Topics in Brain Computer Interfaces
CS295-7

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Spring 2005
From what part of the brain should we record?
Motor Systems

SMA: involved in the planning of complex movements and in two-handed movements.

Primary motor cortex (M1)

Posterior parietal cortex

Supplementary motor cortex (SMA)

M1: directly involved in producing motor actions.

Posterior parietal cortex: involved in transforming visual information to motor commands.

Premotor Cortex: involved in the sensory guidance of movement and motor planning.

Premotor cortex (PMA)
Motor System

Primary motor cortex (M1)

- Hip
- Trunk
- Arm
- Hand
- Foot
- Face
- Tongue
- Larynx
What is represented?

Using wrist and fingers

Using elbow as fulcrum

Using shoulder as fulcrum (outstretched arm)

Adapted from R. Shadmehr
Signing Your Name

**Prefrontal Cortex**: I’ll sign my name.

**Posterior Parietal**: combine visual and somatosensory information to localize pen wrt body.

**Premotor cortex**: plan motion of hand wrt target path.

**Cerebellum**: formulate details of movement in terms of dynamics.

**Primary Motor Cortex**: sends motor commands down spinal cord.

**Brain Stem** maintains stable posture during writing.
Summary

**Posterior Parietal Cortex:** Transforms visual cues into plans for voluntary movements.

**Motor cortex:** Initiating and directing voluntary movements

**Brainstem Centers:** Postural control.

**Spinal Cord:** Reflex coordination

**Basal Ganglia:** Learning movements, initiating movements.

**Cerebellum:** Learning movements and coordination

Visual cues

**Motor neurons**

**Skeletal Muscles**
Motor Control
Controlling a Motor Prosthesis

MI arm area of motor cortex.
* know that activity of cells related to hand motion
* accessible (in monkeys and humans)
* hypothesis: natural for controlling continuous motion of a prosthesis
How can we record the neural signals?
Sensing the Brain

- fMRI: 10^3 neurons
- EEG: 10^4
- MEG: 10^3
- LFP: 10^2
- Optical imaging: 10^1
- Spikes: 10^0

Non-invasive

Invasive

Source: Matt Fellows

Course (mm) - SPACE - Fine (microns)

Fast (msec) - TIME - Slow (sec)
Cyberkinetics Array

100 “ideal” microelectrodes
10x10 grid,
4x4 mm platform
1 or 1.5 mm long, Si shafts,
Pt coated tips
Glass separation
Parylene insulation coating
Array

Utah = Bionic = Cyberkinetics array.

Fixed electrode depths - can’t move them to get a better signal. Take what you get and make the most of it.

Inventor: Richard Normann, Univ. of Utah.
WARNING:
Graphic images of surgical procedure follow.
Preclinical Safety: Removal and Re-implantation

First Implant | Explant | Second Implant
---|---|---
F1 Original Implant | F2 + 4 wks Removed | F3 +3 months

Donoghue Lab

Arrays can be removed and reimplanted. Successful recordings can be obtained from reimplanted arrays.
Surgical Methods

Intended to follow human neurosurgical procedures and methods.
- Limit duration
- Eliminate most foreign materials
- Use established surgical methods

Bone flap fixation
Skin closure

Percutaneous Connector
Recorded waveforms
Chronic Implants

* 39 implants in 17 macaque monkeys
  (February 1996-April 2003)
* Recordings for 1098 days

Many neurons every day (19 tests over 110 days)

\[ n = 80 \pm 7 \text{ in } 3 \text{ recent MI implants} \]

Blue - no recording
Red - best recordings

From: Selim Suner

Donoghue Lab
Implant Challenges

- Electronics
  - Miniaturization
  - Encapsulation
  - Telemetry
  - Heat dissipation
  - Low power
  - On board signal processing and spike sorting

Nurmikko and Patterson
Chip-scale integration of array and electronics.
Long term vision

Nurmikko and Patterson
Integrated Microelectrode Array with Ultralow Power Preamplifiers, Multiplexer, and Buffer (~10 mW)

Photovoltaic Power Supply, ADC, Clock Circuits, VCSEL (laser), etc.

Skin

Tether cable (minimal)

Optical fiber: (laser light)
- Power/Clock Input
- Signal out (> 1 Gb/s)

OK also with other telemetries
What do the neural signals encode?
“If spikes are the language of the brain, we would like to be provide a dictionary... perhaps even providing the analog of a thesaurus.”

Some Terminology

Sequence of spikes from a single neuron = “spike train”

Interspike Interval (ISI)

ISI Distribution (normalized histogram)
Neural “Coding”

• How do cells represent information?
  • ie, how is representation “coded” in action potentials.

• If we understand the encoding then we can tackle the “decoding” problem.
  • inference – from activity to encoded property
Neural Coding

What are the possibilities?

You’ve got action potentials and now you want to represent “move the hand to the right”. How might you do it?
Neural Coding

What are the possibilities?

1. Localist encoding in on/off response.

2. Rate coding.

3. Precise timing – pattern of spiking carries information.

4. Ensembles code information that individuals can’t.

5. Synchronous firing within and across ensembles (it is the interdependencies that matter).
Neural Coding

• **Localist** view – each neuron codes a particular value
  - “computer”-like model where neurons are binary
  - at the low level cells represent things like orientation
  - at the high level they represent complex information

• Problems?
Neural Coding

Population codes

• distributed representation

• information encoded in the overall activity of many cells

• graded response – level of activity conveys information. Not binary.
Orientation Selectivity

Hubel & Weisel, 1962
Cracking the Neural Code

"rasters"

Source: Rob Kass
Orientation Tuning

A

B

$\frac{s}{Hz}$

$s$ (orientation angle in degrees)
Estimating Firing Rate

\[ \text{rate} = \frac{\text{(# of spikes in time bin)}}{\text{(length of time bin)}} \]

Related to the probability a cell will spike (fire) in a given time interval.

Typically consider 50-70ms time bins.

Source: Zemel & McNaughton, NIPS2000 tutorial