Biosciences in the 21st century

Lecture 2: Innovations and Challenges

Dr. Michael Burger

Outline:

Review of last time

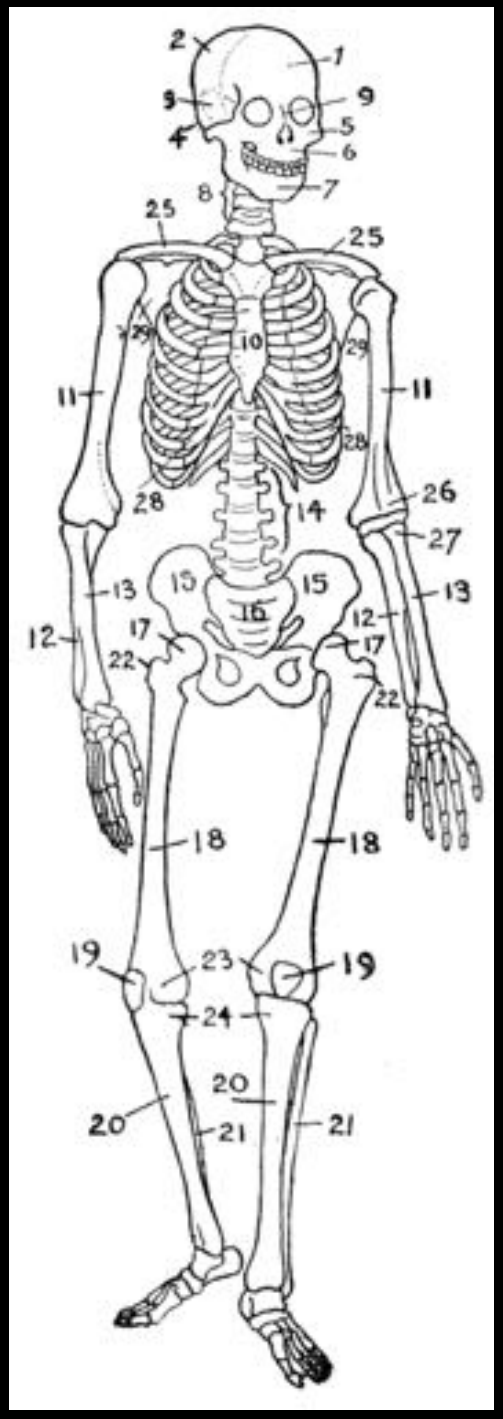
Organization of the nervous system (in brief)

The mapping concept

Bionic implants and our cyborg future

Auditory function and cochlear implants

Restoring paralysis: promising technology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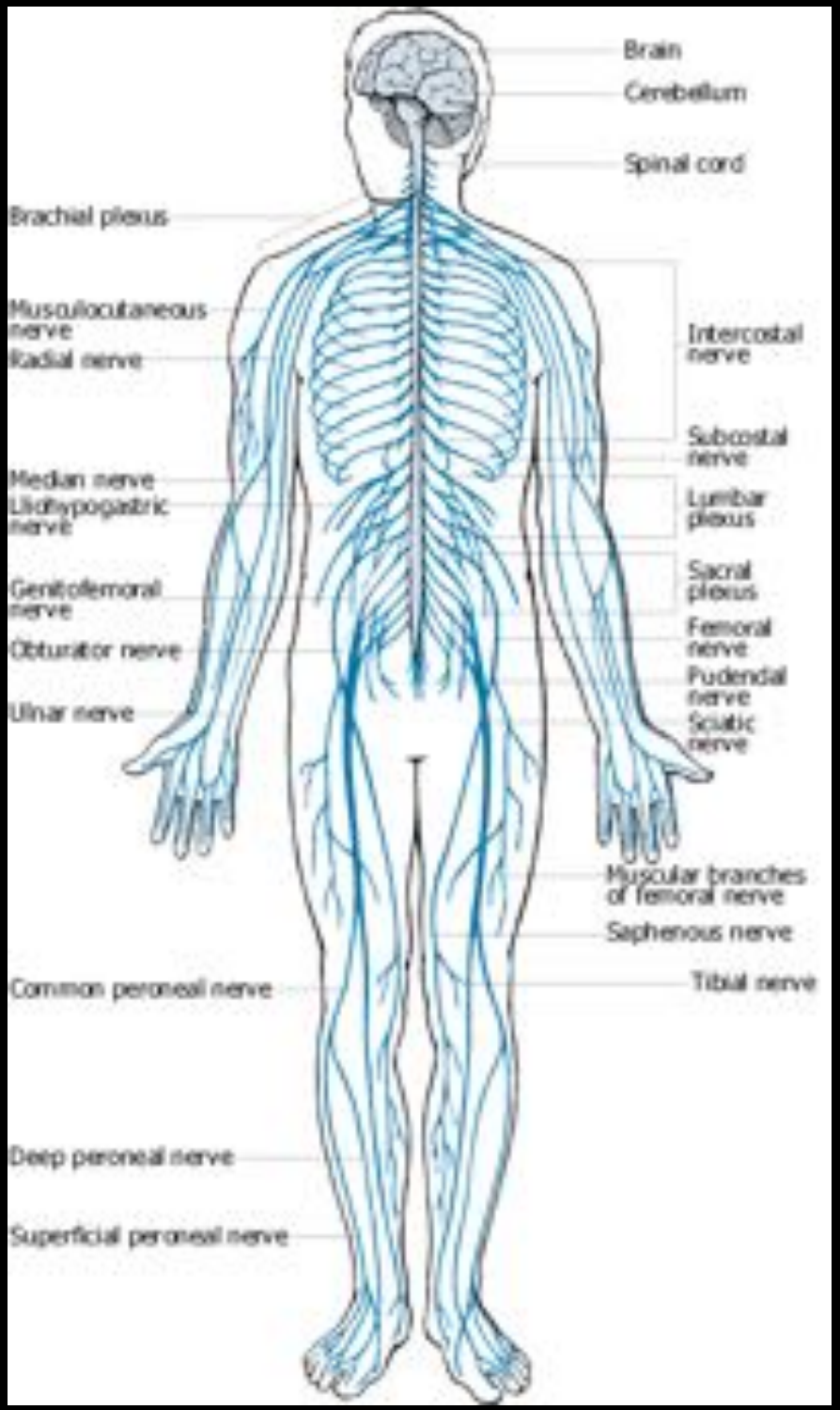
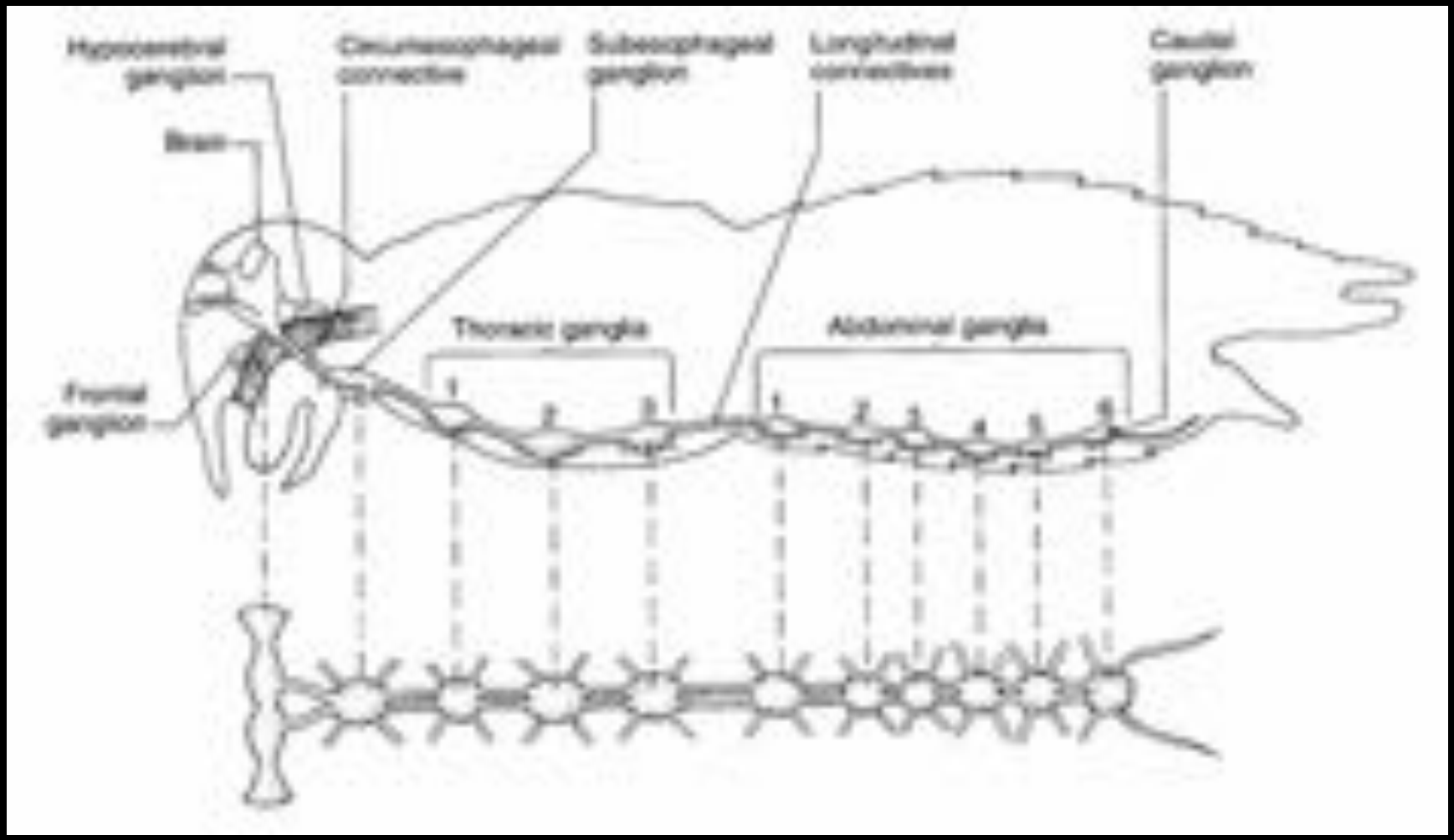


https://www.denverpost.com/2010/03/10/new-body-worlds-exhibit-gets-to-heart-of-circulatory-system/

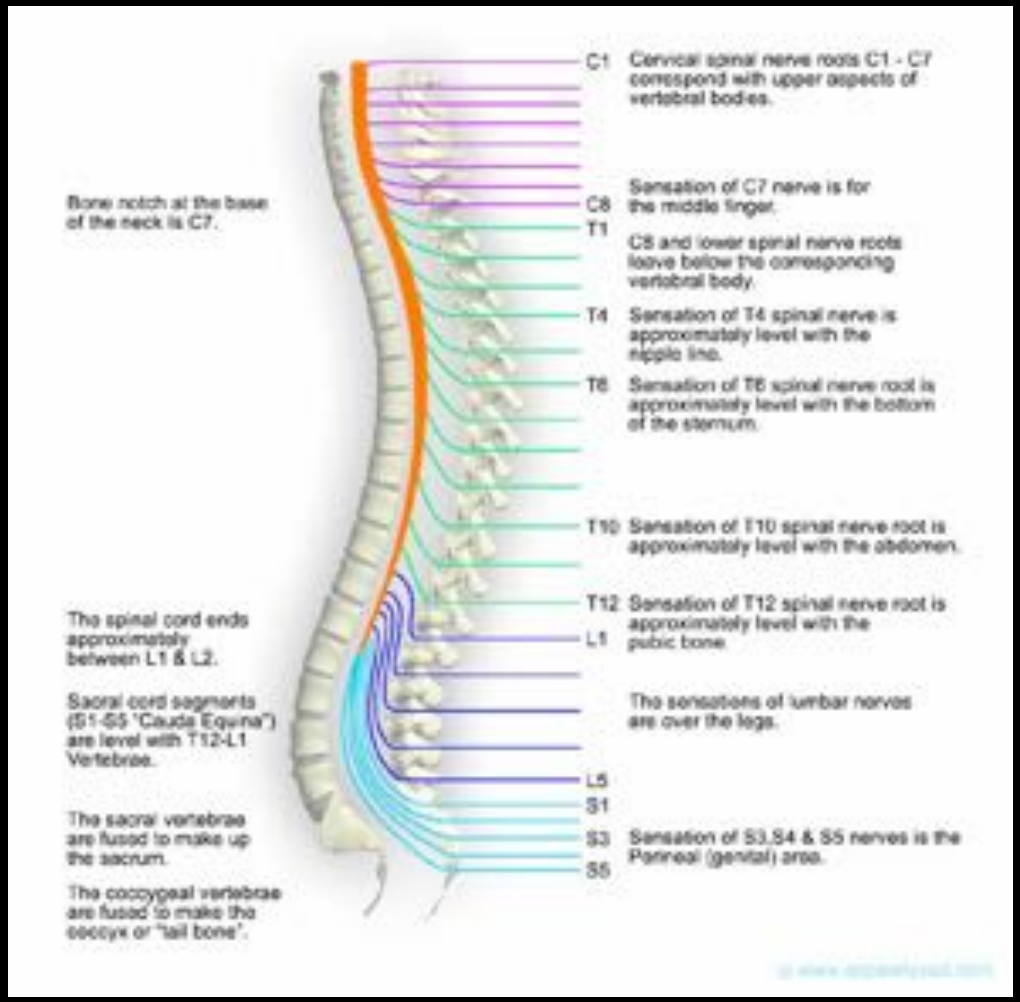
Nervous system is segmented in invertebrates



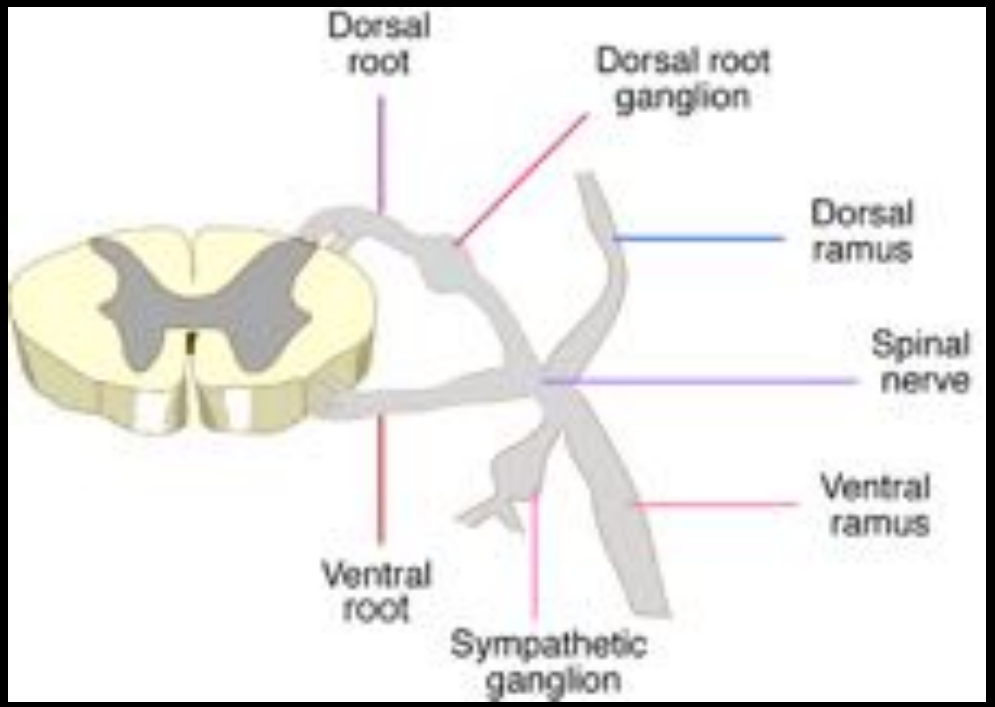
Each segment is controlled by its "own" bit of brain

and in vertebrates.....

Human stage 11 embryo

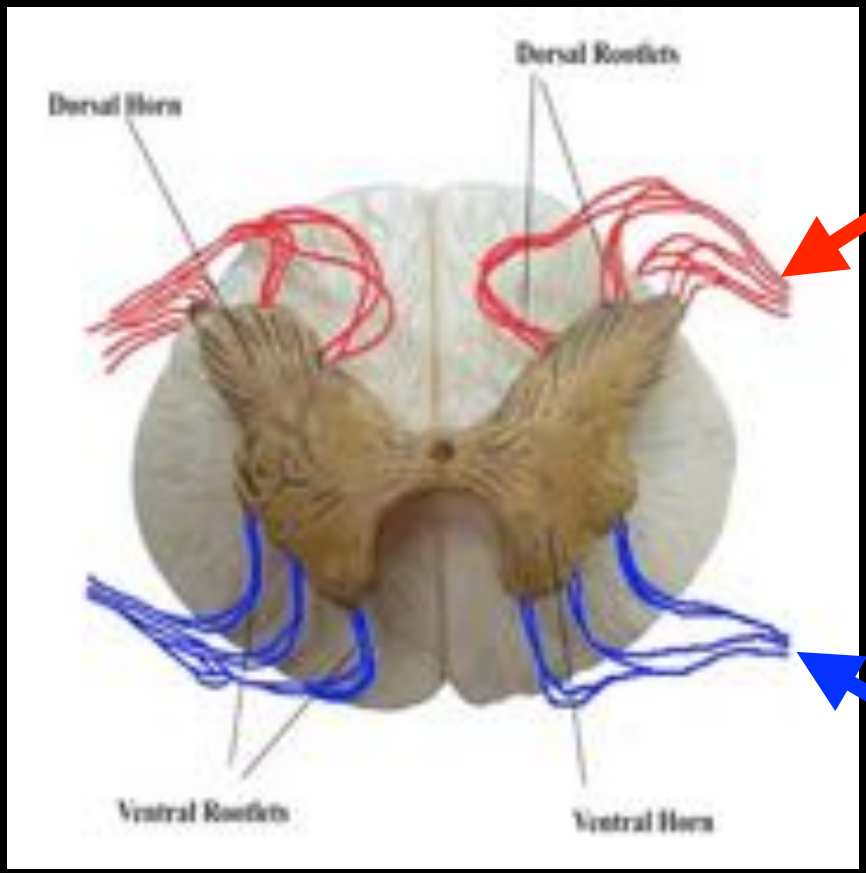


Each segment has repeatable structures



http://embryology.med.unsw.edu.au/wwwhuman/Stages/Stage10L.htm

Each segment has its own inputs and outputs

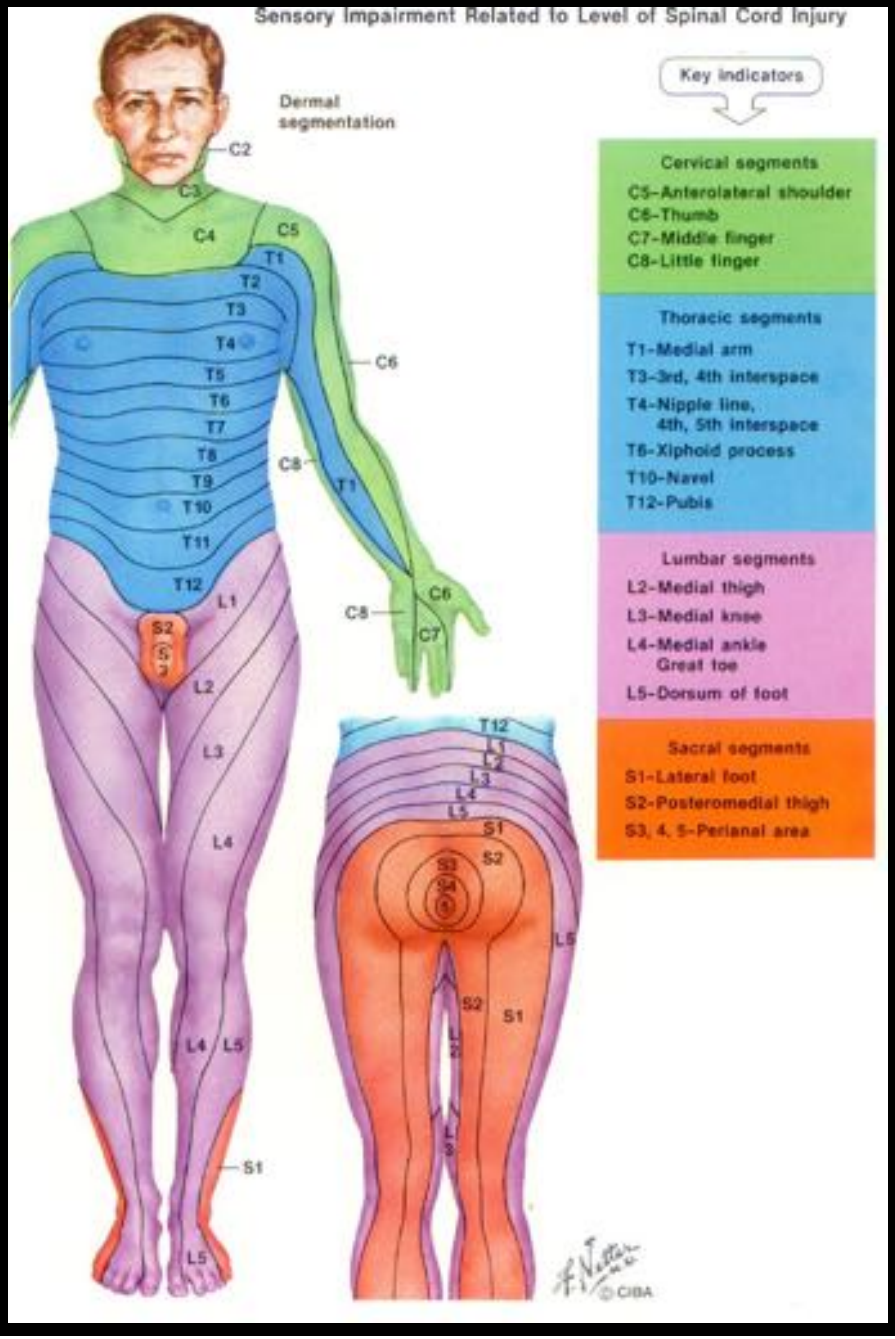


Afferents (inputs;
i.e. sensory neurons)

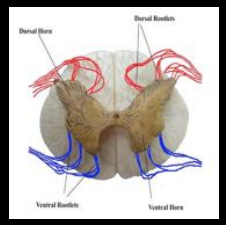
Efferents (outputs;
i.e. motor neurons)

Let's consider the somatosensory system....

each vertebral segment is connected to a particular patch of skin

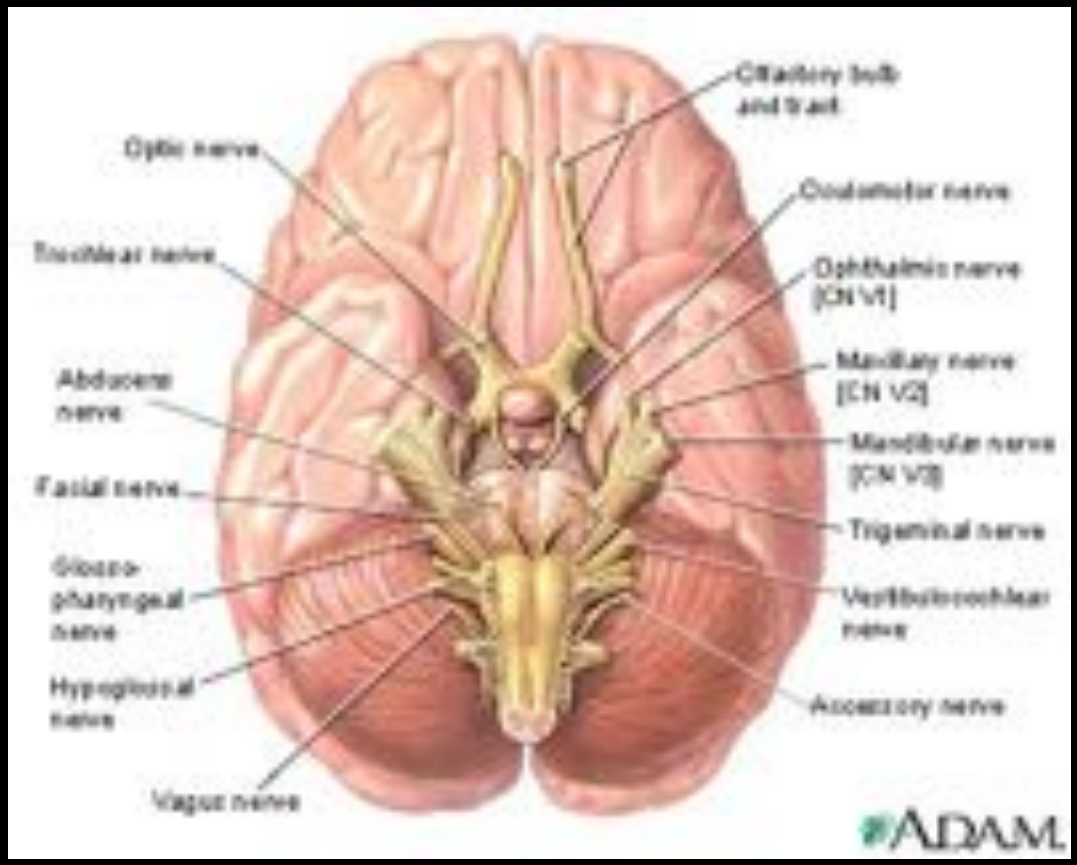


The area of skin innervated by one segment is called a "dermatome"

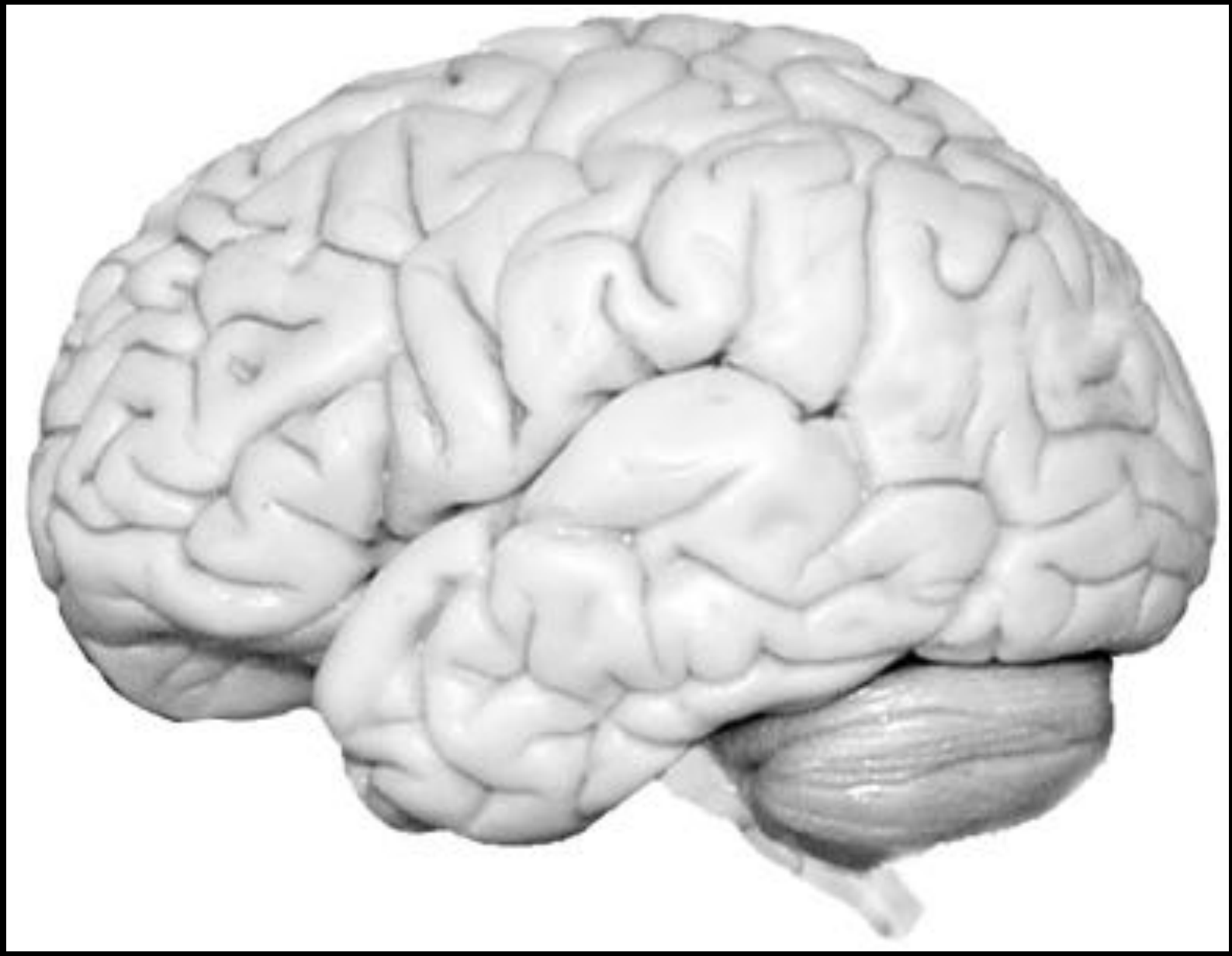


You will see that this organization is preserved at every level of processing

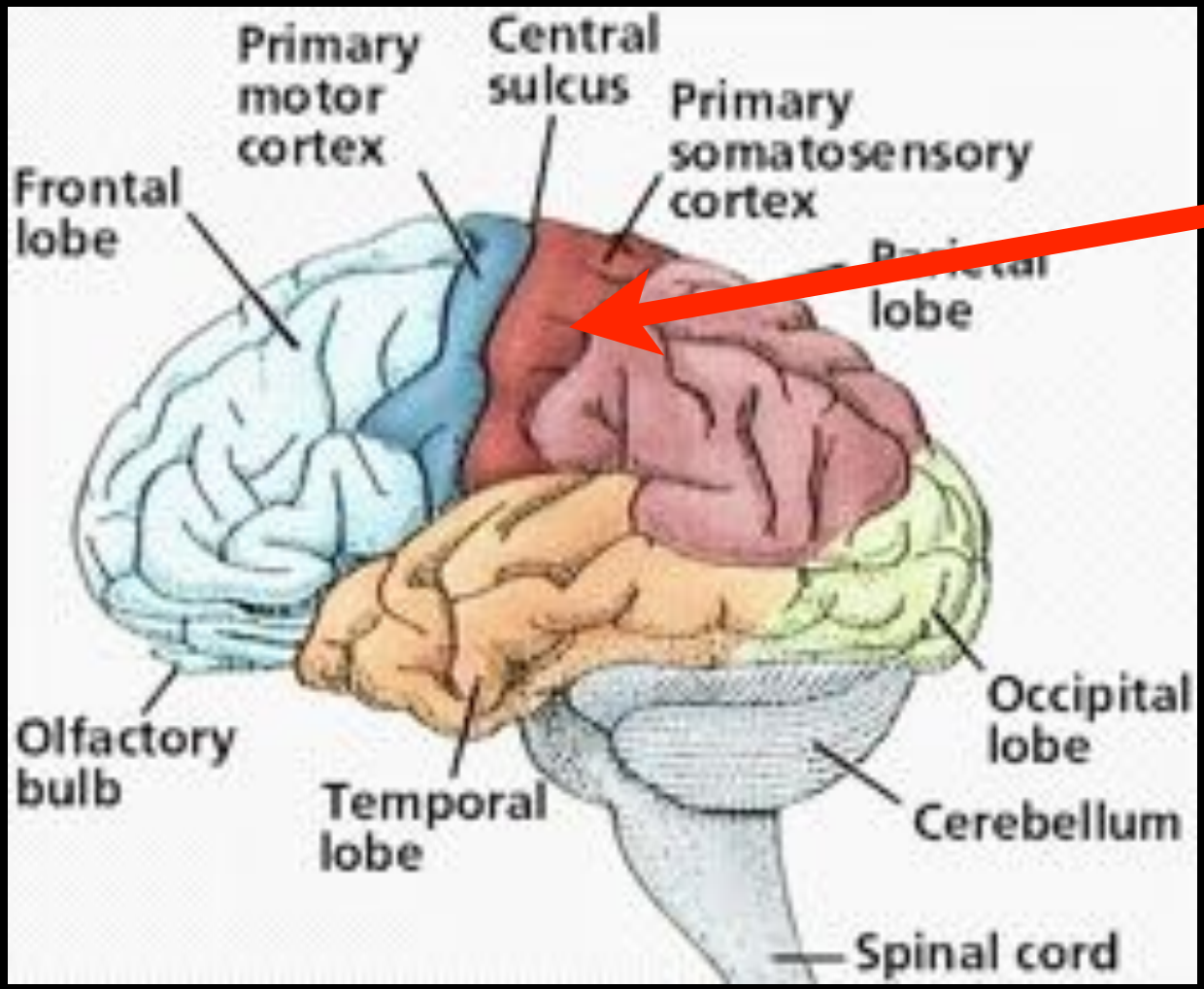
The brain *(also segmented)* has its own afferent and efferent nerves



The neocortex is an elaboration of the foremost segment, and it has a highly organized structure



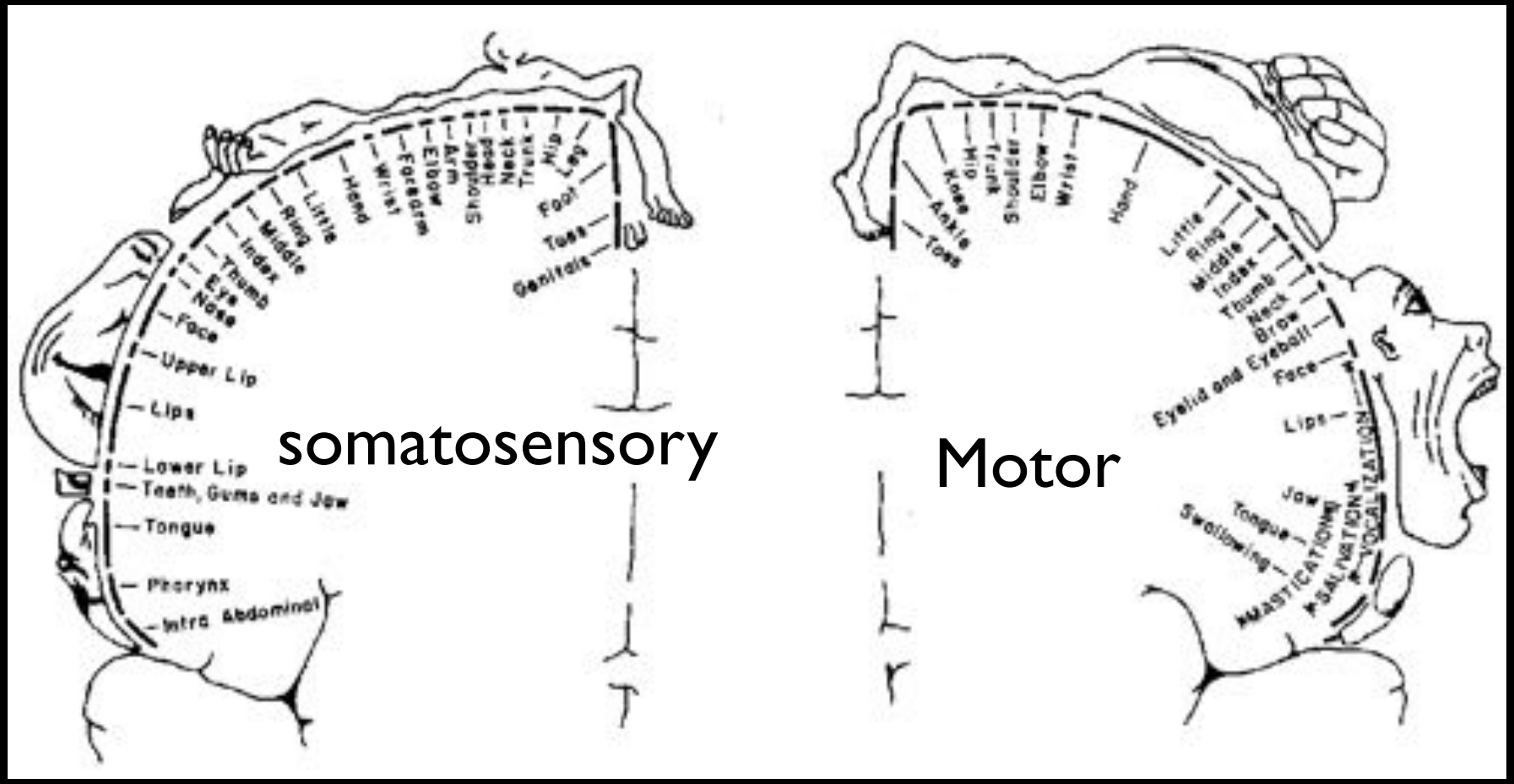
The cortex has functionally distinct regions



a closer look at the somatosensory cortex...

http://www.emc.maricopa.edu/faculty/farabee/BIOBK/cerebrum_1.gif

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.

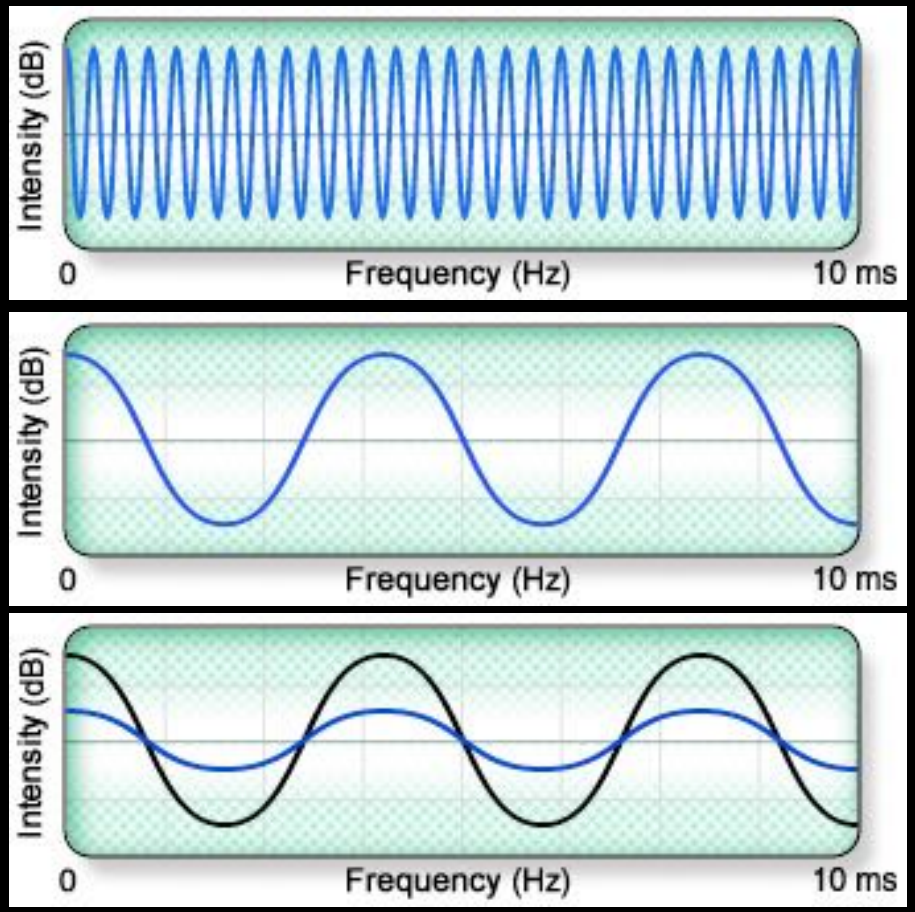
Long term: stem cells, tissue engineering, gene therapies will correct the *mechanisms* of disease, not just the symptoms

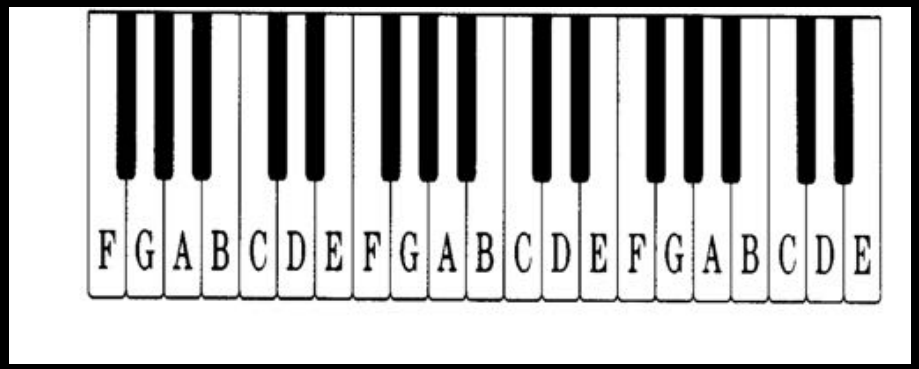
The intermediate term: current research in nanoscale engineering, computer science, and neuroscience will lead to technological interventions that provide solutions to neurological disease

The dawn of the brain machine interface...

The most successful machine/neuron interface thus far is the cochlear implant

Sound is defined by frequency

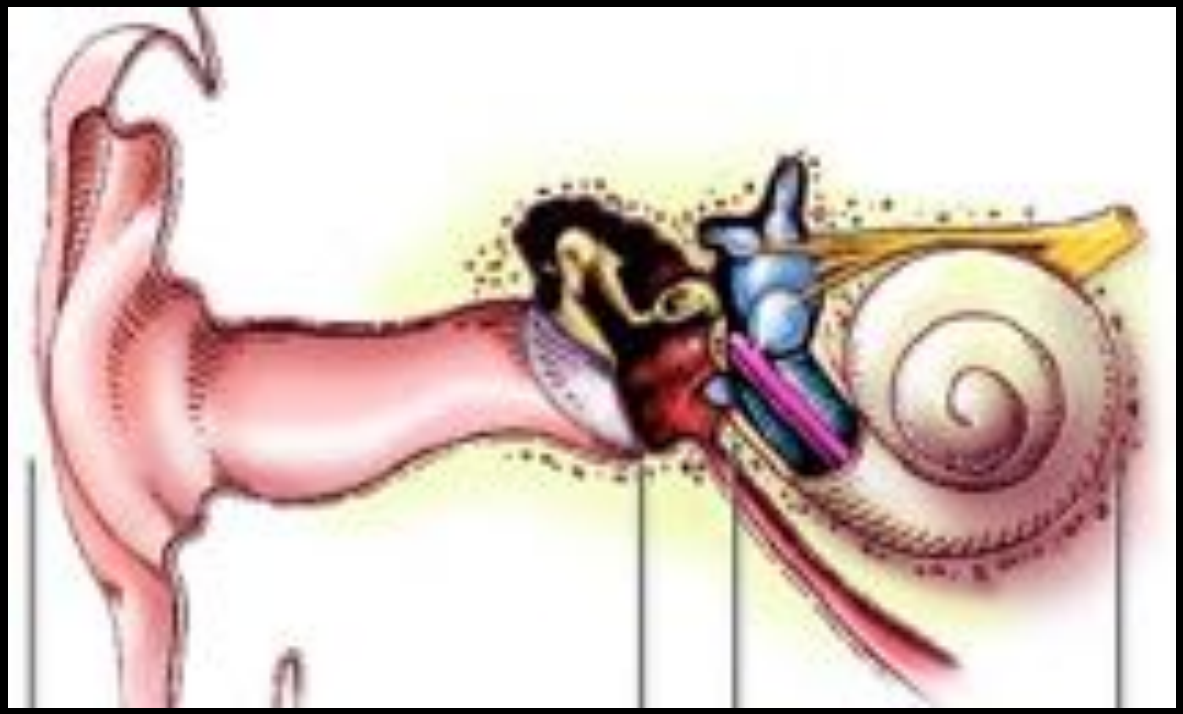




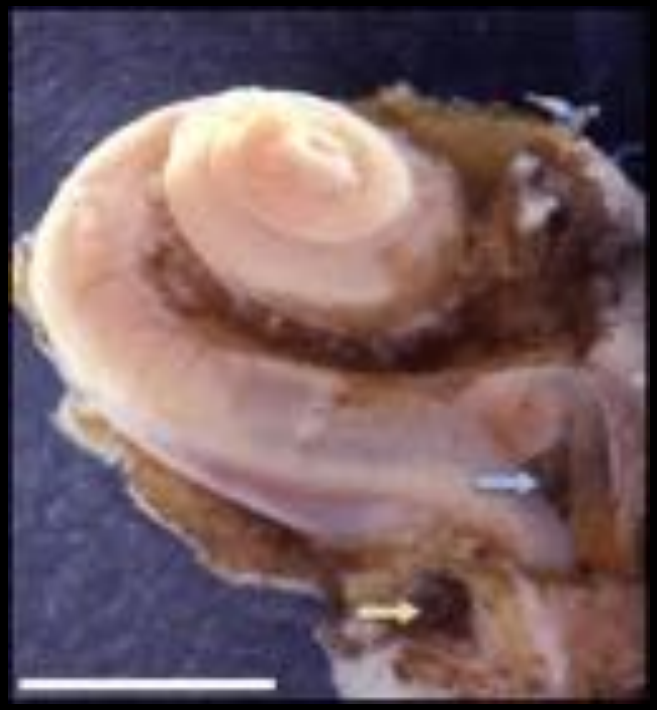
Outer ear

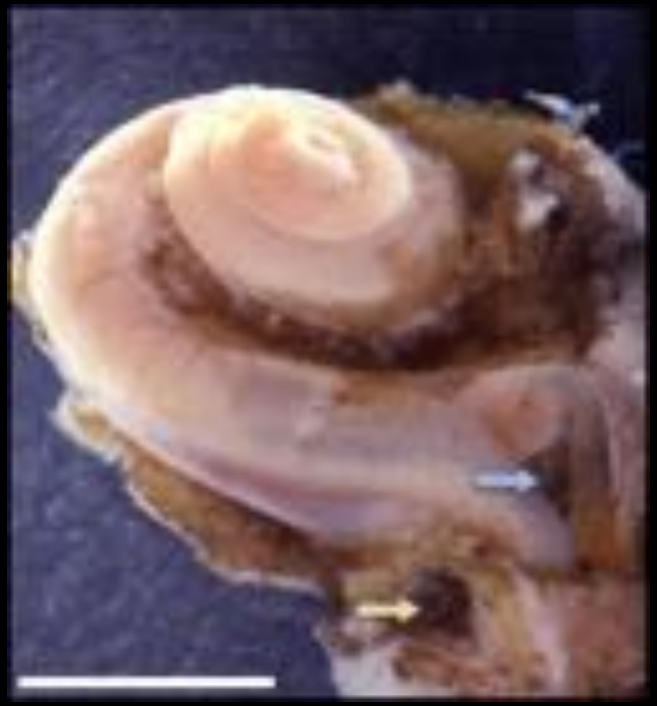
Middle ear

inner ear (neural)

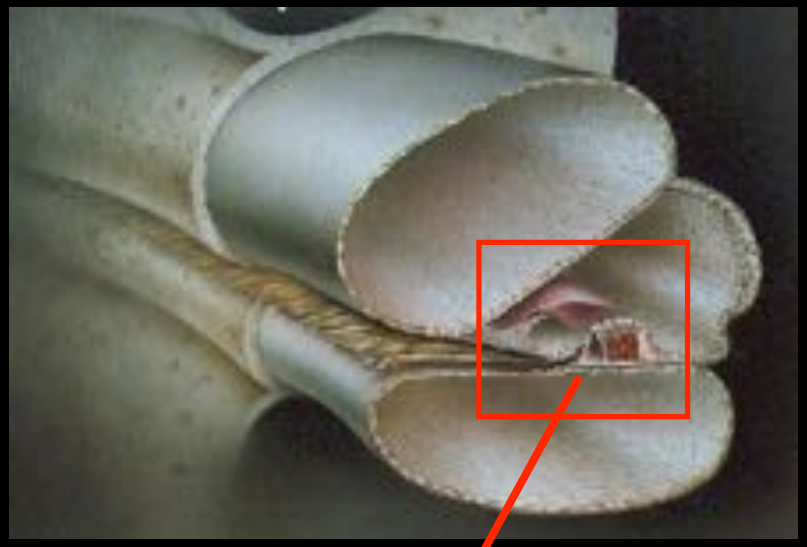


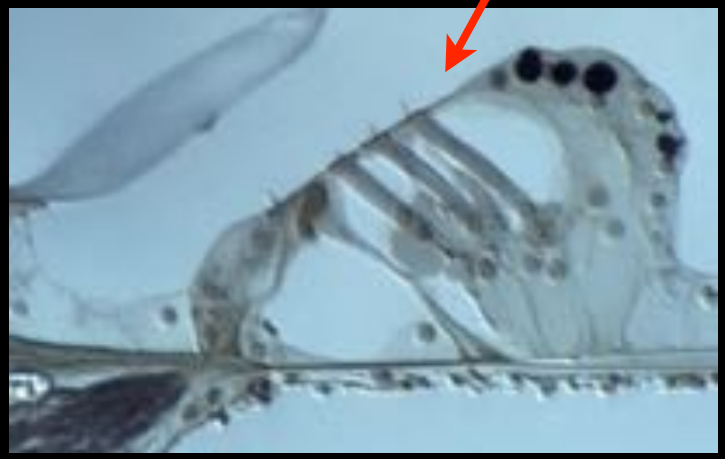
The cochlea

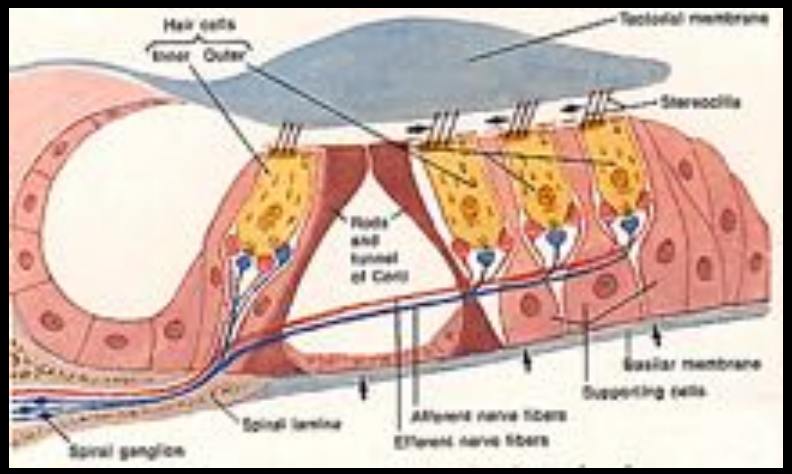




Organ of Corti
-hair cells
-support cells
-basilar membrane
-Primary Auditory Afferents!!







Organ of Corti

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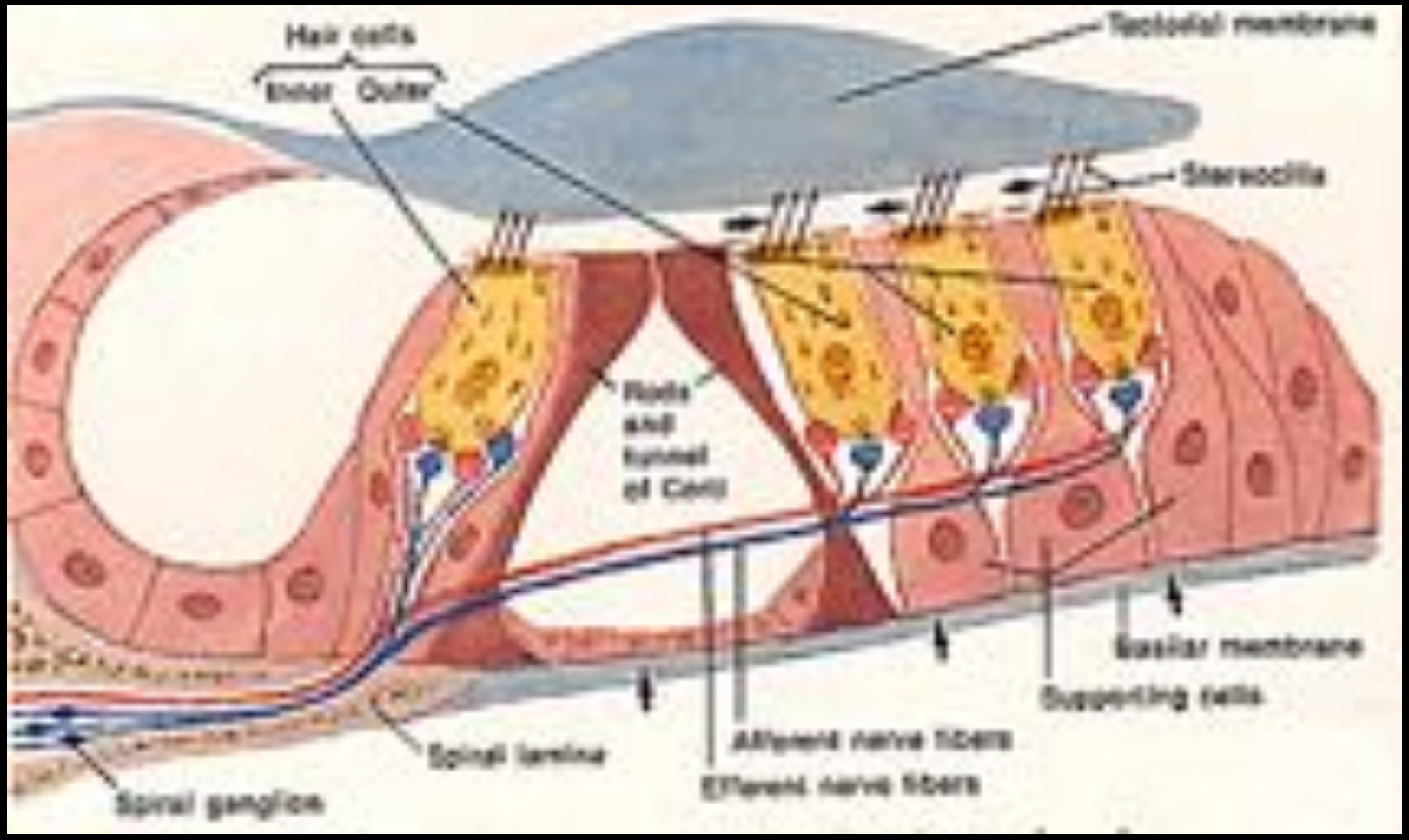
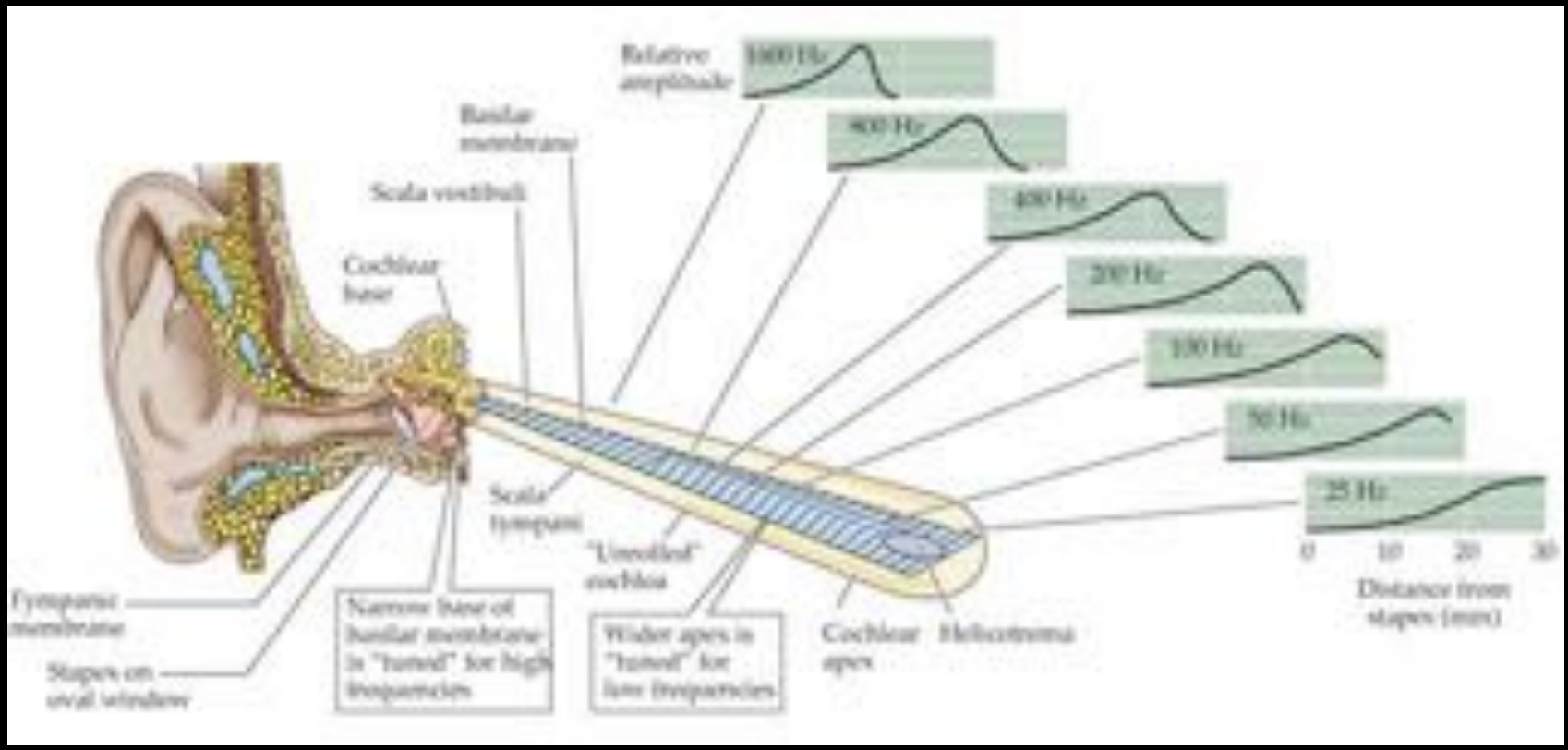


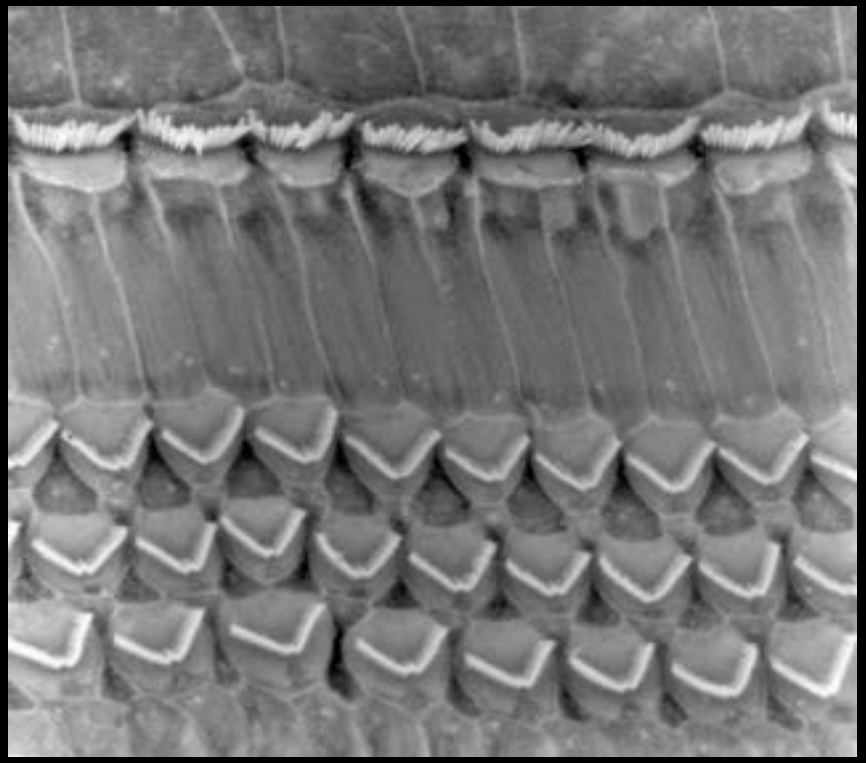
The inner ear translates stimulus frequency to a topographic place



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

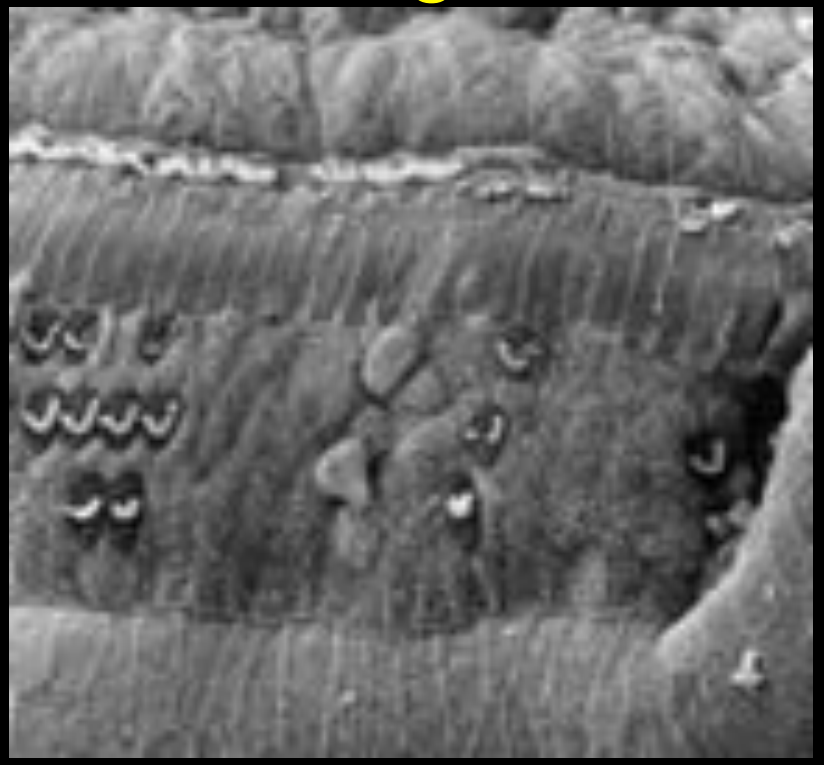
normal



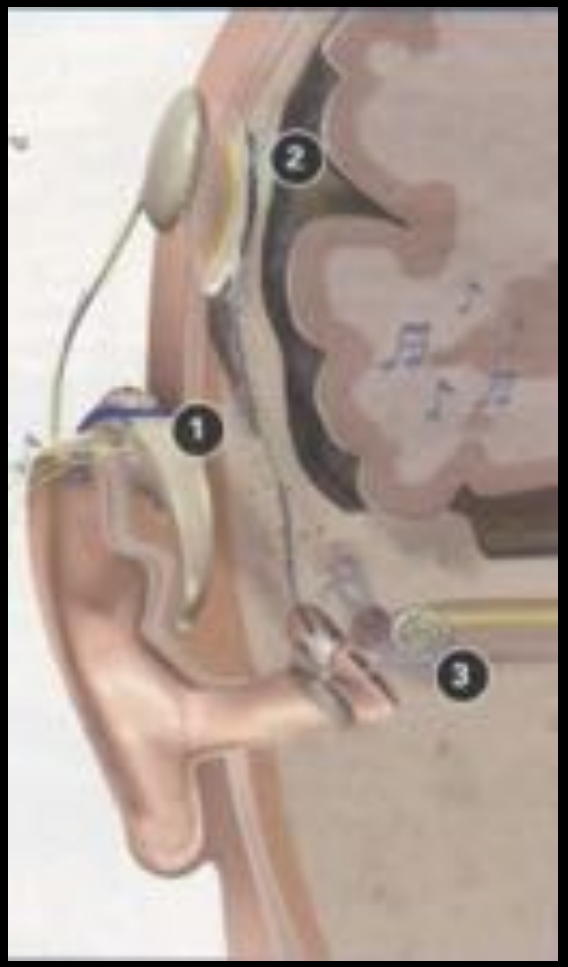
inner hair cells

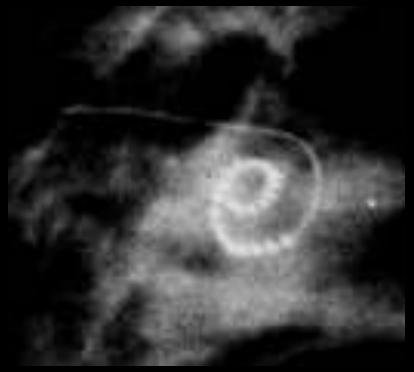
outer hair cells

damaged

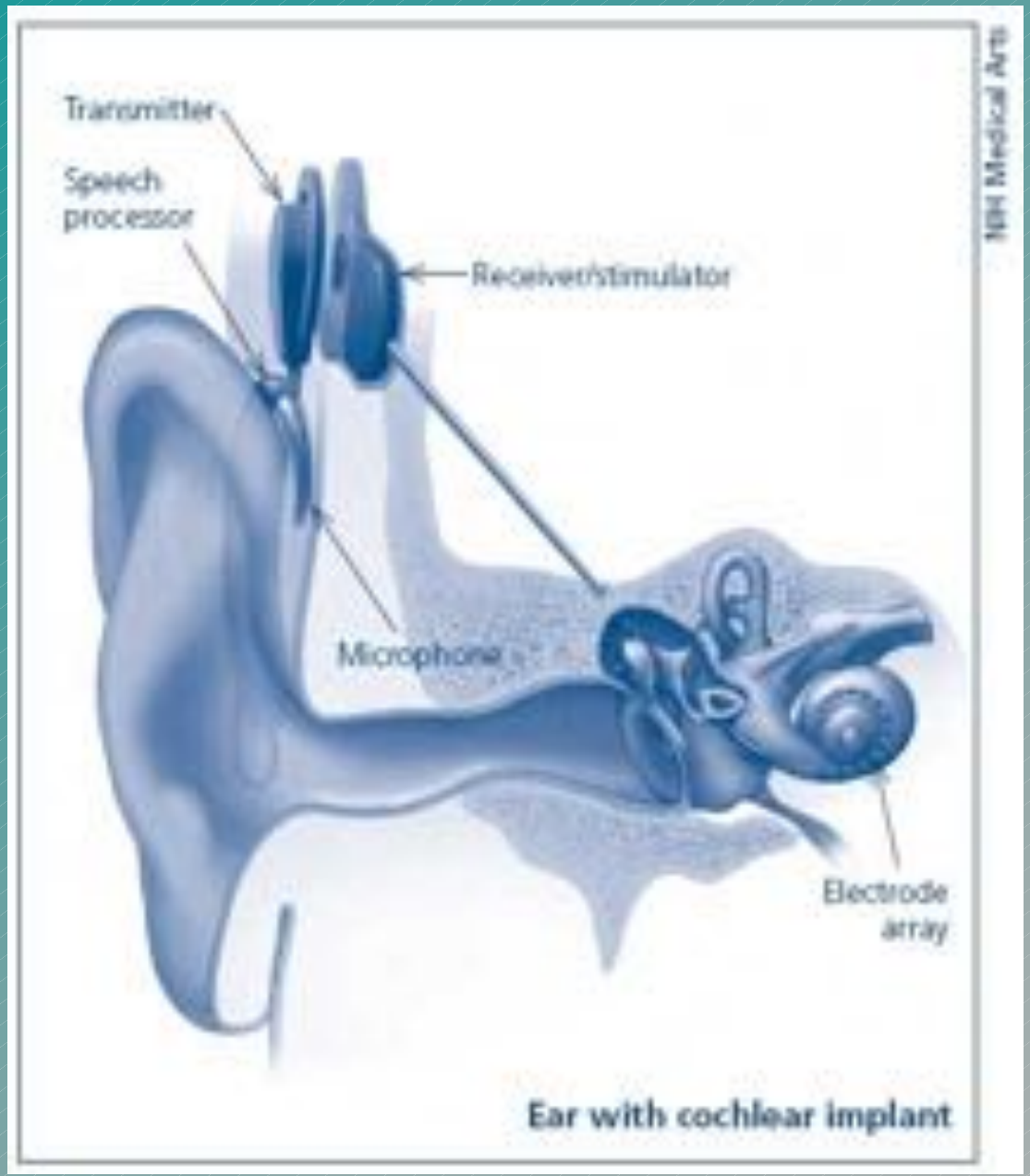


The cochlear implant is an electrode array positioned to stimulate the auditory afferents directly, in the absence of hair cell function





Cochlear Implant



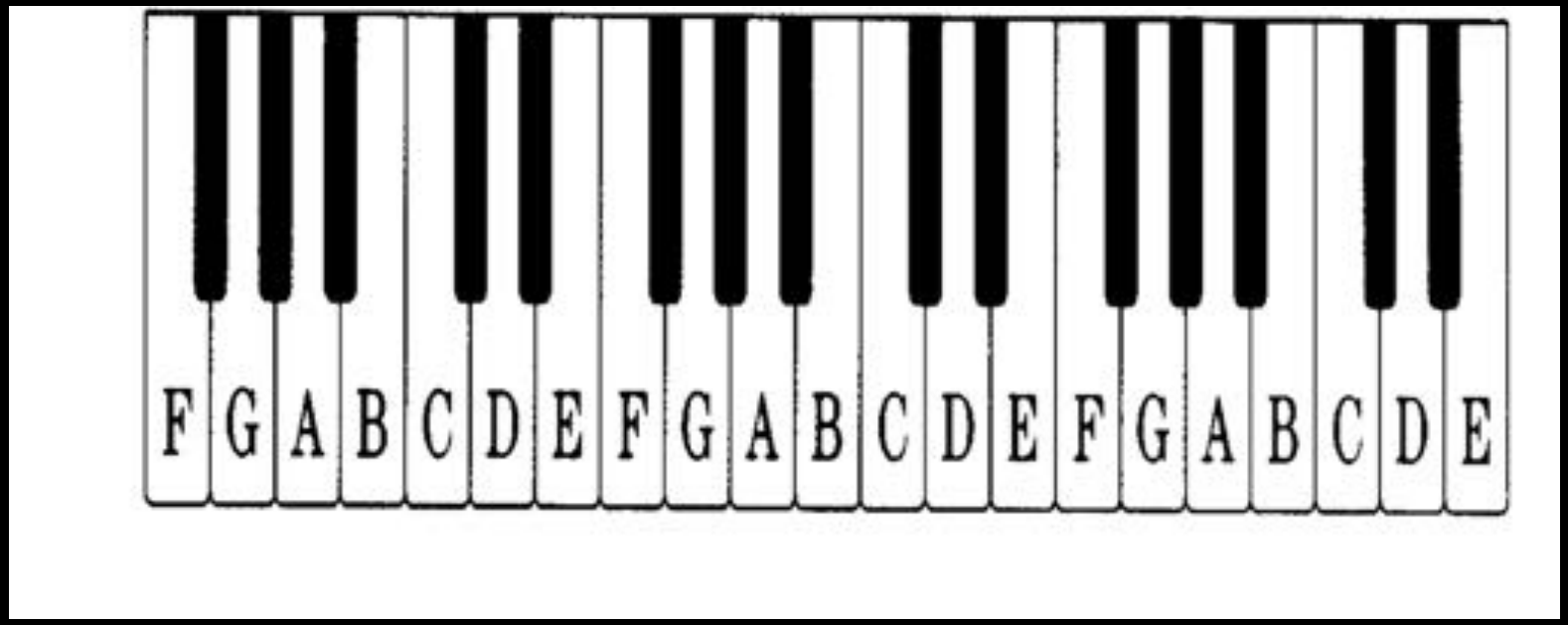
- Two elements
  - External
  - Internal

- A microphone
- A speech processor
- A transmitter and receiver/stimulator
- An electrode array

- Bypasses damaged part of the ear

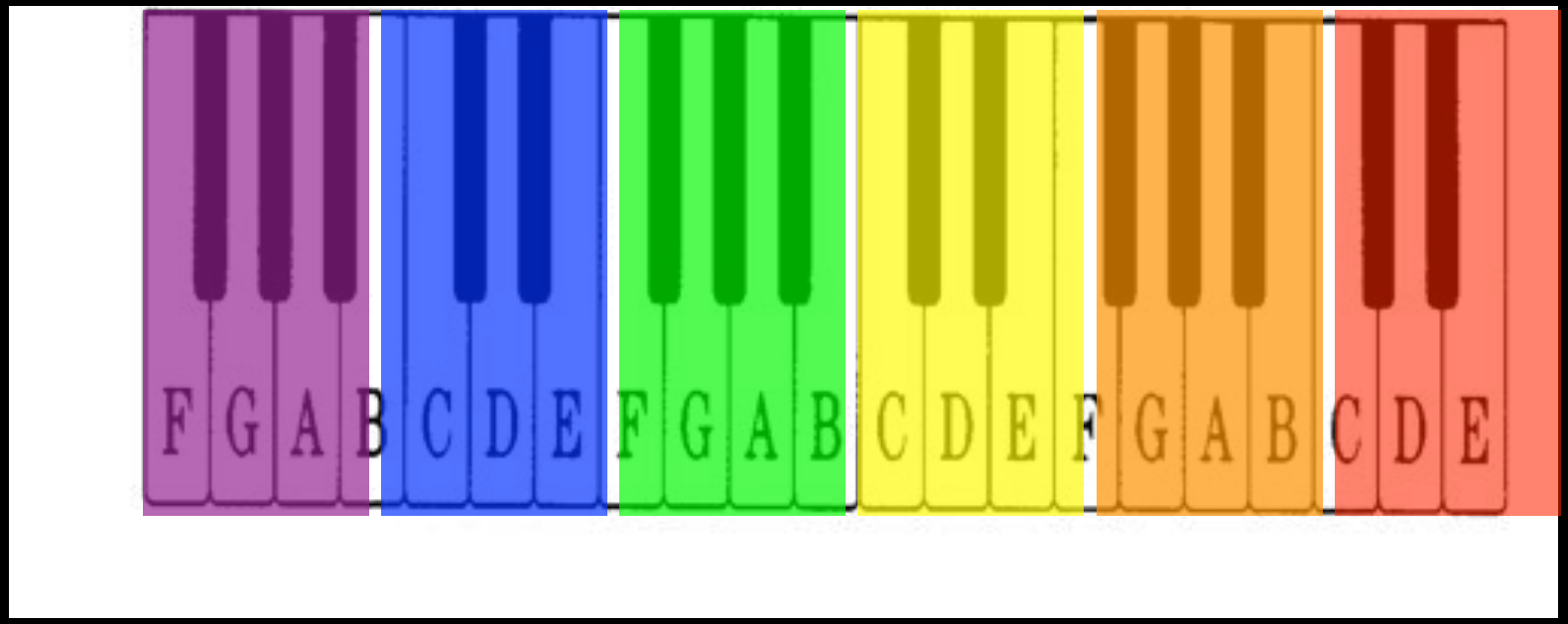
- Directly stimulates auditory nerve

The limit of implantation, is frequency resolution because todays best electrode has a max of 23 inputs to the ear



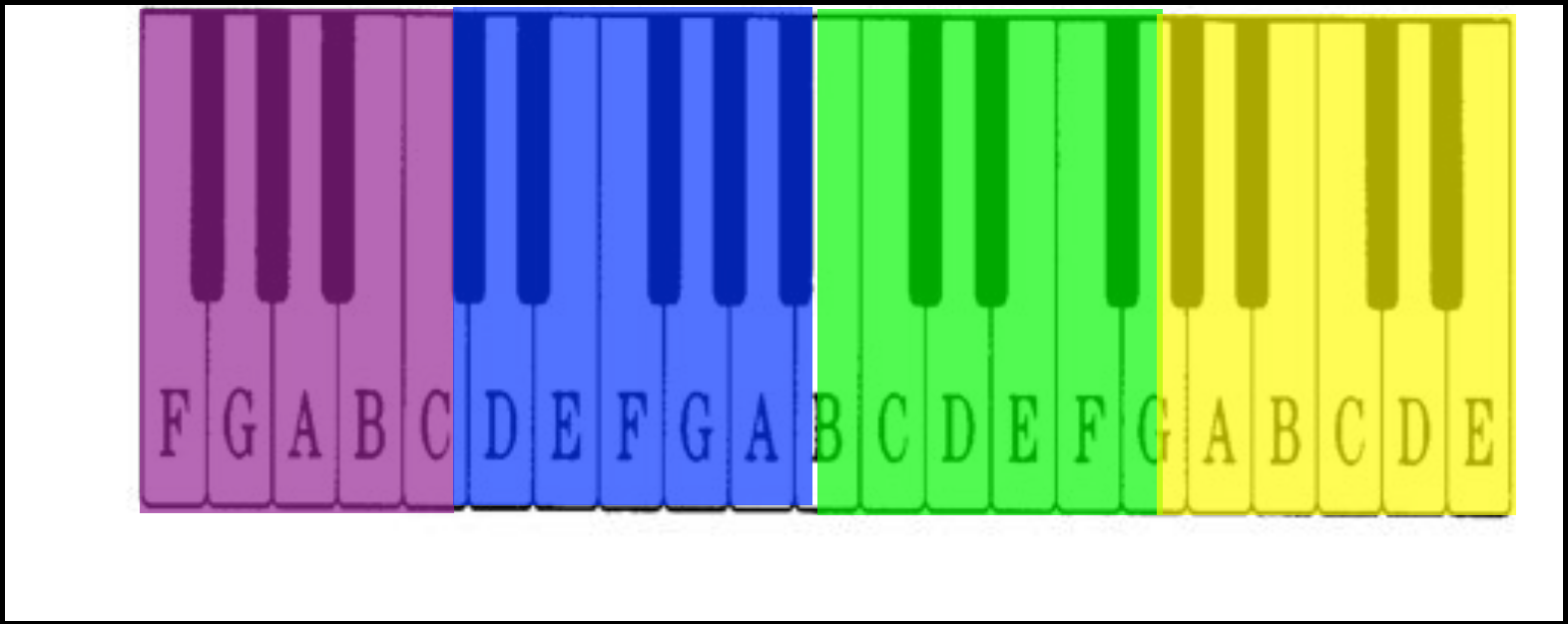
Normal Hearing

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....

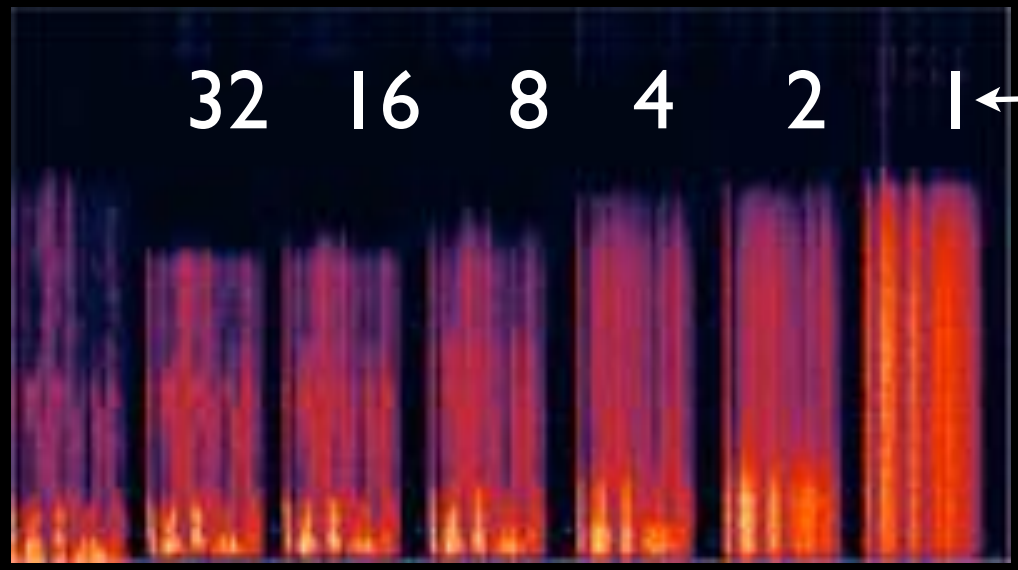
32 16 8 4 2 1

Frequency

Time

Frequency

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



Frequency

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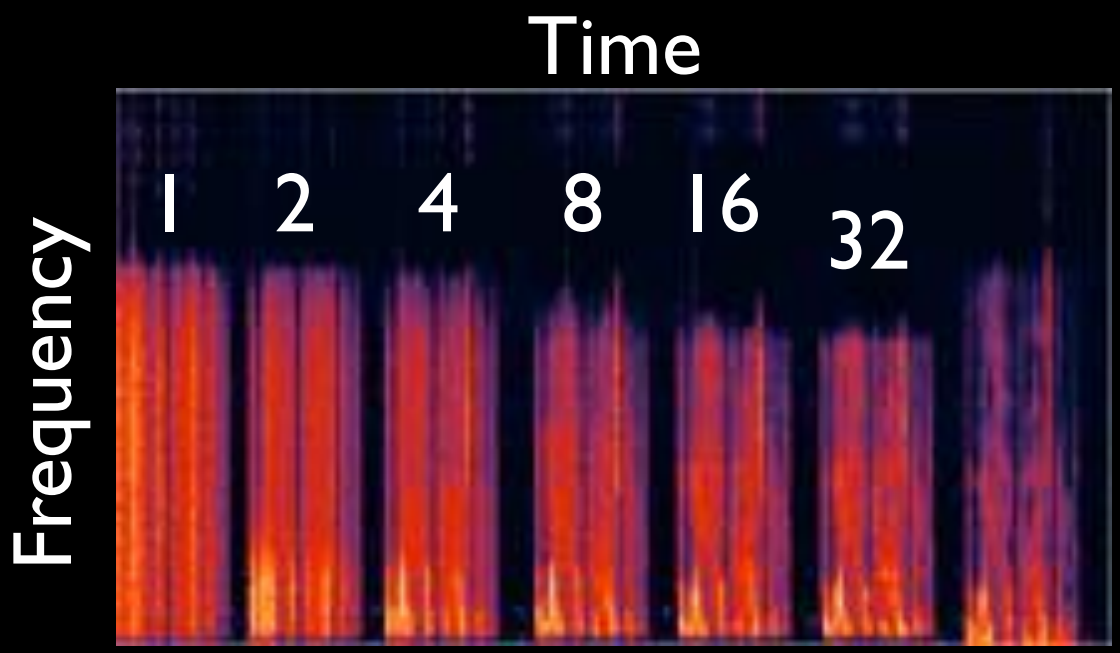
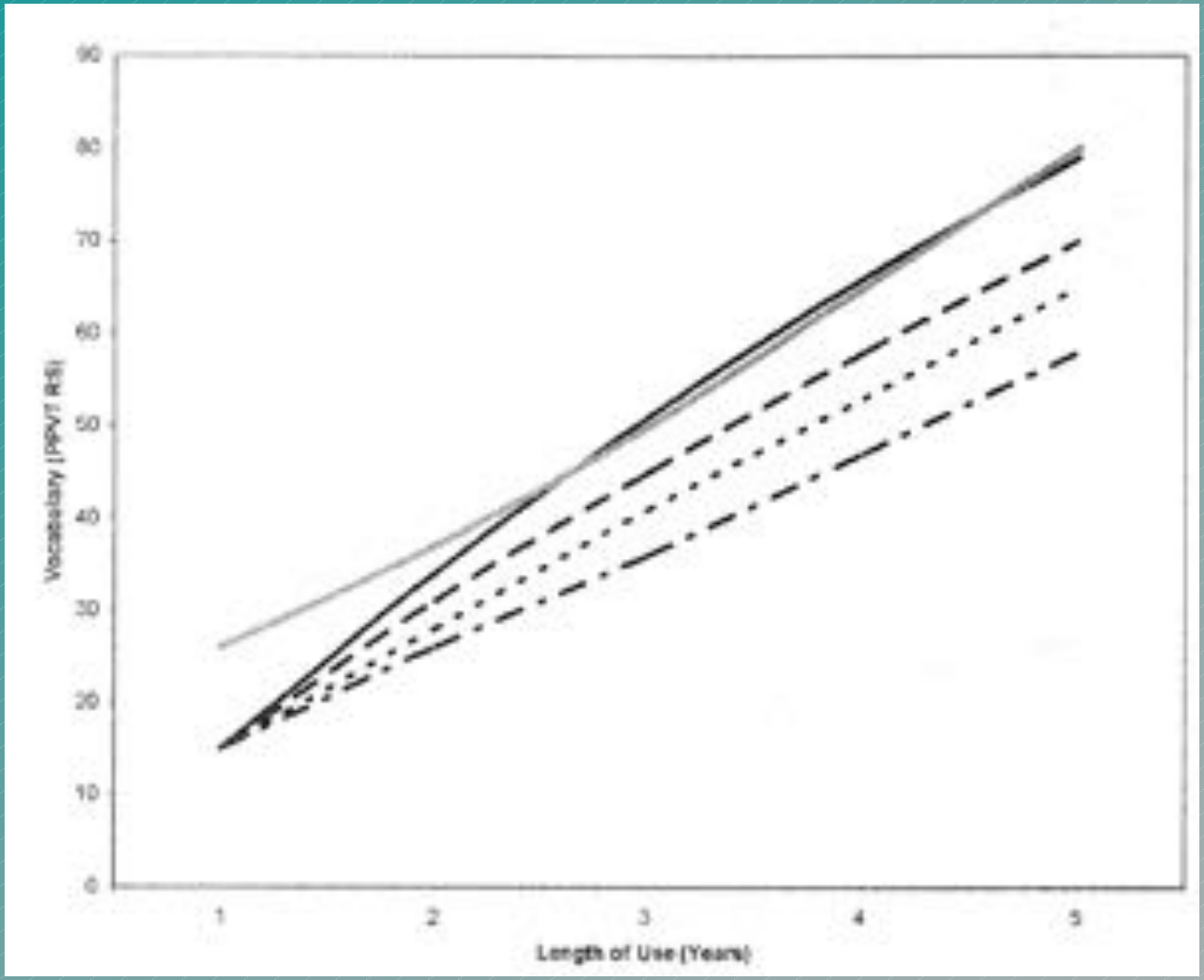


Age Matters
Vocabulary



Normal ears

< 2.5 years

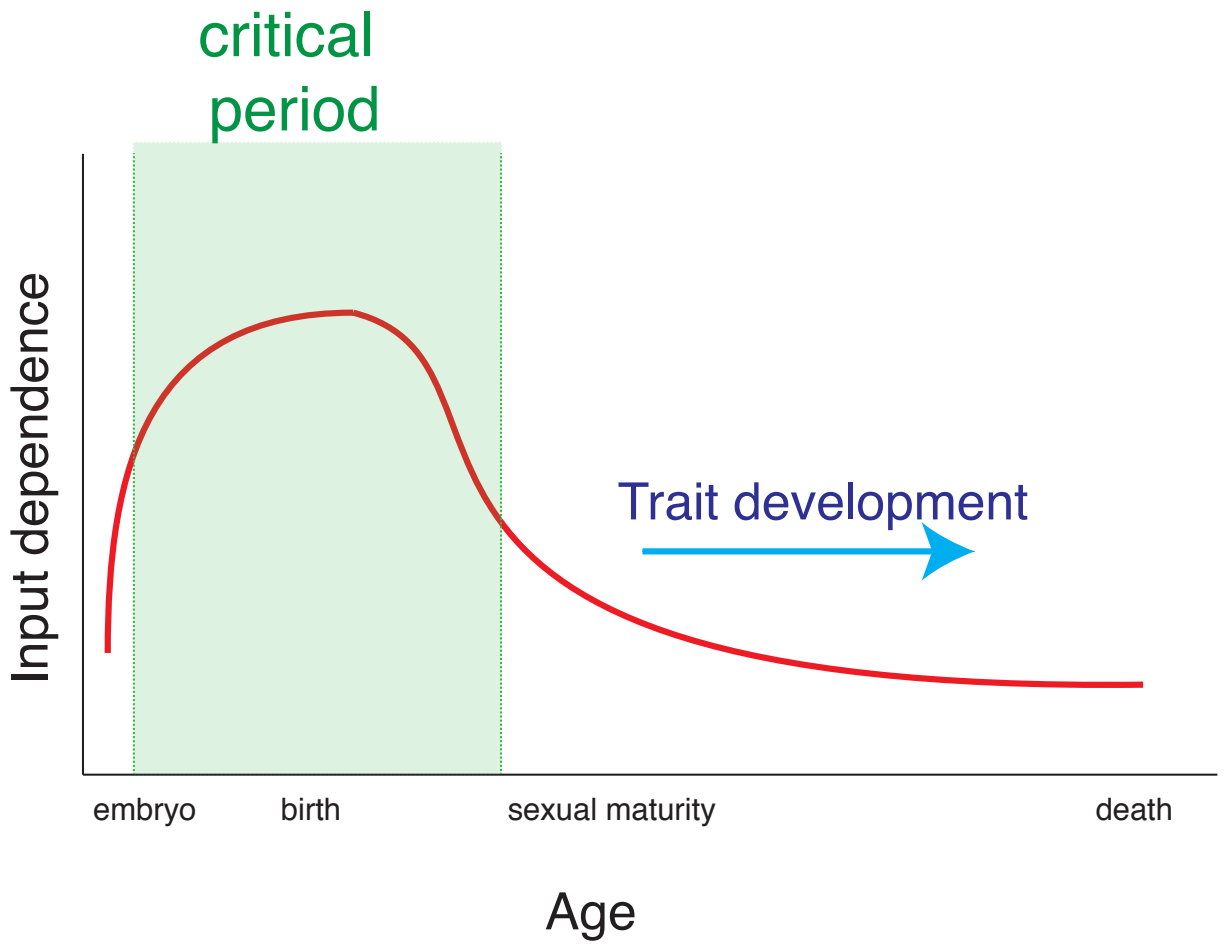
2.5-3.5 yrs

3.6-7 yrs

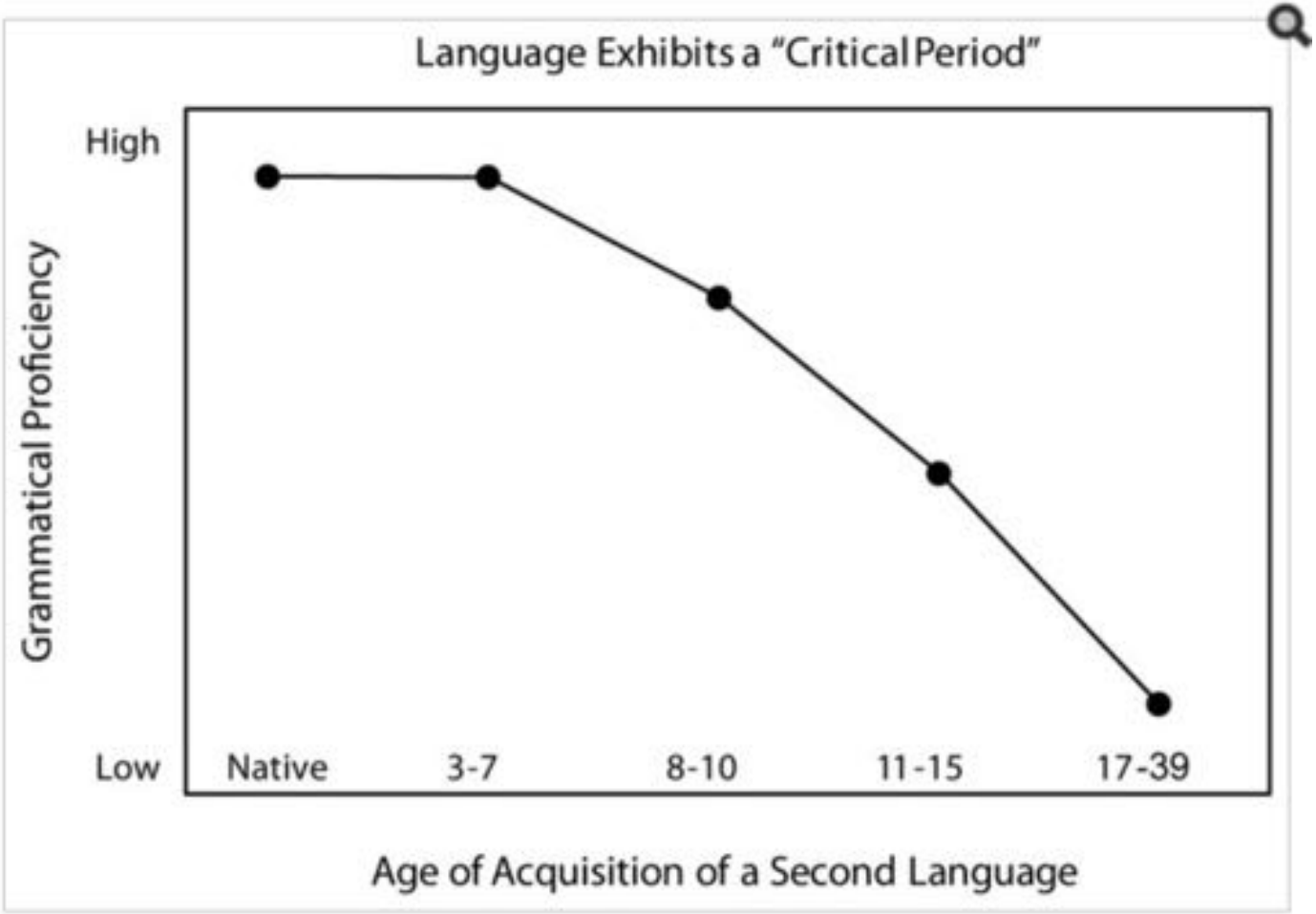
7.1-10 yrs

The point here: deaf children can recover near normal language ability if they are implanted early enough

(Connor et al. 2006)

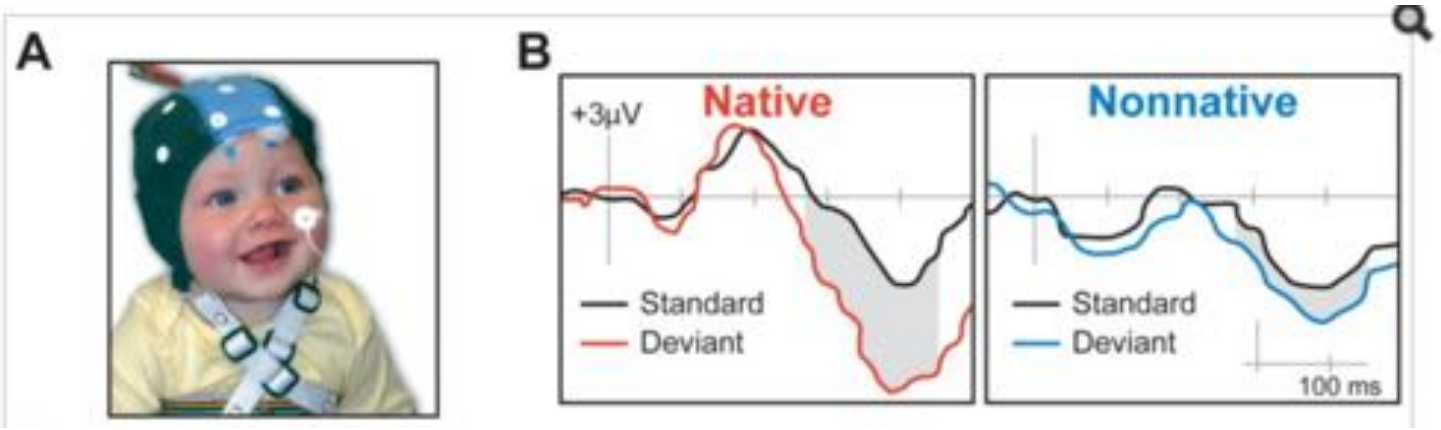

critical
period
Input dependence
Trait development
embryo
birth
sexual maturity
death
Age

Critical Periods in Language Development



Neuron. Author manuscript; available in PMC 2011 Sep 9.
Published in final edited form as:
Neuron. 2010 Sep 9; 67(5): 713–727.
doi: 10.1016/j.neuron.2010.08.038

Pre-lingual children can discriminate “native speech sounds” from nonnative



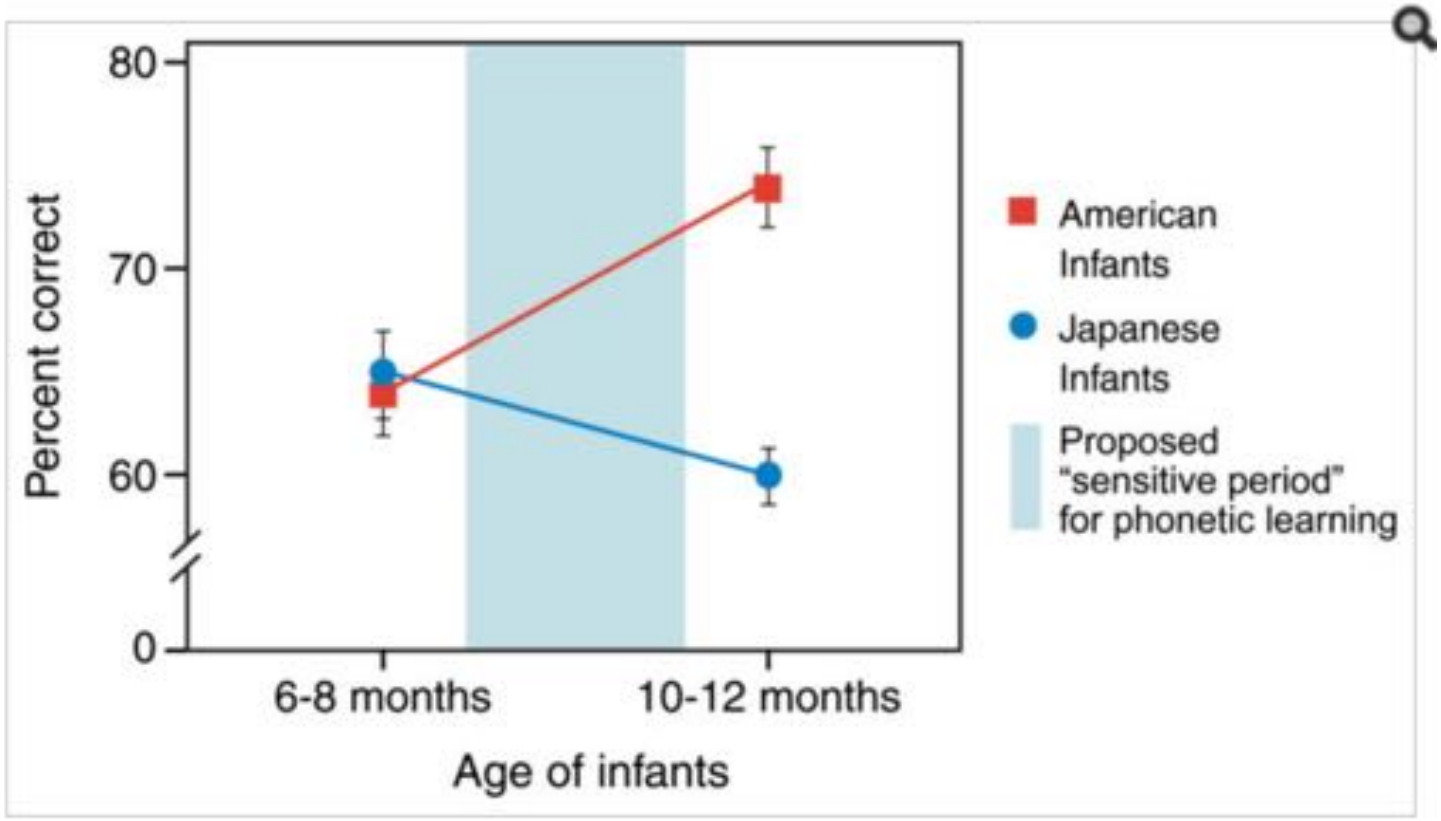
7.5 month infant discrimination in MMN of native vs non native contrast

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

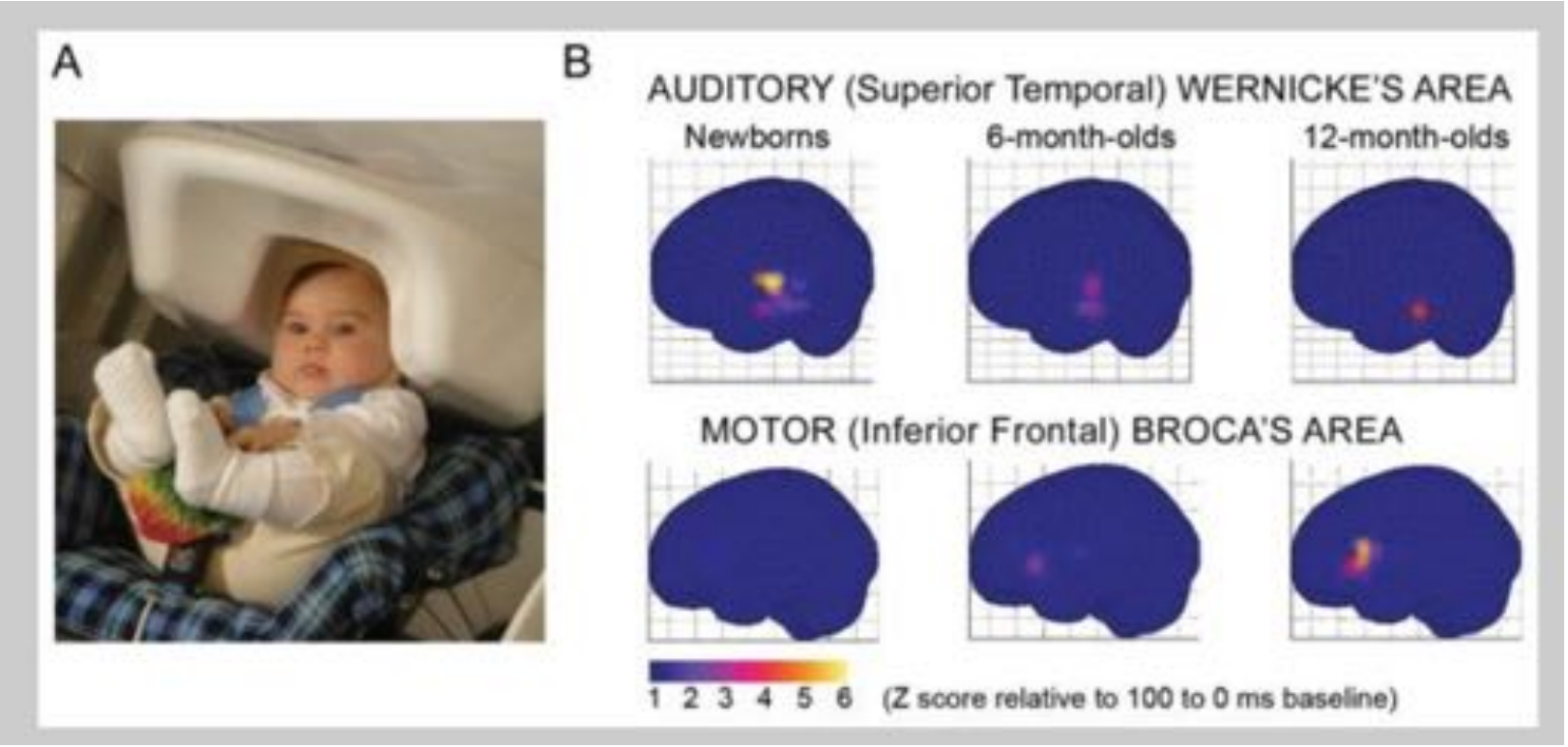
/r/ and /l/

rake

lake


80
70
60
0
Percent correct
6-8 months
10-12 months
Age of infants
American Infants
Japanese Infants
Proposed "sensitive period" for phonetic learning

Auditory and motor areas associated with speech are refined in the first year of life



Infant speech perception activates Broca's area: a developmental magnetoenceohalography study. Neuroreport. 2006;17:957–962.

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.