Biosciences in the 21st century

Lecture 2: Innovations and Challenges

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Outline:

Review of last time

Organization of the nervous system (in brief)

The mapping concept

Bionic implants and our cyborg future

Auditory function and cochlear implants

Restoring paralysis: promising technology
Nervous system is segmented in invertebrates

Each segment is controlled by its “own” bit of brain.
and in vertebrates........

Each segment has repeatable structures

http://embryology.med.unsw.edu.au/wwwhuman/Stages/Stage10L.htm
Each segment has its own inputs and outputs.

Afferents (inputs; i.e. sensory neurons)

Efferents (outputs; i.e. motor neurons)
Let’s consider the somatosensory system....
each vertebral segment is connected to a particular patch of skin

The area of skin innervated by one segment is called a “dermatome”

You will see that this organization is preserved at every level of processing
The brain (*also segmented*) has its own afferent and efferent nerves.
The neocortex is an elaboration of the foremost segment, and it has a highly organized structure.
The cortex has functionally distinct regions a closer look at the somatosensory cortex...
The somatosensory and motor cortex contain orderly maps of the body surface.

The representation is distorted because more brain tissue is devoted to the most sensitive areas.
This distorted representation gave rise to the concept of the homunculus or “little man in the brain”

The point is: the brain is organized into maps of important features and functions
The point is: the brain contains maps of features and functions.

We learned this in the 1950’s!

The more that we understand about the structure and function of each region of the nervous system, the more likely we are to be able to develop an intervention when things go wrong.....
Neurological Medicine:

**Today:** mainly concerned with limiting damage as it happens, or slowing degenerative processes.

Sometimes medication can correct deficiencies in neurotransmitter systems etc.

**Long term:** stem cells, tissue engineering, gene therapies will correct the *mechanisms* of disease, not just the symptoms.

**The intermediate term:** current research in nanoscale engineering, computer science, and neuroscience will lead to technological interventions that provide solutions to neurological disease.
The dawn of the brain machine interface...
The most successful machine/neuron interface thus far is the cochlear implant.
Sound is defined by frequency

![Graphs showing sound waves with intensity and frequency](image.png)
The cochlea

Outer ear

Middle ear

Inner ear (neural)
Organ of Corti
- hair cells
- support cells
- basilar membrane
- Primary Auditory Afferents!!
Organ of Corti
-hair cells
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-Primary Auditory Afferents!!
The inner ear translates stimulus frequency to a topographic place.

This “tonotopic” organization is the primary mapping feature in the auditory brain.
The most common cause of hearing loss is hair cell damage and death; in mammals they do not regenerate.
The cochlear implant is an electrode array positioned to stimulate the auditory afferents directly, in the absence of hair cell function.
Cochlear Implant

- Two elements
  - External
  - Internal
- A microphone
- A speech processor
- A transmitter and receiver/stimulator
- An electrode array

- Bypasses damaged part of the ear
- Directly stimulates auditory nerve
The limit of implantation, is frequency resolution because today's best electrode has a max of 23 inputs to the ear.
The limit of implantation, is frequency resolution

6 channel hearing
The limit of implantation, is frequency resolution

4 channel hearing
Cochlear implants compress sound into bandpass filter channels, but only a few are needed to make sense of the world....

32 16 8 4 2 1
Cochlear implants compress sound into bandpass filter channels, but only a few are needed to make sense of the world....

Frequency

Time

# of band filters

32 16 8 4 2 1
Cochlear implants compress sound into bandpass filter channels, but only a few are needed to make sense of the world....
Age Matters
Vocabulary

The point here: deaf children can recover near normal language ability if they are implanted early enough (Connor et al. 2006)
Input dependence

embryo birth sexual maturity death

Age

critical period

Trait development
Critical Periods in Language Development
Pre-lingual children can discriminate “native speech sounds” from nonnative

7.5 month infant discrimination in MMN of native vs non native contrast

This study measured the “mismatch negativity” an electrical signal in your brain that occurs during ‘novel’ stimuli
/r/ and /l/

rake

lake
The graph shows the percent correct responses for American and Japanese infants over different age groups. The x-axis represents the age of infants, with two categories: 6-8 months and 10-12 months. The y-axis represents the percent correct. American infants show an increase in percent correct from 6-8 months to 10-12 months, while Japanese infants show a decrease. The vertical shaded area indicates the proposed "sensitive period" for phonetic learning.
Auditory and motor areas associated with speech are refined in the first year of life

One area of my research is to develop mobile apps that simulate cochlear implants.
Summary:

The brain is highly organized into functional maps (somatotopic, tonotopic, etc.) where neighboring neurons process similar information.

One function of the ear is to transmit sound frequency information to the brain.

Auditory transduction is achieved by hair cells that translate mechanical energy into electrical energy.

Cochlear implants bypass hair cells by stimulating auditory nerve fibers directly.
Summary:

Small electrode arrays and computers can bypass motor systems to operate prosthetic devices etc. This strategy is highly likely to help patients with neurological disease.