Neural Interfaces
An Update in Rehabilitation Applications

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Cochlear Implant

- Prototypical neural interface
- 324,000 people implanted as of 2012
- If implanted by age 3, saves $30-50k on special education
- Increasing electrode density along the tonotopic cochlea (1-50 electrodes), waterproof, stereo
Subretinal electronic chips allow blind patients to read letters and combine them to words


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Timeline

1875 – Richard Caton first recognized electrical activity of the brain
1929 – Hans Berger father of EEG
1970 – Real time Detection of Brain Events in EEG - Jacques Vidal
1978 - First BCI for the Blind
1990’s – EEG, months to control a computer cursor ~100 characters per hour
2002 – Dobelle implanted a 68 electrode visual prosthesis on Jens Neumann
2005 – Monkey feeds itself with Invasive BCI and robotic arm, 61% accurate
2007 – BrainGate 2
2009 – Toyota/Riken EEG Wheelchair, 95% with 1 ms latency
2009 – Rise of mass produced commercial EEG BCI
2013 – 7 Degree of Freedom control of JHU APL Arm

Yang Dan et al. 1999 - Implanted in the thalamus of cats
Neural Interfaces

Eponyms:

BCI - Brain computer interface
BMI - Brain machine interface
MMI - Mind-machine interface
DNI - Direct neural interface
STI - Synthetic telepathy interface
NP - Neuroprosthetics
Convergence

- Neuroscience development
- Fast, low power and inexpensive computer processing
- Advancements in engineering and microfabrication
- Vision
- Hearing
- Taste
- Balance
- Proprioception
- Cutaneous
- Sympathetic
- Internal (memories, cognition etc.)
Consequences of Paralysis

Primary - loss of muscle control

Secondary – Atrophy, contracture, pressure ulcers, CV disease, GU and Resp. infection.

Tertiary – lost productivity cost, direct long term care costs

High level SCI = greater need for replaced functions and fewer available control options
2004
Priorities of Patients with SCI

Jennifer S. French, MBA, Kim D. Anderson-Erisman, PhD, Maria Sutter, BARCH

- Many are willing to endure two to three months of less independence in order to gain additional function.
- The ideal time to have surgery following the initial onset of SCI for the majority of the respondents was within one to five years post injury.

(Anderson 2004, French, Anderson-Erisman et al. 2010)
Neural Bridge

Patient Populations:
- Spinal Cord Injury
- Brachial Plexus Injury
- Amyotrophic Lateral Sclerosis

Neural Extension

Patient Populations:
- Amputation
- Peripheral Nerve Injury
- Neuromuscular disease

Neural Substitution

Patient Populations:
- Stroke
- Brain Injury
Schematic: Components of Brain Computer Interface

Operating Protocol
Example: BCI2000 Software

Signal Acquisition
- EEG
- ECoG
- Single Unit

Signal Processing
- Feature Extraction
  "Is Signal Present?"
- Signal Translation
  "Convert Signal to Command"

Device Output
- Simple: Cursor Control
- Intermediate: Wheel Chair Control
- Complex: Robotic Limb Control
Fig. 2. Interfaces for recording neural signals from the cerebral cortex. A) 128 channel active EEG electrode system with electrodes held in pre-defined positions; g.tec medical engineering GmbH, Austria. B) Inset: 100-electrode, ‘Cereport’ array allows intracortical single cell and LFP recording (Blackrock Microsystems, Salt Lake City, UT). Two arrays implanted in M1 and S1 in a monkey. C) ECoG electrodes used for monitoring and localization of epileptic foci during operative procedure. Adapted from Roland et al. (2013).
EEG - BCI Control Methods

Good temporal resolution
Poor Spatial resolution (around 1 cm)
  – little access to subcortical structures
Signal to noise ratio poor,
  no fluorescent lights, impaired by muscle EMG
P300 – Generated when people recognize something visually
SCP – Slow cortical potentials
SMR- Sensorimotor rhythm


A spelling device for the paralysed.

80% of stroke have impaired fine upper extremity function. (WHO 2010)

Patient with severe UE paresis do not benefit from current rehabilitation strategies as they cannot perform therapeutic movements.

Pontine Stroke with locked in syndrome
  Motor control

Additional unrealized targets
- Aphasia receptive/expressive
- Motor apraxia
- Ataxia.
- Neglect
Does BCI feedback of Motor Imagery Increase Fugl-Meyer Scores?

- Randomized controlled trial
- 20 patients post subcortical stroke
- All given 6 sessions with standard therapy + BCI feedback
- BCI feedback was either real, measuring premotor activation with kinesthetic motor imagery, or sham
- Increased distal Fugl-Meyer sub score for hand and fingers in the real premotor cortex feedback group.

(Mihara et al. 2013)
Closed Loop Control

Feedback:
Vision – fatiguing with inherent non-naturalistic processing and latency
Goal - integrating multimodal naturalistic information
proprioception, mixed cutaneous afferents,
Functional priorities, assistive technology, and brain-computer interfaces after spinal cord injury

Jennifer L. Collinger, PhD; Michael L. Boninger, MD; Tim M. Bruns, PhD; Kenneth Curley, MD; Wei Wang, MD, PhD; Douglas J. Weber, PhD

57 Veterans surveyed
Functional priorities, assistive technology, and brain-computer interfaces after spinal cord injury

Jennifer L. Collinger, PhD;¹⁻³⁺ Michael L. Boninger, MD;¹⁻⁴ Tim M. Bruns, PhD;² Kenneth Curley, MD;⁵ Wei Wang, MD, PhD;²⁻³ Douglas J. Weber, PhD¹⁻⁴
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![Bar chart showing the percentage of participants who rate BCI technologies as very helpful for tetraplegia and paraplegia across different technologies.](chart.png)
Figure 7.
Likelihood of study participants to have surgery to implant brain-computer interface (BCI) electrodes.
Functional priorities, assistive technology, and brain-computer interfaces after spinal cord injury

Jennifer L. Collinger, PhD;1,3-4 Michael L. Boninger, MD;1-4 Tim M. Bruns, PhD;2 Kenneth Curley, MD;5 Wei Wang, MD, PhD;2-3 Douglas J. Weber, PhD1-4
Utah Electrode Arrays
Utah Electrodes Arrays

Longevity:
Two+ years with continued recording of local field potentials, decreased single neuron recording

Utah Electrode Arrays
BREAKTHROUGH: ROBOTIC LIMBS MOVED BY THE MIND
**Figure 2: Neural units during the days after the implant**

The blue dots represent the number of neural units recorded during brain–machine-interface sessions done 10–98 days after the implant. The red squares represent the neural units tuned to movement velocity with $R^2 > 0.1$ (equation 1). For reference, four-dimensional training began on day 24 and seven-dimensional training on day 32.
• Spatial targeting using LEDs
• Cone Sstacking
• ARAT (Action Research Arm Test)

Perfomrance Index

Path Efficiency

Collinger et. al 2014
• Spatial targeting using LEDs
• Cone Sstacking
• ARAT (Action Research Arm Test)
Barriers to Widespread Adoption:

Technical
  Tissue Interface
  Calibration
  Complexity
  Modularity - developing common protocols
  Invasiveness
  Effort / Naturalism
  Heterogeneity of brain lesions.
Barriers to Widespread Adoption:

Validation of Utility
  - Rehabilitative tool vs. chronic assistive device
    - Show superiority to validated rehabilitation tools (task oriented rehab., repetitive high intensity exercises, constraint induced therapy)
    - Increase autonomy/decrease care burden
    - Enable novel tasks or make routine tasks faster/easier
Barriers to Widespread Adoption:

Reliability

- Environmental Tolerance
- Battery life
- Repair cost (additive manufacturing?)
- Poor situational flexibility (i.e., synchronous recognition)
Barriers to Widespread Adoption:

Access and Other
Cost
Commercialization
Cosmetic acceptance (wireless)
Obsolescence
What about Functional Electric Stimulation (FES)?

- Why is it so fatiguing?
- Alternative strategies
This technology has had a huge impact on my life. Not only does it allow me to stand for functional use, like reaching high objects or going thru narrow doorways, it has also allowed me to stay healthy. What we need to understand is that you may see someone who is paralyzed but that is only one component. Perhaps they can not walk or stand, but we also have daily battled against medical or secondary complications that can be life threatening like infections from pressure ulcers or kidney failure. This technology allows me to easily combat those medical complications. Finally, the technology give a social aspect. I can stand at the 7th inning stretch of a baseball game, at a standing ovation at a concert and even walk down the isle at our wedding. Those are aspects that we don't always think about when developing technology.

http://www.reddit.com/r/IAmA/comments/26al4x/i_am_jennifer_french_paralympian_active_user_of/
Commercialization

KICKSTARTER

947 backers
$215,438 pledged of $100,000 goal
0 seconds to go

Funded!
This project was successfully funded on January 22, 2014.

EPOC headset
High resolution, multi-channel, portable EEG system. 14 EEG channels plus 2 references offer optimal positioning for accurate spatial resolution.

In Stock | Ships globally except Russia and Ukraine.
DIY EEG Wheelchair Control
An epidural spinal cord stimulator (Medtronics, RestoreADVANCED) was implanted at T11-12 over spinal segments L1-S1I. Transmagnetic stimulation over the M1 cortex was confirmed to not elicit EMG activity, connoting complete injury. Able to volitionally recruit muscles based on which electrode was active in which pattern.
Altering spinal cord excitability enables voluntary movements after chronic complete paralysis in humans

Claudia A. Angeli, V. Reggie Edgerton, Yury P. Gerasimenko and Susan J. Harkema

A. Epidural Stimulation ON/OFF

B. Force and Duration Modulation
Future Directions
Closed Loop Control


Electrically stimulate S1

Record signals from M1

Convert to stimulus pulses

Decode motor intent

Move robot arm

Read sensor output from arm
Maintaining high spatial and temporal resolution while reducing chronic tissue injury

Fig. 2. Soft microelectrode array. Optical images of stretchable microelectrode arrays with silicone rubber substrate and thin gold film patterned traces.
FIGURE 2 | Output effects evoked by intraspinal stimulation. (A) Electrical stimuli were delivered to a single intraspinal electrode while the monkey performed a two-dimensional wrist task, acquiring targets in wrist flexion and extension. (B) Muscle responses evoked by a single pulse at 90 μA. The vertical scale bar at right indicates mean percent increase (MPI) over baseline. EMGs were recorded from: flexor carpi ulnaris (FCU), flexor digitorum superficialis (FDS), palmaris longus (PL), flexor carpi radialis (FCR), extensor carpi ulnaris (ECU), extensor digitorum 4 and 5 (ED45), extensor digitorum communis (EDC), extensor carpi radialis (ECR), brachioradialis (BR), biceps brachii (BB), pectoralis (PEC), and deltoide (DEL).
Molecular Machines: Optogenetics & Gated Ion Channels

Gaining a new lexicon: stimulation and inhibition
Optrode

(a) Schematic diagram of the optrode structure, showing the optical fiber, gold coating, stainless steel tube, and polyamide tube.

(b) Scanning electron microscopy (SEM) image of the optrode tip, showing the optical fiber and gold coating.

(c) Optical micrograph of the optrode, highlighting the optical connector (LC type) and electrical wire for electrophysiology.

(d) Diagram illustrating the placement of the optical fiber in the polyamide tube and the stainless steel tube.

(e) Waveform recordings from transgenic mouse, transduced rat, and transduced non-human primate, with indicated voltage levels of 50 μV and 100 μV over 1 second.

University of Utah Health Care
Figure 1. Targeting ChR2 to specific motor neuron axons within the sciatic nerve.
Active Programs

1. **REPAIR (Reorganization and Plasticity to Accelerate Injury Recovery)**
   Extending the scale of invasive BCI to multiregion, multiscale recordings to make faster
   More capable BCI.

2. **RAM (Restoring Active Memory)** – A program to implant large scale
   invasive BCI, decode declarative memory formation and then develop a
   neuroprosthetic to augment declarative memory formation

http://www.darpa.mil/Our_Work/BTO/Programs/Restoring_Active_Memory_RAM.aspx
...progress will be incremental and researchers must avoid creating false expectations that could damage the credibility of these new technologies.
Questions