Understanding the Neural Basis of Volitional State through Continuous Recordings in Humans

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March 6, 2018

Outline

1. Volition in it's simplest form – decoding motor activity
   -- Brief overview of decoding motor activity in patients with tetraplegia / early decoding of language
   -- examples of current capabilities
   -- future, technical directions
   -- the practical issue of larger scale volition in development of brain computer interfaces

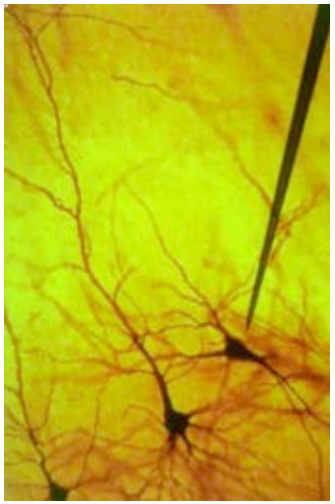
2. Deconstruct aspects of volition in a reductionist framework

3. Moving toward clinically relevant continuous analysis of volition state – experimental approaches

4. Summary and implications

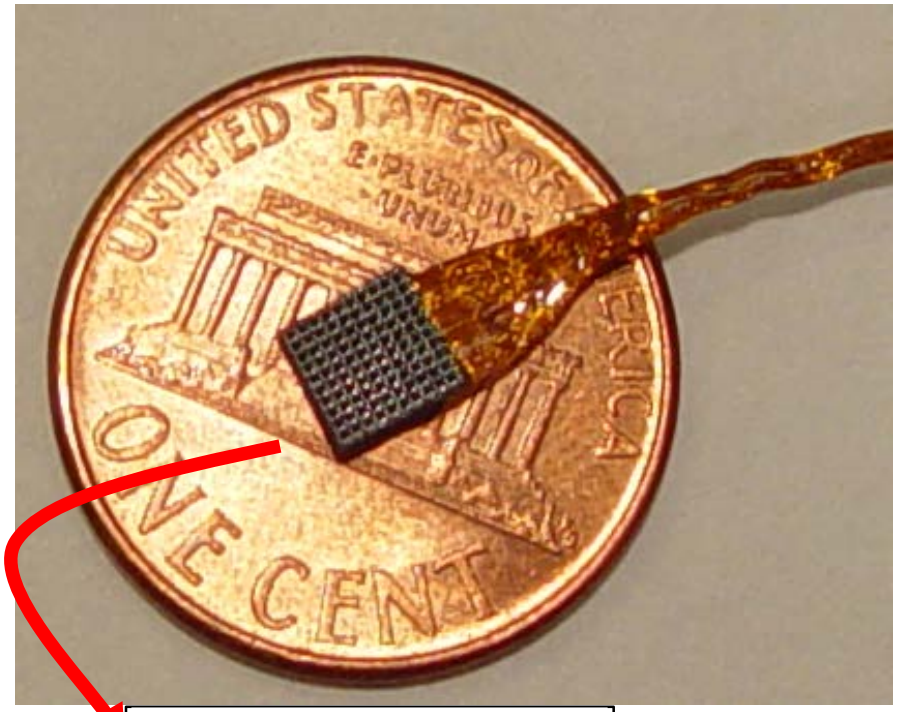
Decoding motor activity relies on intracortical recordings of neuronal activity

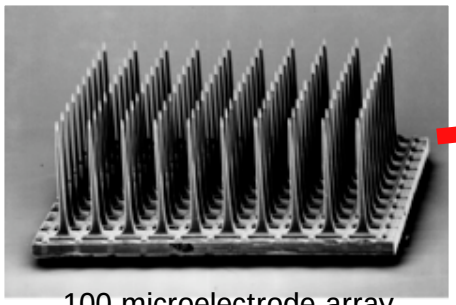
Available signals:
Spikes (APs)
Multi-unit activity
LFPs



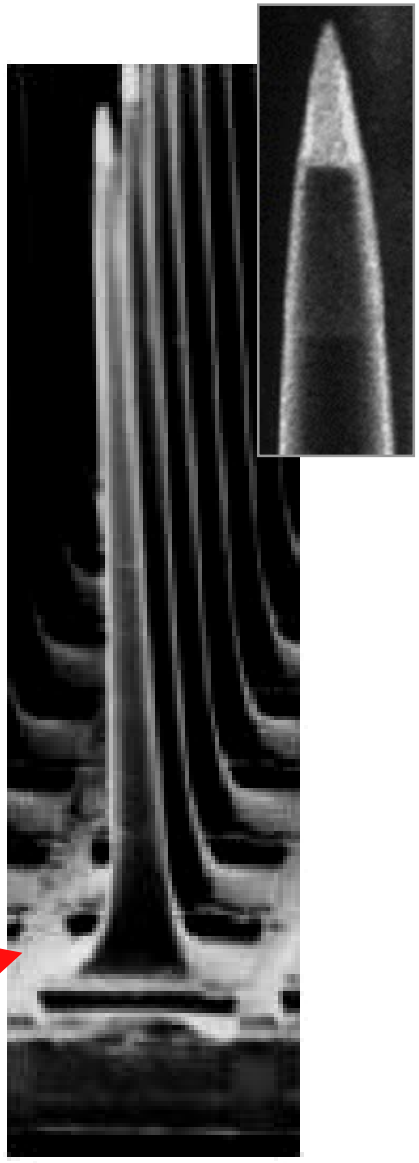
Inventor: Richard Normann
U. Utah
Developed by Donoghue lab
Cyberkinetics, Inc.

100 microelectrode array

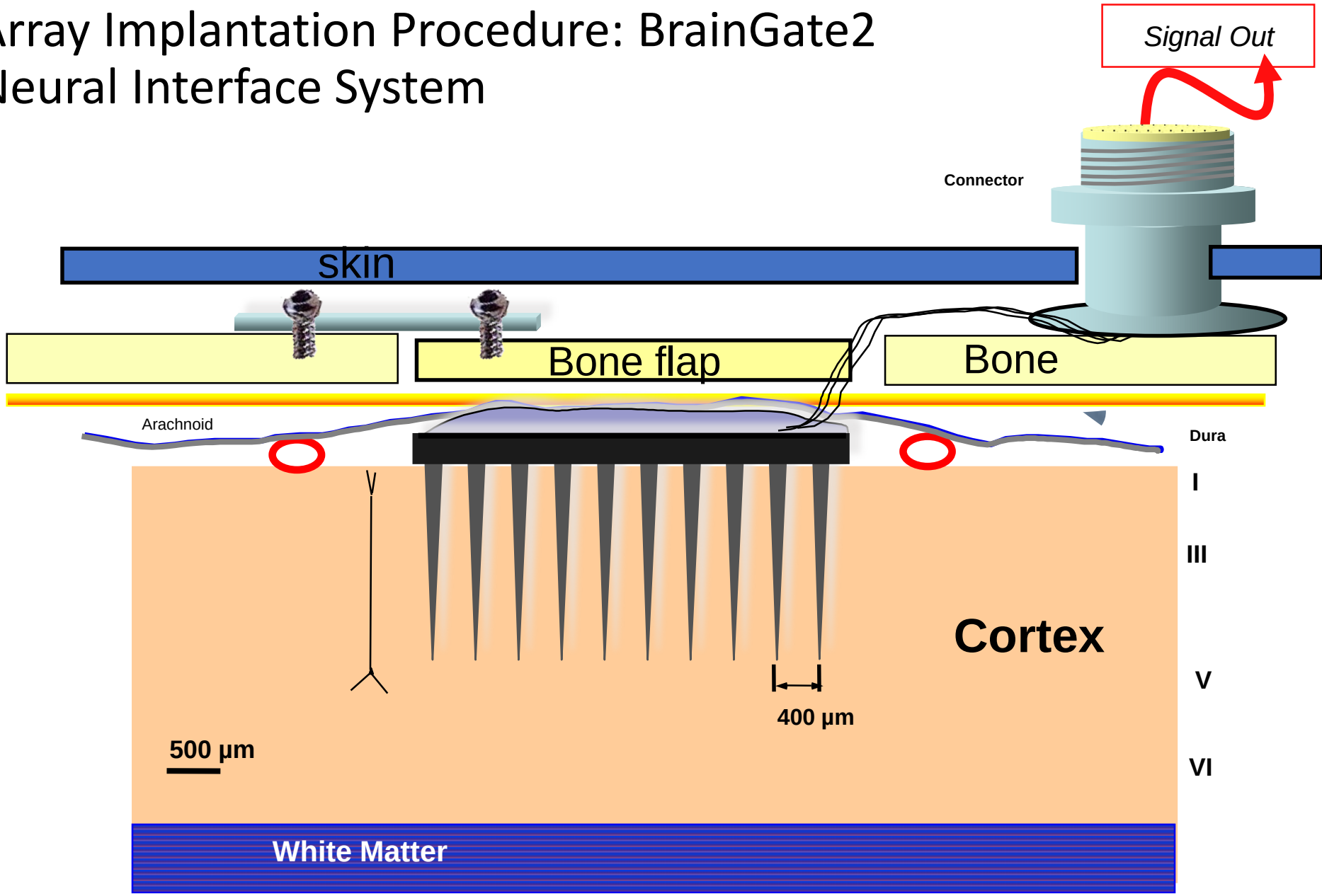




100 microelectrode array



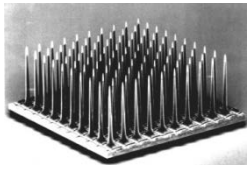
Array Implantation Procedure: BrainGate2 Neural Interface System

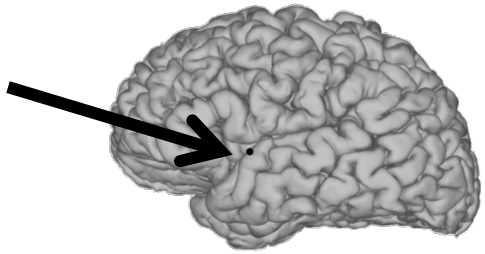


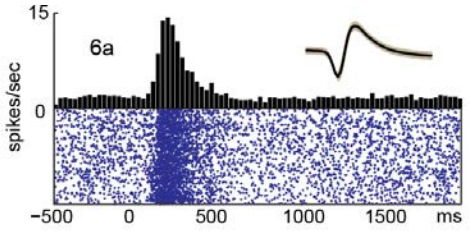
J. Donoghue and L. Hochberg

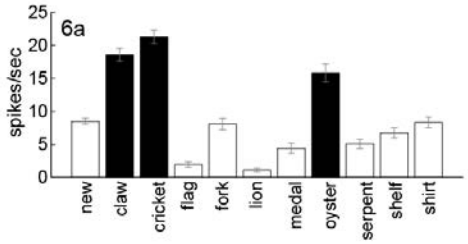
Single unit ‘decoding’ of language processing

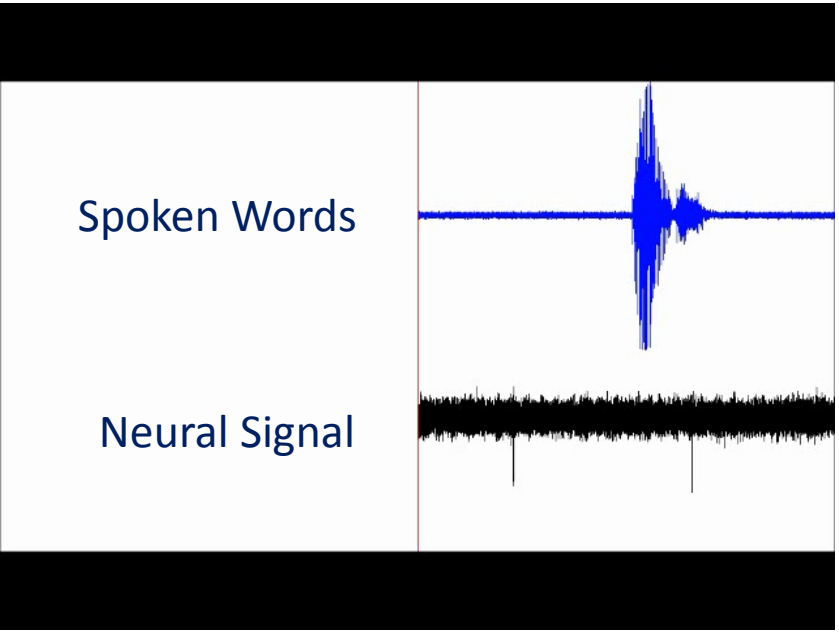
Single neurons in ~layer IV of superior temporal gyrus are ‘tuned’ to specific words / phonemes

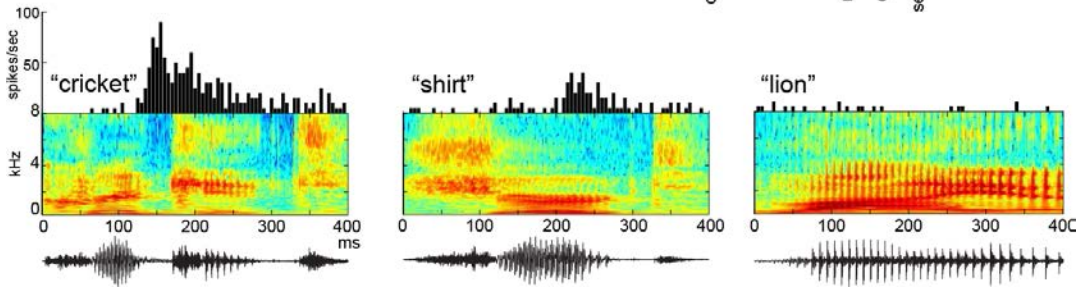








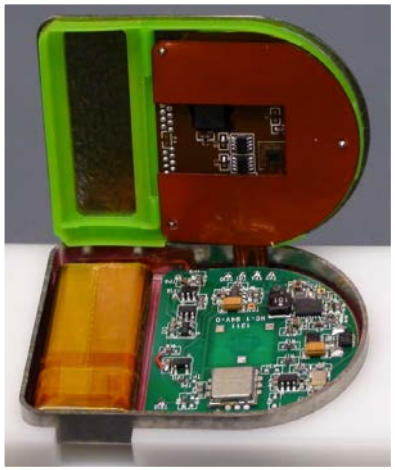




No significant firing to non-word sounds, tones and decreased firing to time reversed words (not shown)

Chan, A., et al, *Cerebral Cortex,* 2014

Device development: Fully implanted, wireless system to allow for continuous, real-time decoding



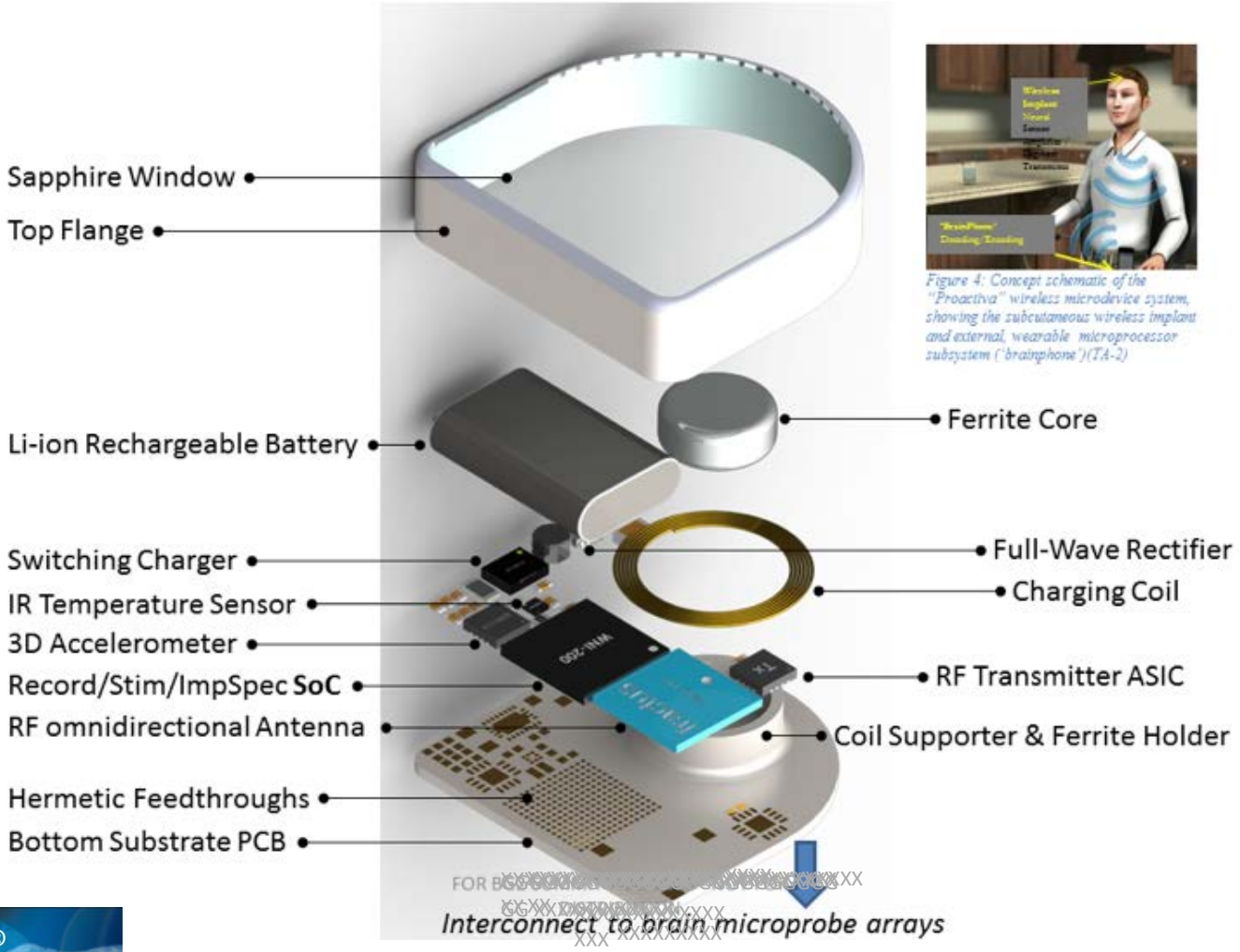


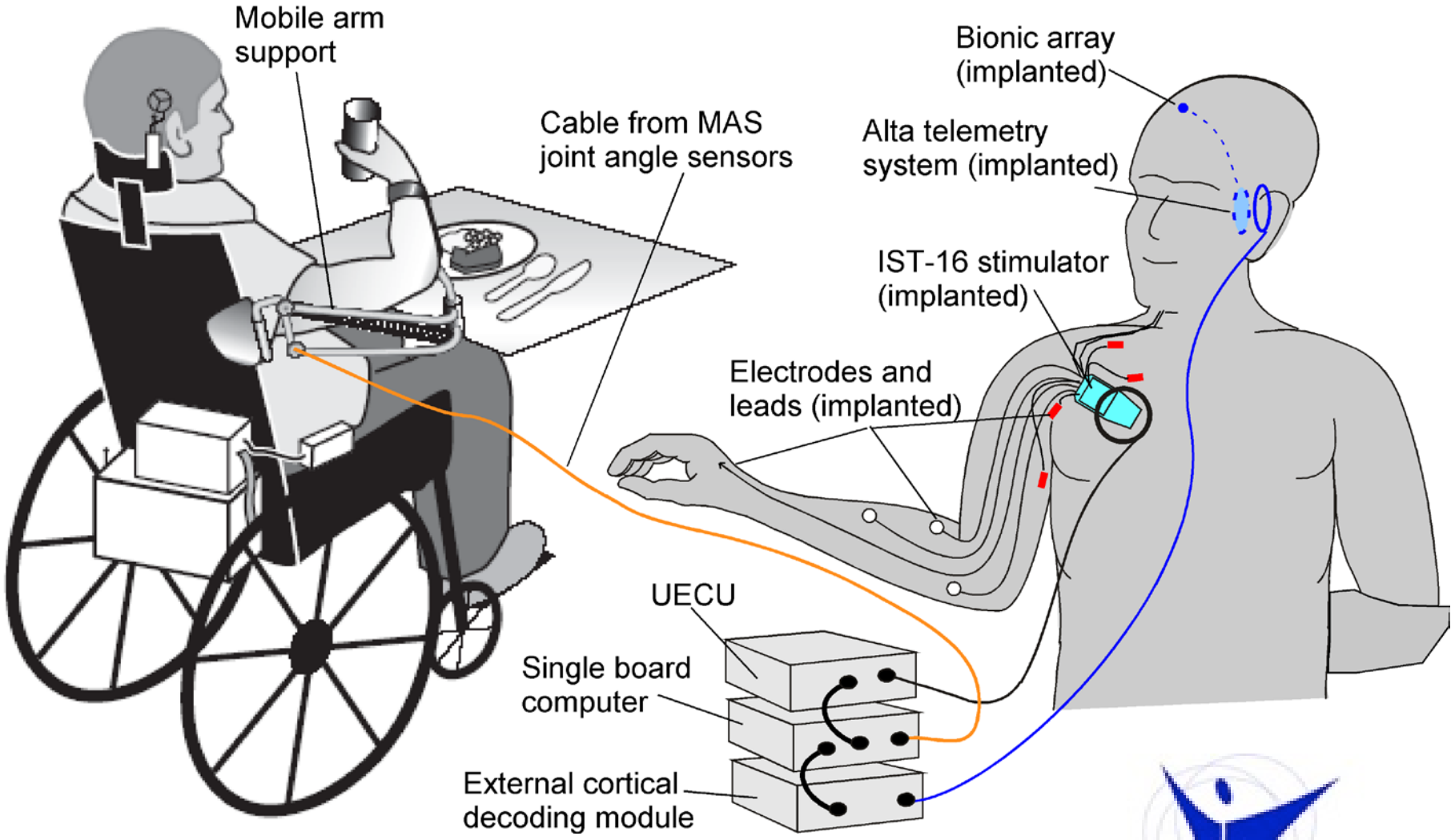
Figure 4: Concept schematic of the "Proactiva" wireless microdevice system, showing the subcutaneous wireless implant and external, wearable microprocessor subsystem ('brainphone')(TA-2)

THE BRAIN INITIATIVE®

A. Nurmikko et al, in *Neurobionics* ed. R.L. Shepherd (2016)

BRAIN UH2-NS095548, Hochberg and Nurmikko

Device development: Integration into system which can allow for direct muscle activation



Kirsch/Peckham/Taylor – Case Western

Conceptual development: Getting to real time systems in everyday life

Current approach = task based in controlled test environment

-- forced choice (at best, menu of options)

Can we move away from these constraints?

-- What does the person want to do in larger context?

-- Enable activities in natural settings

-- Allow participant to switch what they are doing at will

= knowing volitional state (in a very reduced sense – vs. a more legal or even philosophical sense)

Conceptual development: Getting to real time systems in everyday life

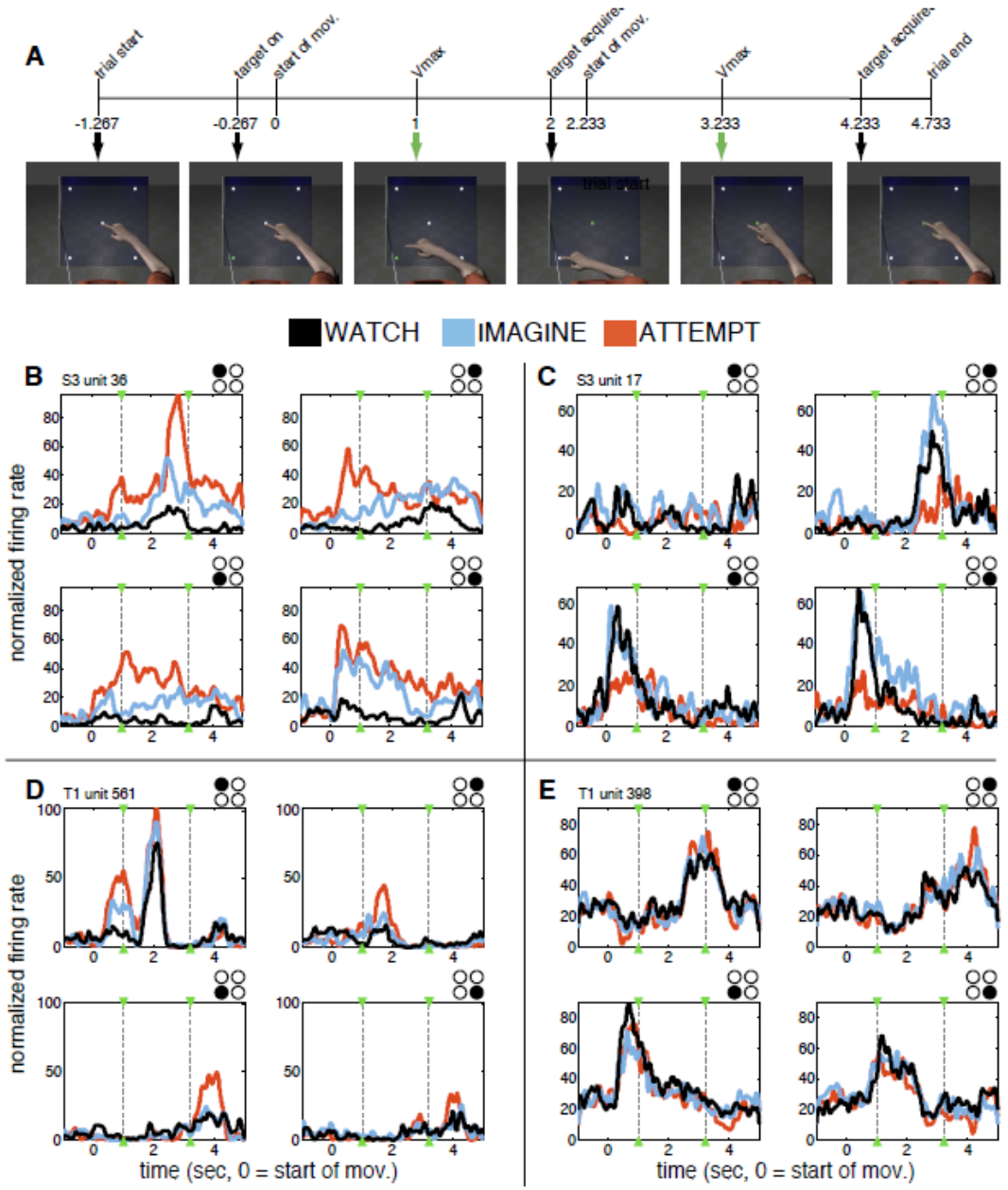
First approach; explore neural differences between different, defined volitional conditions

Watch – participant watches a specific movement
(represents passive / receptive activity)

Imagine – participant imagines performing the same type of movement
(represents internal thought)

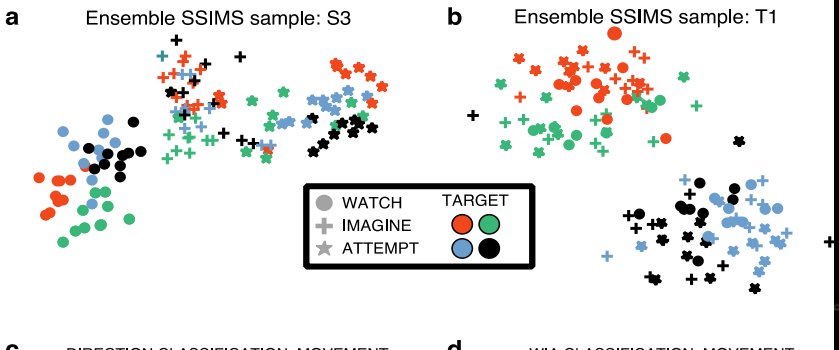
Act – participant tries to perform the same type of movement

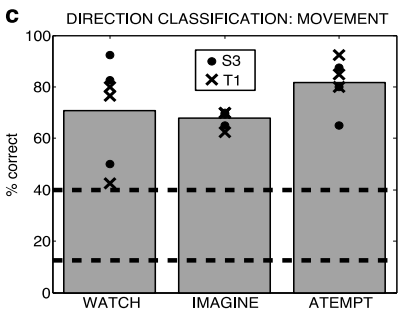
Single neurons in motor cortex encode different volitional states in the WIA

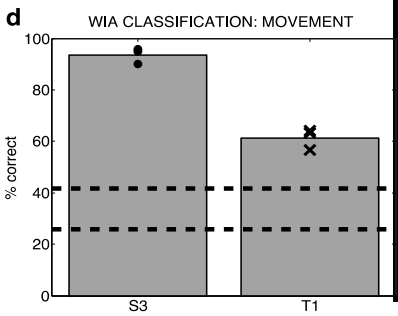


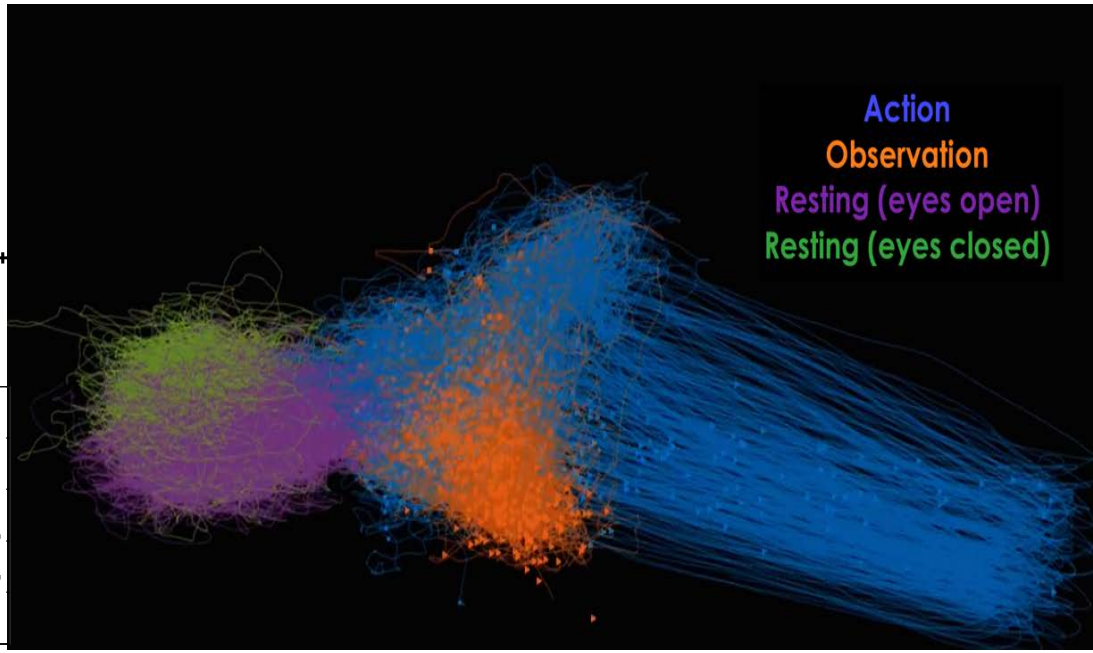
Vargas-Irwin, et al, in submission

Decoding volitional state (at the WIA level) using dimensionality reduction techniques









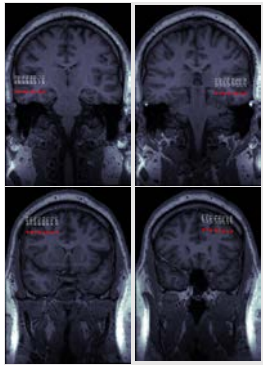
Cash, U01-NS098968, with MGH, Brown, BIDMC, BWH and Vargas et al, submitted

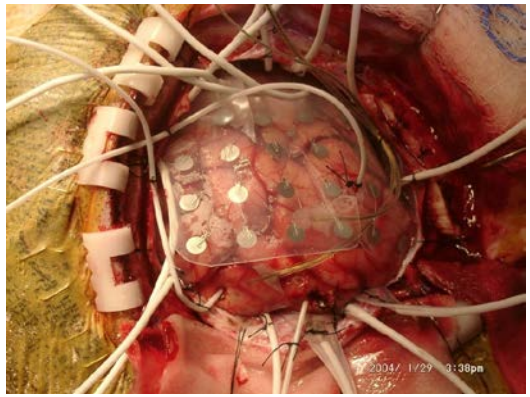
Volitional states outside of motor area and in continuous data - participants with epilepsy

~ 3 million people in US have epilepsy (a propensity to suffer recurrent seizures)

~ 30% of these patients continue to have seizure despite medical therapy.

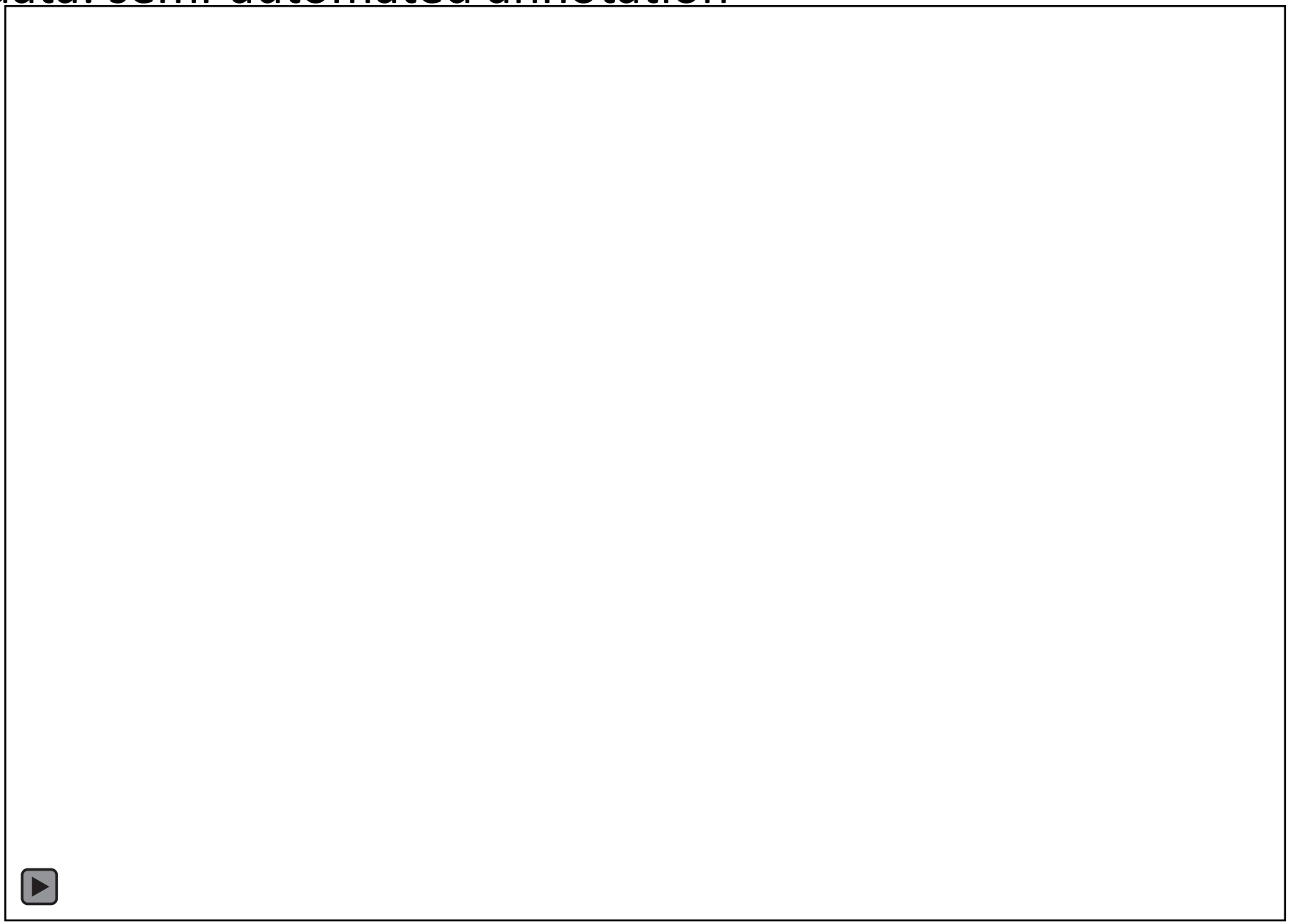
-- to better understand their epilepsy and determine a possible surgical approach to curing their epilepsy some patient come into the hospital for days –> weeks of monitoring using electrodes that are placed inside the skull



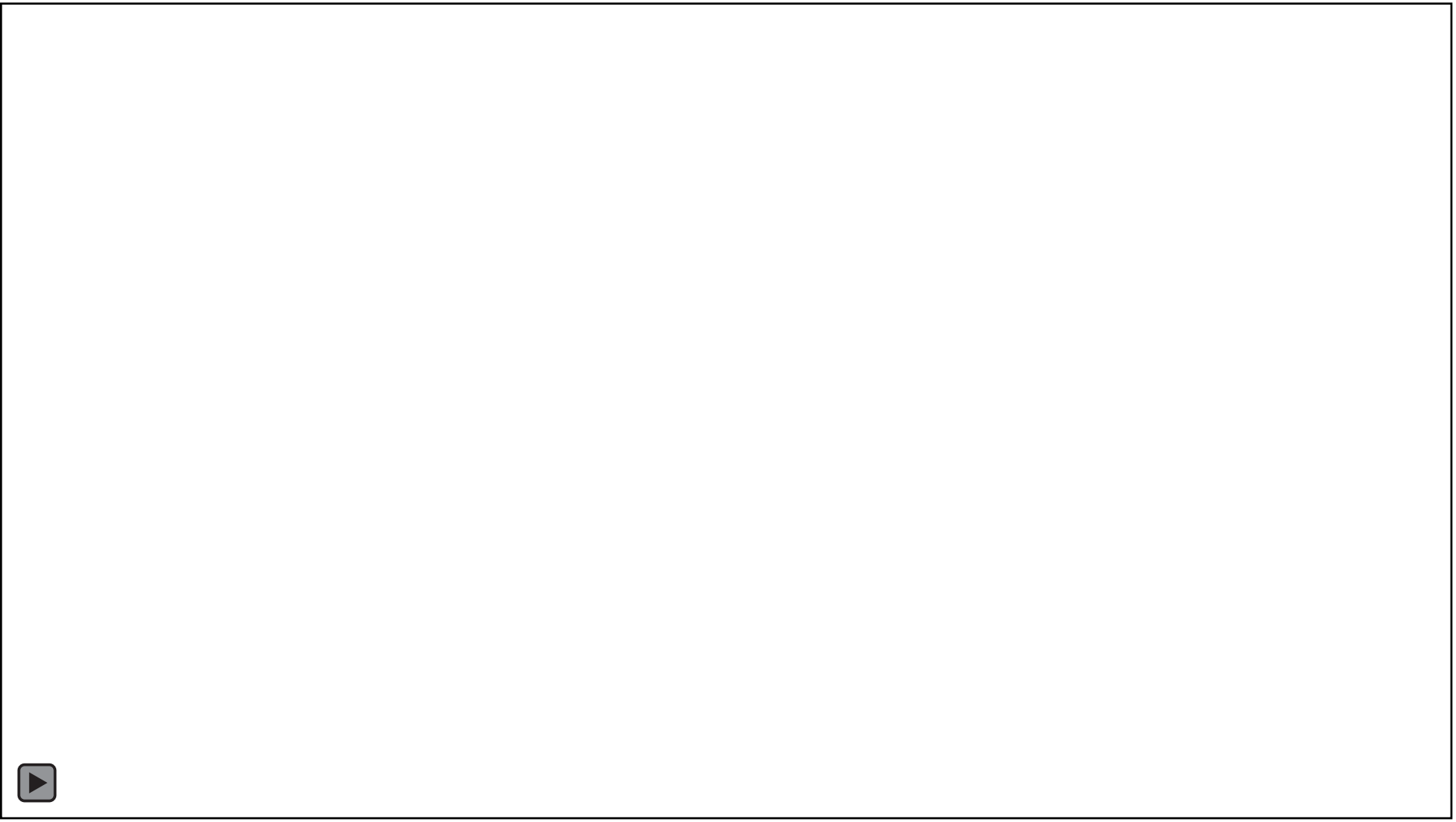


-- Opportunity to explore detailed questions of neurophysiology in semi-natural environment (continuous, multiple types of interactions / states)

Understanding volitional (motor) states by using spontaneous data: semi-automated annotation



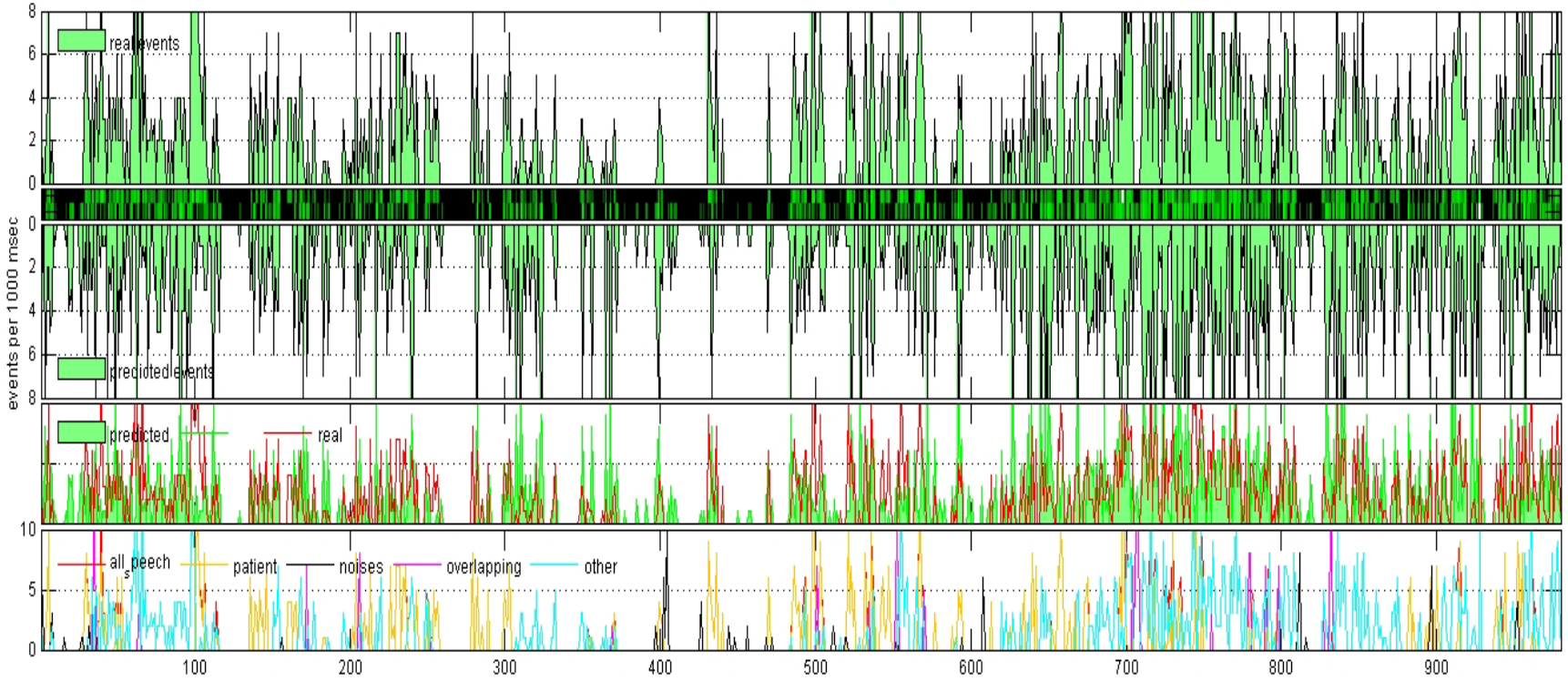
Understanding volitional (motor) states by using spontaneous data: semi-automated annotation



Cash, U01-NS098968, with MGH, Brown, BIDMC, BWH

Understanding volitional (language) states – Listen, Think, Respond (LTR)

Language equivalent for the WIA motor task which ‘forces’ a separation between different volitional states using a structured conversation and examination of ongoing, spontaneous conversation.



SVM based decoding of a neural recording (grid over dominant hemisphere) matched to a manually annotated conversation shows preliminary evidence that we can use neural data to separate heard and spoken speech – now working on decoding content.

Cash, U01-NS098968, with MGH, Brown, BIDMC, BWH

Understanding the Neural Basis of Volitional State
Spontaneous Data – Summary

Motivation driven by desire to move toward better therapeutic interventions for people suffering from neurological injuries.

Early stages of decoding cognitive function at any level let alone high level, abstract cognitive function … especially volitional aspects (and the related / overlapping issues of will, intent, etc.

… and especially in natural settings.

However, beginning to develop the technical capabilities to monitor multi-level neuronal information

-- at a wide scale (across the brain or at least in multiple areas)
-- at high temporal resolution
-- for long periods of time (indefinitely) and continuously
-- with increasingly sophisticated analytic approaches that can handle large sets of multi-dimensional data (see also earlier panel on big data) at the level of the individual (rather than group statistics).

Invasive / research

Understanding the Neural Basis of Volitional State
Spontaneous Data – Summary

Multiple invasive techniques are already in use and expanding rapidly:

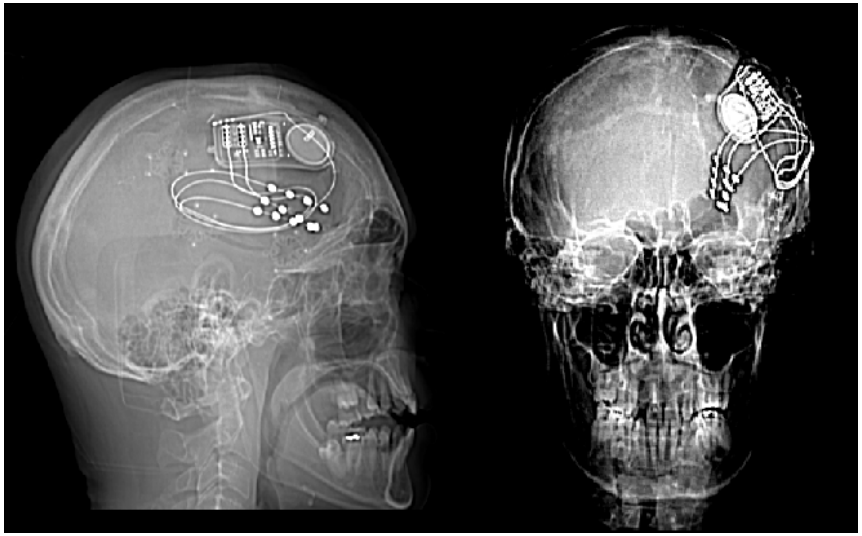
Deep Brain stimulation for movement disorders / OCD, etc.

-- chronically implanted systems

-- increasingly designed to record, decode, stimulate

Responsive Neurostimulation Systems (RNS, Neurpace, Inc)

-- Record, categorize, stimulate – for epilepsy control



Newer, minimally invasive approaches – wearable systems, subdermal systems , etc.

Understanding the Neural Basis of Volitional State
Spontaneous Data –Implications

Increasing technologies allowing for continuous monitoring of brain activity – expanding set of data which can be folded into the legal environment (adding to genetics, imaging, etc).

But, these embryonic stage neuroscientific forays into questions of volition, intent, etc. do not (yet) map onto legal frameworks.

Prospective approaches – not clear how to use them within justice system

-- As discussed, recovery of memory, past volition etc. is tremendous challenge.

-- Use in prediction also fraught.

-- Use as part of 'prevention', especially when coupled to neuromodulation approaches (e.g. Gunduz talk) opens major ethical, practical, legal issues and might be near horizon issue to tackle.

Much larger question of policy – to what extent can 'machines' be used to make decisions.

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Interdisciplinary Research Team

Engineering

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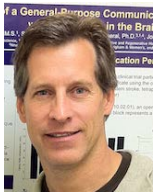
Systems Engineering

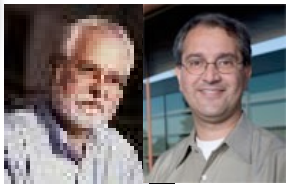


John Simeral

Neurology

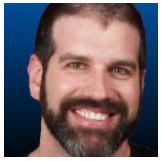
Leigh Hochberg

Neuroscience



John Donoghue,
Krishna Shenoy

Program Manager



David Rosler

Neurosurgery

Emad Eskandar, Jaimie Henderson,
Jonathan Miller, Jennifer Sweet

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Michael Burkhart
Margy Bowker
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David Brandman
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Chethan Pandarinath
Anisha Rastogi
Dave Rosler
Jad Saab
Nick Schmansky
Ben Shanahan
Sergey Stavisky
Beth Travers
Wilson Truccolo
Carlos Vargas-Irwin
Marco Vilela
Ben Walter
Frank Willett
Kaitlin Wilcoxen
Daniel Young

Collaboration for U01 Multisite Volition Project

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Garth Rees Cosgrove
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Brown University (BrainGate)

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David Rosler
Wilson Truccolo
Thomas Serre
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Jaimie Henderson
Krishna Shenoy
Christine Blabe

Case Western University (BrainGate)

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Benjamin Walter

Funding: NIH/NINDS