BRAIN-MACHINE INTERFACES FOR PEOPLE WITH SPINAL CORD INJURY

Jennifer Collinger, PhD
University of Pittsburgh
VA Pittsburgh Healthcare System

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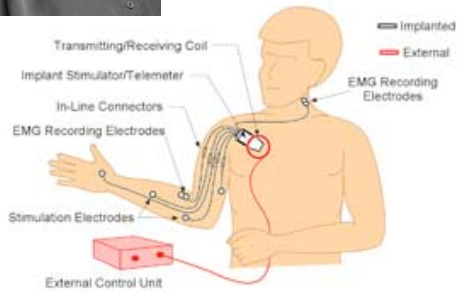
Motivation

- 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-machine interface (BMI) will establish a direct link between the brain and an external device
  - Potential for high degree-of-freedom, intuitive control

What is a BMI?

Multi-channel neural recording → Signal processing and feature extraction → Decoding movement or intention → Control signal for an external device

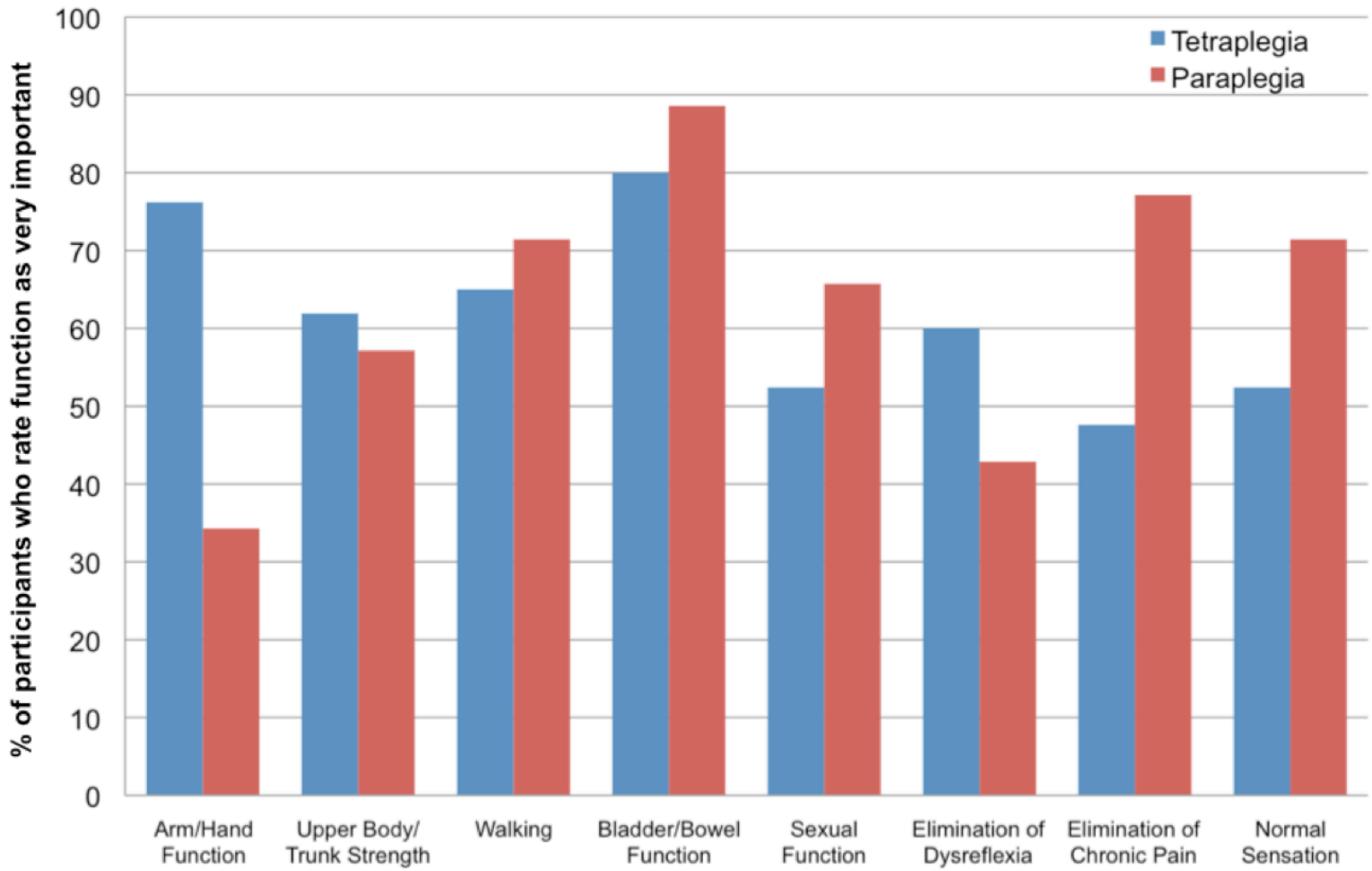


Feedback

Who are our end users?

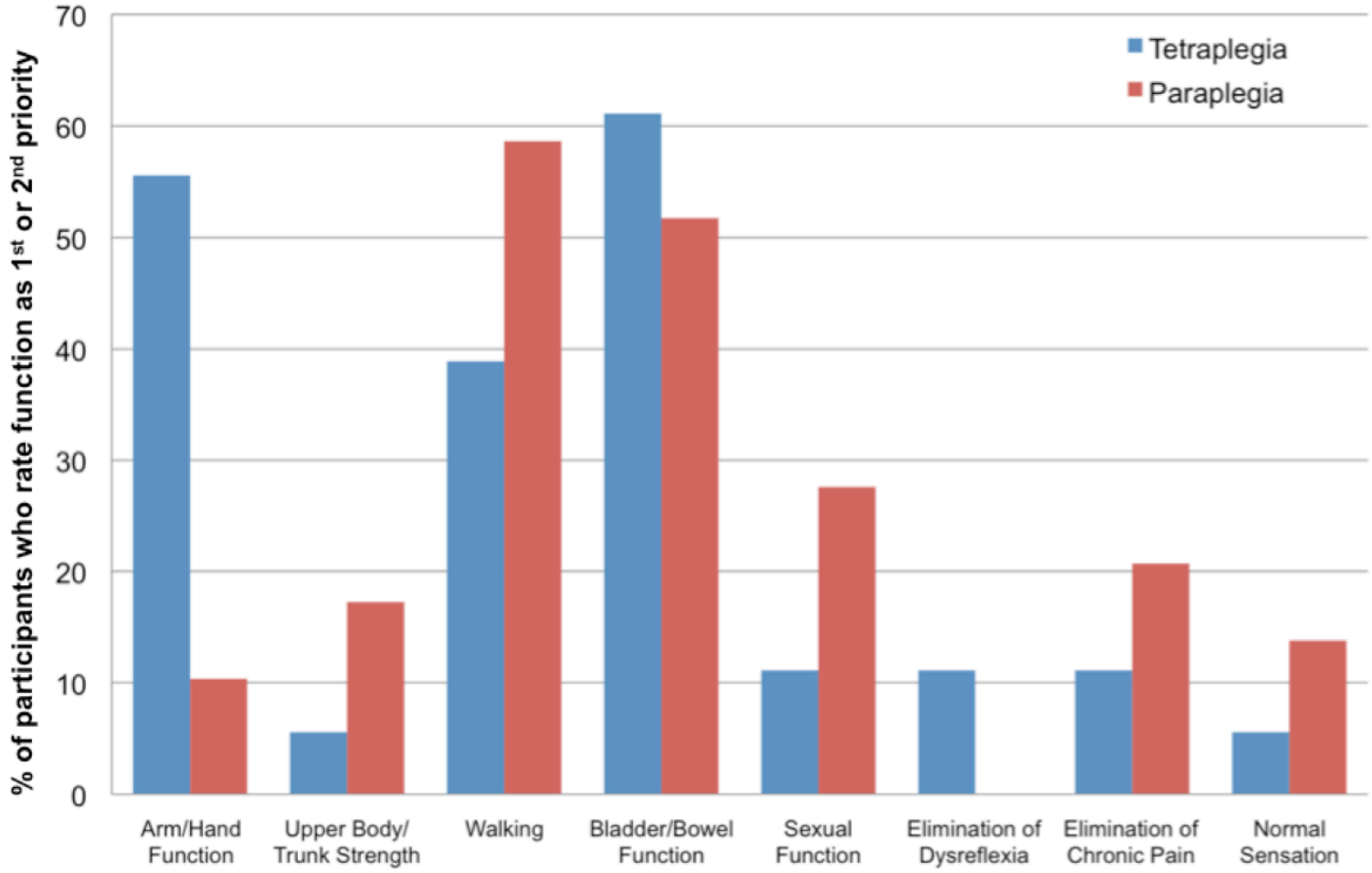
- People with mobility or communication-related impairments whose needs are not met by traditional assistive technology
- BMI can benefit from user-centered design
  - Recording modality
  - Risk/benefit tradeoffs
  - Type of terminal device(s)

What do they want?



Collinger et al., in review

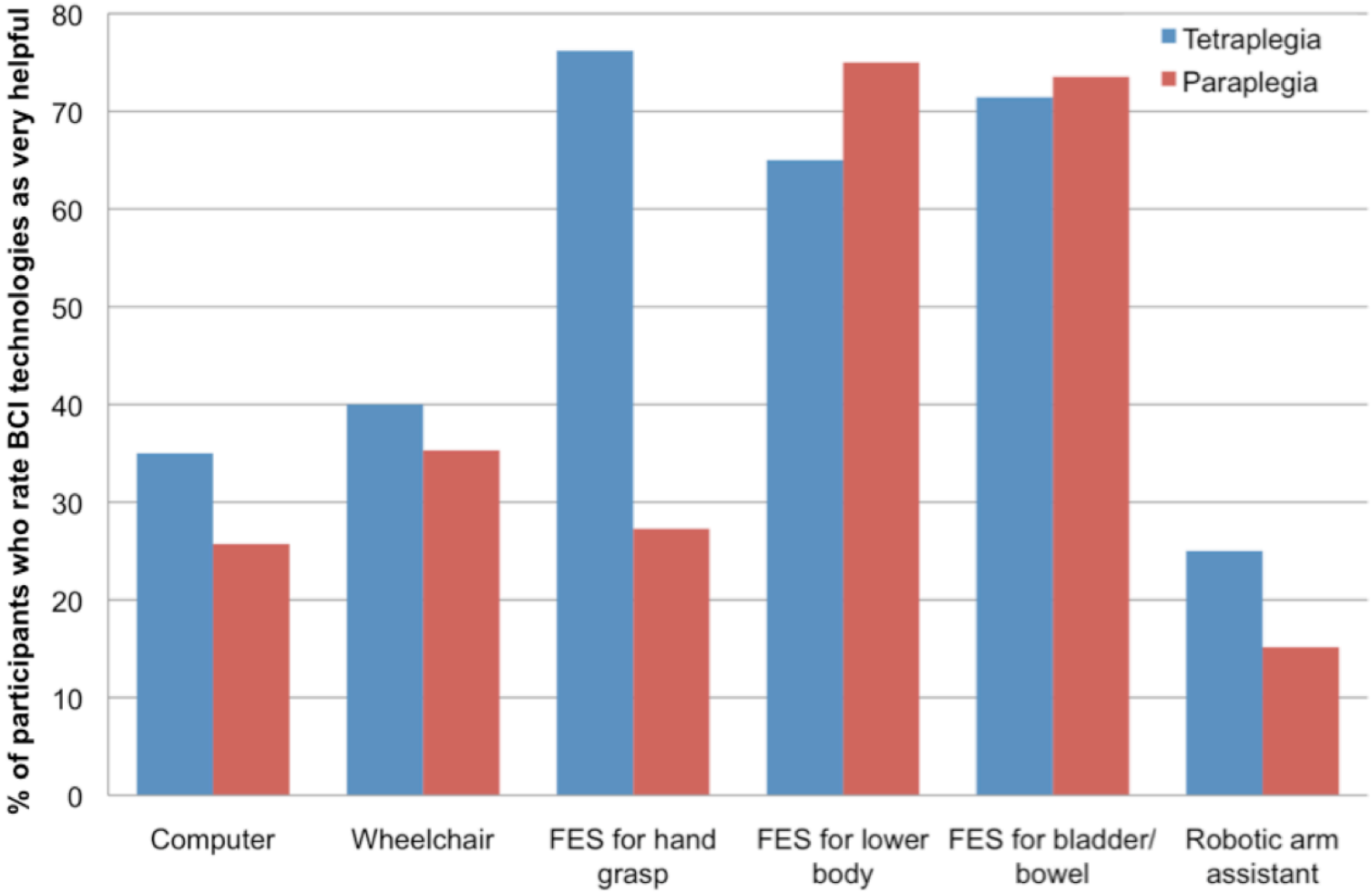
Top functional priorities



BMI familiarity and preferences

- How many people had heard of BMI technology?
  - 75% of individuals with tetraplegia
  - 53% of individuals with paraplegia
- How many would be interested in using a BMI to assist with daily activities?
  - 86% of individuals with tetraplegia
  - 81% of individuals with paraplegia

BMI-controlled assistive technology



BMI design characteristics

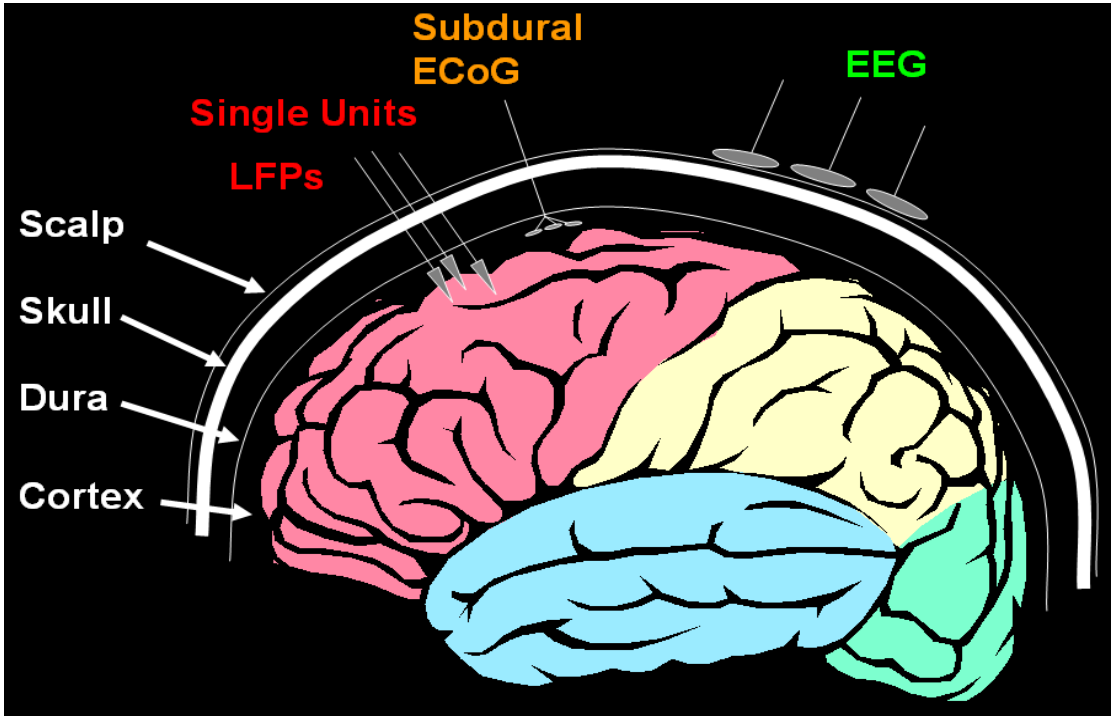
- Independent operation was most important
- Training time was the least important
  - 51% would come to a lab/clinic as often as needed
  - 23% would come 2-3 times per week
  - 21% would come once per week
  - 1 person not willing to travel for training
- 70% rated non-invasiveness as very important
- More than half would "definitely" or "very likely" consider having surgery to implant BMI electrodes

Priorities for users with ALS

- Most important features of a BMI
  - 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)
- BMI-controlled assistive technologies
  - Power wheelchair and robot arm control trended towards a more significant interest

Huggins et al. 2011

Neural Signal Acquisition Methods

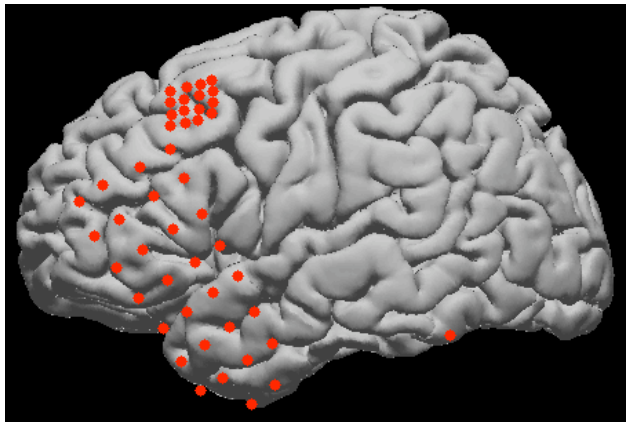


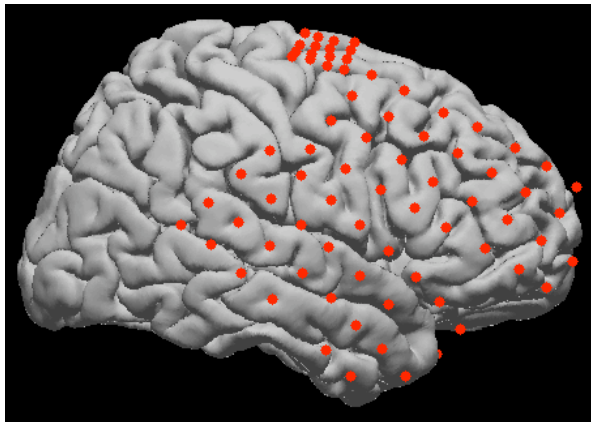
SU: Single-unit recording

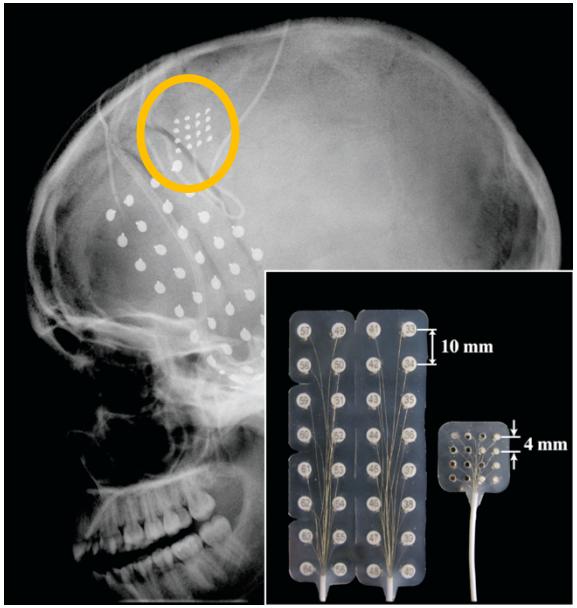
ECoG: Electrocorticography

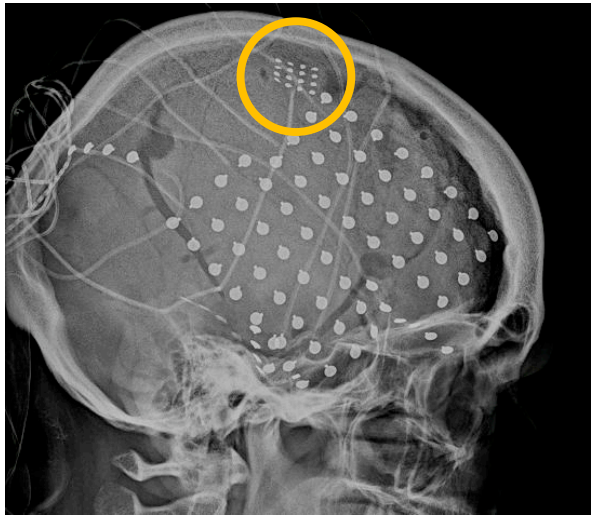
EEG: Electroencephalography

ECoG studies in epilepsy patients









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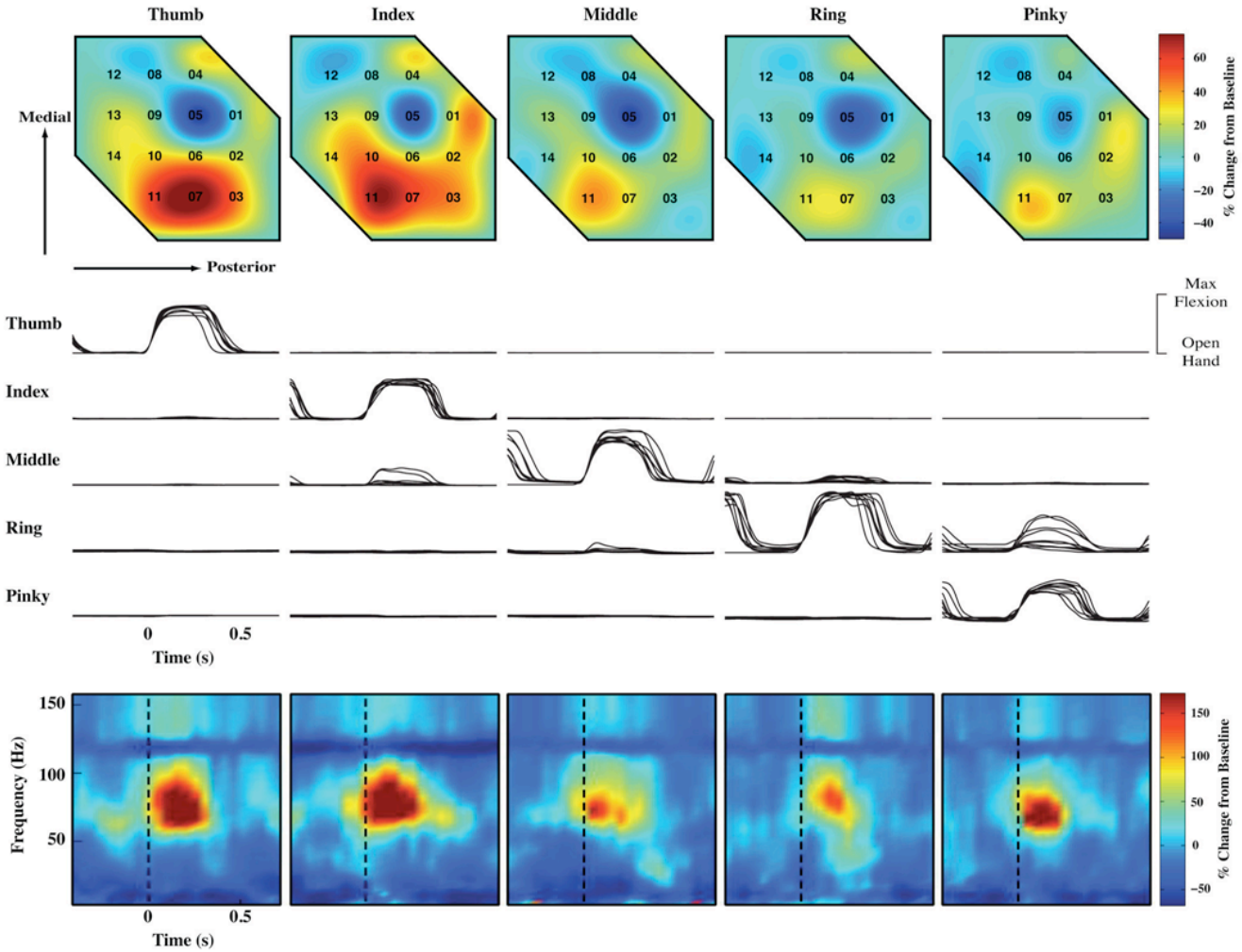
Modulation by finger movement

Spatial pattern of frequency response (60-120 Hz) during movement

Kinematics: PIP Joint Angle

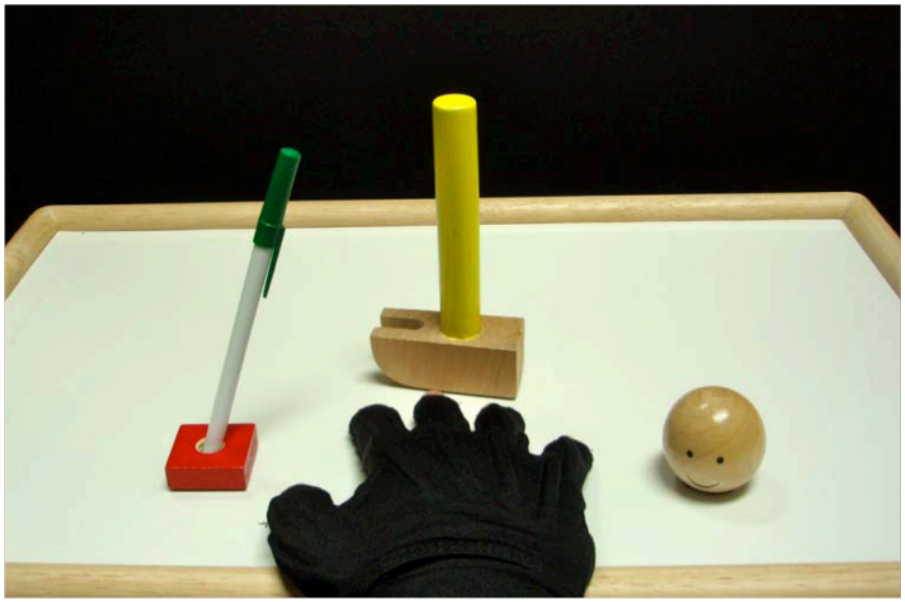
Time-Frequency Response: Channel 11

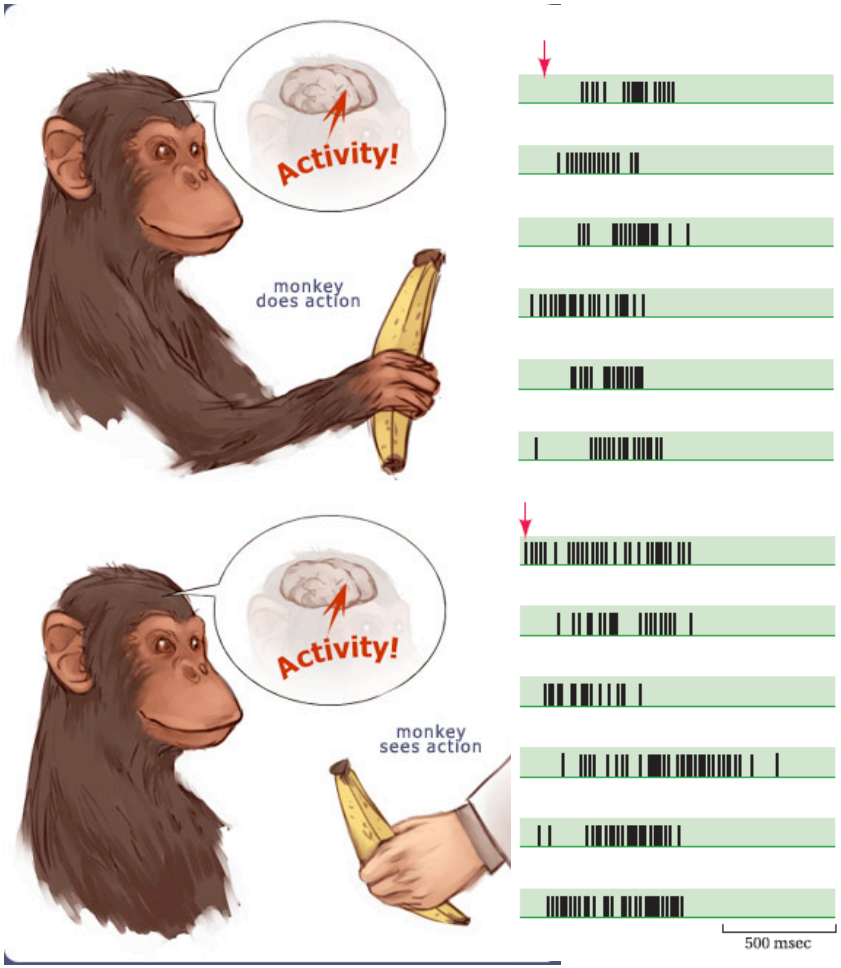


Offline Decoding Accuracy: 73%

Wang et al. 2009

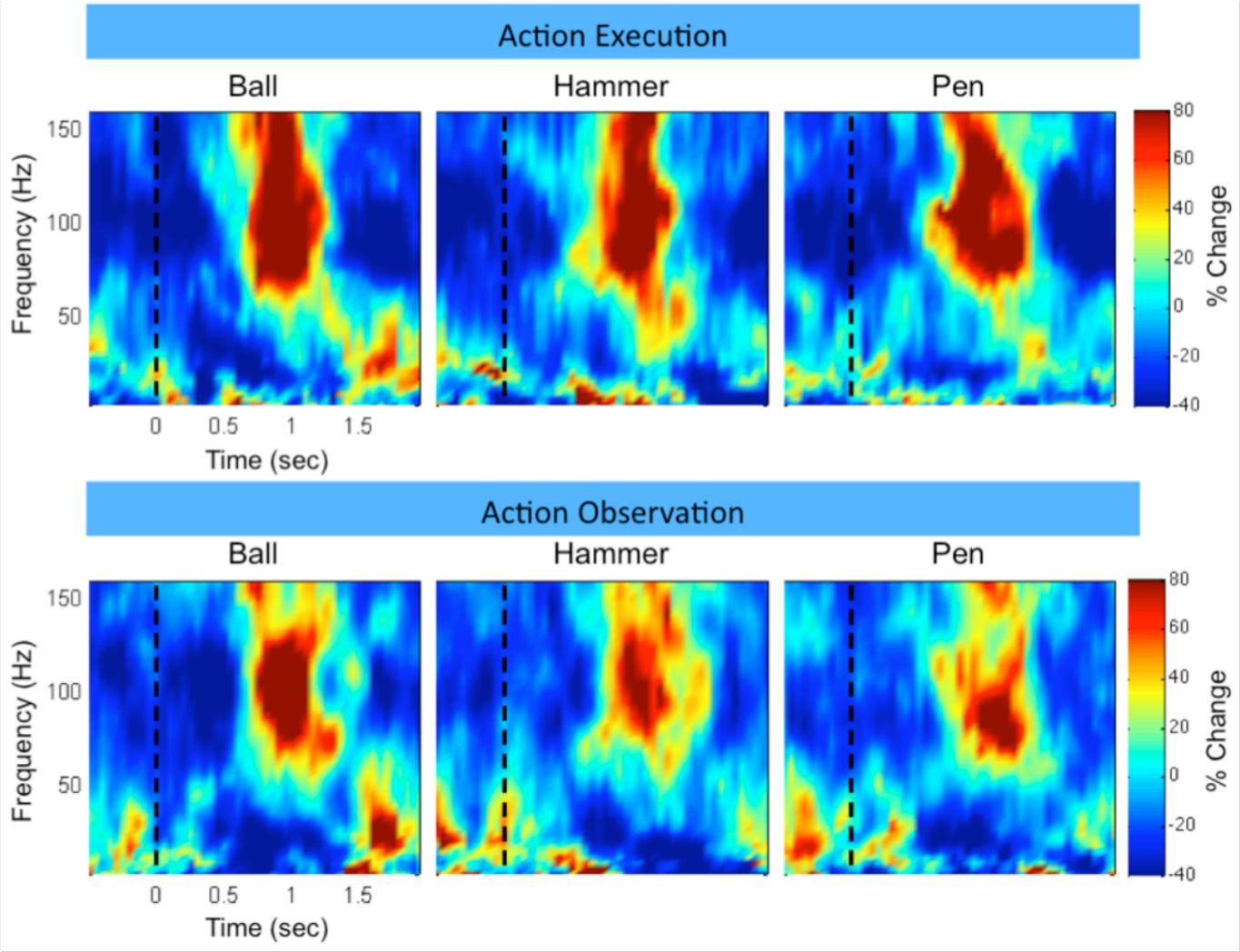
Grasping: execution & observation



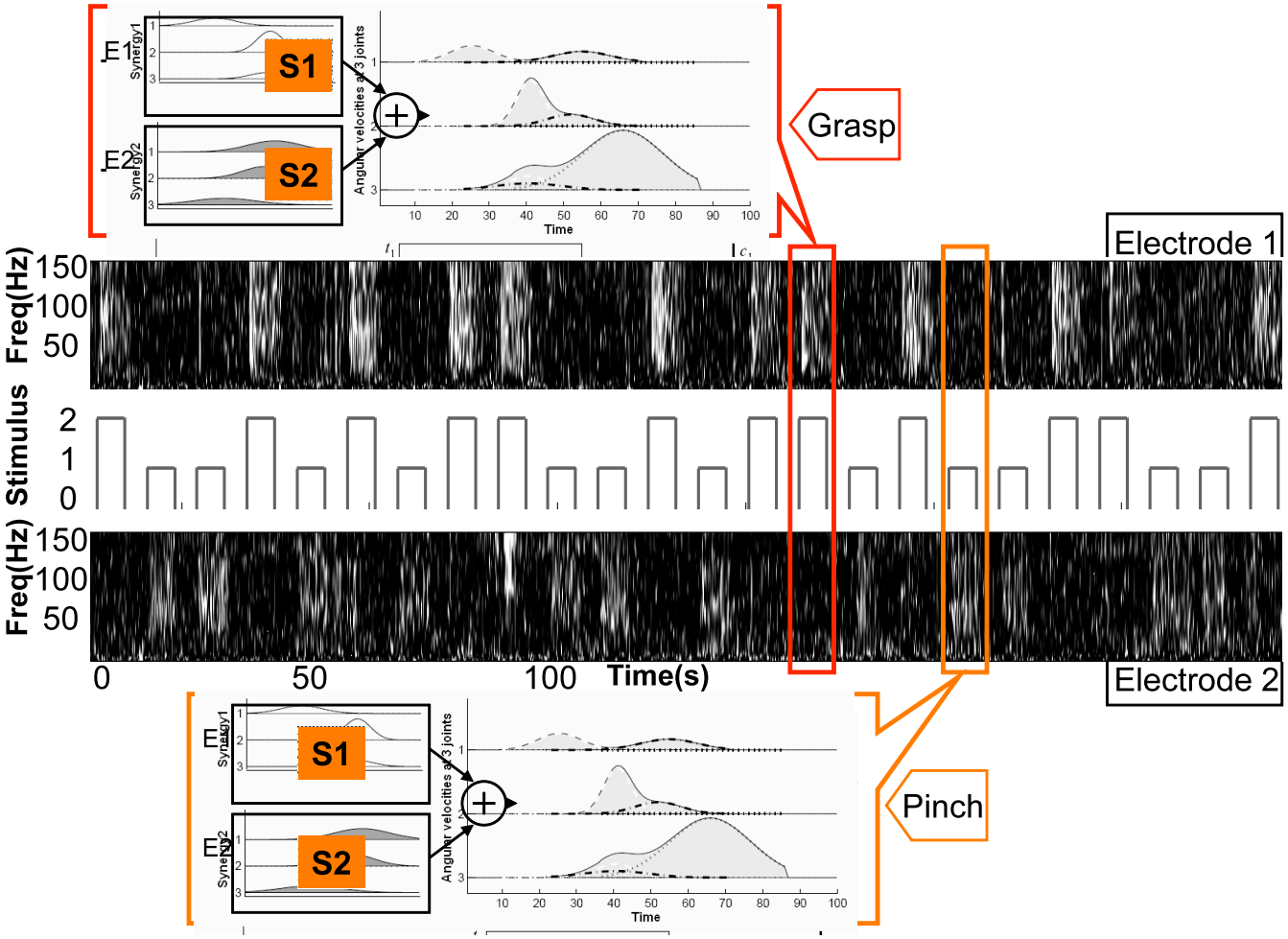


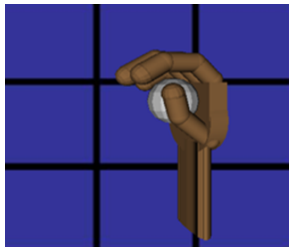
Fabbri-Destro & Rizzolatti 2008

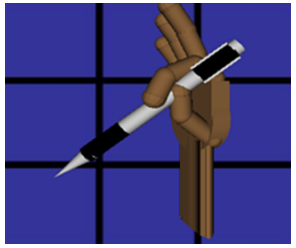
Congruent neural activity



Online control of hand grasping



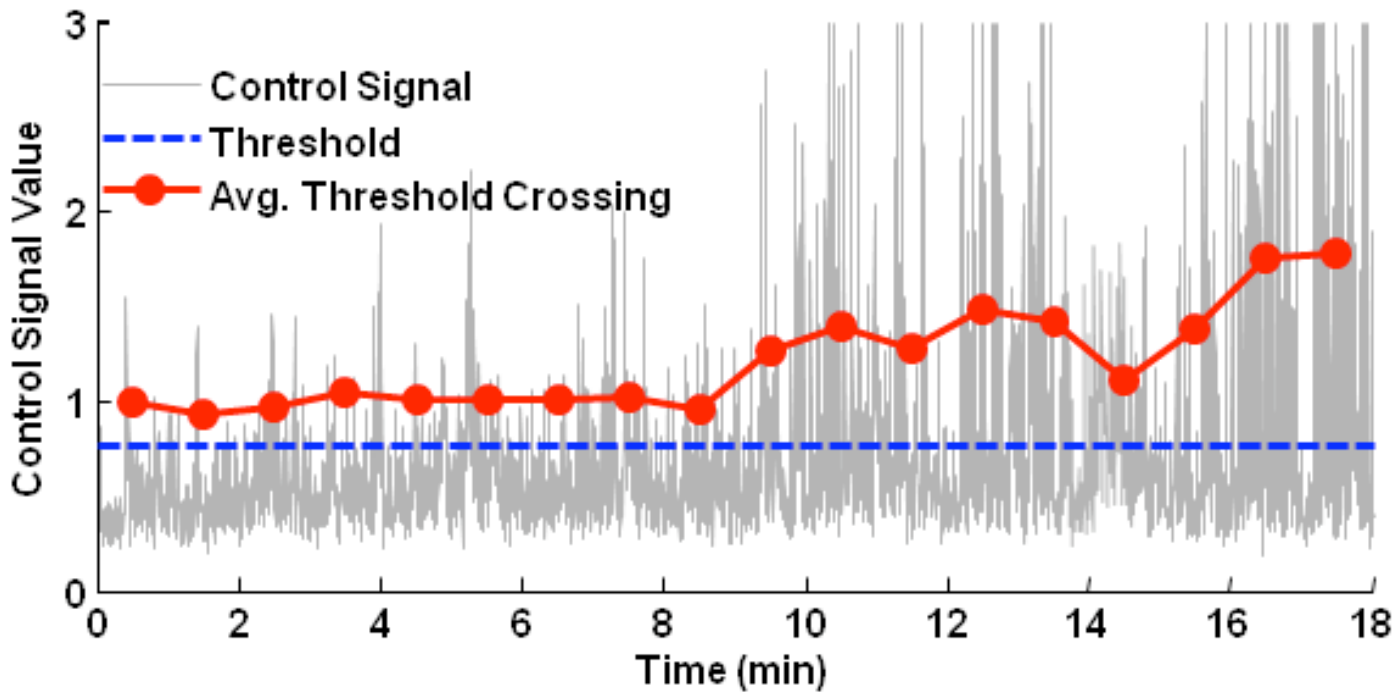




Vinjamuri et al. 2009

1-D control demonstration

Increased depth of modulation with BMI video game training

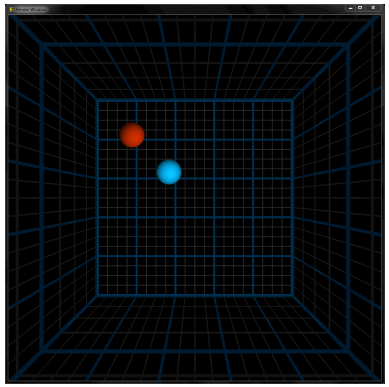


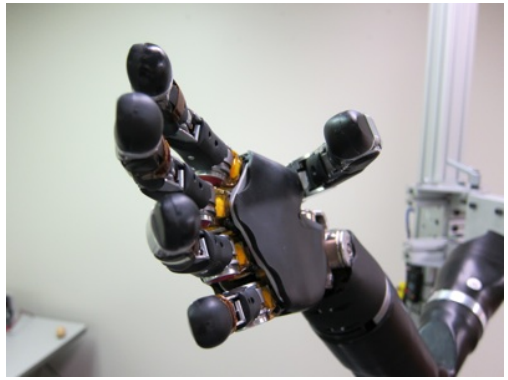
Transitioning to spinal cord injury

- Our research group (and others) have conducted ECoG studies in individuals with epilepsy, but there are limitations
- Current BMI work in individuals with disabilities includes non-invasive methods and BrainGate
- We proposed an ECoG-based study to take advantage of FDA-approved technology and allows for longer term testing in individuals with motor impairments
  - Will guide the development of a fully-implantable, permanent BMI system

Objectives

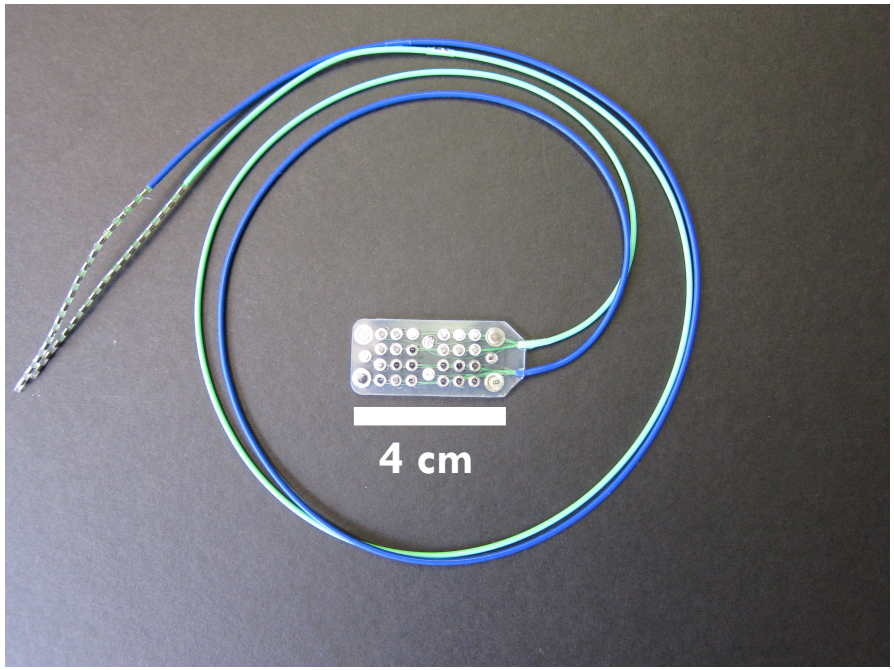
- Demonstrate successful control of an ECoG BMI
  - Derive the relationship between intended action and neural activity recorded with ECoG
  - Demonstrate successful control of a computer cursor and robotic arm using neural data recorded with an ECoG BMI



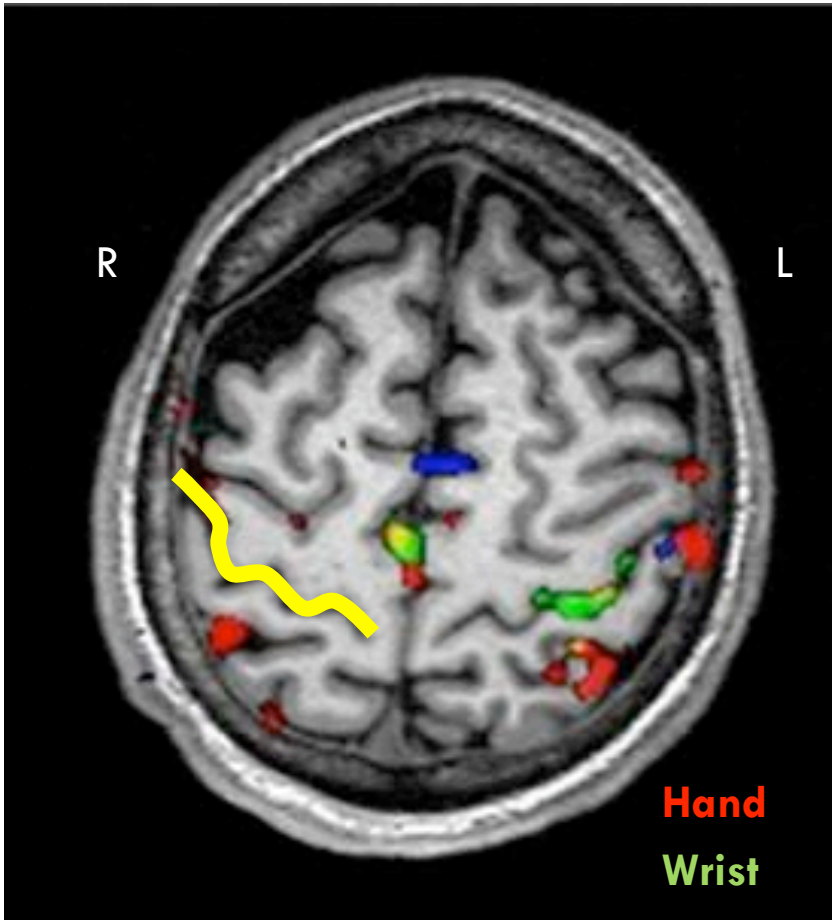


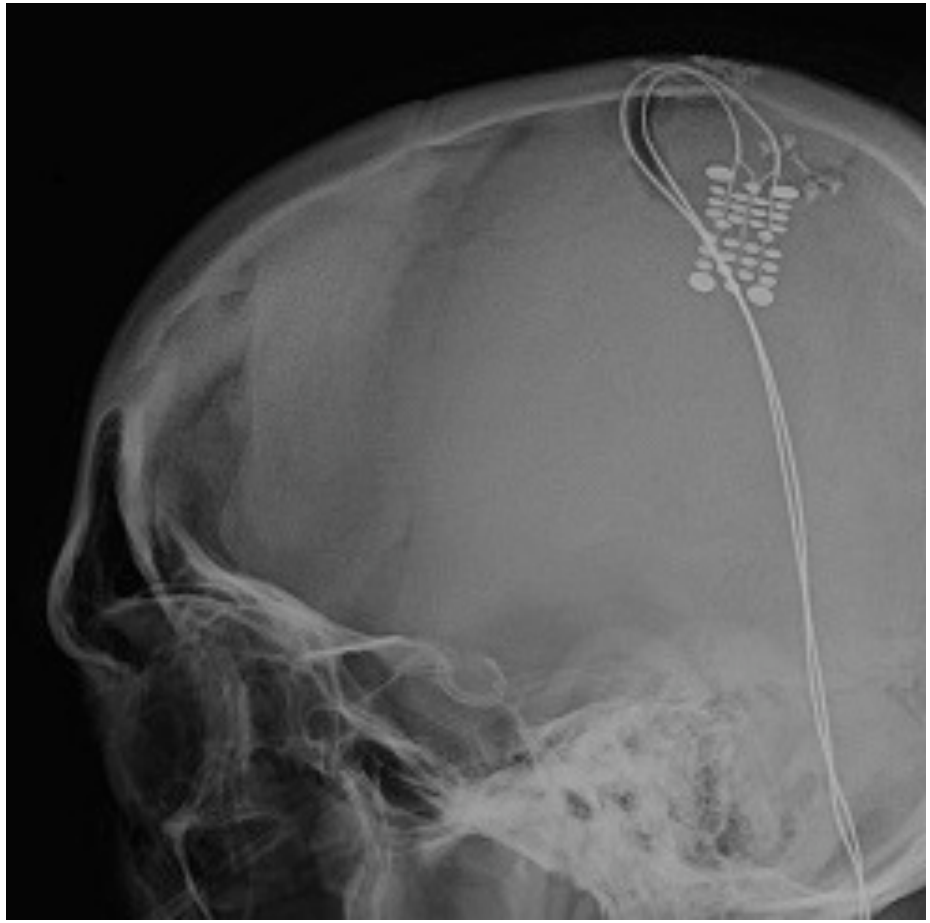
- 29 day study in a 30 year old participant, 7 years post-SCI, C4 ASIA A

MicroECoG recording

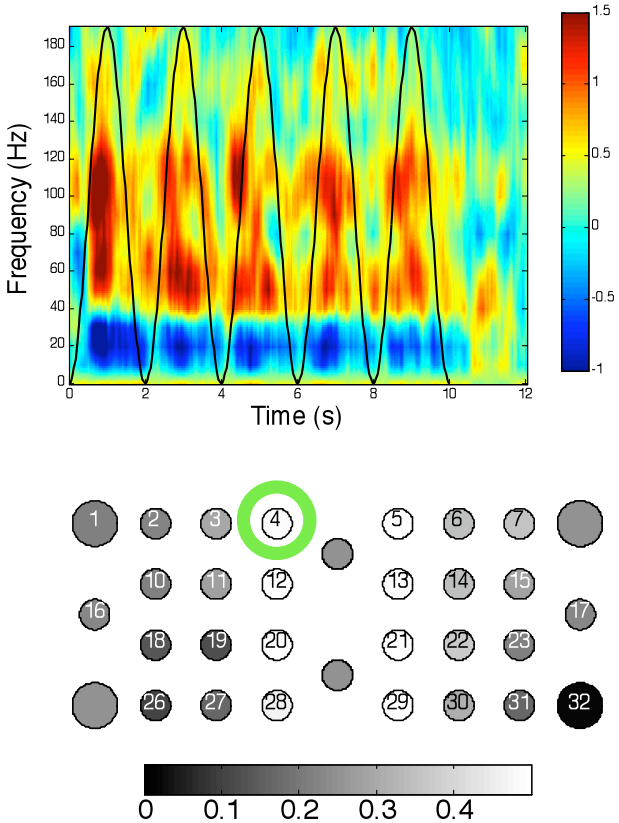


fMRI-guided implantation

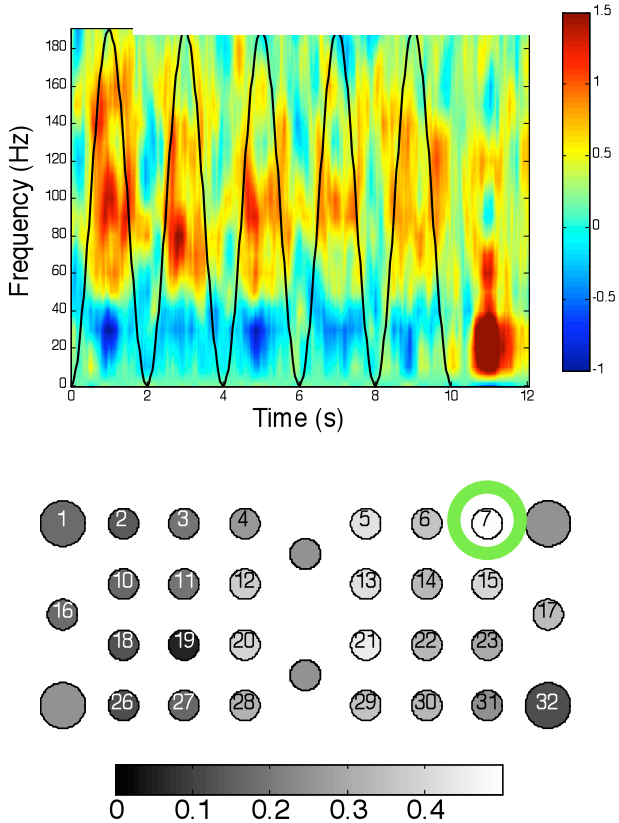




Imagery modulates motor cortex activity after SCI



Hand opening/closing

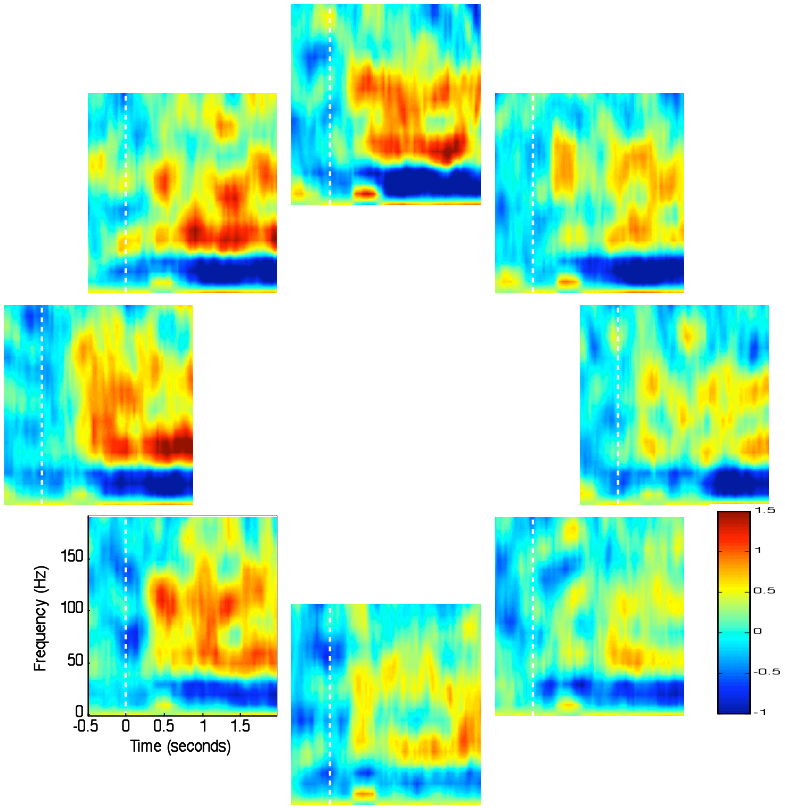


Elbow flexion/extension

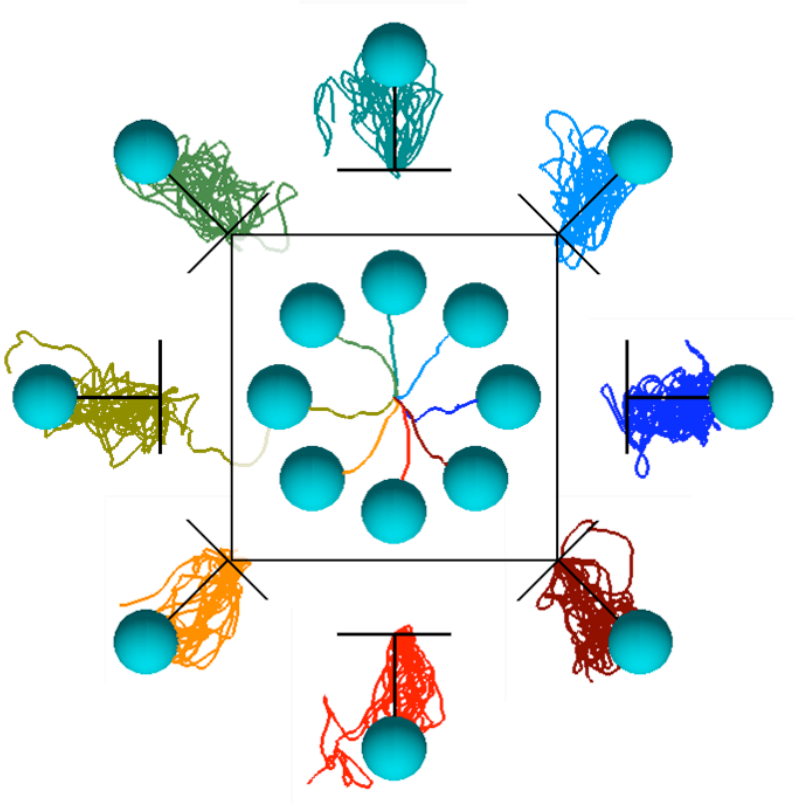
Action observation modulates motor cortex activity after SCI

2D Cursor Control

ECoG signal modulation and 2D cursor trajectories



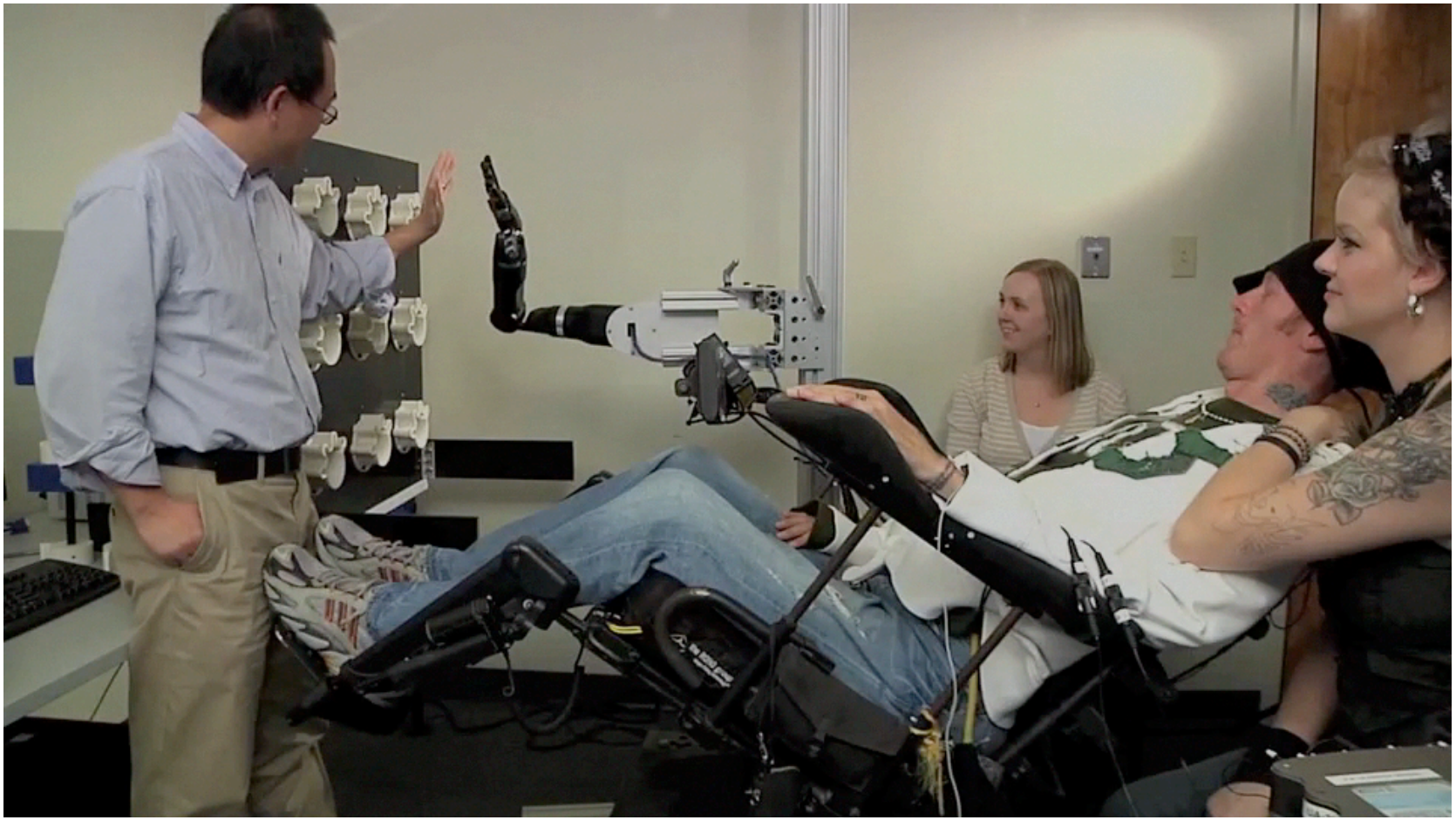
Channel 4



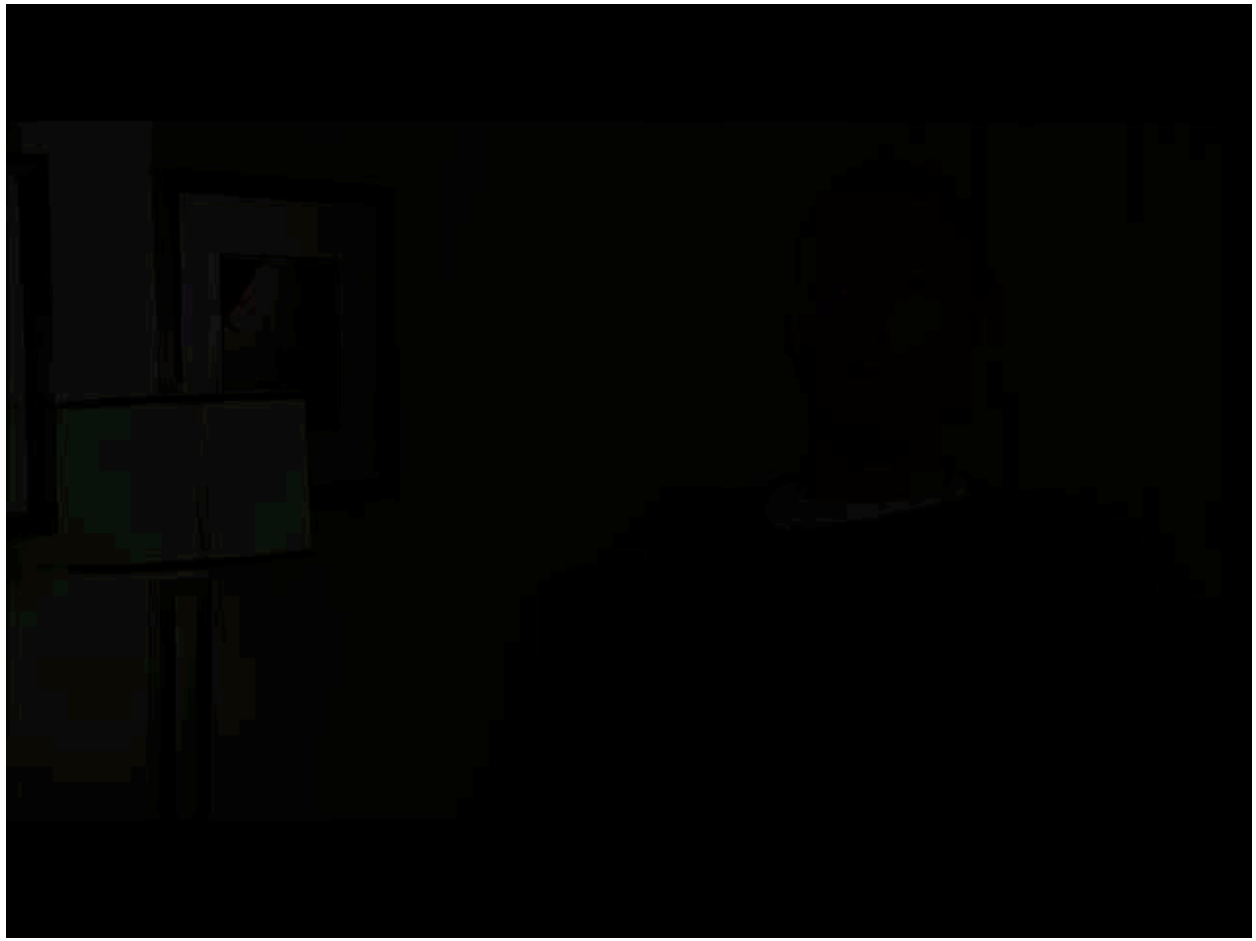
Average success rate: 87% over 176 trials

3D Cursor Control

3D Control of the MPL

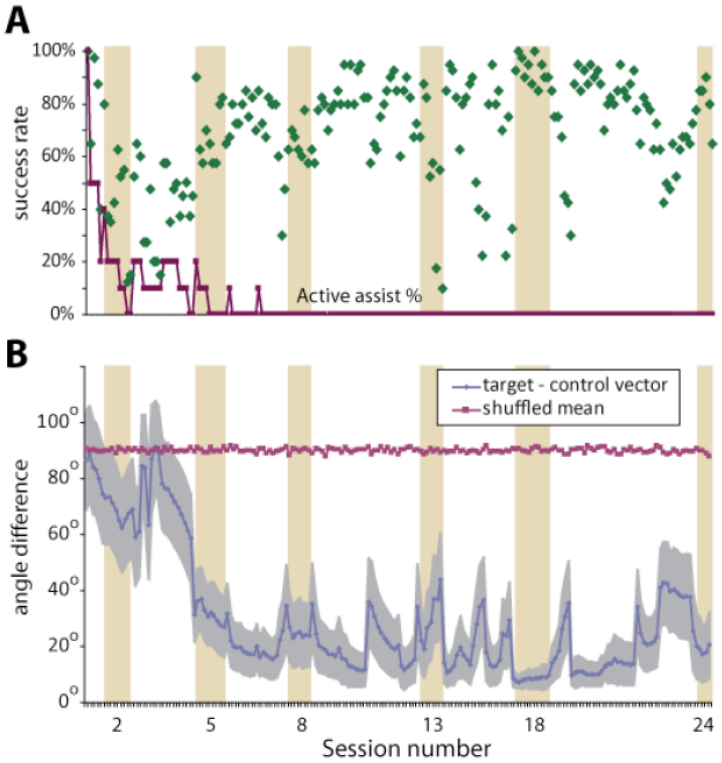


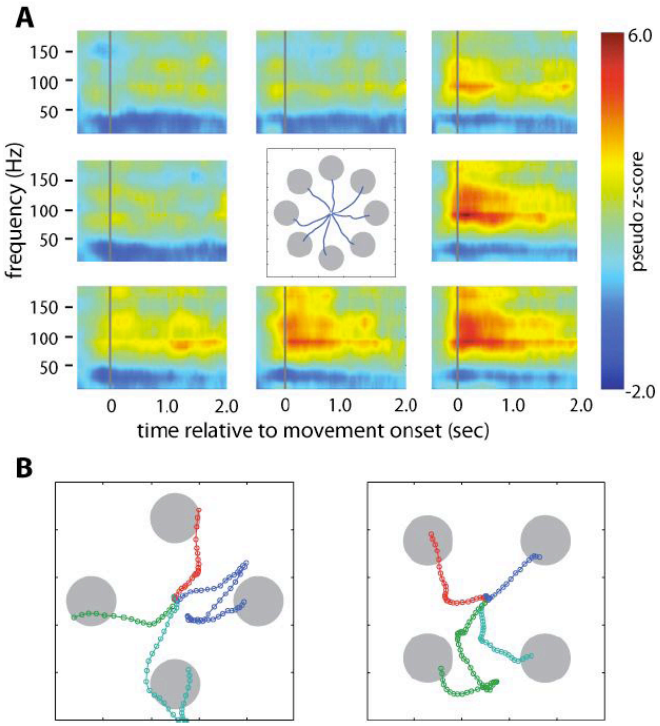
Meet our participant



What's next?

- Additional degrees of freedom
- Long-term studies

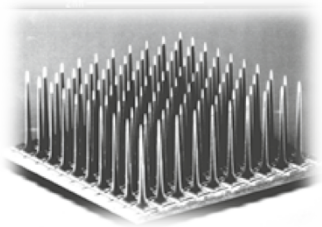


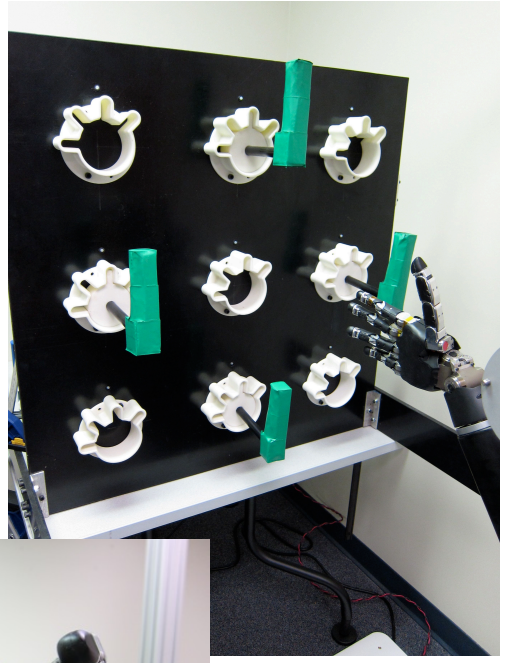


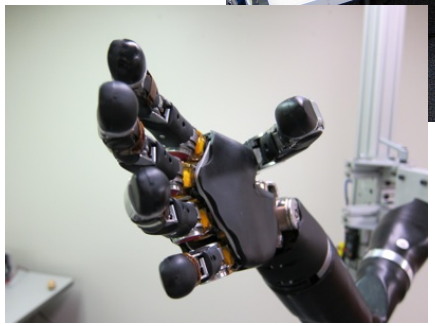
Ashmore et al. 2012

Microelectrode BMI

- Conducted under an IDE
  - Investigate the safety and efficacy of using NeuroPort Arrays for chronic recording of neural activity from the motor cortex of individuals with tetraplegia
  - Demonstrate that individuals with tetraplegia can learn to control external devices with using neural signals recorded with the NeuroPort Arrays







Modular Prosthetic Limb (MPL)

NHP control of a robotic arm

Conclusions

- We are at a point where we can begin long-term studies in persons with disabilities
- Consumers are interested
- There is so much to learn!
  - Engaged users, signal differences, training strategies
- Translation to a clinical product requires additional technological development and clinical data to support safety and efficacy of the BMI systems

Research Support

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- DARPA Revolutionizing Prosthetics Phase 3. Johns Hopkins University. SPAWAR Contract No N66001-10-C-4056 20100630.pdf
- NIH/NINDS, Grand Challenge on Optimal Cortical Control of DARPA Revolutionizing Upper-Limb Prosthetics (3R01NS050256-05S1)
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Thank you!

Questions?