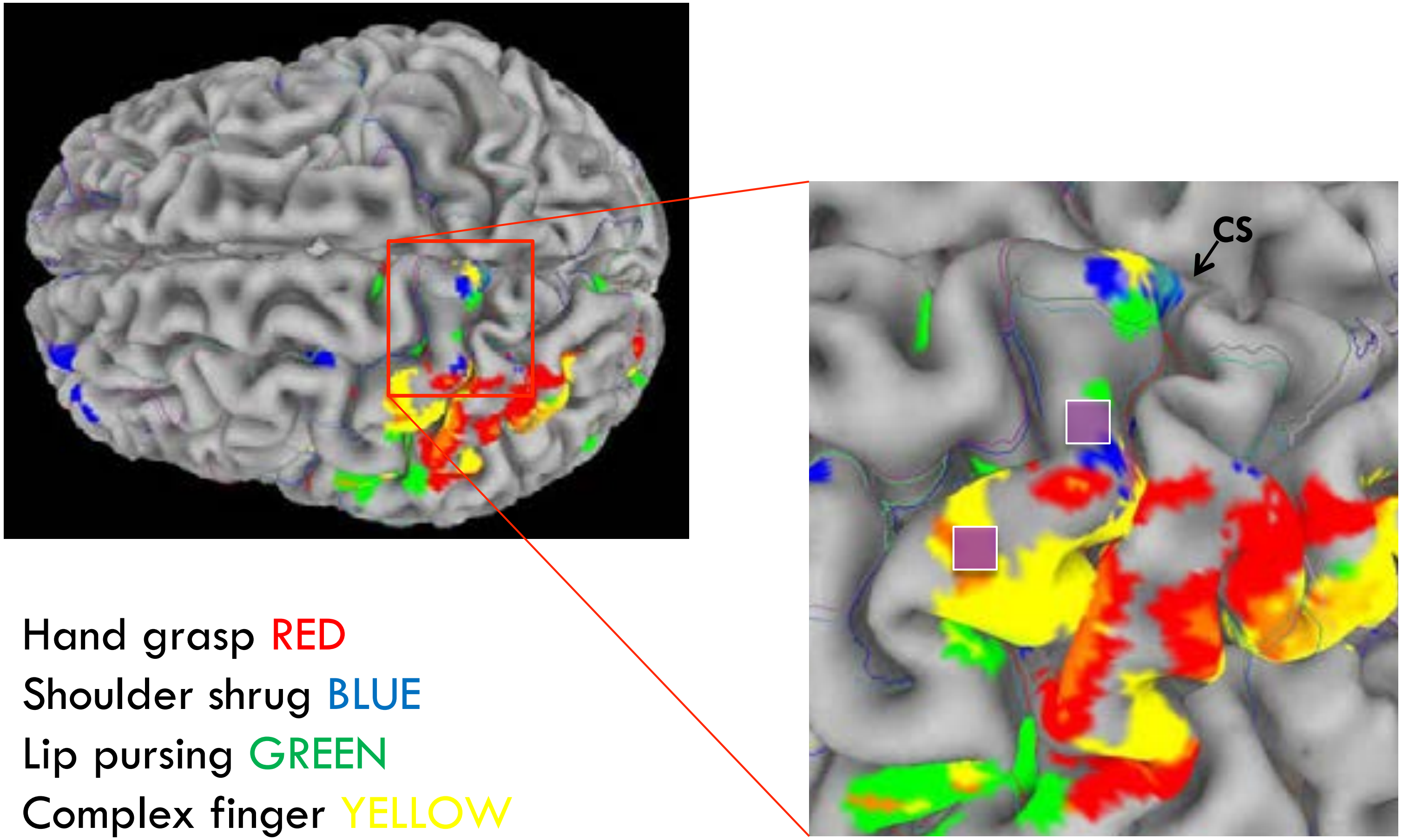
Collaborators: Device Regulation

- Blackrock Microsystems

- Johns Hopkins University
  Applied Physics Laboratory

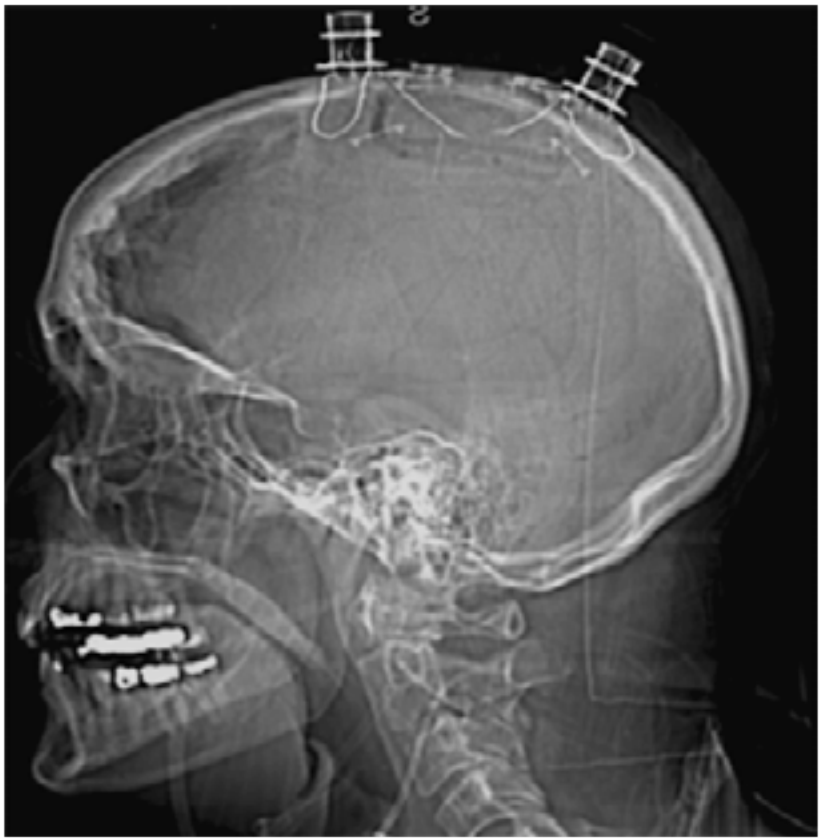
- FDA: Investigational Device Exemption
  - Basic science research
  - Clinical protocol development

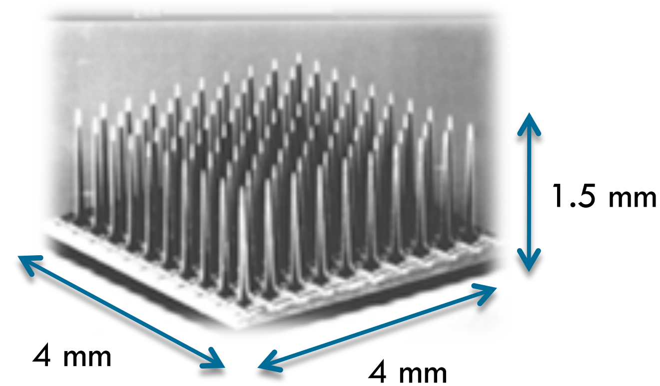
Presurgical planning



Hand grasp RED
Shoulder shrug BLUE
Lip pursing GREEN
Complex finger YELLOW

Implantation surgery: 2/10/12

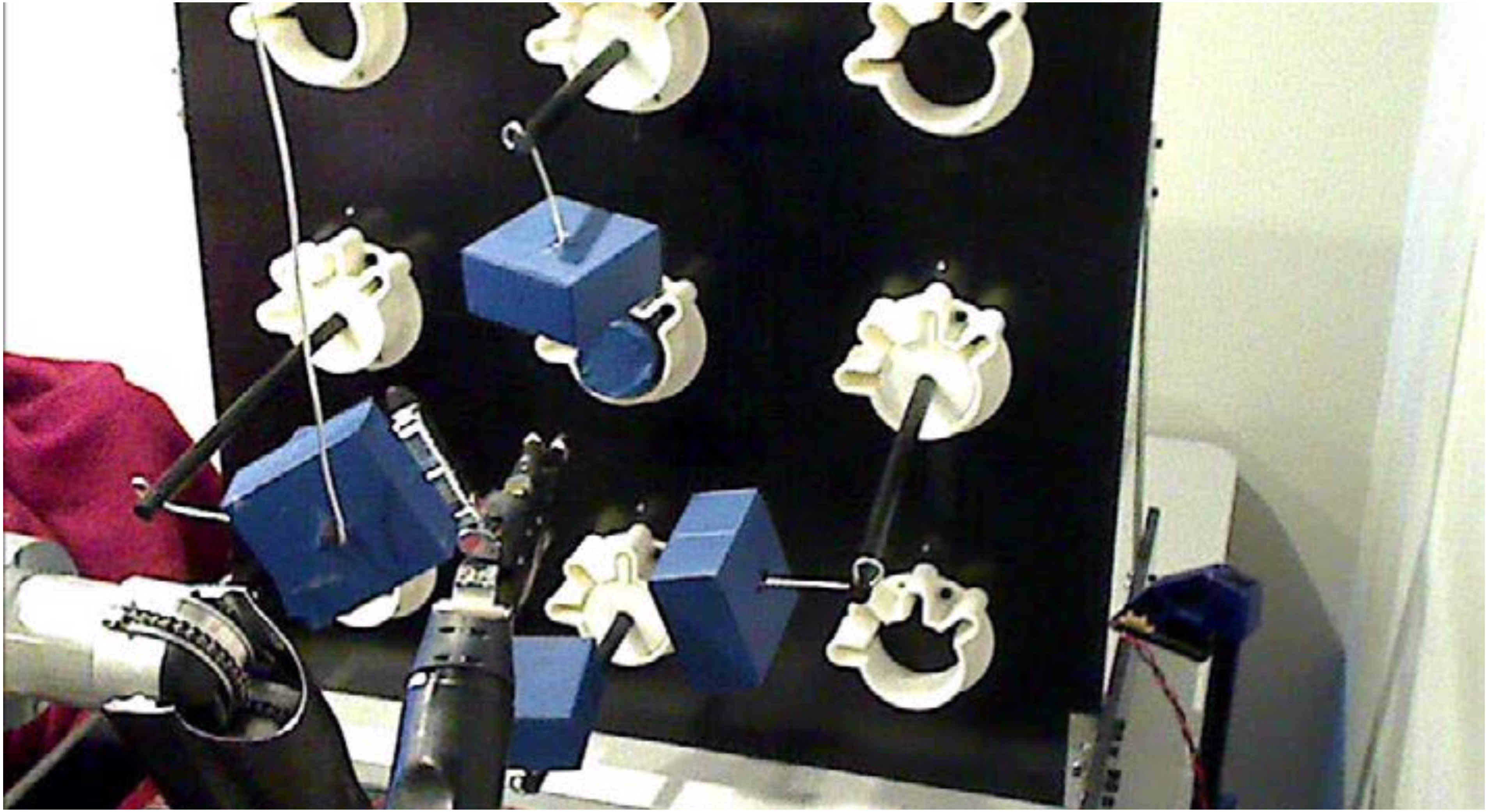




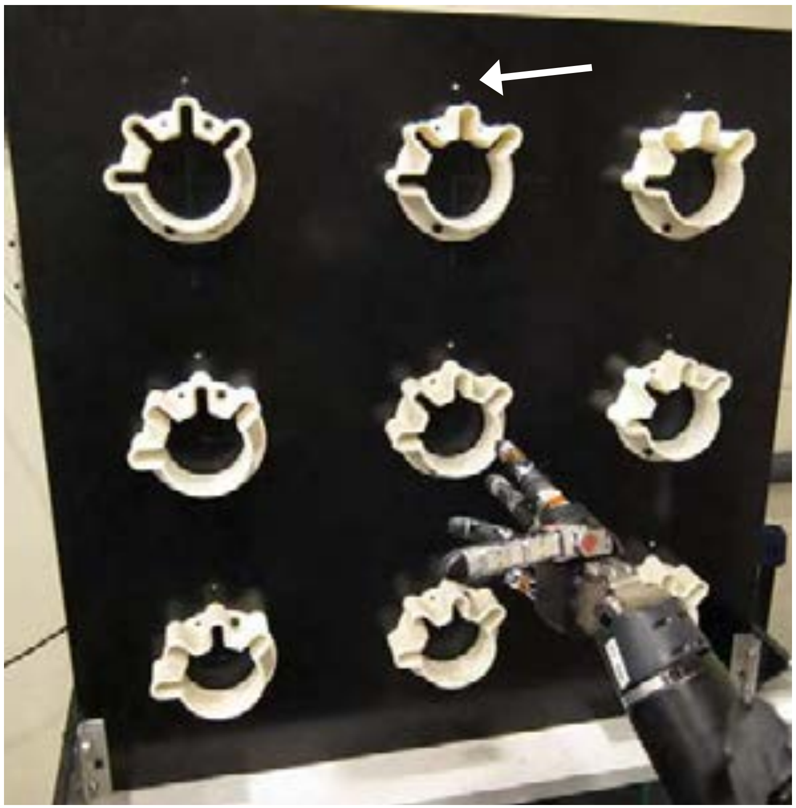
Collaborators: Surgical

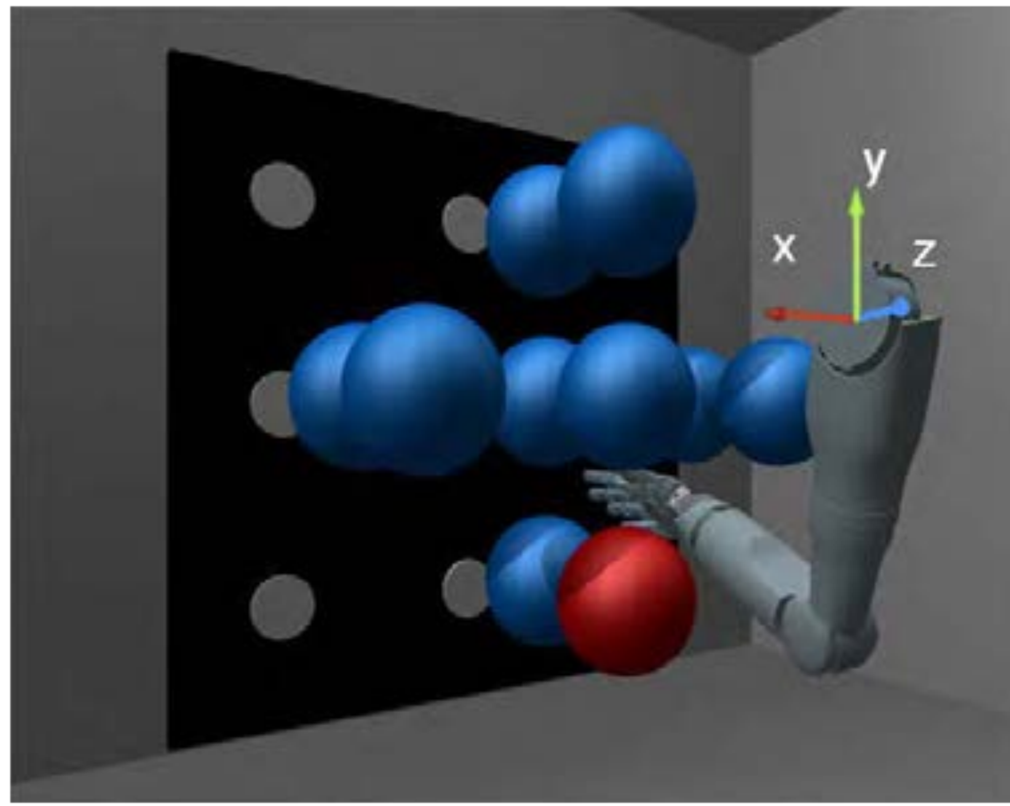
- Neurosurgery
  - Minimize risk, ensure device function
- Neurophysiology
  - Array placement
- Anesthesiology
  - Screening for co-morbidities
  - Special considerations
    - tetraplegia, spastic, or flaccid paralysis
    - autonomic hyperreflexia
    - receptor up-or-down regulation at the neuromuscular junction
    - cervical fusions
    - tracheostomy
- Psychology

3D control: 2/21/12



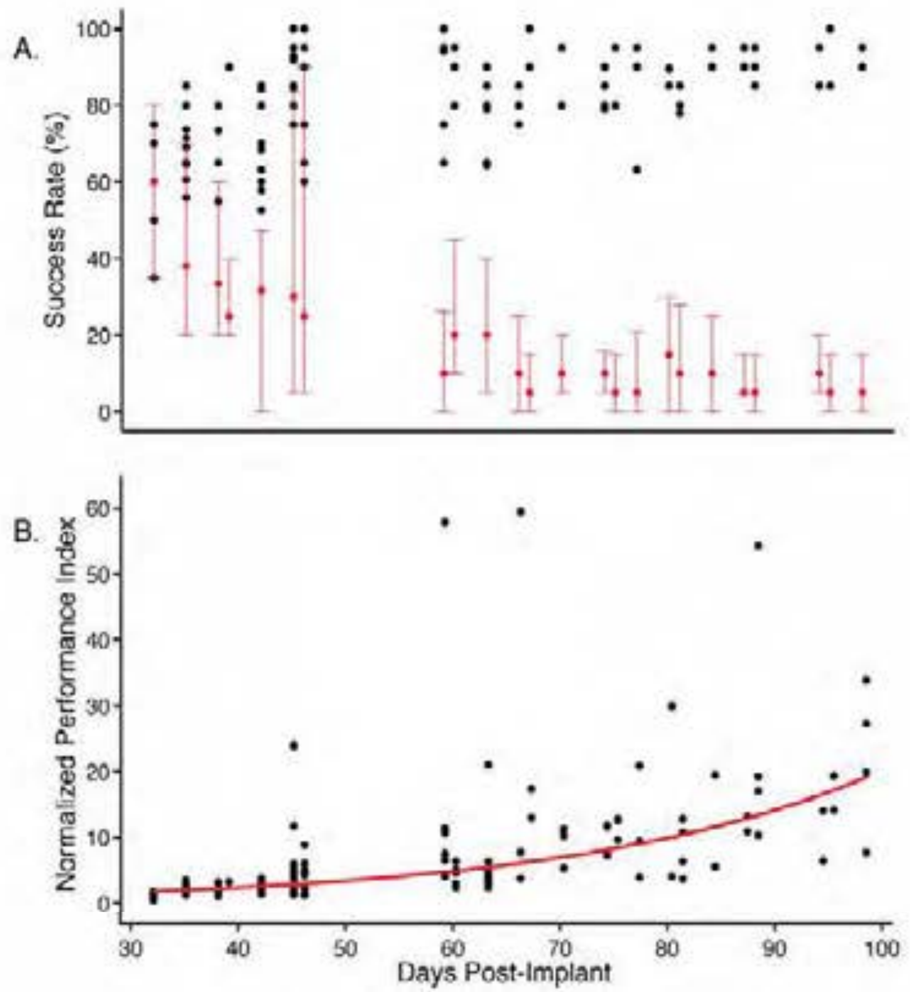
7D sequence task



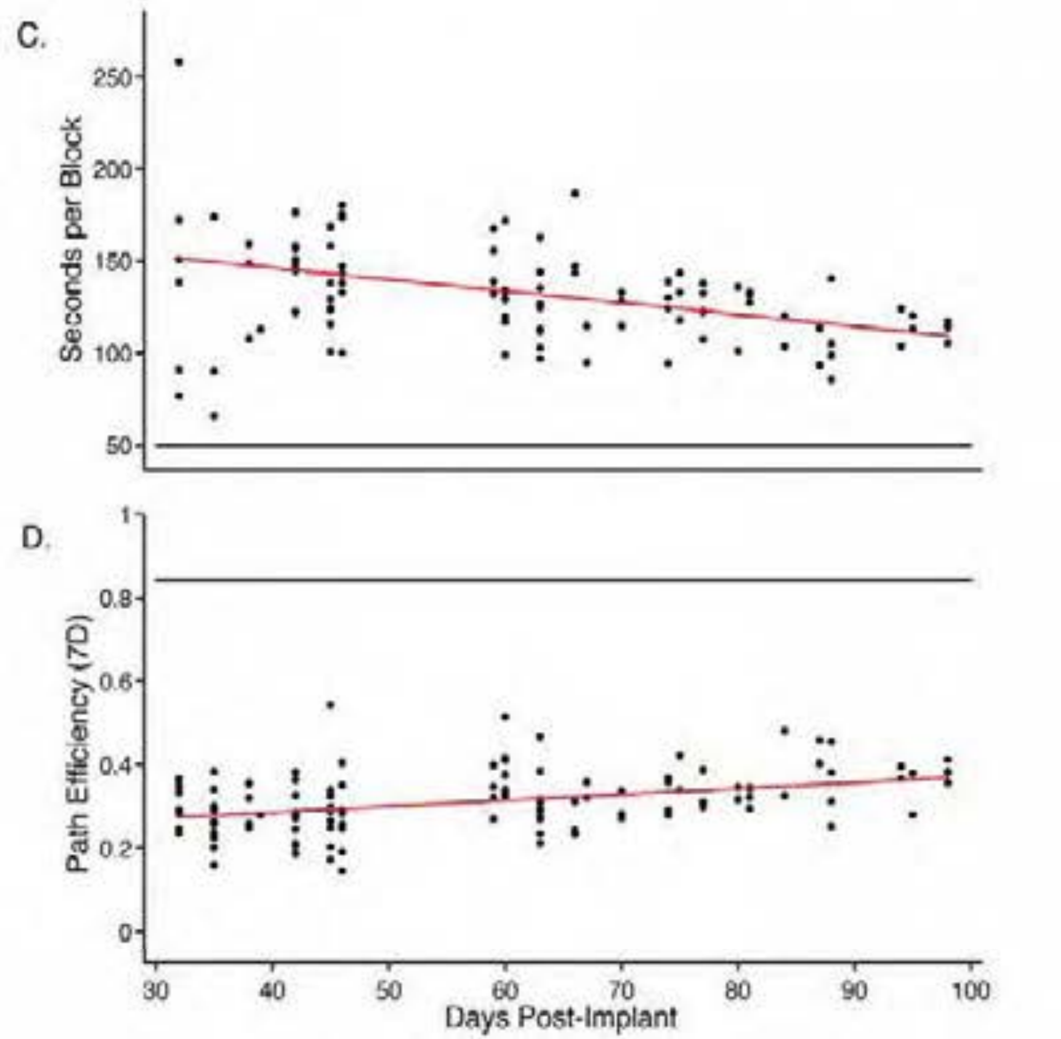


7D sequence task: 5/14/12

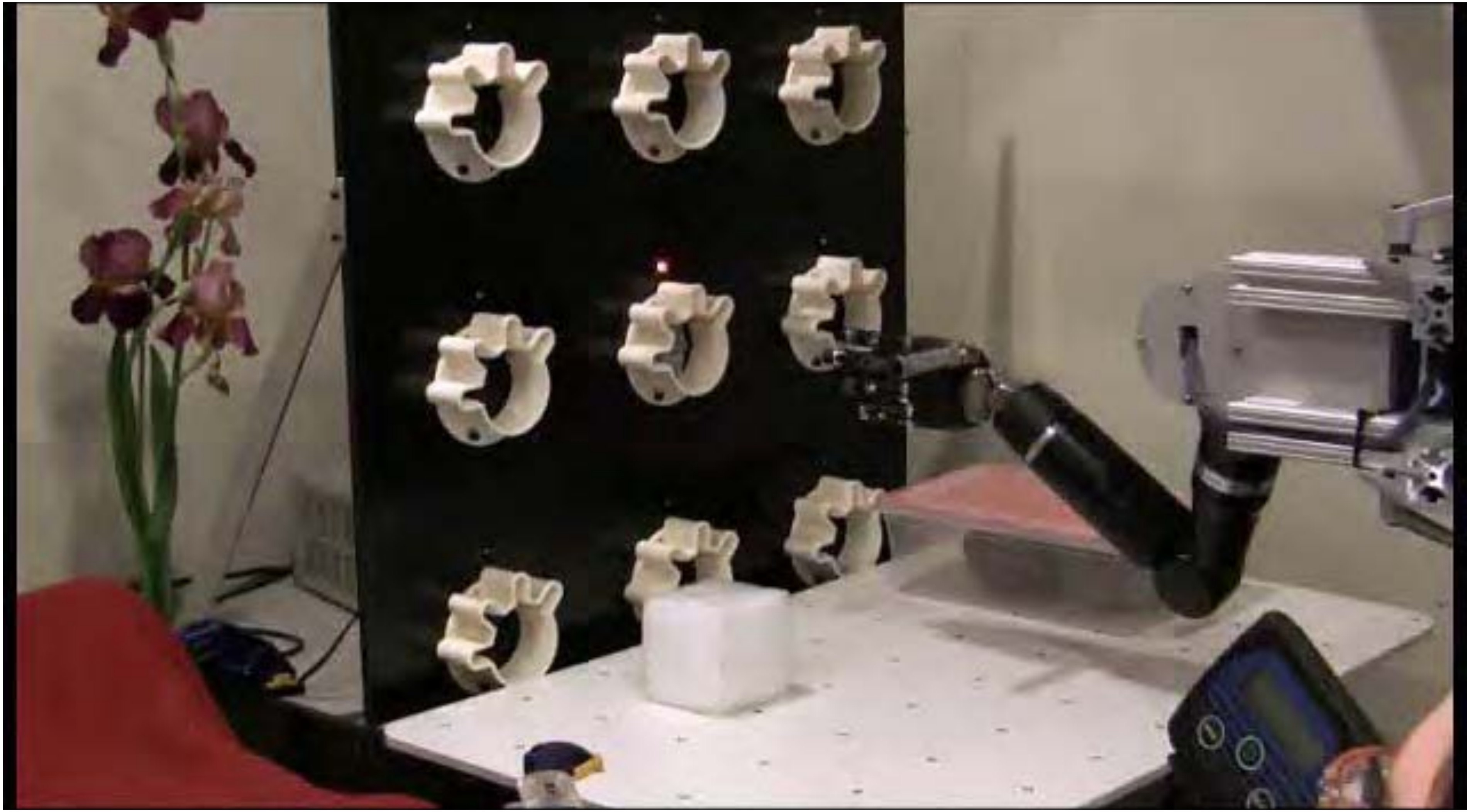
Results: 7D performance



Results: 7D performance



Action Research Arm Test (ARAT)



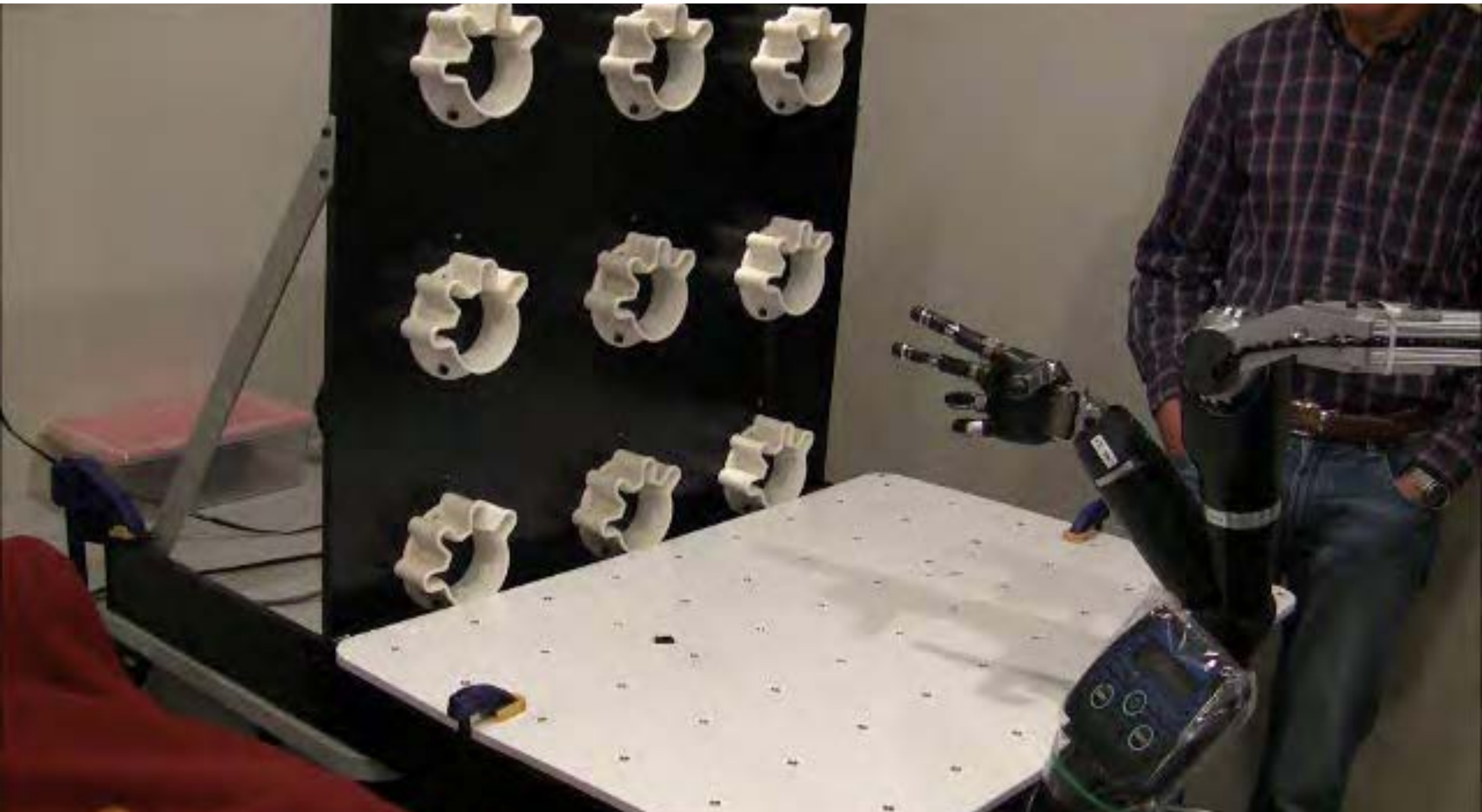
ARAT Performance

- 9 of 19 possible tasks were evaluated

  - Each scored from 0-3
- Score ranged from 15-17 (out of 27) with BCI
  - Δ 5.7 points is clinically significant
- Mean completion time ranged from 9.5-21.3 s

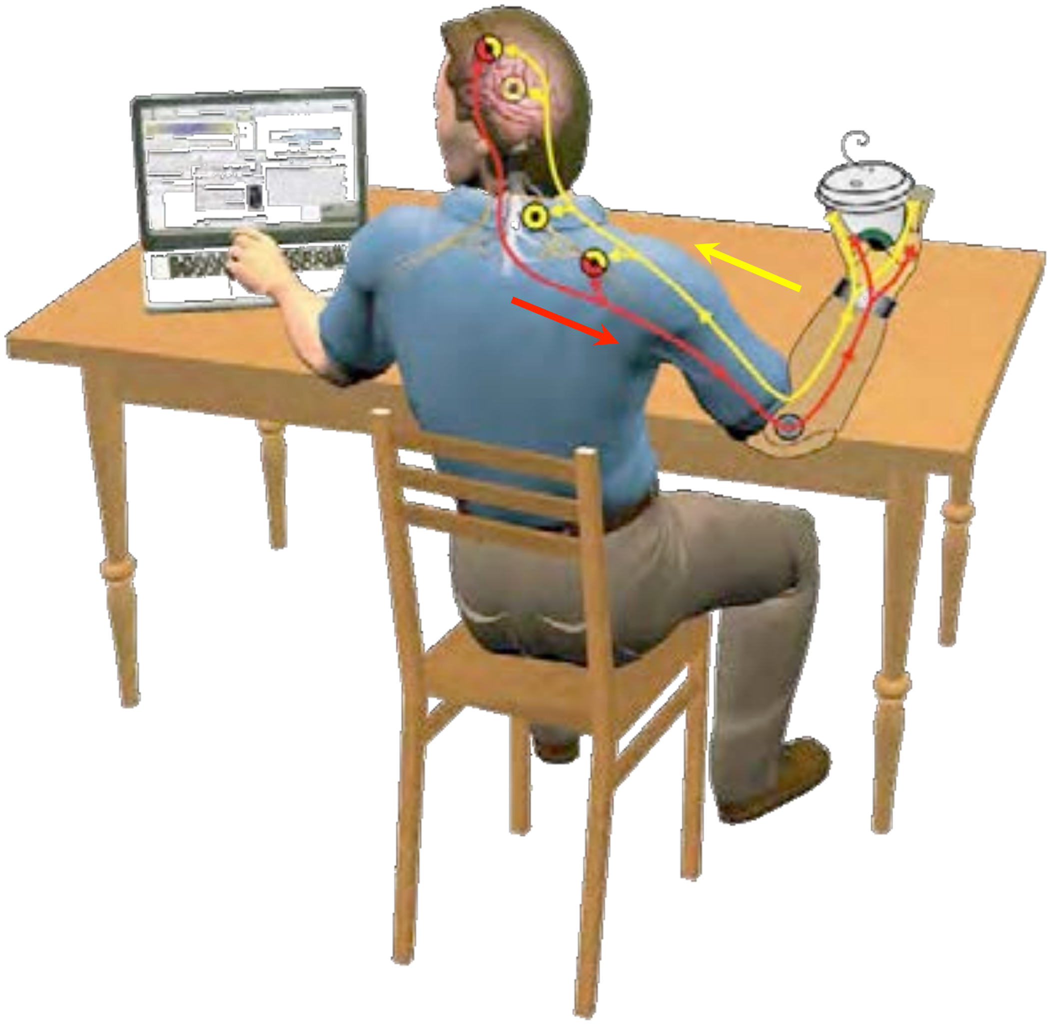
Different grasp strategies

Hand shaping (8D control)



Chocolate

Sensory feedback is crucial for normal motor control



Barriers to Clinical Translation

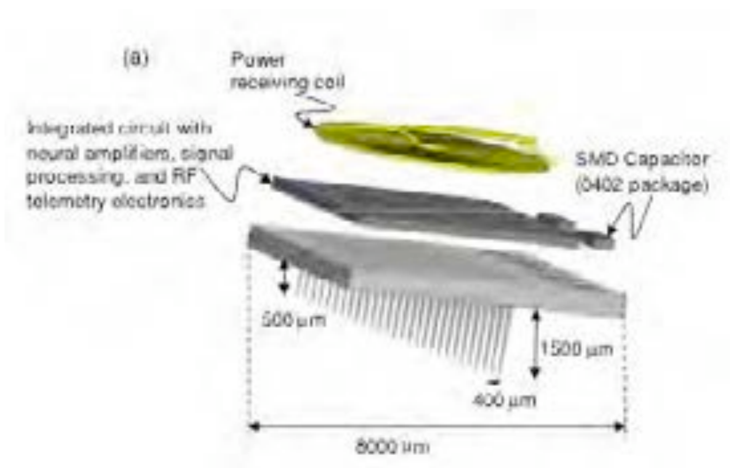
Recording quality/stability

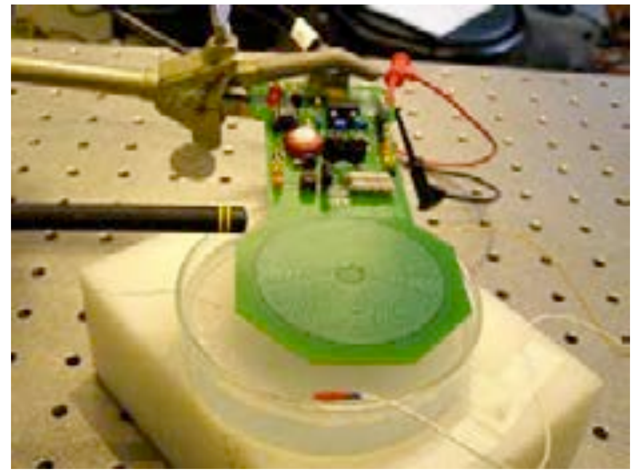
- Host/tissue interface

  - Possible solutions: Electrode geometry, materials, coatings
- Resolution vs. invasiveness tradeoff
- Effects of distractions/noise
- Recalibration

Schwartz et al. 2006

Telemetry





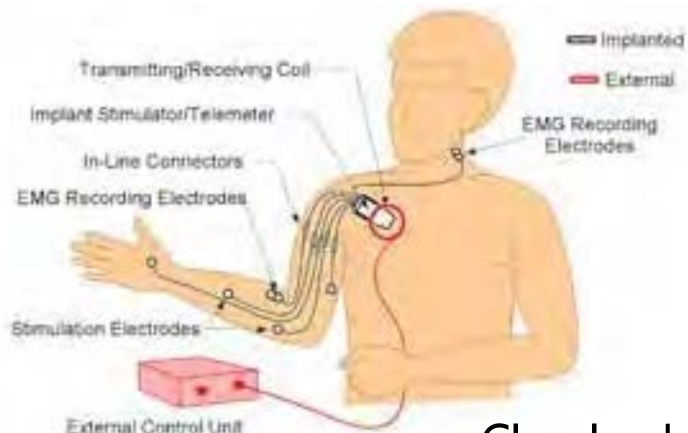
- How much information is needed?
- Data acquisition system portability?

- Reduce infection risk
- Independent operation

- System complexity

Sharma et al. 2011

Integration with other technology



Cleveland FES

JHU

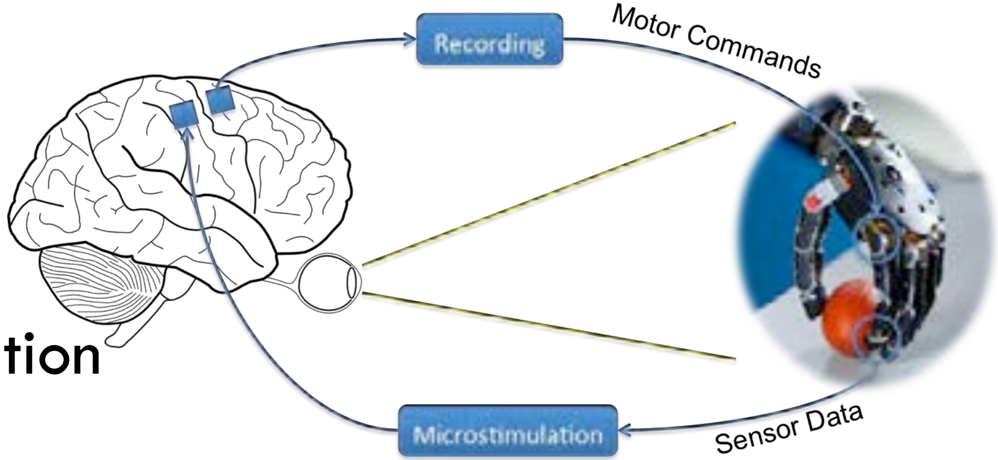
HERL

UC Santa Cruz

DEKA

Sensory feedback

- Each modality has advantages and challenges
  - Visual
  - Non-invasive
  - Cortical surface
  - Intracortical microstimulation
  - Optical stimulation
  - Peripheral nervous system



Other challenges?

- Meeting performance expectations
- Independent operation or remote monitoring
- Cost
- Clinician and patient education

Summary

- BCIs have applications for rehabilitation and assistive technology
- An intracortical BCI enabled a participant to perform natural reaching and grasp movements with skill approaching that of an able-bodied individual
- Additional work is needed to overcome barriers to clinical translation → multidisciplinary team

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