



Bionic Hearing:

The Science and the Experience

Ian Shipsey

TALK OUTLINE

The physiology of natural hearing

Causes of Deafness (10% of our citizens cannot hear well)

Solutions for hearing loss:

The cochlear implant.

Political & social issues

The future of cochlear implants

The Outer Ear

Pythagoras reasons sound Is a form of mechanical energy

The videos shown in this talk are based on "Auditory Transduction" by Brandon Pletcsh which was awarded 1st place in the NSF/AAAS Science and Engineering Visualization Challenge 2003. Video edited by S. Lichti and I.S.

Tympanic Vibrations

The tympanic membrane & ossicles

1543

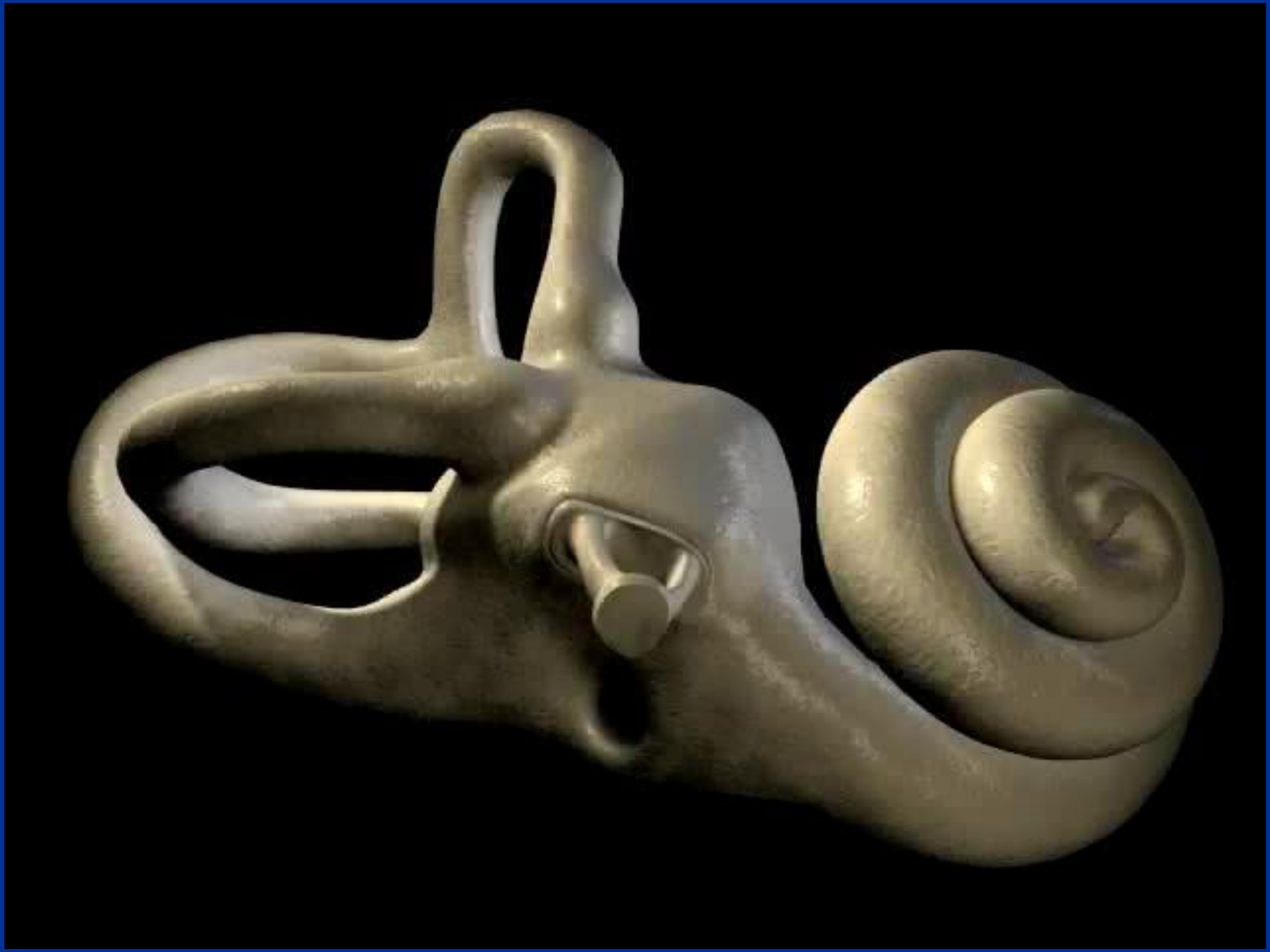
Anatomist Andreas Vesalius describes the structure of the middle ear.

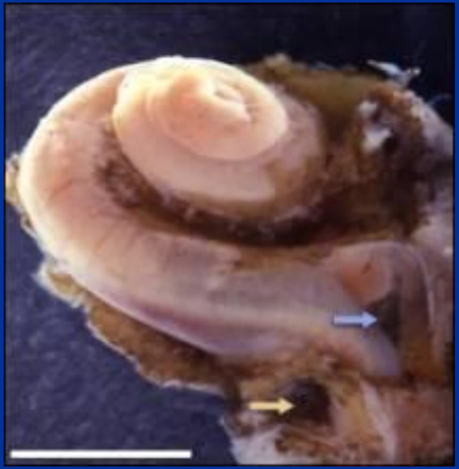
The tympanic membrane & ossicles

Through the ossicles the vibration of the tympanic membrane is transmitted to the stapes

Bony Labyrinth stapes and round window

The bony labyrinth, cochlea and it chambers

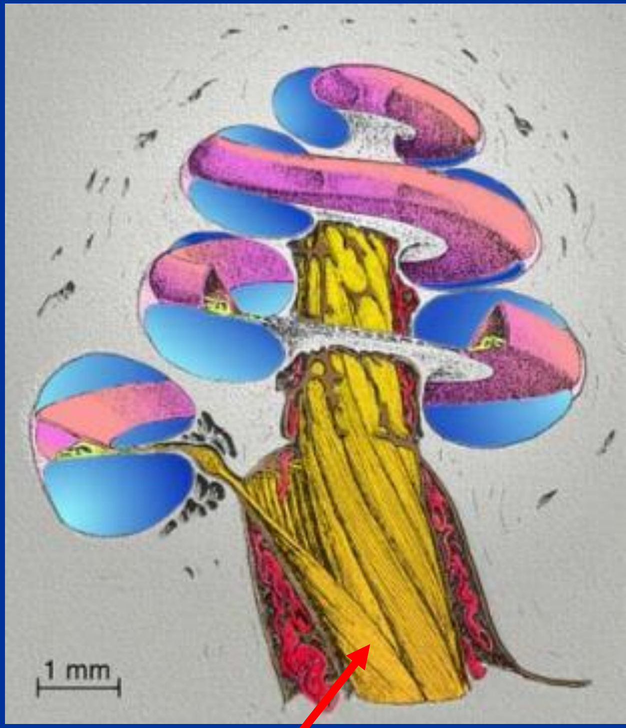




The cochlea is small (about the size of a pea) and light so that it is sensitive to low levels of vibration corresponding to soft sounds

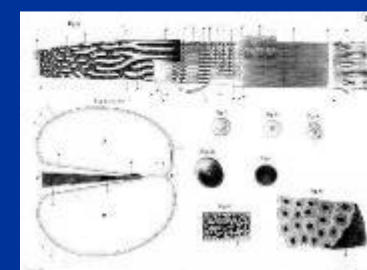
1561 Gabriello Fallopio discovers the snail-shaped cochlea of the inner ear.

The Cochlea houses the Organ of Corti



Auditory
Nerve

Organ of Corti



1st detailed study of Organ of Corti by Alfonso Corti

Original figures (scanned) from: Zeitschrift für wissenschaftliche Zoologie (1851)

Hair cells are a mechano-electric transducers

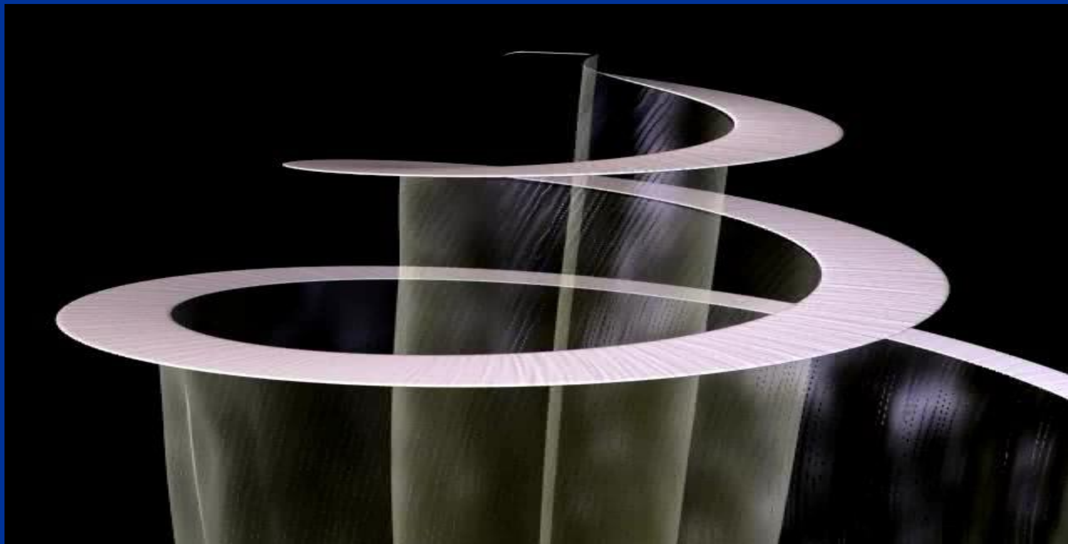
3,500 inner and 12,500 outer hair cells per cochlea

The Basilar Membrane is a Frequency Analyzer

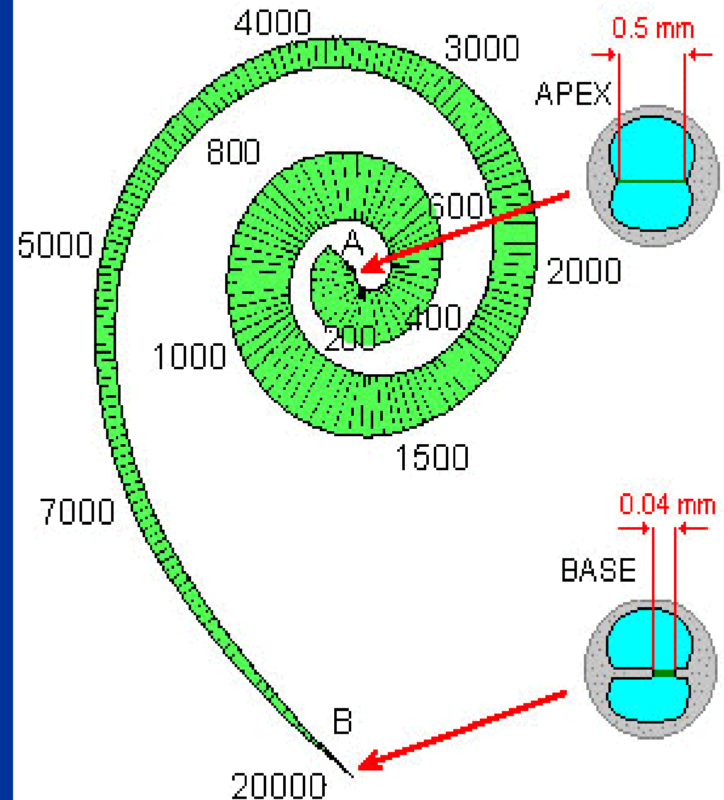
Helmholtz was the first to recognize the role of the basilar membrane in pitch perception

The relationship between pitch and place: Tonotopic Organization

Tonotopic Organization



Low pitch



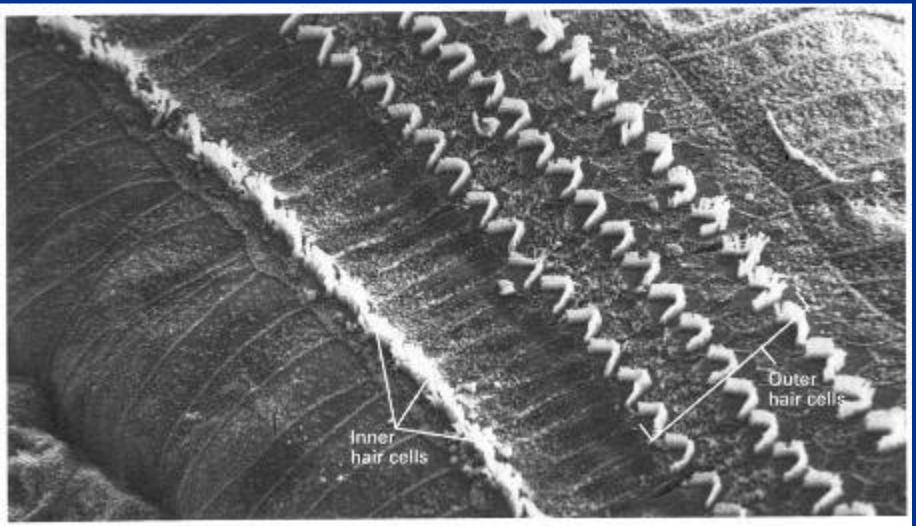
High pitch

Georg von Békésy (Nobel 1961)
Experimentally measured basilar membrane (BM) displacements providing the first observation of tonotopic organization

While this is how we hear loud sounds and perceive pitch, how about soft sounds?

Middle C = 256

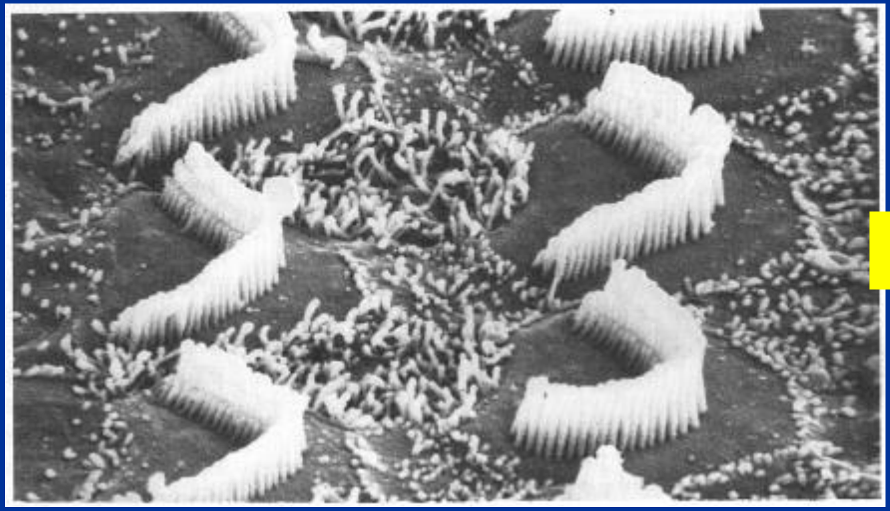
Rows of Hair Cells in the healthy cochlea

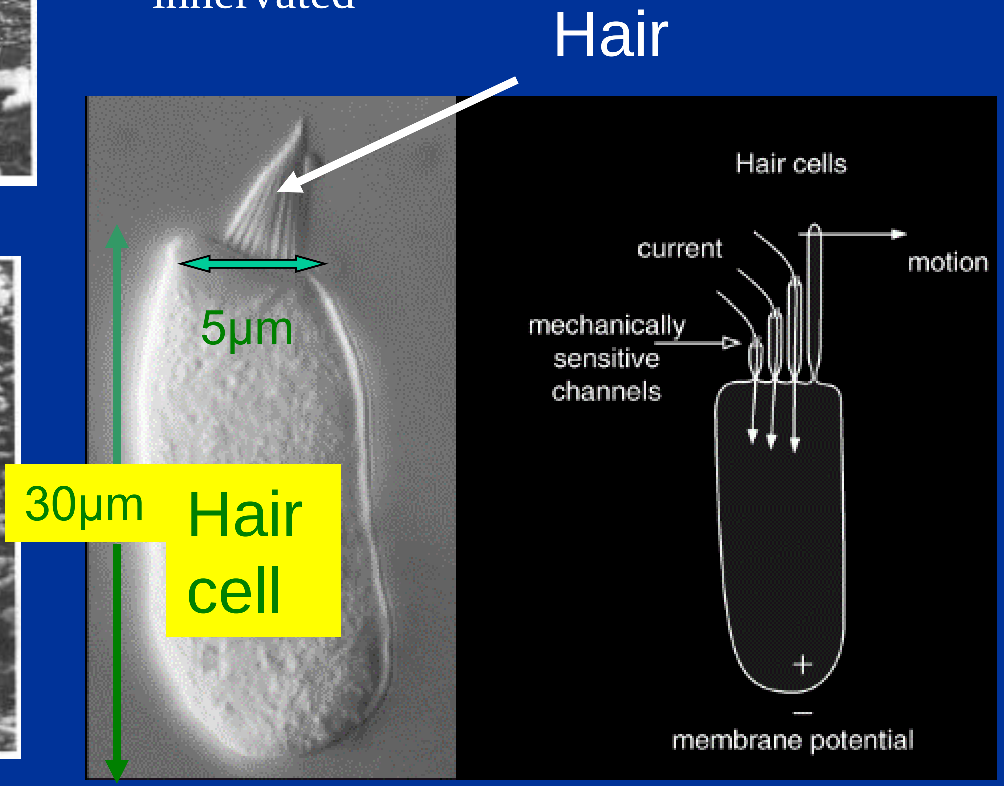


Per cochlea:

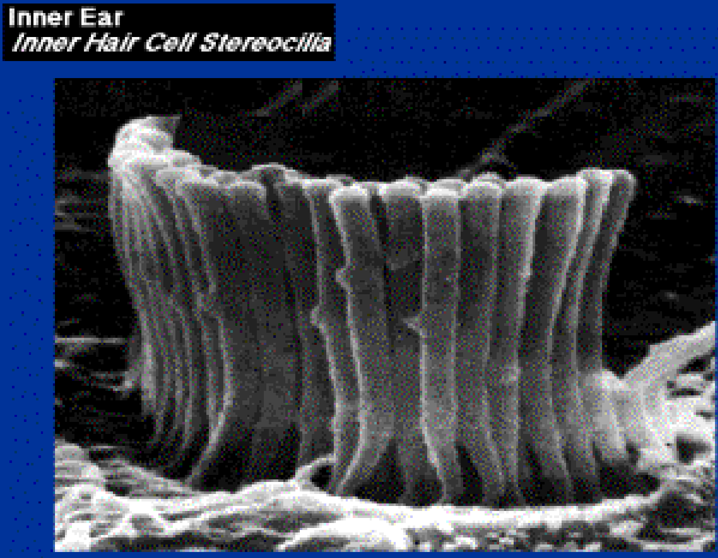
Inner hair cells 3,500 afferent (signals go the brain)

Outer Hair Cells 12,500 Sparsely innervated

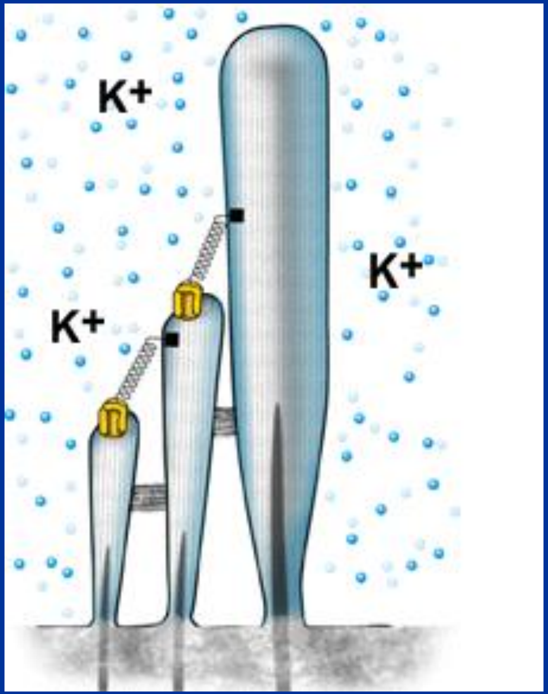


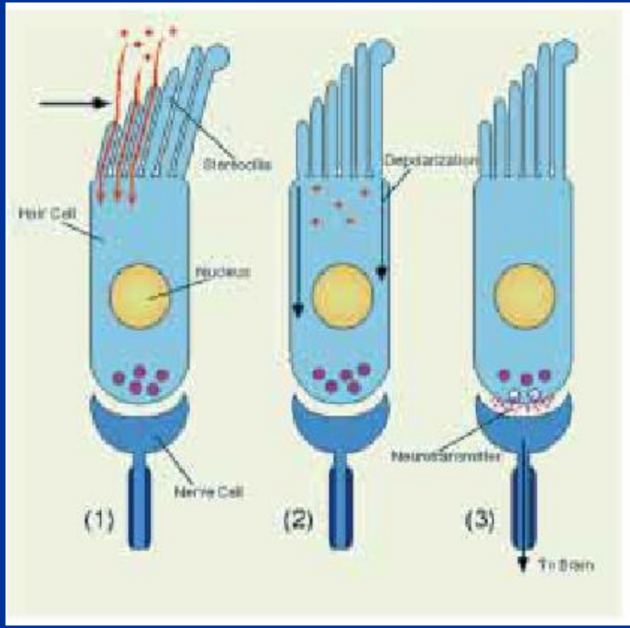


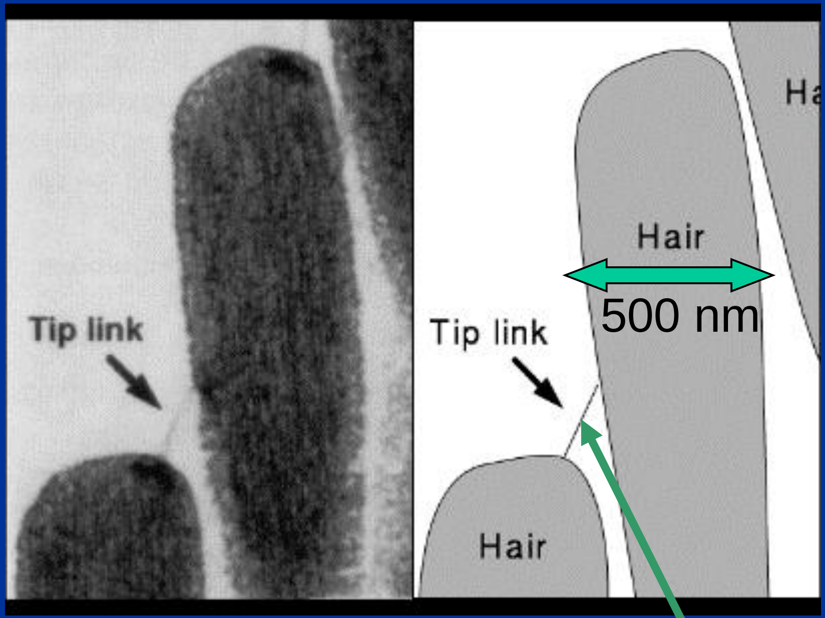
Hair cells are mechano-electrical transducers



1980' s







<10nm diameter

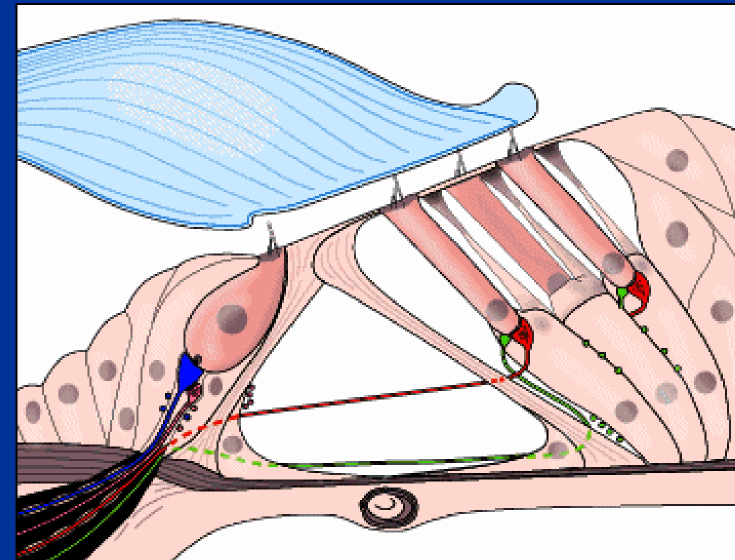
Both inner and outer hair cells work this way

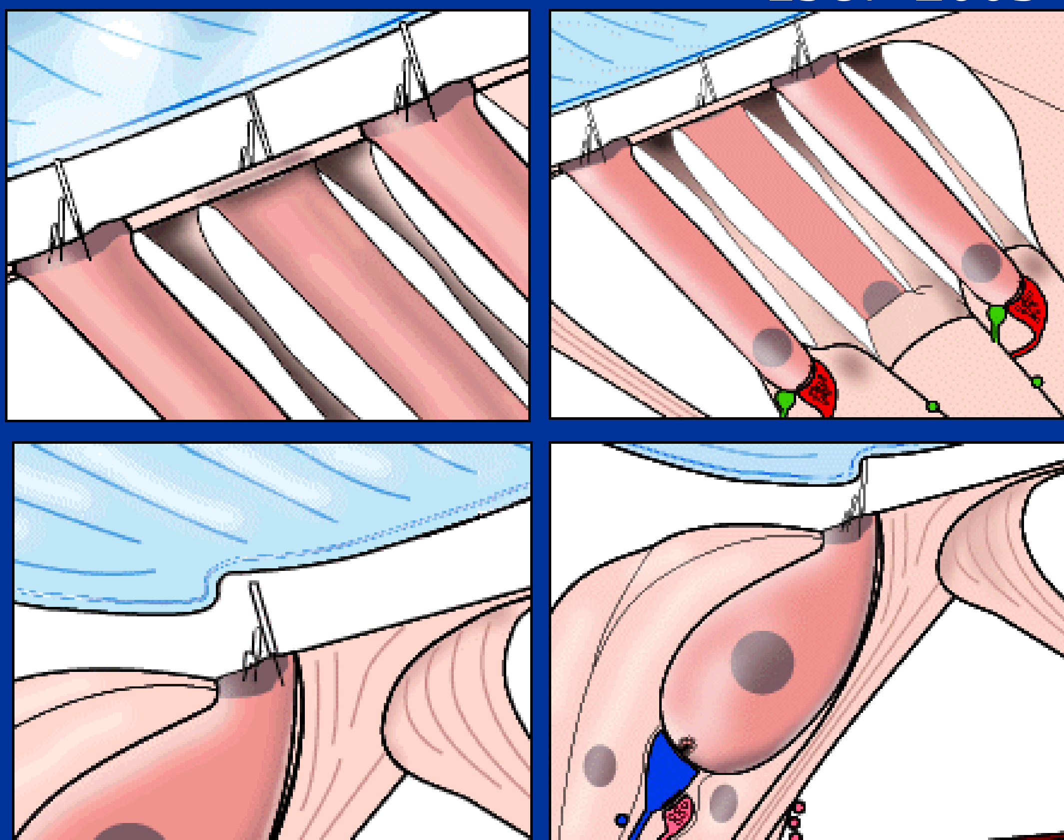
The inner hair cells send signals to the brain that are interpreted as sound. What do the outer hair cells do?

1987-2003

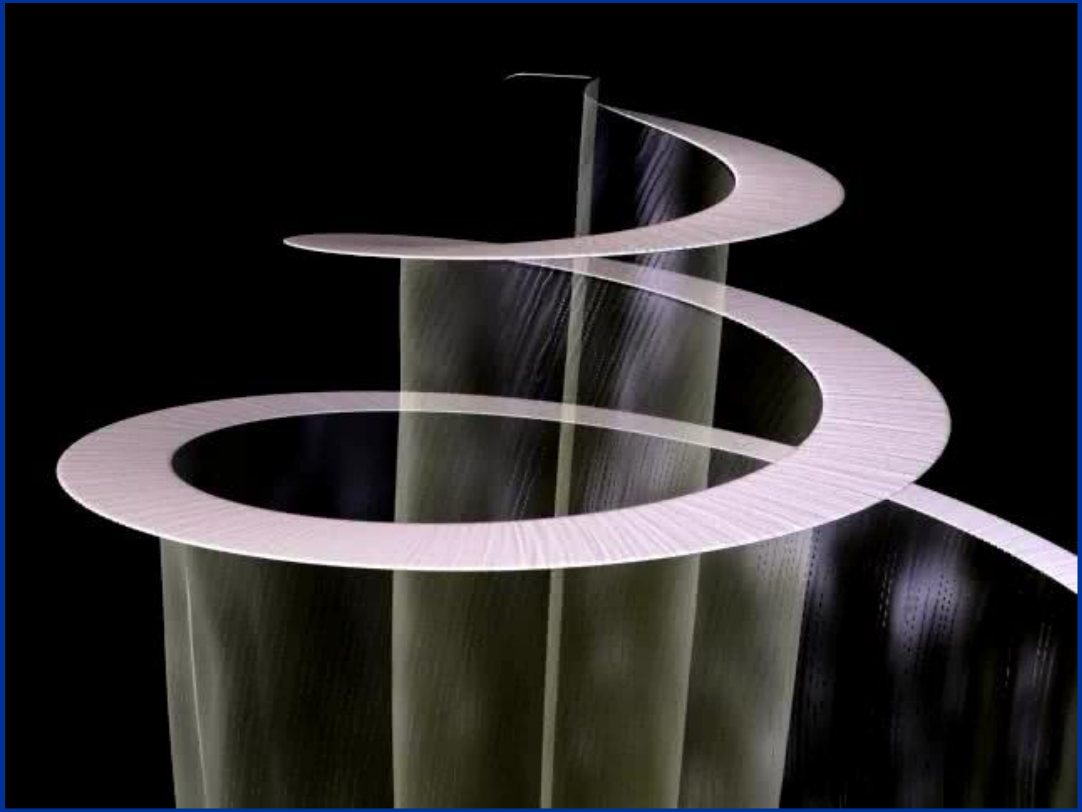
The inner hair cells send signals to the brain that are interpreted as sound. What do the outer hair cells do?

Outer hair cells are mechanical amplifiers they contract during transduction enhancing BM displacements increasing sensitivity to soft sounds and improve pitch perception





Auditory Perception



From the motion of air molecules to electrical signals on the auditory nerve..

The Five Main Causes of Hearing Loss

1. Heredity.
2. Infections, (ex: bacterial meningitis, rubella).
3. Acute or chronic exposure to loud sounds.
4. Prescription drugs, such as ototoxic antibiotics (streptomycin and tobramycin) and chemotherapeutic agents, such as cisplatin.
5. Presbycusis, the hearing loss of old age,

Me in 1989

All of us

10% of our citizens cannot hear well

The main types of hearing loss

1) Conductive (the ossicles no longer function)

2) 70% of hearing loss is sensorineural (loss of hair cells)

(a) vast majority of cases involve loss of *some* hair cells (mild, moderate hearing loss)

➔ hearing aids

(b) (4%) Loss of *large* numbers of hair cells

Hearing aids do not help: no matter how loud the amplified sound the transduction mechanism (i.e. hair cells) are absent and so no electrical signals are produced and sent to the brain

➔ Cochlea Implant (CI)

The first cochlea implant (1800)….

Volta placed two metallic probes in both ears and connected the end of two probes to a 50-volt battery, and observed that:

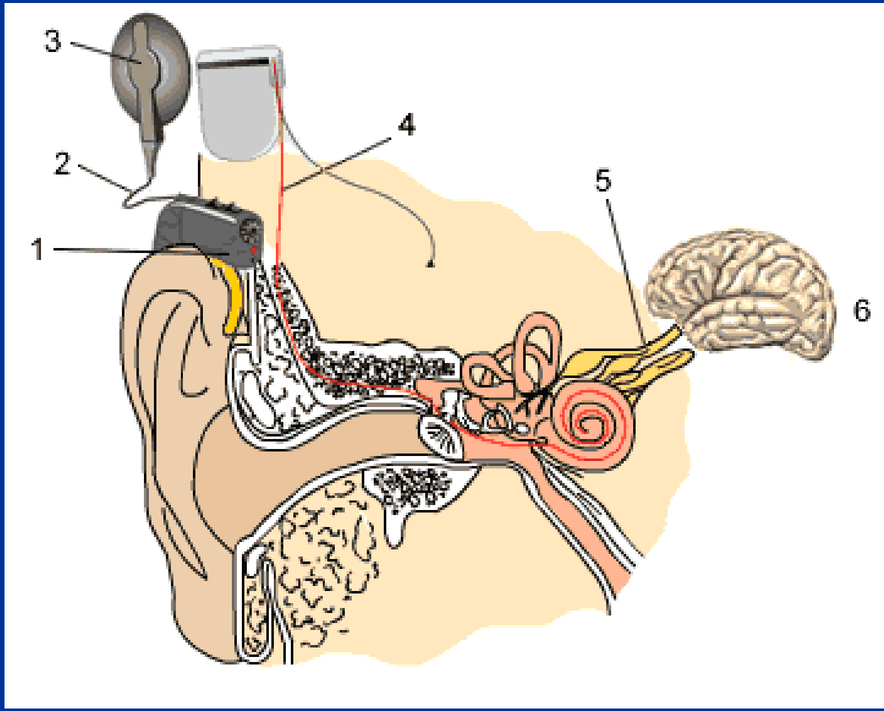
"... at the moment when the circuit was completed, I received a shock in the head, and some moments after I began to hear a sound, or rather noise in the ears, which I cannot well define: it was a kind of crackling with shocks, as if some paste or tenacious matter had been boiling...

The disagreeable sensation, which I believe might be dangerous because of the shock in the brain, prevented me from repeating this experiment..."

Alessandro Volta,
Philosophical Transactions,
Vol. 90 (1800), Part 2, pp. 403-431.

The Modern Cochlea Implant

Unlike hearing aids, which make sounds louder, a Cochlear Implant bypasses the non-functional hair cells of the ear and delivers weak electrical signals directly to the auditory nerve.



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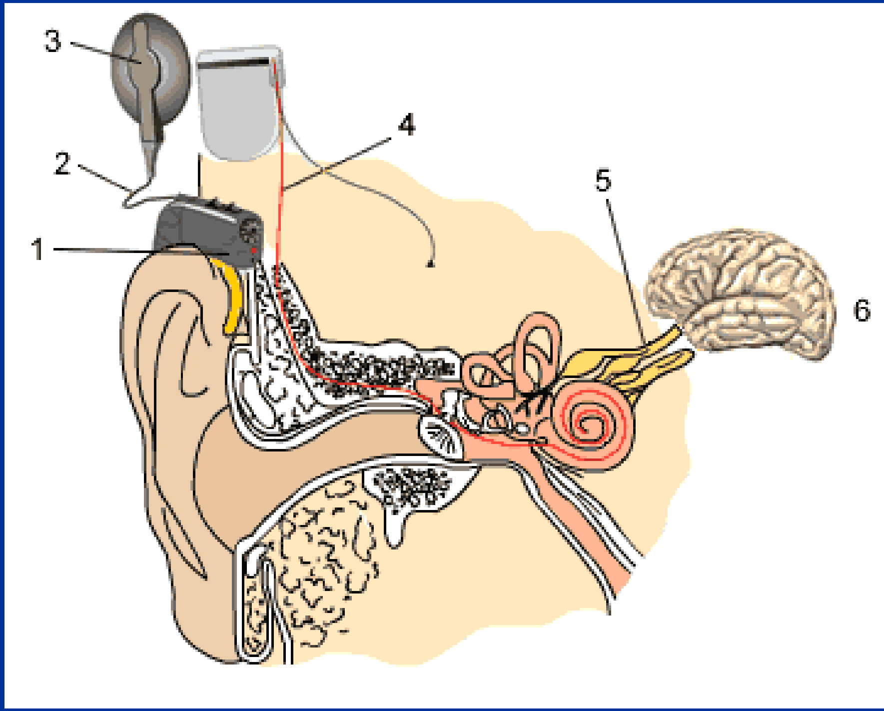

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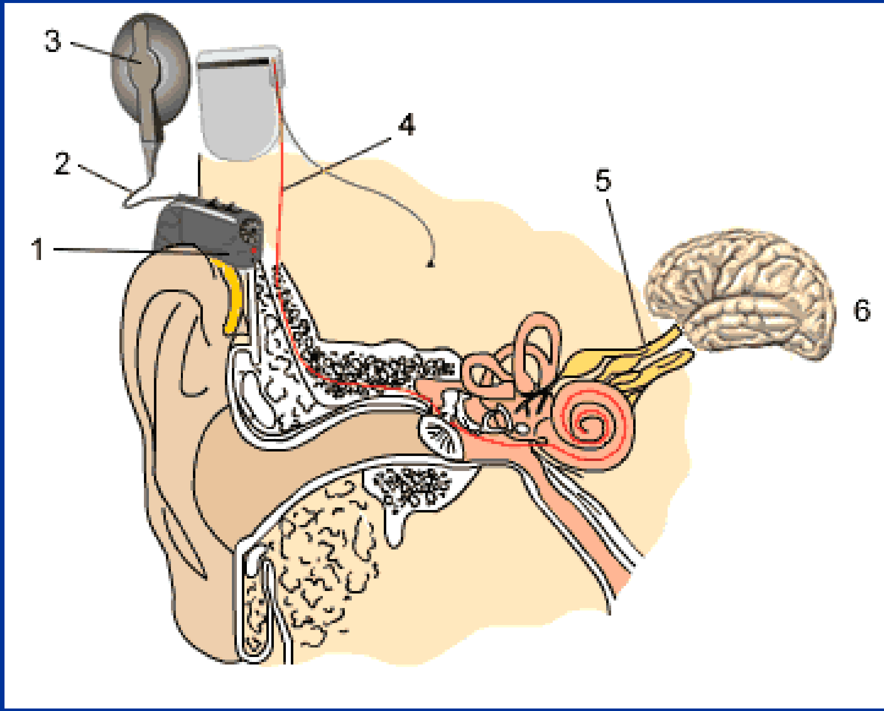

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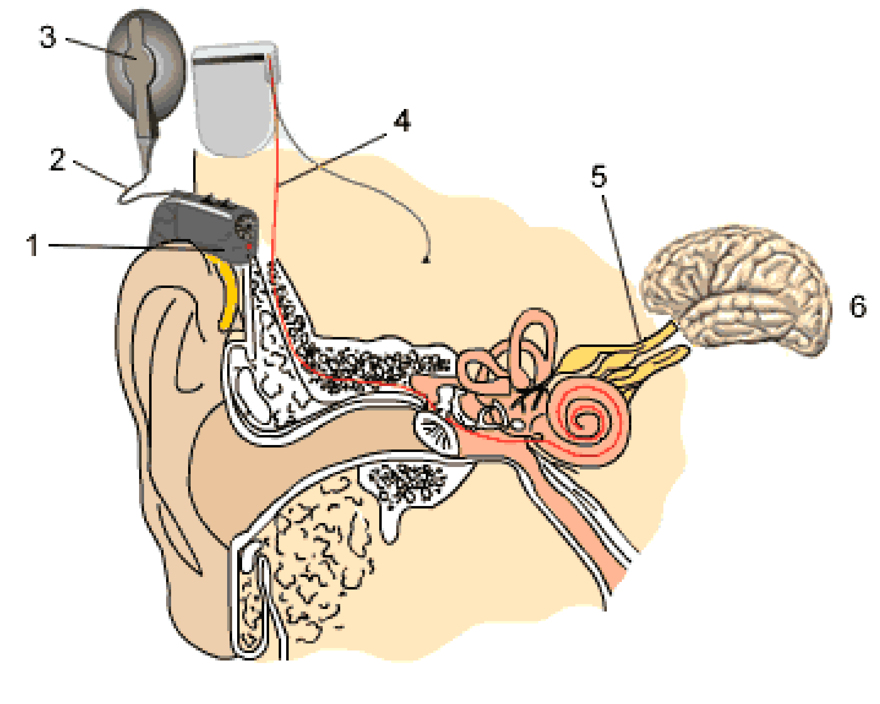

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4. The implant (ASIC) reads the program (data) and follows the instructions sending a pattern of analog electrical pulses to multiple electrodes in the cochlea.

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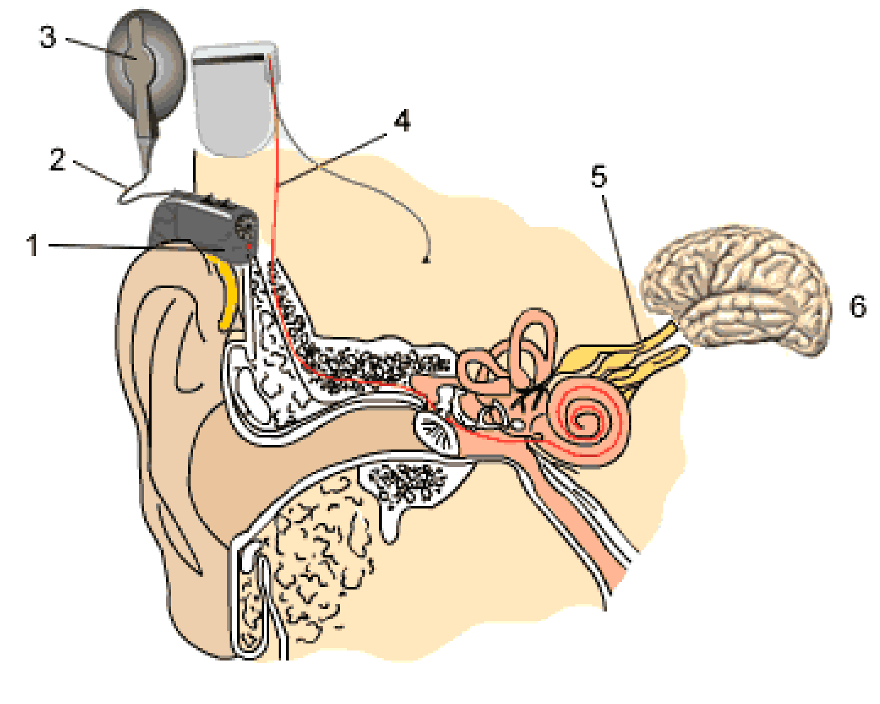

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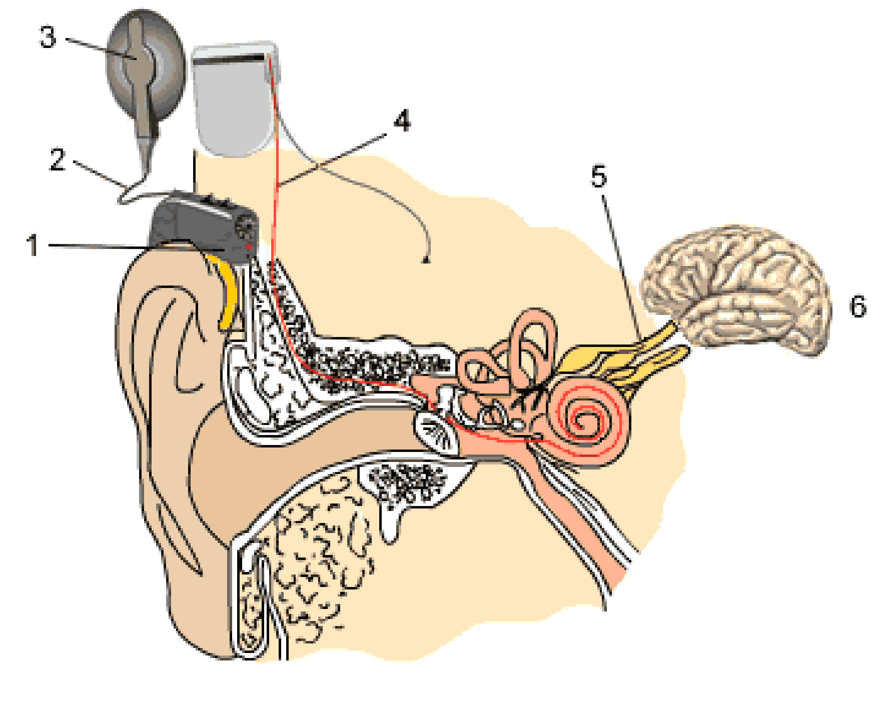

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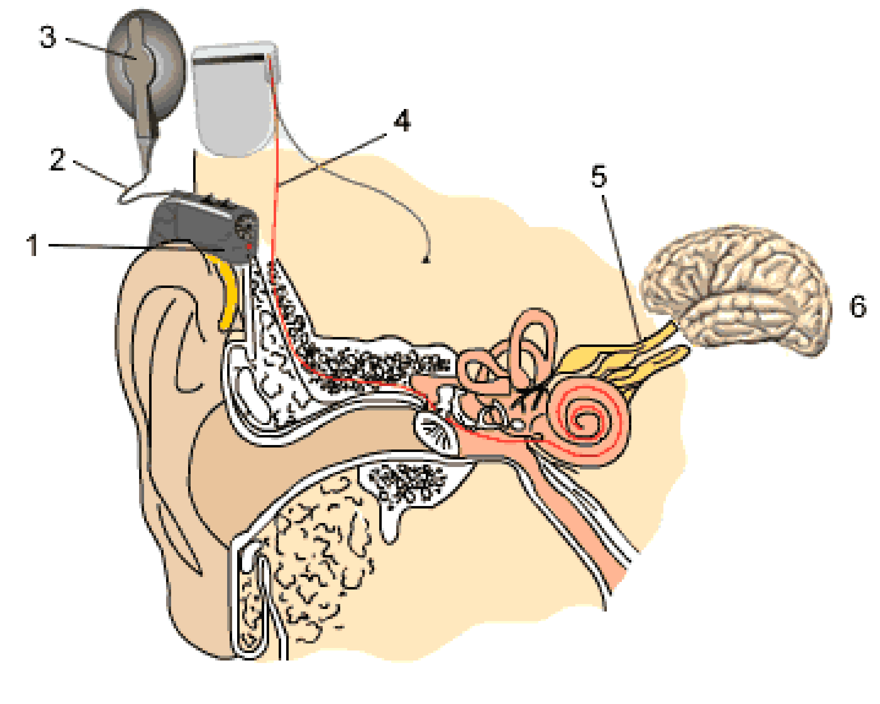
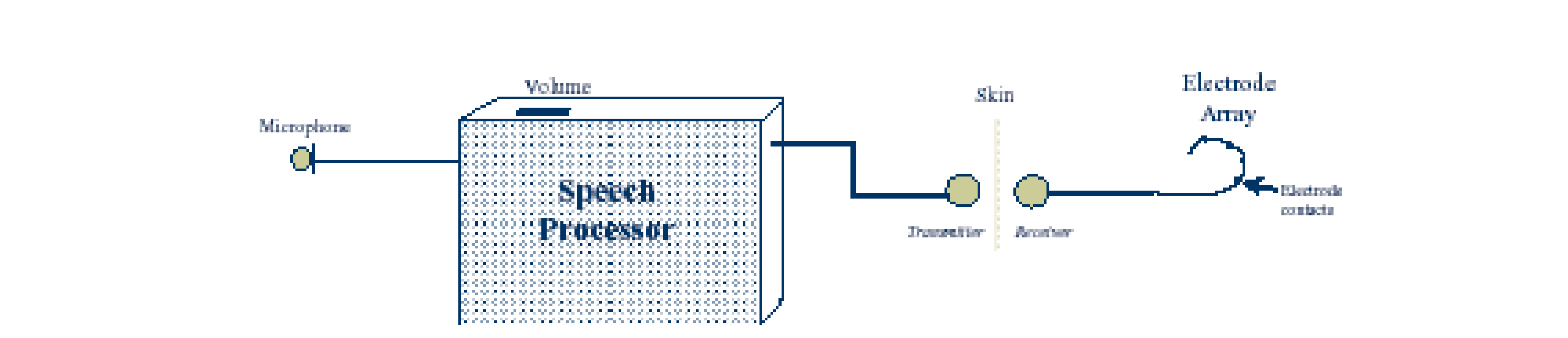
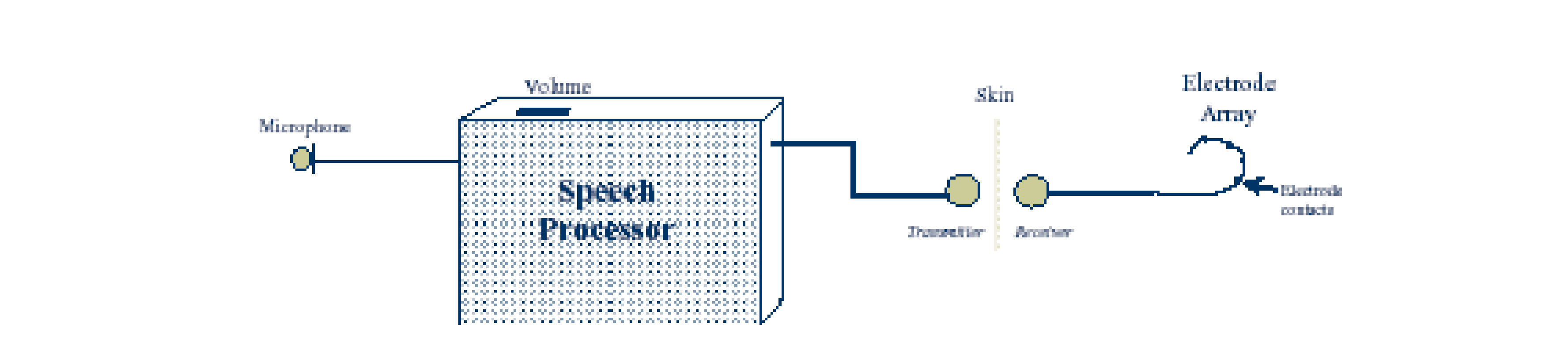
5. The auditory nerve picks up the electrical pulses and sends them to the brain.
6. The brain recognizes the signals as sound.





In natural hearing high frequency sound stimulates the cochlea and auditory nerve at the base, low frequency sound at the apex.



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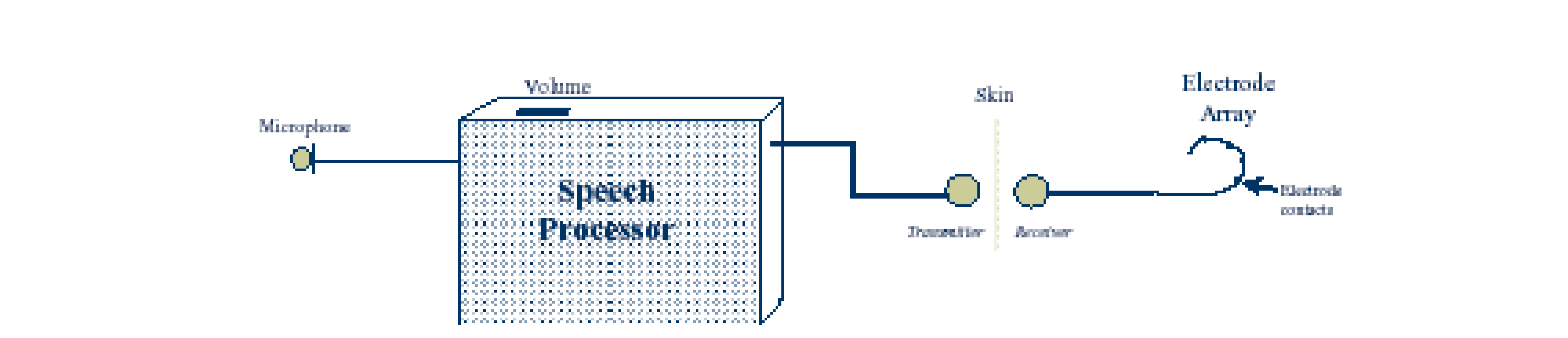
The key idea: the cochlea implant exploits the natural arrangement of the cochlea & auditory nerve by using 10-22 electrodes each placed at a separate location in the cochlea.



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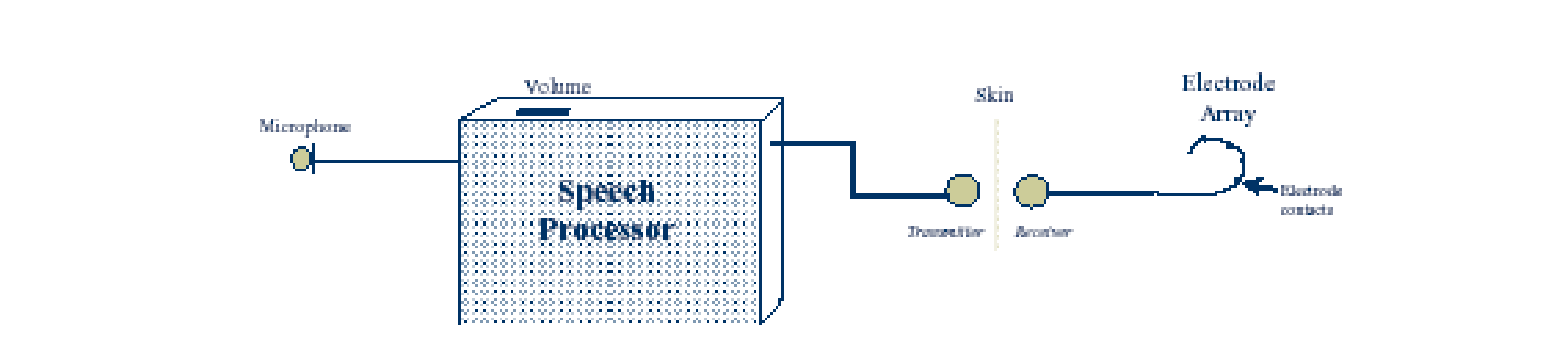
The speech processor continuously measures and sorts the sound signal by pitch and loudness.



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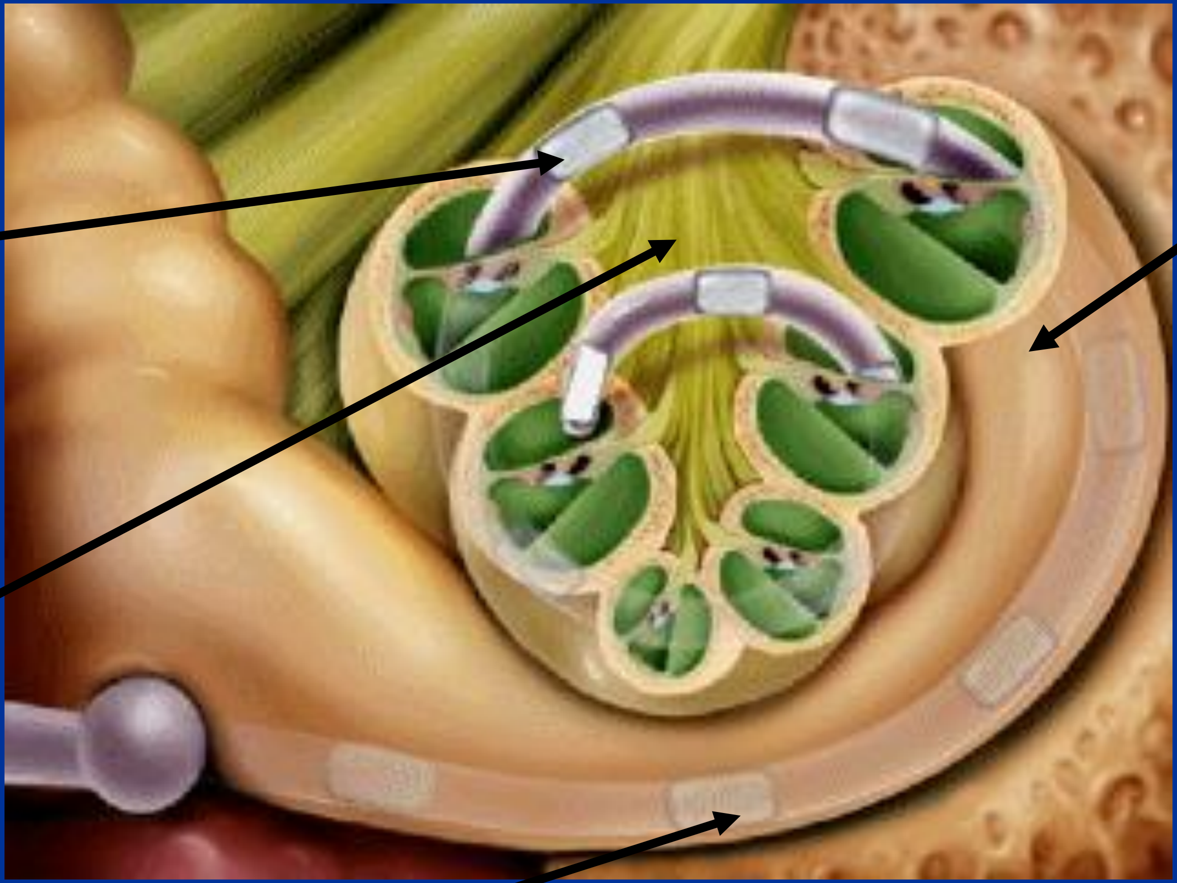
High frequency sounds are sent to electrodes at the cochlea base
Low frequency sounds are sent to electrodes at the cochlea apex



electrode

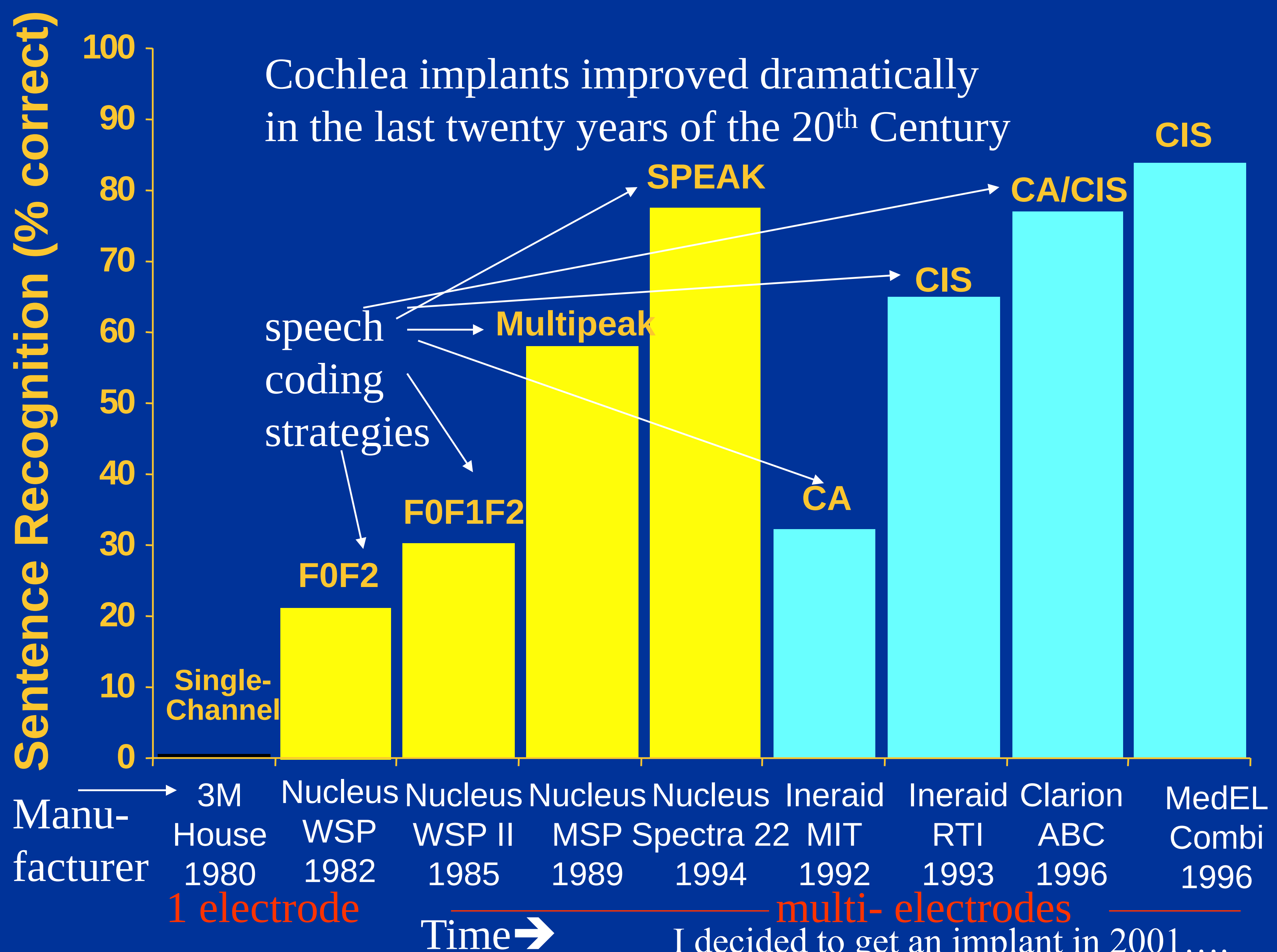
auditory
nerve

grey rectangles
Represents
electrodes

cochlea

white
represents
a pulsed
electrode

18,800
pulses
per second



Cochlea implants improved dramatically
in the last twenty years of the 20th Century
Sentence Recognition (% correct)
100
90
80
70
60
50
40
30
20
10
0
speech
coding
strategies
Single-
Channel
F0F2
F0F1F2
Multipeak
SPEAK
CA
CIS
CA/CIS
CIS
Manu-
facturer
3M
House
1980
Nucleus
WSP
1982
Nucleus
WSP II
1985
Nucleus
MSP
1989
Nucleus
Spectra 22
1994
Ineraid
MIT
1992
Ineraid
RTI
1993
Clarion
ABC
1996
MedEL
Combi
1996
1 electrode
multi- electrodes
Time
I decided to get an implant in 2001….

Who can have a Cochlear Implant?

(Requirements on this slide are for USA, they vary by country)

- Requirements for Adults (I'll discuss children separately)
  - 18 years old and older (no limitation by age)
  - Bilateral moderate-to-profound sensori-neural hearing loss (with little or no benefit from state of the art hearing aids in a 6 month trial) ~1 million citizens now qualify but only ~71,000 CI's in U.S. (42,600 Adults, 28,400 children: FDA 12/2010)
  - Psychologically suitable
  - No anatomic or medical contraindications

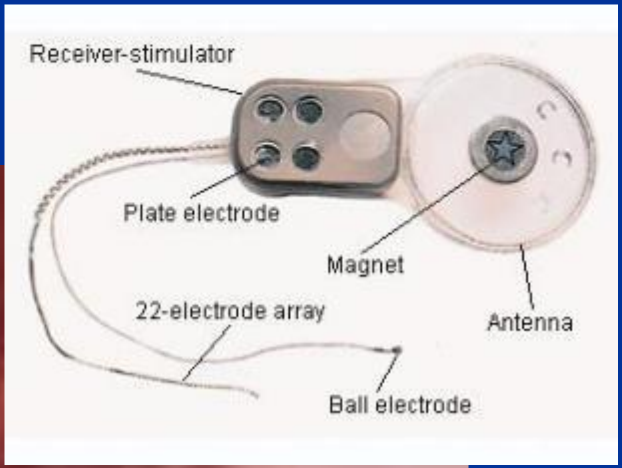
If the requirements are met:

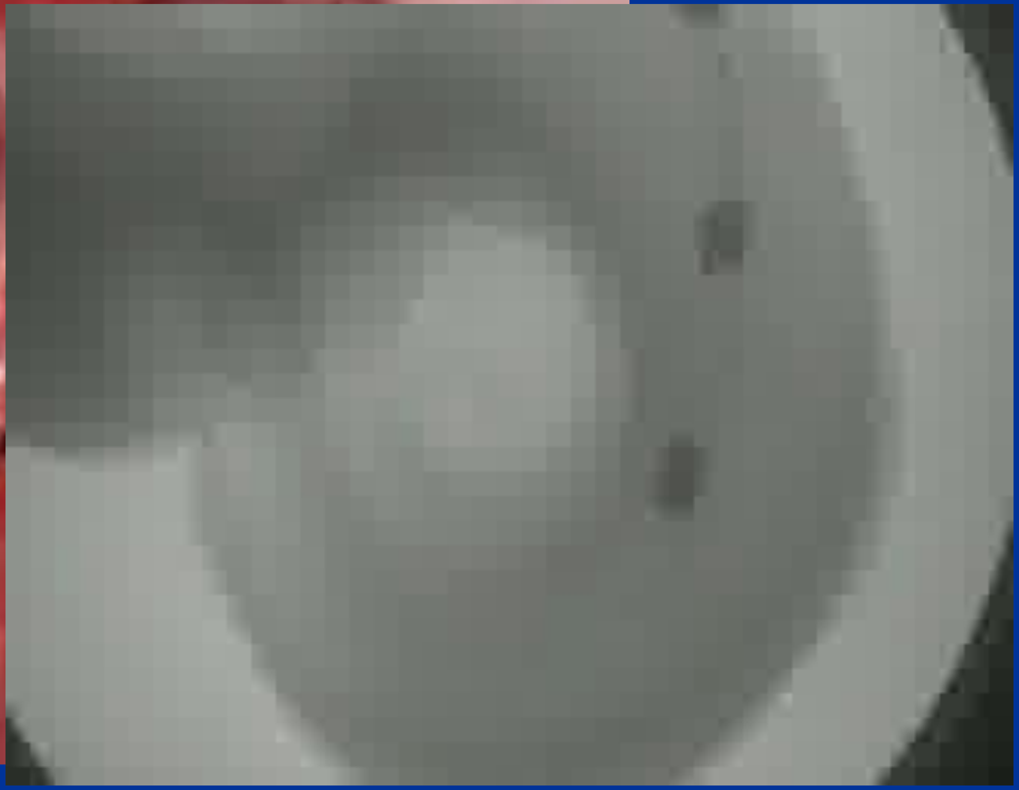
Extensive audiological and medical testing, CT Scan/MRI,

Patient chooses device: 3 major manufacturers of state of the art multi channel implants: Cochlear (Australia), MEDEL (Austria), Clarion (U.S.). All devices have similar performance the patient is the largest variable in the outcome

- Wait for surgery (can be many months….)
- Finally surgery day arrives

Surgical Technique





Surgery 2-4 hrs under general anesthesia

Postoperative Management

- Complication rate <5%
- Wound infection/breakdown
- Facial nerve injury
- Vertigo
- Device failure—re-implantation usually successful
- Avoid MRI
- Wait ~8 weeks for wound to heal before the device is activated and the patient hopefully hears sound

While waiting wonder how to pay the medical bill

Porter & Gadre (Galveston, TX)

The cost of a CI: Insurance Issues (in the US)

A CI costs ~$60,000 - $100,000 including evaluation, surgery, post operative hospital care, extensive audiological (re)habilitation.

Medicare/Medicaid pays total/partial cost. Some private insurers refuse to cover the devices, most (90%) provide excellent coverage.

"The reimbursement levels have forced eight hospital to close CI programs due to the cost of subsidizing the implants." (B. March President Cochlear America)

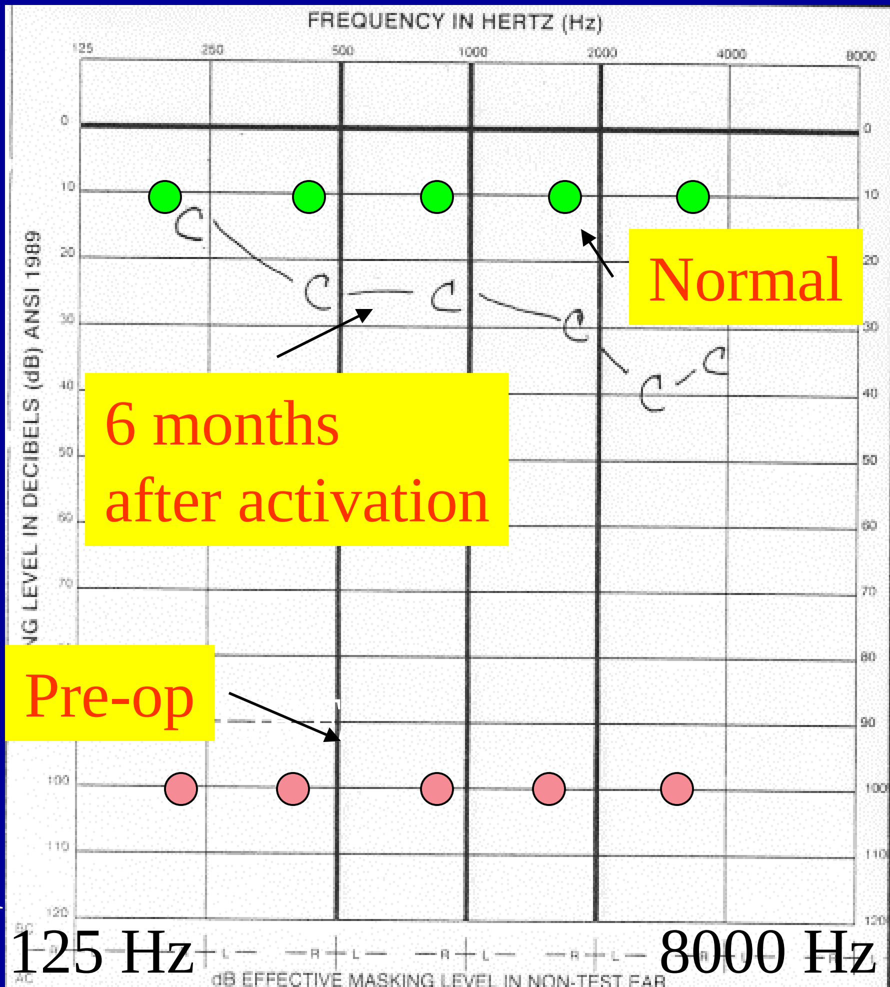
Other hospitals ration services by putting children on waiting lists
Currently~ 45,000 US children are CI eligible but only 28,400 have a CI (FDA, 12/2010)
(and only 6% of CI eligible adults have a CI, in Western Europe it is about x2 higher)

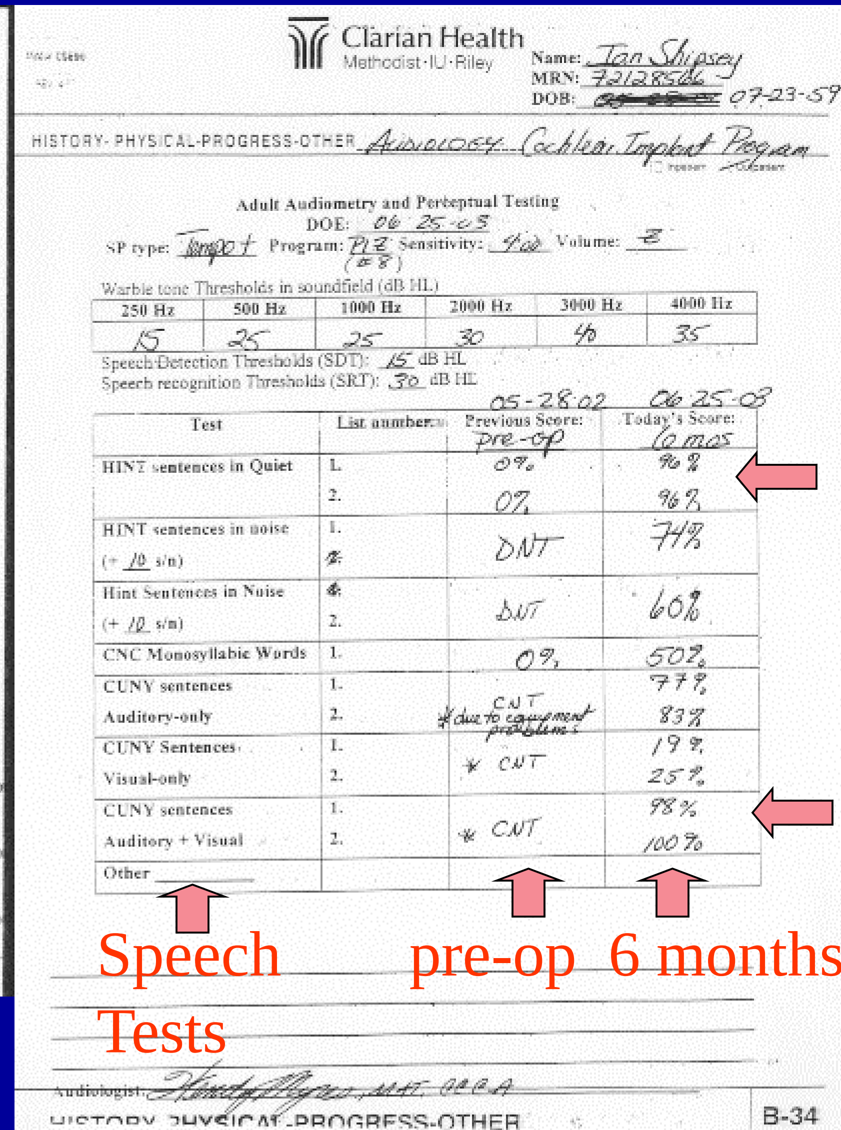
And yet the cost of CI is small compared to the cost in government aid for education and training estimated at $1 million over the course of a lifetime (not to mention the massive human cost).

"Ultimately this is about the way society views hearing. Being deaf is not going to kill you and so the insurance companies do not view this as necessary."
D. Sorkin, VP Consumer Affairs, Cochlear Corp. (A manufacturer). "

I was one of the lucky ones the cost of my implant was fully covered by insurance
Finally the day the device is activated arrives…….

How well does it work? My experience




Clarian Health
Methodist · IU · Riley

Name: Jan Shipsey
MRN: 72128586
DOB: 07-23-59

HISTORY-PHYSICAL-PROGRESS-OTHER Audiology Cochlear Implant Program

Adult Audiometry and Perceptual Testing
DOE: 06-25-03
SP type: Tempo+ Program: P/Z Sensitivity: 4/ab Volume: 3

Warble tone Thresholds in soundfield (dB HL)

250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz
15	25	25	30	40	35

Speech Detection Thresholds (SDT): 15 dB HL
Speech recognition Thresholds (SRT): 30 dB HL

Test	List number	Previous Score: 05-28-02 pre-op	Today's Score: 06-25-03 6 mos
HINT sentences in Quiet	1.	0%	96%
	2.	0%	96%
HINT sentences in noise (+ 10 s/n)	1. 2.	DNT	74%
Hint Sentences in Noise (+ 10 s/n)	1. 2.	DNT	60%
CNC Monosyllabic Words	1.	0%	50%
CUNY sentences Auditory-only	1.	CNT * due to equipment problems	77%
	2.		83%
CUNY Sentences Visual-only	1.	* CNT	19%
	2.		25%
CUNY sentences Auditory + Visual	1.	* CNT	98%
	2.		100%
Other			

Audiologist:
HISTORY-PHYSICAL-PROGRESS-OTHER B-34

My test scores are no longer exceptional.

75% of recent postlingually deaf patients with state of the art devices can use the phone.

Why does the CI work so well 3,500 inner hair cells ➔ replaced by 10 electrodes?

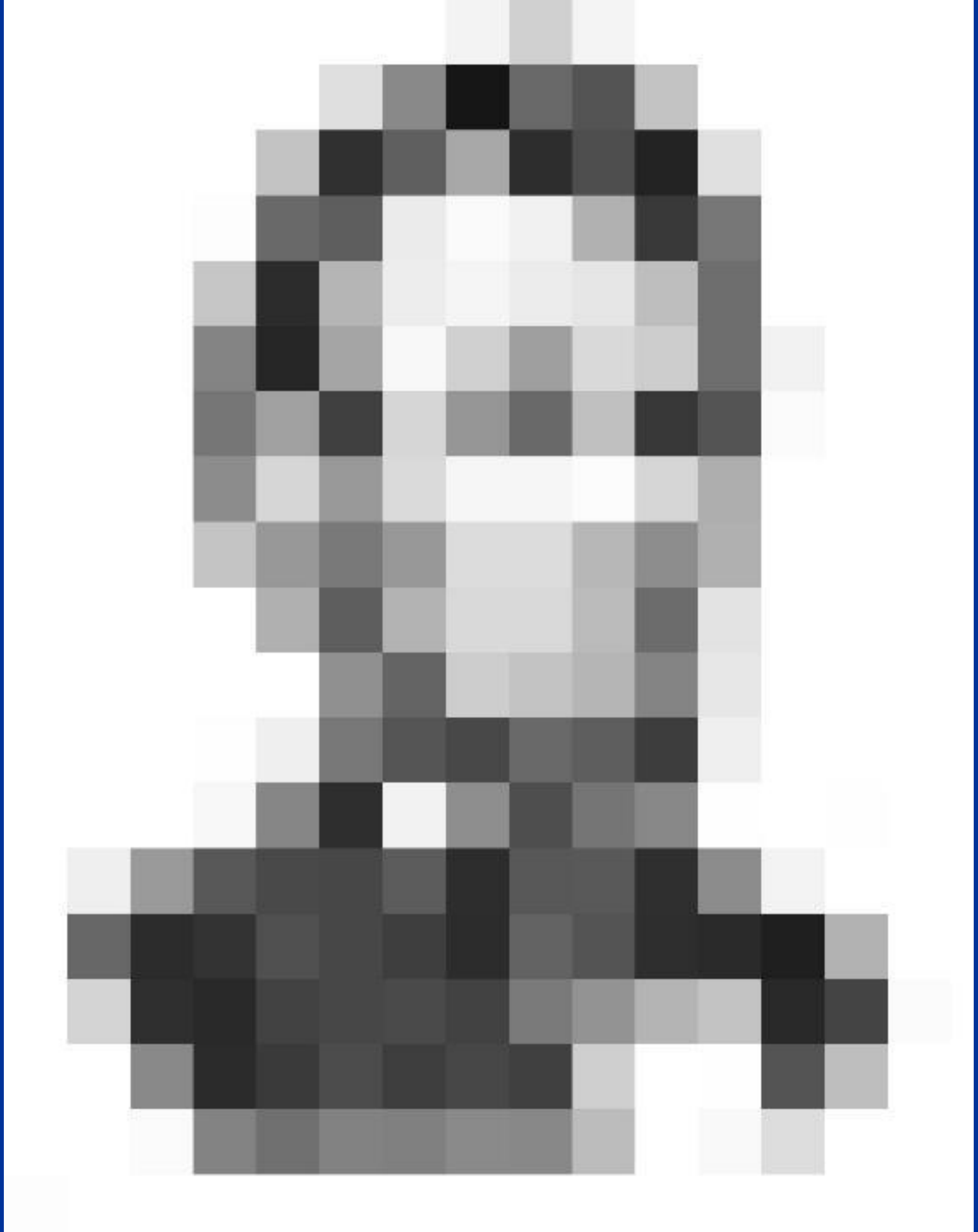
Hearing doesn't end at the cochlea

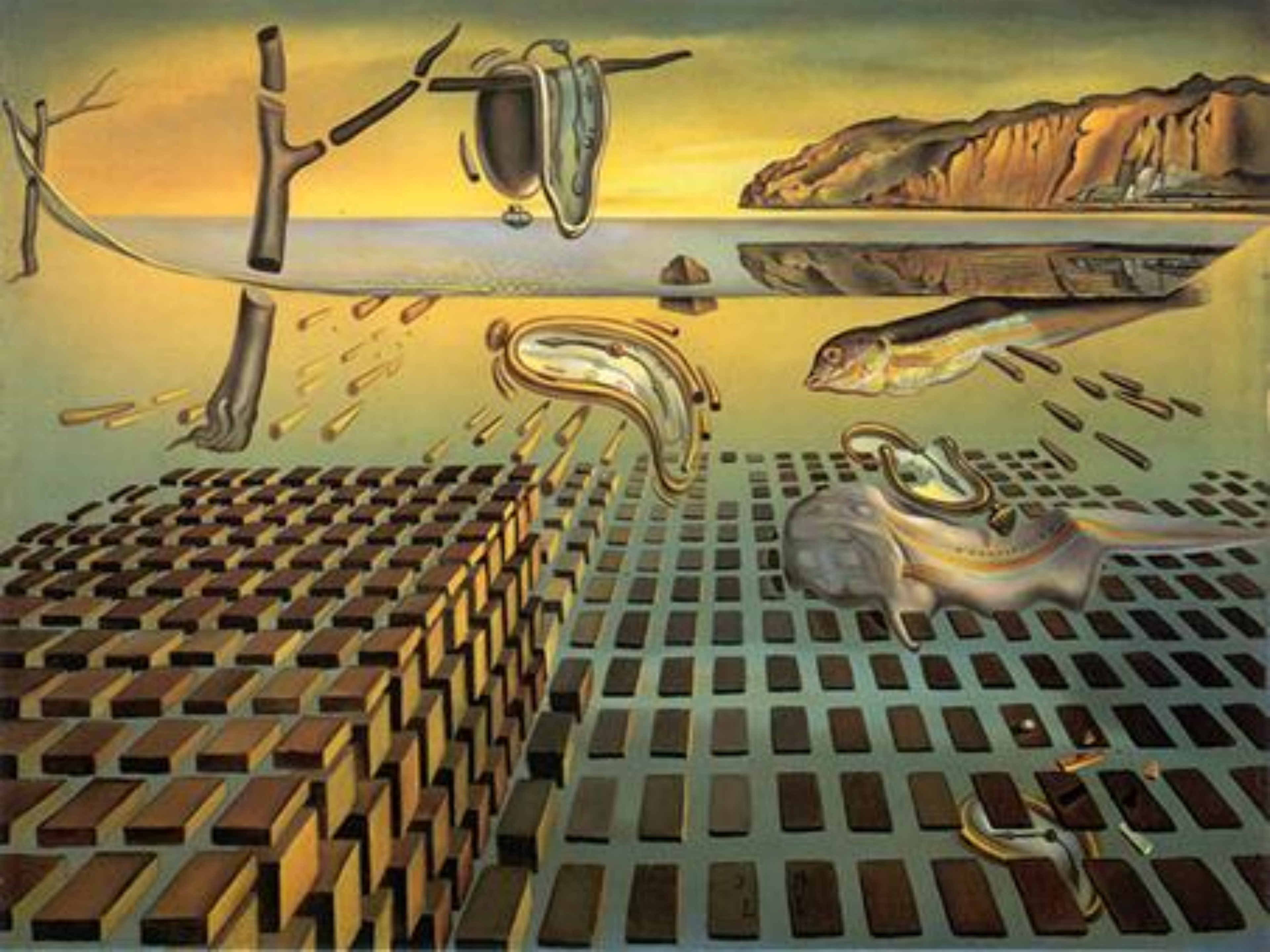
Perception (visual or auditory) is a dynamic combination of top-down and bottom-up processing

- The need for sensory detail depends on the *distinctiveness* of the object and the *level of familiarity*

"If you see a huge gray animal in the distance you don't need much detail to know that it is an elephant"

Visual examples…

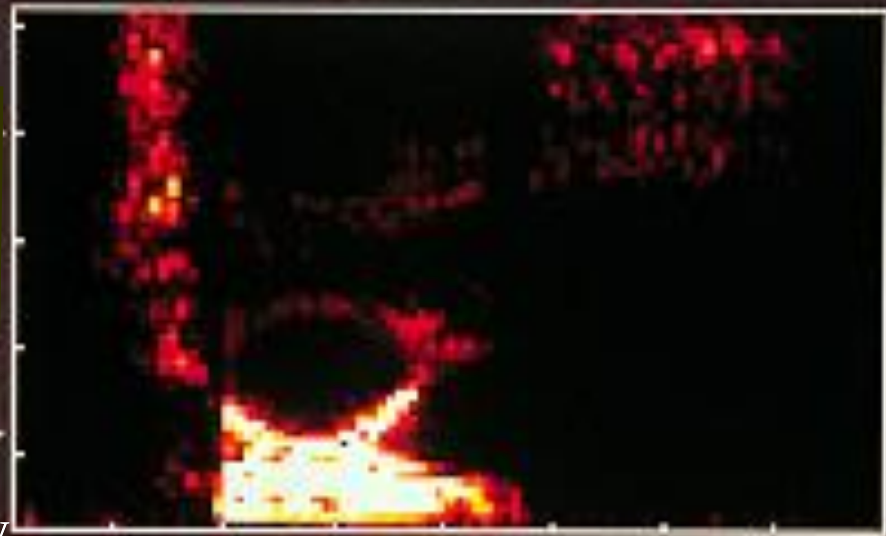




“CHOICE”

High frequency

FREQUENCY (0-5 KHz)



Low frequency

TIME

SPECTROGRAPH

Intensity of the sound is color coded, white is loudest

High frequency

ELECTRODE

Low frequency

TIME

ELECTRODOGRAPH

Images courtesy of M. Svirsky, Indiana

Optimizing Cochlear Implants to maximize speech recognition

- What features of the pattern of neural output from the cochlea are most critical?

Amplitude?

Temporal? (pulse rate of the implant)

Number of locations at which auditory nerve is stimulated } frequency

Place of stimulation

Spectral Resolution (# of places of stimulation)

1-channel

2-channel

4-channel

8-channel

16-channel

Original

← Like Volta

"1 channel" = stimulate the auditory nerve at one place; this corresponds to a cochlear implant with 1 electrode;

sound is perceived but there is no frequency information provided

"2 channel" = stimulate at two places 1 electrode at each place, the first electrode conveys lower frequency sound the second conveys higher frequency sound

I have 8 channels

8 channels & original sound similar to me

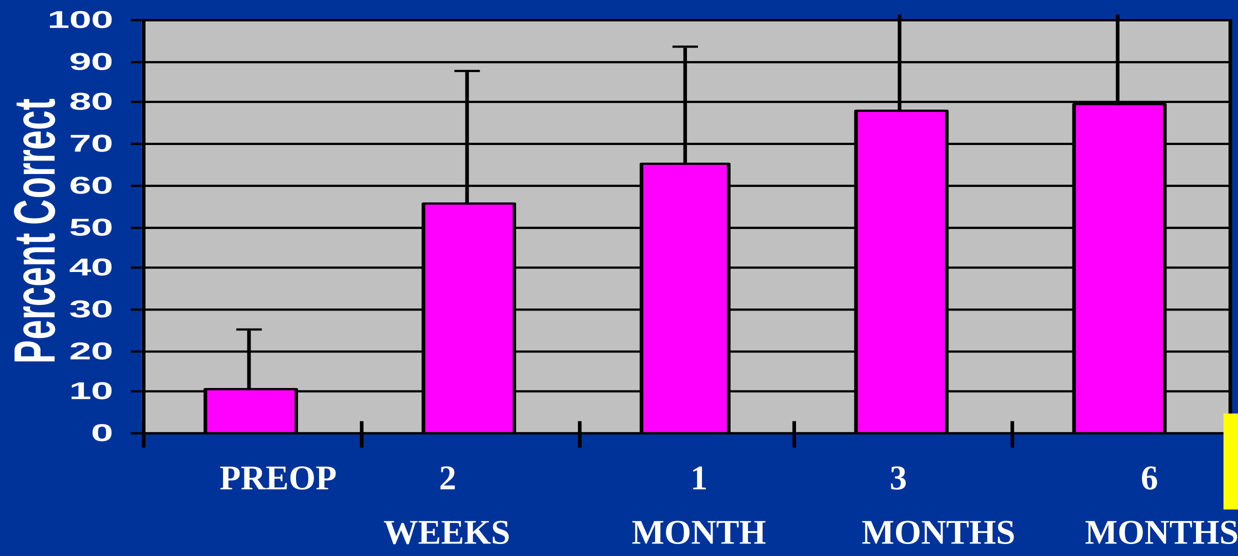
For me with time vocal memory made voices via the CI sound rich and beautiful (many implantees experience this)

Implant simulations by Arthur Boothroyd, based on the work of Robert Shannon

The Cochlear Implant Learning Curve

It takes time to adjust to the limited sensory detail provided by the cochlear implant, i.e. to learn how to understand speech with a cochlear implant

%



Time ➔

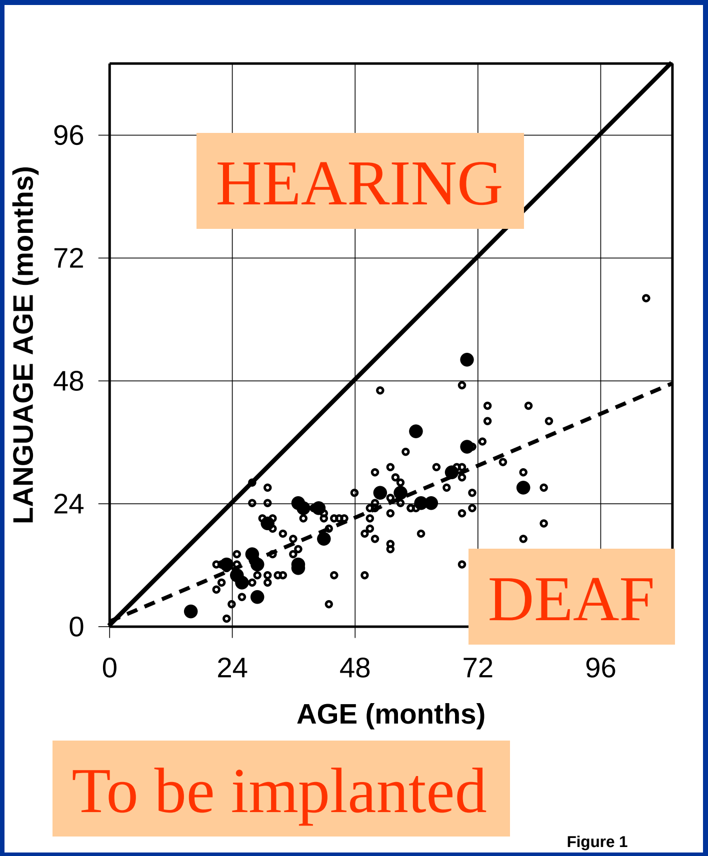
The adult brain is quite plastic

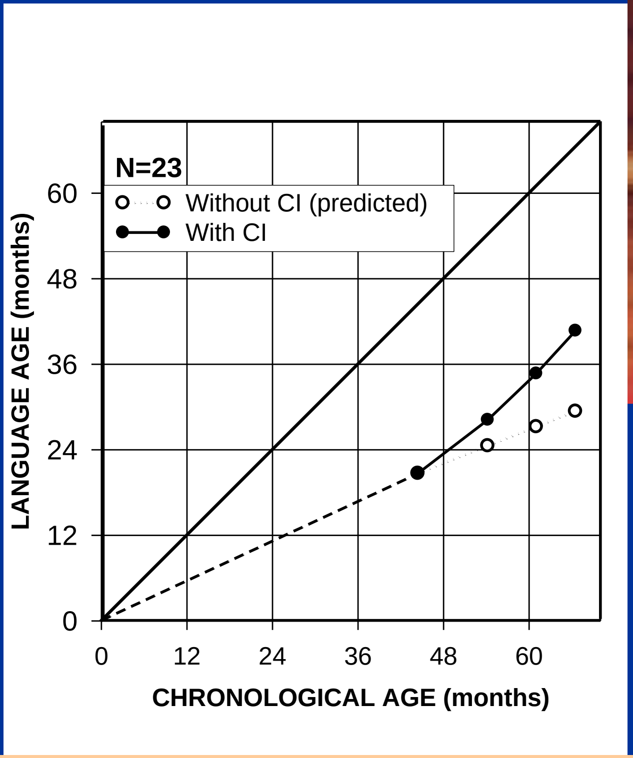
All of the adults in this study were post lingually deaf (they had the advantage of being able to use top down processing to understand speech.) What about prelingually deaf children?

The Deaf Community and Cochlear Implants (in the US)

- **People can lead full and satisfying lives without emphasizing speech when they are part of the Deaf community (learning to read is important, learning speech is less so.)**
- **In the 1990s strong opposition to pediatric implants while generally neutral towards adult implantation.**
- **An implant will delay a deaf child's acquisition of sign language (a deaf child's "natural language") and assimilation into the Deaf community.**
- **1991 position statement National Association of the Deaf: "*deplores the FDA decision to approve pediatric implantation as being unsound scientifically, procedurally, and ethically.*"**
- Since 2000, the Deaf community tends to regard cochlear implantation as a personal decision. **2000 position statement (www.nad.org):**
  - **Emphasizes taking advantage of technological advancements that have the potential to improve the quality of life for deaf & hard of hearing persons, and "*strongly supports the development of the whole child and of language and literacy.*"**

Language Development in Profoundly Deaf Children With Cochlear Implants (Svirsky, Miyamoto et al. Indiana U.)





Before & at 3 intervals after implantation

"Despite a large amount of individual variability, the best performers in the implanted group seem to be developing an oral linguistic system based largely on auditory input from a cochlear implant"

Cochlear Implants and Music

Due, in part, to a small number of electrodes, the CI user has poor pitch perception compared to natural hearing.
In most cases, this does not hinder speech comprehension but music appreciation relies on the ability to recognize pitch

➔Melody recognition is extremely difficult (lyrics help)

Music through a CI

Original

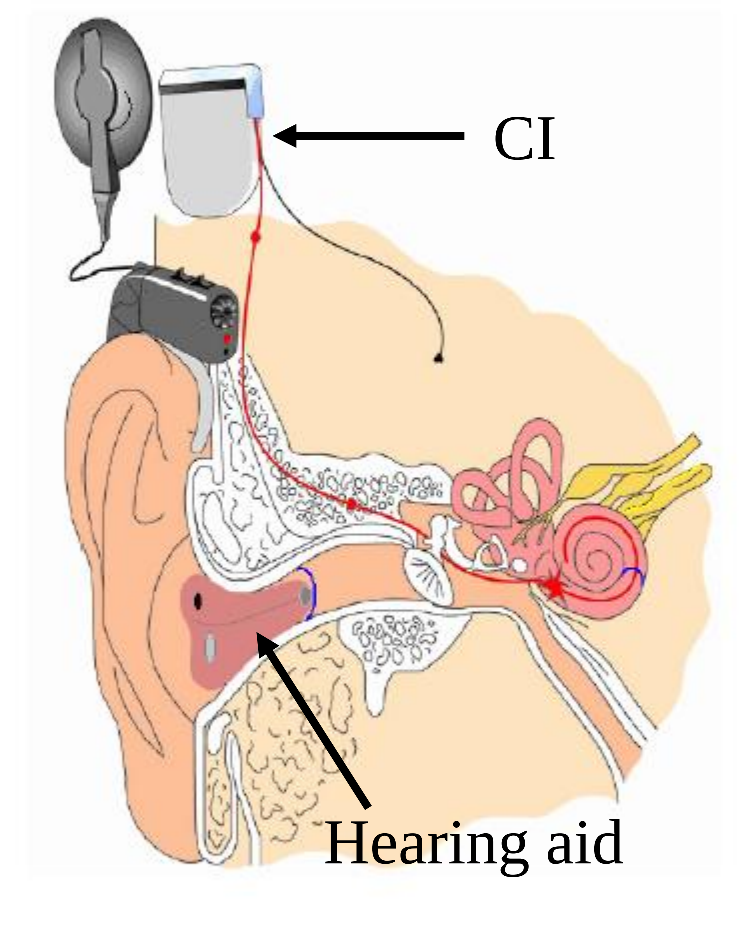
(These two musical demonstrations sound the same to me)

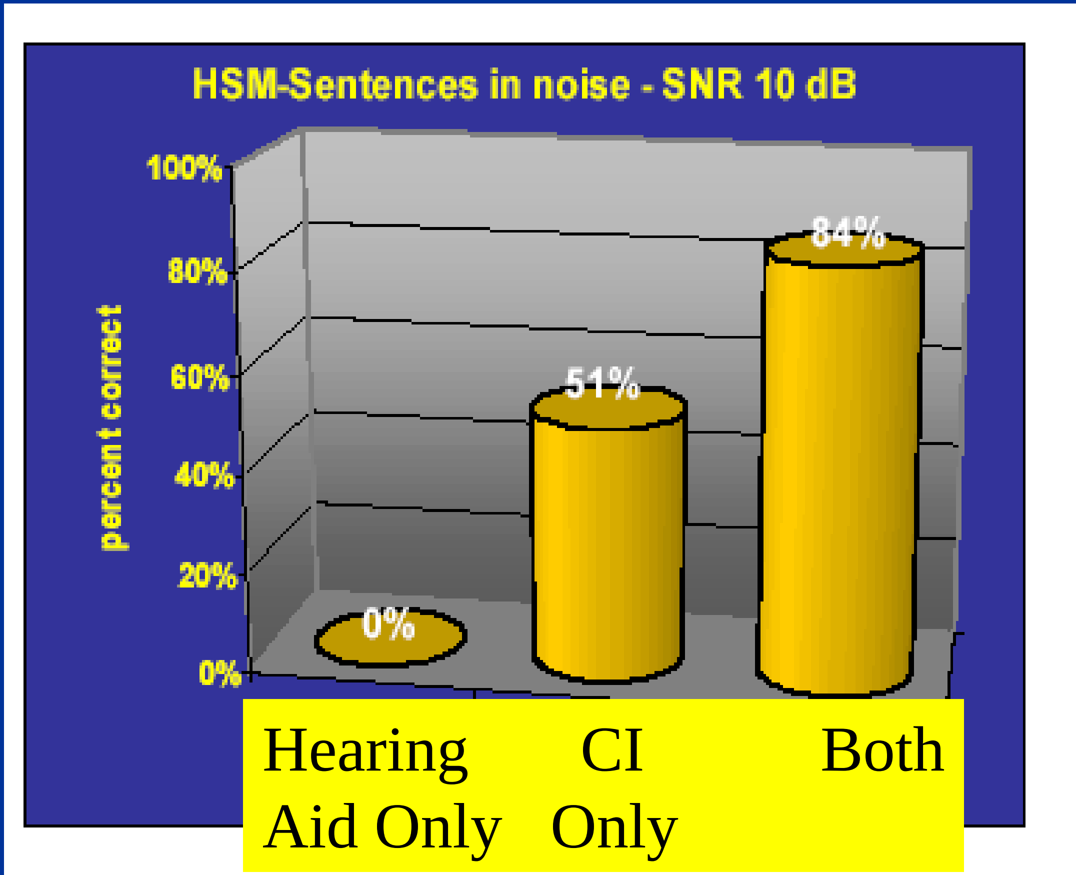
However, if I know before the music is played what it is and I have heard it before I was deaf I (and many implantees) can use musical memory as a form of top down processing to make the music as beautiful as it ever was.

Improving Cochlear Implants

1) Cochlear Implant + Hearing Aid in same ear

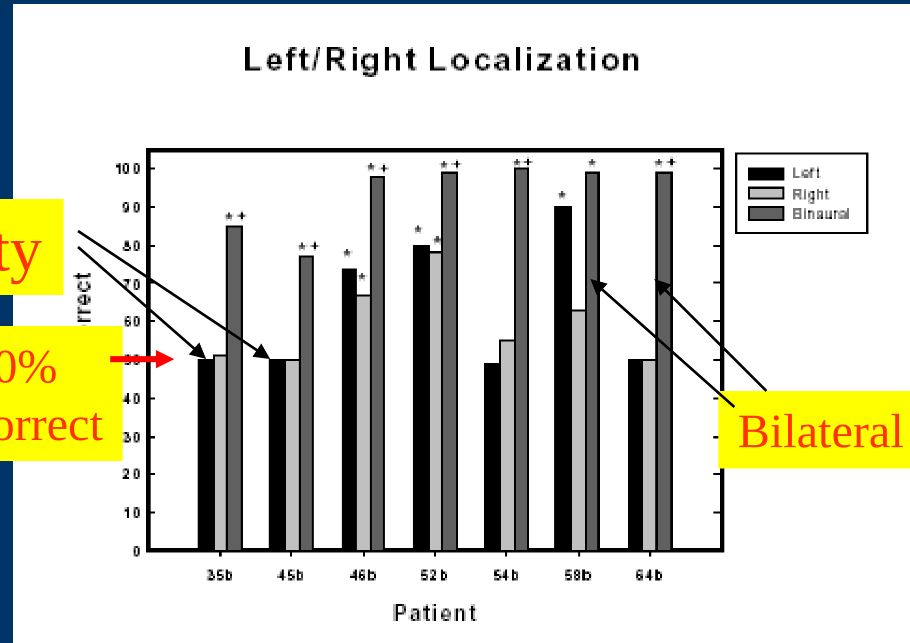
Targets patients with reasonable low frequency hearing (usually with hearing aid)
but little high frequency hearing (which is commonly lost with age)
by adding a short CI electrode for high frequency stimulation





2) Bilateral cochlear implants are 2 implants better than one?

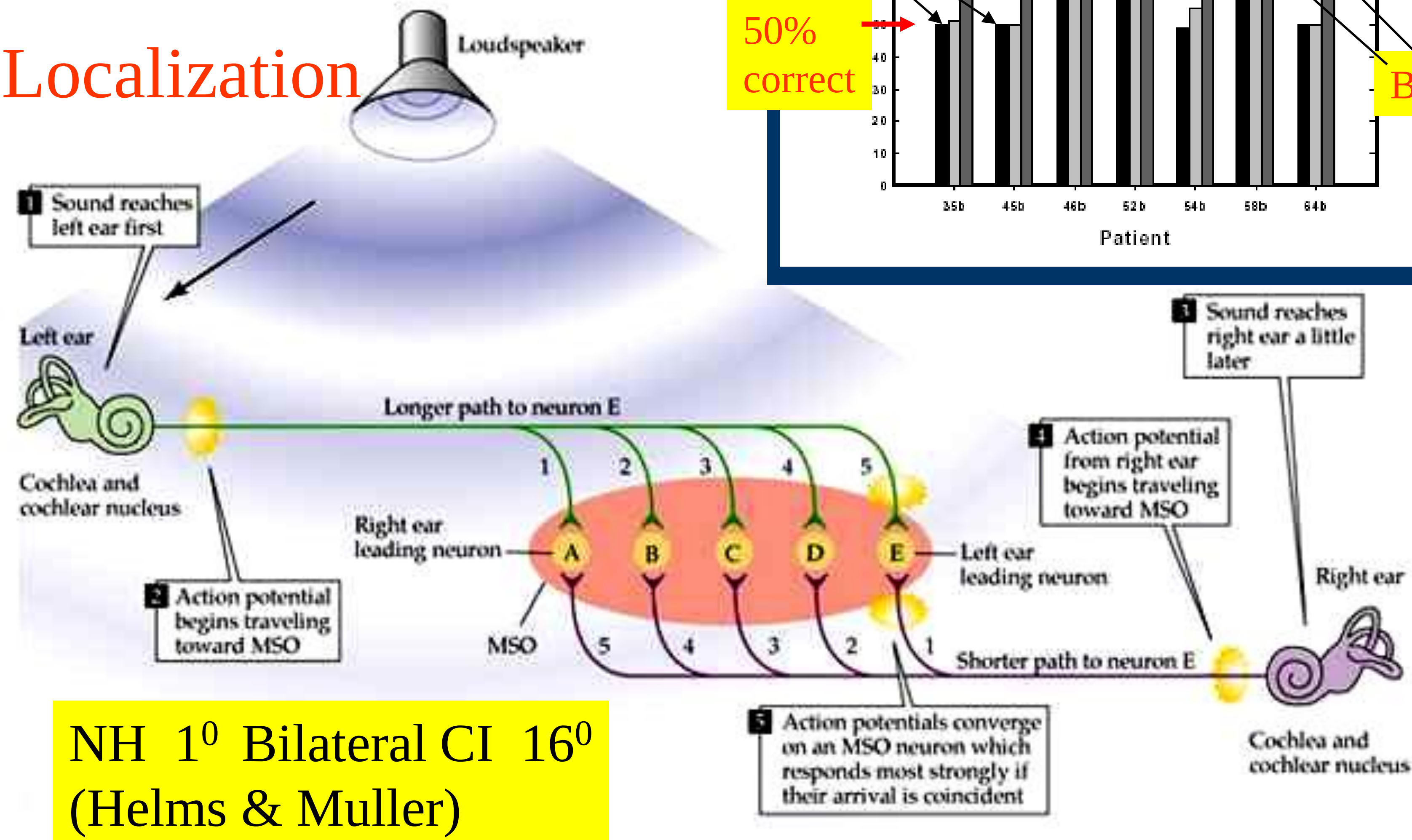
With one CI there is no directionality



50% correct

Bilateral

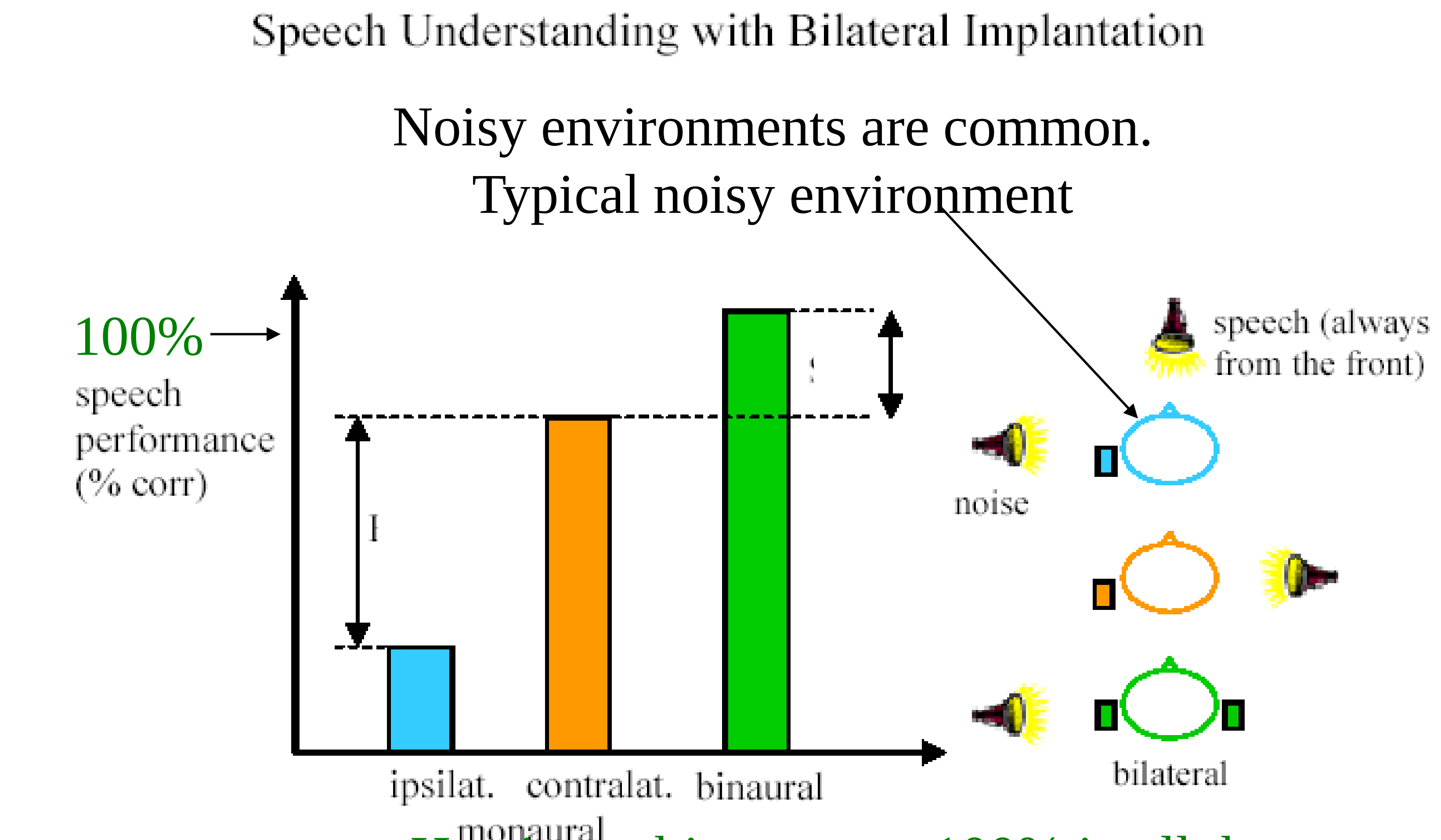
Localization



NH 1^0 Bilateral CI 16^0
(Helms & Muller)

Bilateral cochlear implants Benefit #2

Better speech recognition in noise.



Hearing subjects score 100% in all three tests

Benefit #3

For patients who do poorly with 1 CI adding a 2nd CI can lead to dramatic improvement

The future of cochlear implants

* Cochlear implant + hearing aid

* Bilateral Cochlear implants to provide directionality, and, especially, improved speech recognition in noisy environments.

* Increasing the number of channels/greater cochlea coverage to provide fine spectral information
  → improved speech performance & improved music appreciation

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* Reducing power➔ fully implantable device

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* Increasing the number of channels/greater cochlea coverage to provide fine spectral information
  → improved speech performance & improved music appreciation
* Reducing power→ fully implantable device

* CI performance limited by number of surviving auditory nerve neurons: regeneration of neurons

Summary: Implants, Neuroscience & Bio-engineering

- Implants enable the postlingually deaf to hear & in have provided sufficient information to support language development in children

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- Implants are a probe of speech recognition
  - Exploiting tonotopic organization is key to the implant's success
    - number of channels
    - frequency assignments to electrodes
    - ➔the CI learning curve demonstrates adult brain is plastic

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- Music/speech quality (recognition of male/female & accents)
  - Requires fine spectral information which the present generation of CIs does not provide
- Implants, as the first prosthesis to successfully restore neural function, are a benchmark for biomedical engineering.

Final Thoughts 1

A Cochlear Implant is a wonderful example of the power of interdisciplinary science and technology: electrical engineering, computer science, mechanical engineering, physics, chemistry, and biology all working together in a tiny package inside a human being to improve the Human condition.

There are ~500,000 implantees worldwide (2017). With the latest devices ¾ of postlingually deaf adults can use a telephone, and small children can hear their parents voices and *learn to understand them.*

It is critically important that we work to make this technology more widely known and available to all that might benefit from it.

Estimate: 25×10^6 citizens are profoundly deaf; 1.4×10^5 children born each year with profound hearing loss; world CI sales 50,000 (2013)

At a personal level 11 years ago I had my hearing restored. It has enabled me to more easily conduct research & teach, and hear my wife's voice for the first time in 12 years and my daughter's voice for the first time.

Dedication

Richard T. Miyamoto, Surgeon
Professor Emeritus and
Past Chair of Otolaryngology-Head and Neck Surgery
Indiana University School of Medicine

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Brandon Pletsch (IowaMed), Bob Shannon (House Ear Institute),
Mario Svirsky (NYU), Fan-Gang Zeng (UC Irvine)

I have a Dream
The sky is blue, I see it
The grass is green, I see it

I see the beautiful flowers, blue
ocean and bright sunshine

Author:
A young
deaf child

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But why this world feels so lonely
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Why Mama's eyes are full of tears
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I need to learn speech diligently
I slowly learn to speak under Mama's
caring guidance

From one sound, one word,
one phrase and one sentence,
They string my dreams together

I have a dream, I want to hear
the sound of the ocean wave

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I have a dream, I want to use my own voice
to say " I love you, Mama"

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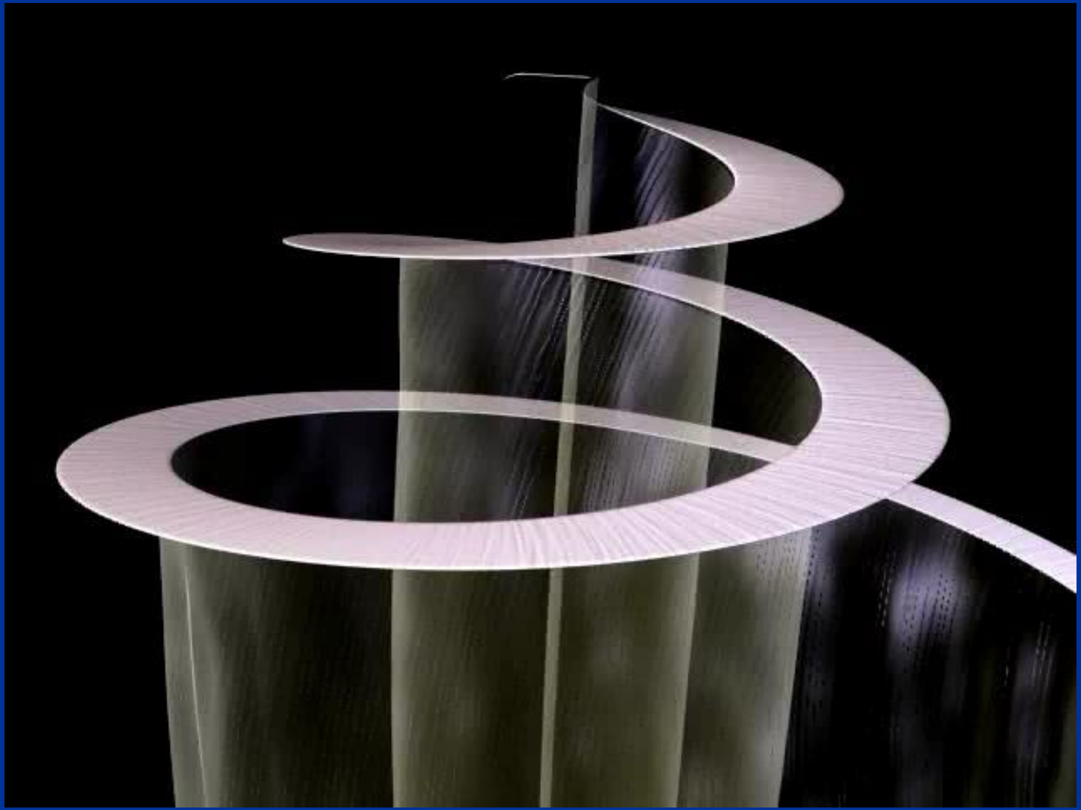
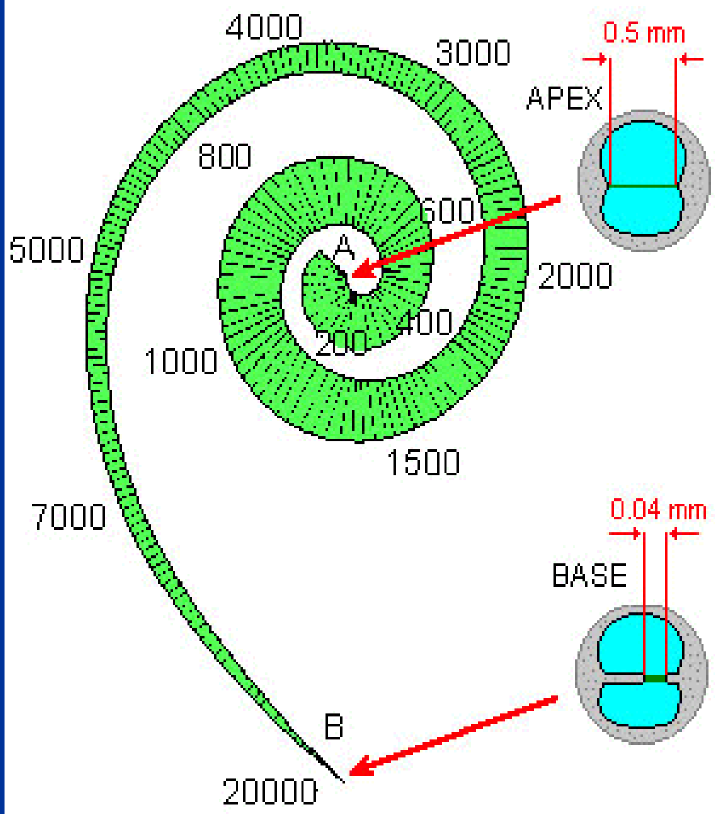
Additional Material

Tonotopic Organization

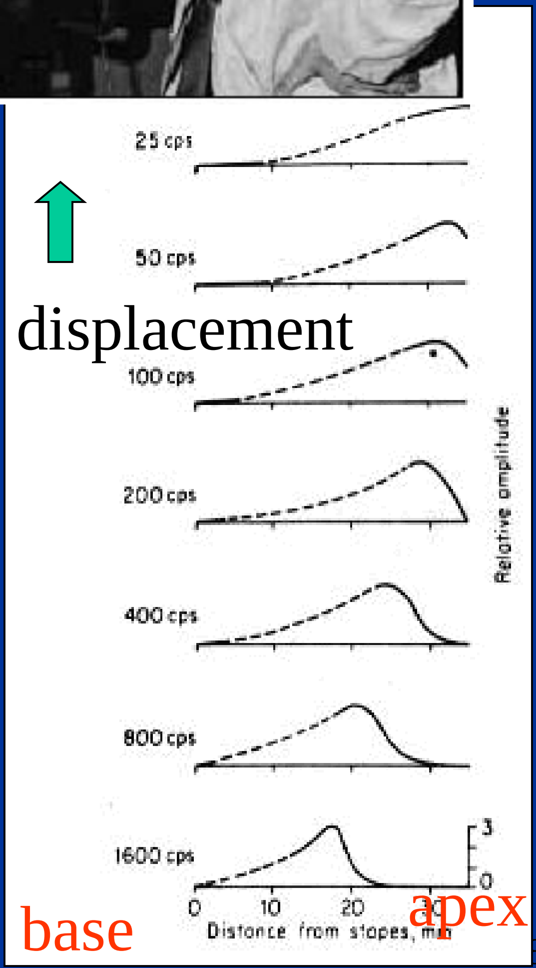




Hermann Ludwig von Helmholtz first theory of the role of BM as a frequency analyzer.

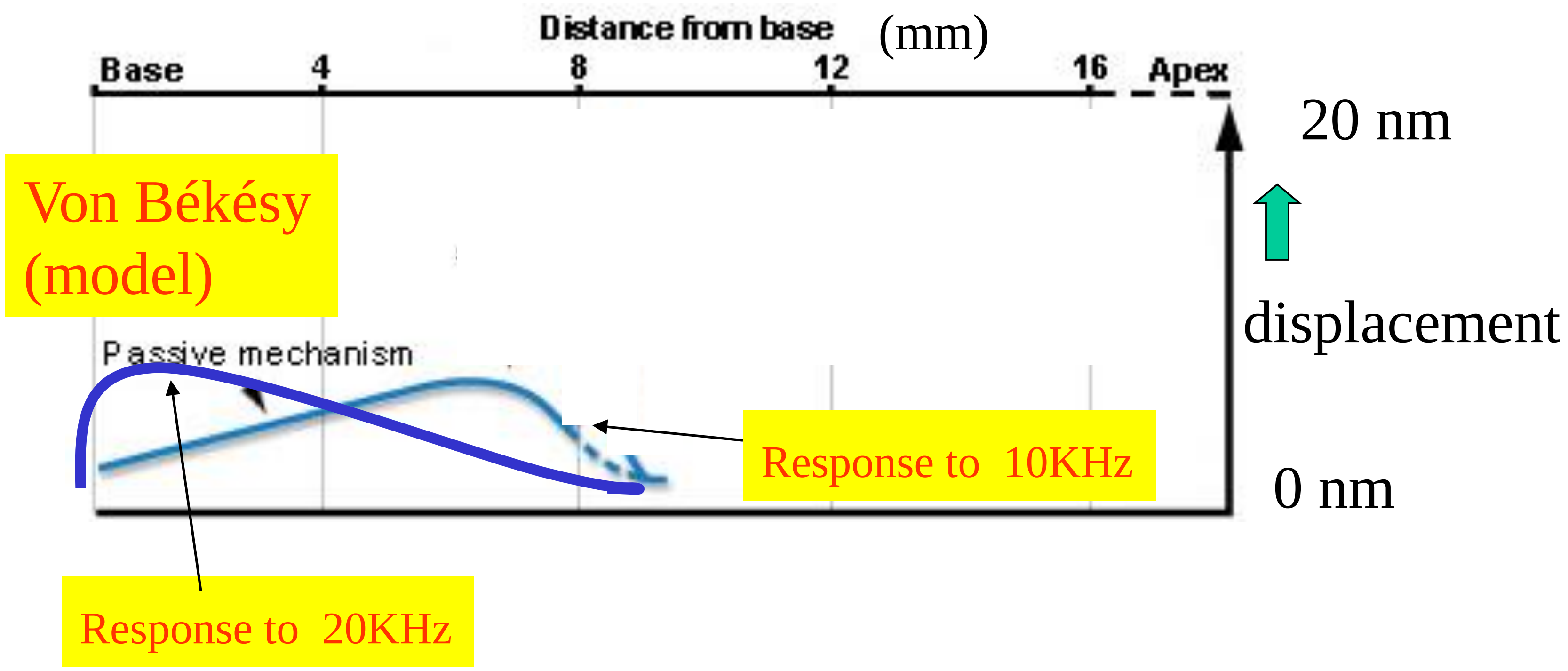
Georg von Békésy
(Nobel 1961)
for observation of tonotopic organization

Experimentally measured basilar membrane displacements in cadavers. Very loud sounds were used to render the displacements visible



Mechanical models could reproduce Von Békésy's observations in human cadavers
Much of the basilar membrane is displaced by each wave, and large overlap between wave shapes even for large differences in stimulus frequency

- ➔ **These models predict the human has poor frequency selectivity ➔ poor perception of pitch. in contrast with psychophysical data on the excellent frequency selectivity of the human cochlea.**
- ➔ **There was another mystery too: how we hear soft sounds?**



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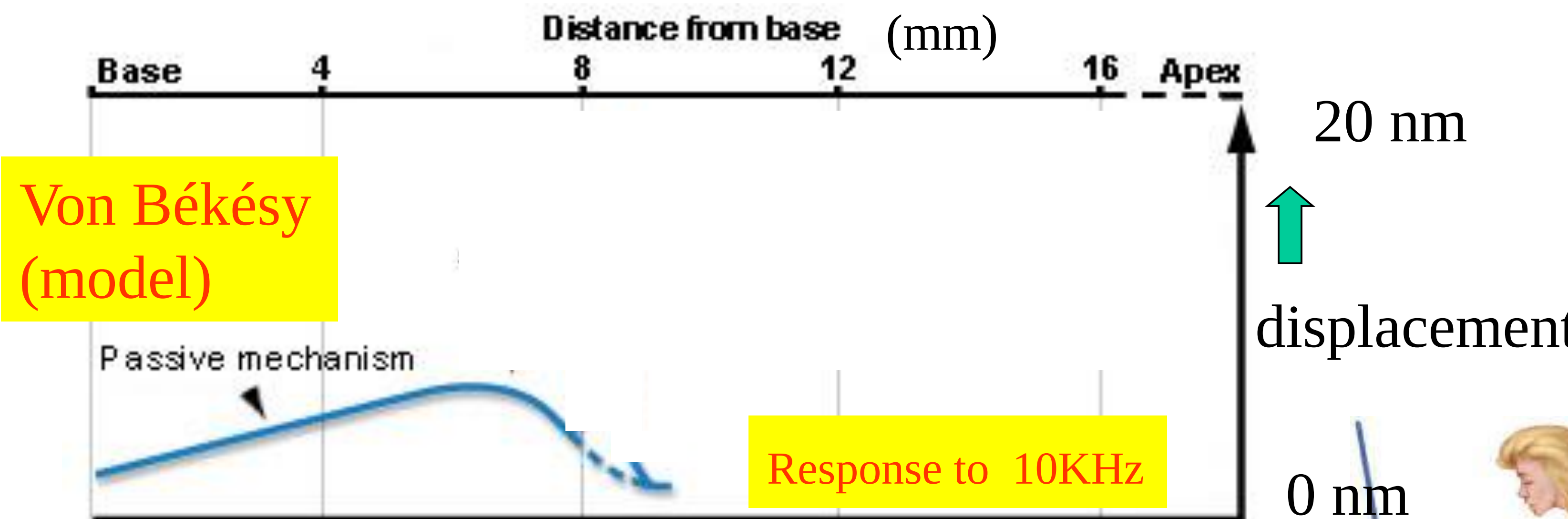
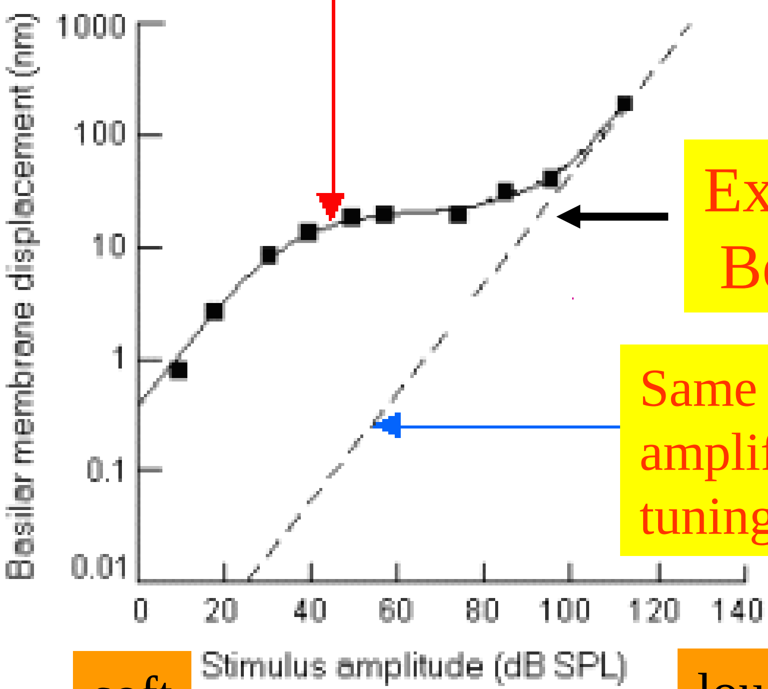


There exists an amplifier within the organ of Corti that increases the displacement of the basilar membrane to make soft sound audible and provides excellent frequency selectivity (i.e. excellent perception of pitch)
(this amplifier is like the *active* child on the swing)

Active amplification

Sensitive modern measurements on living animal cochlea



Expectation from von Békésy

Same animal post mortem, amplification (and fine tuning) are gone

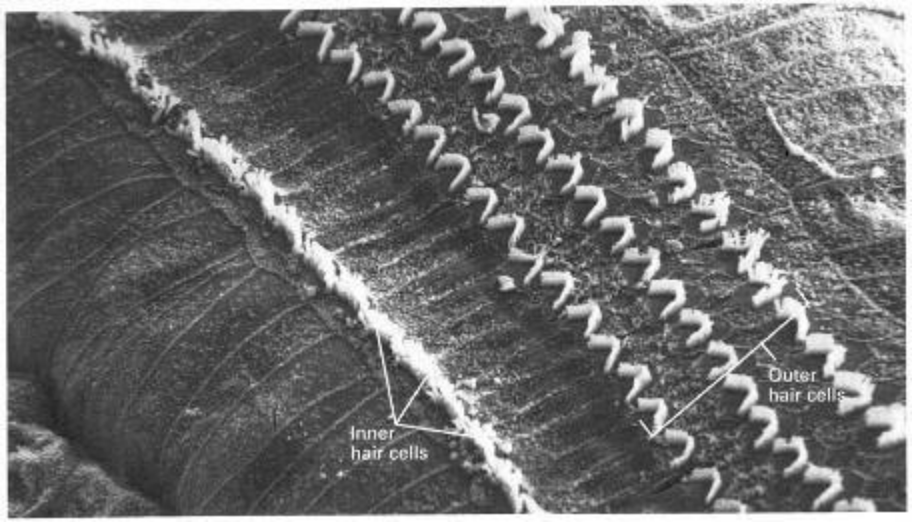
soft

loud

What causes the amplification?

Johnstone et al (1986)

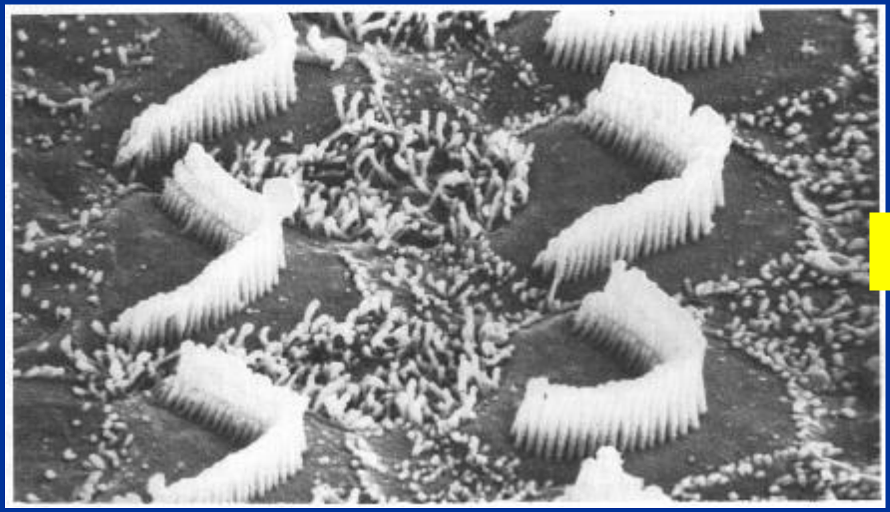
Rows of Hair Cells in the healthy cochlea

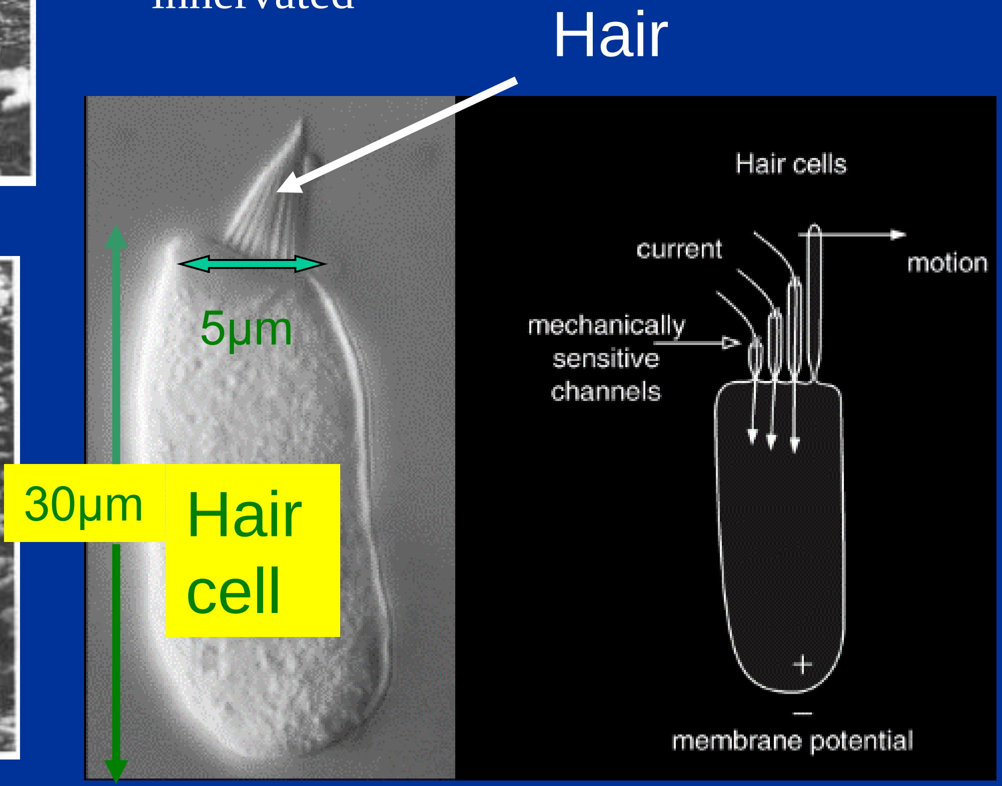


Per cochlea:

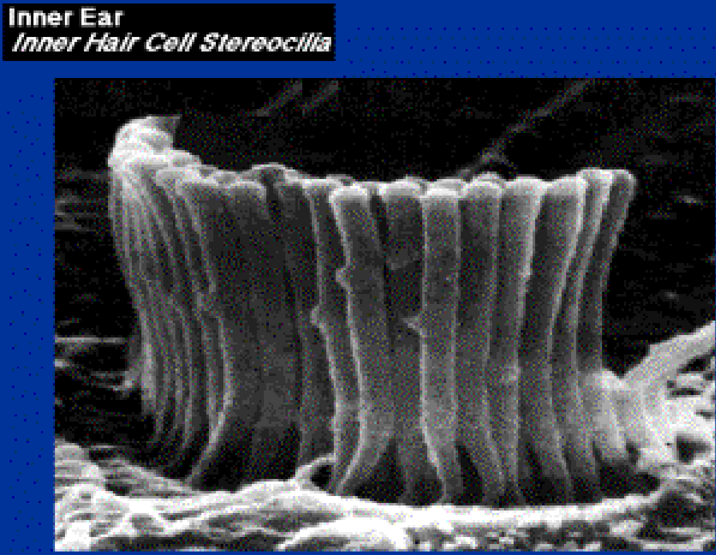
Inner hair cells 3,500 afferent
(signals go the brain)

Outer Hair Cells 12,500 Sparsely
innervated

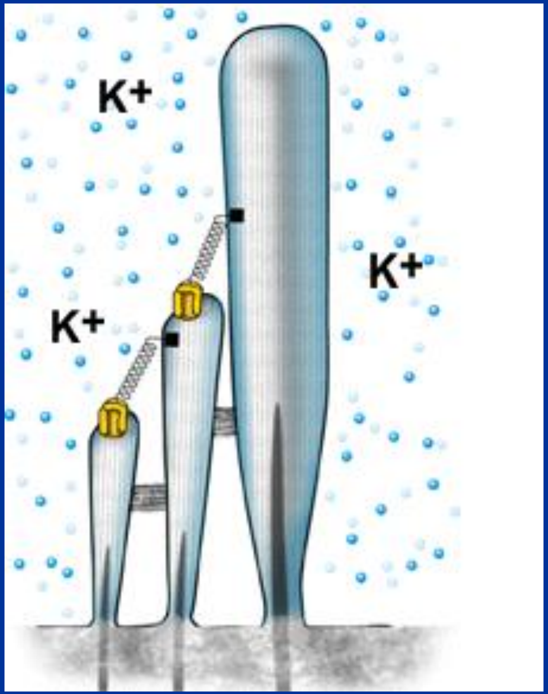


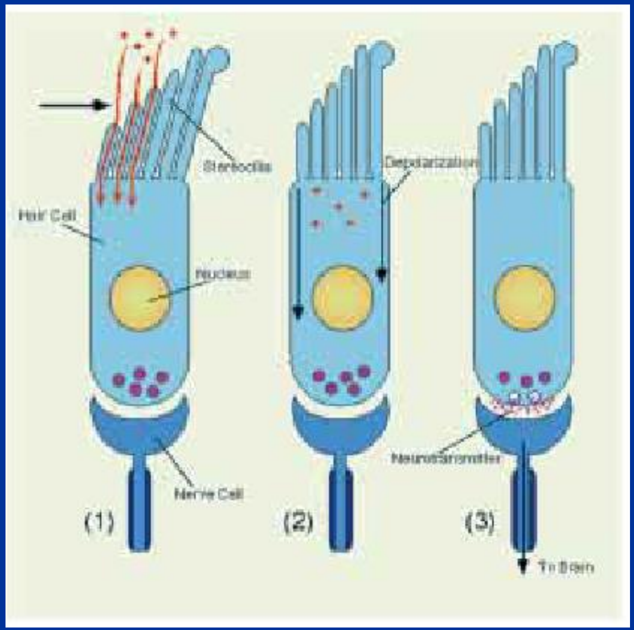


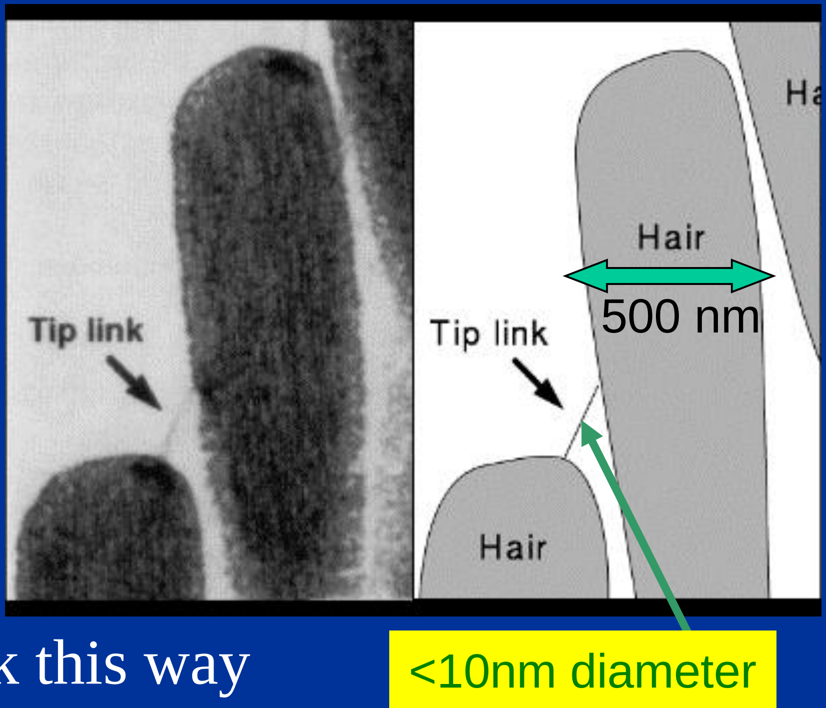
Hair cells are mechano-electrical transducers



1980’s





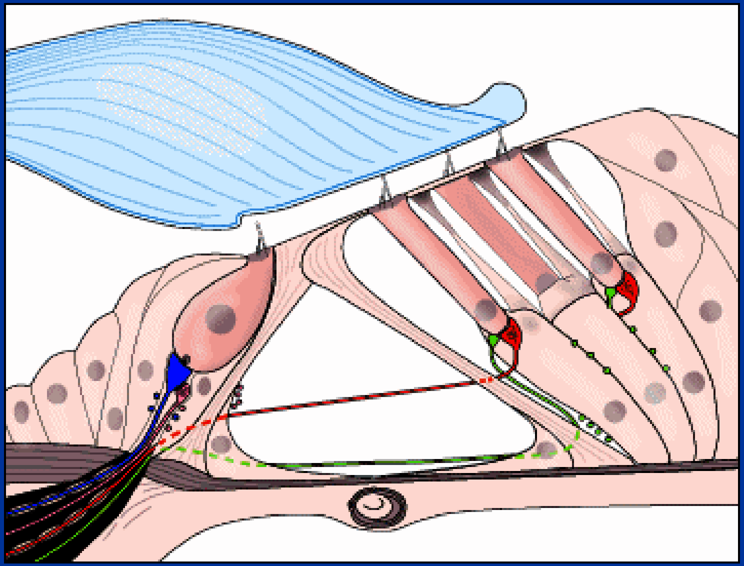


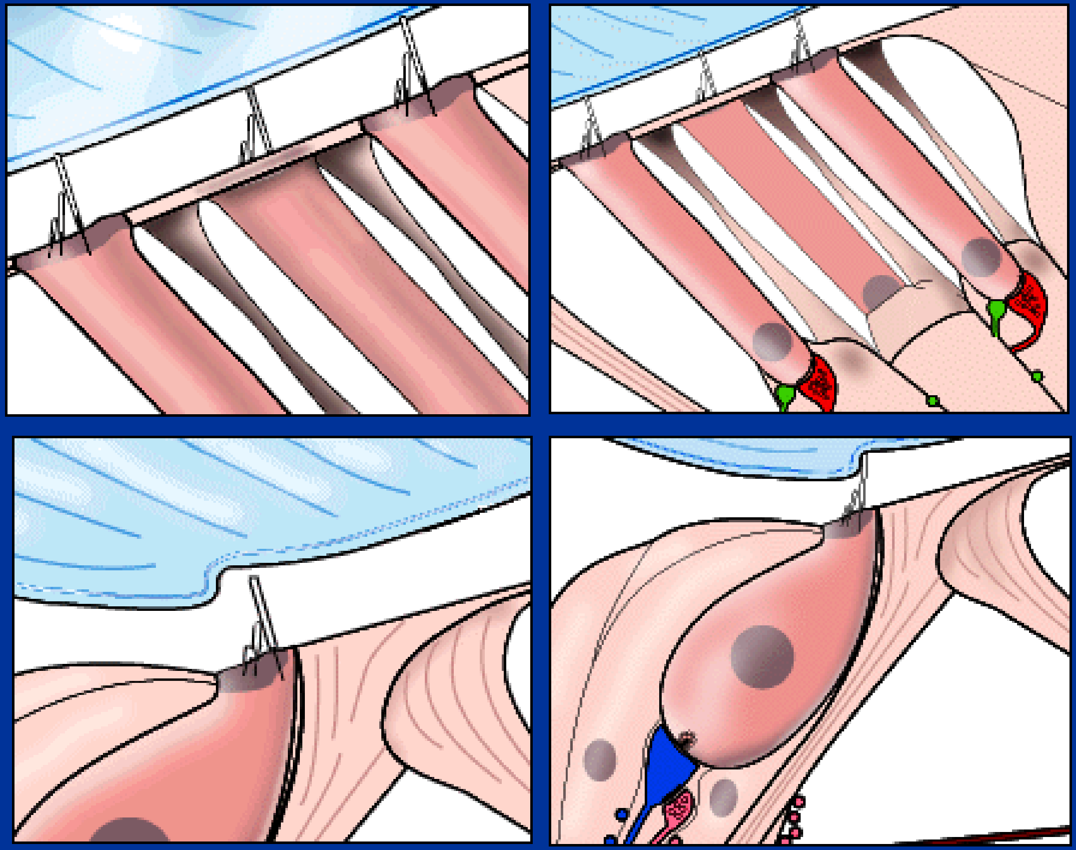
Both inner and outer hair cells work this way

The inner hair cells send signals to the brain that are interpreted as sound. What do the outer hair cells do?

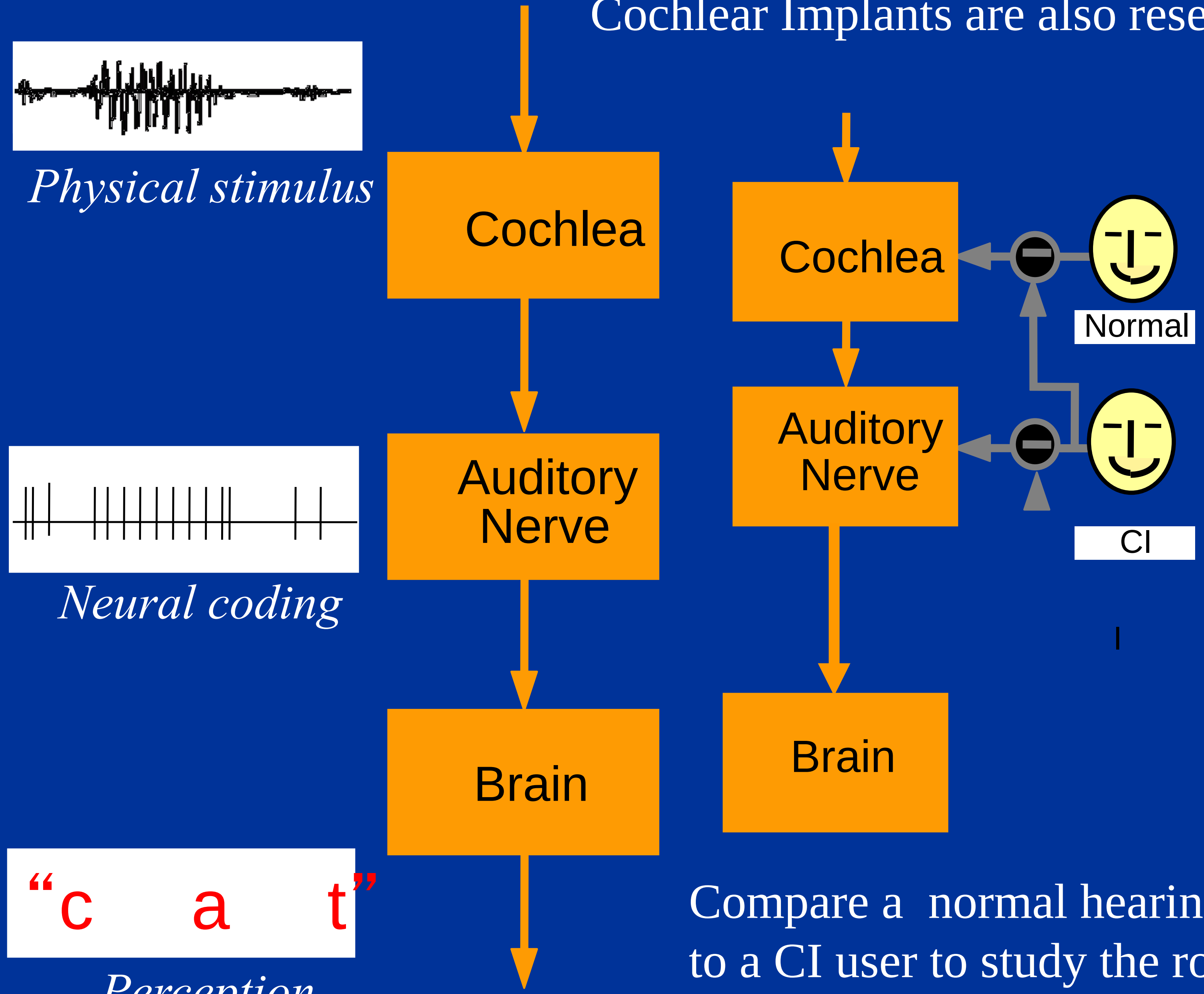
Outer hair cells exhibit electro motility they are *also* electro-mechanical transducers and are the amplifier

1987-2003



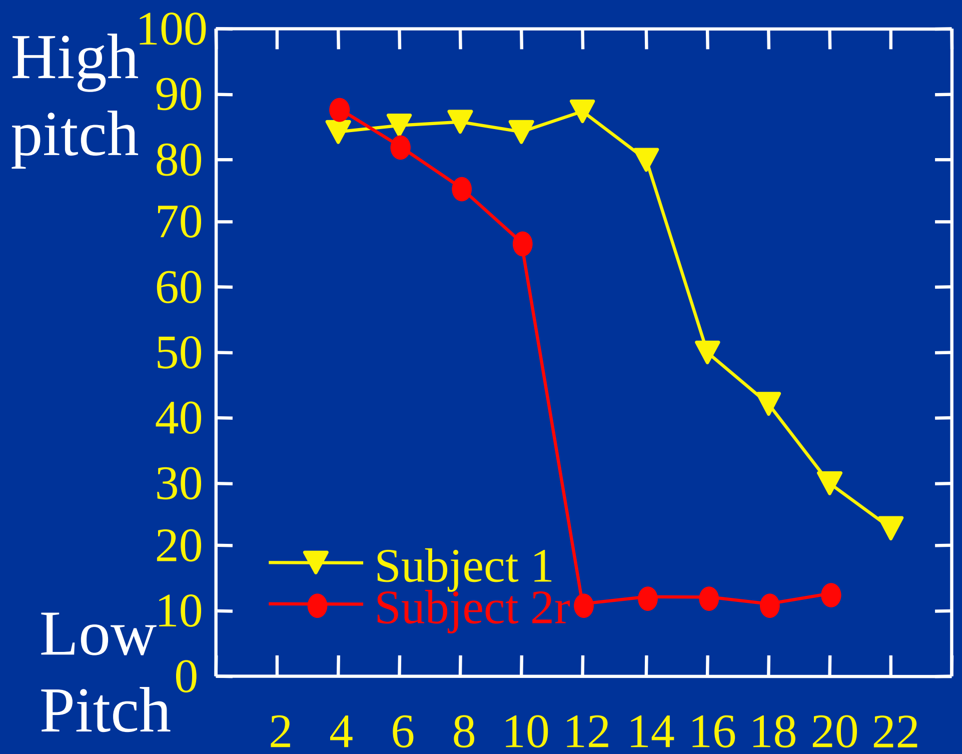


Cochlear Implants are also research tools:



Compare a normal hearing person to a CI user to study the role of the cochlea in auditory processing

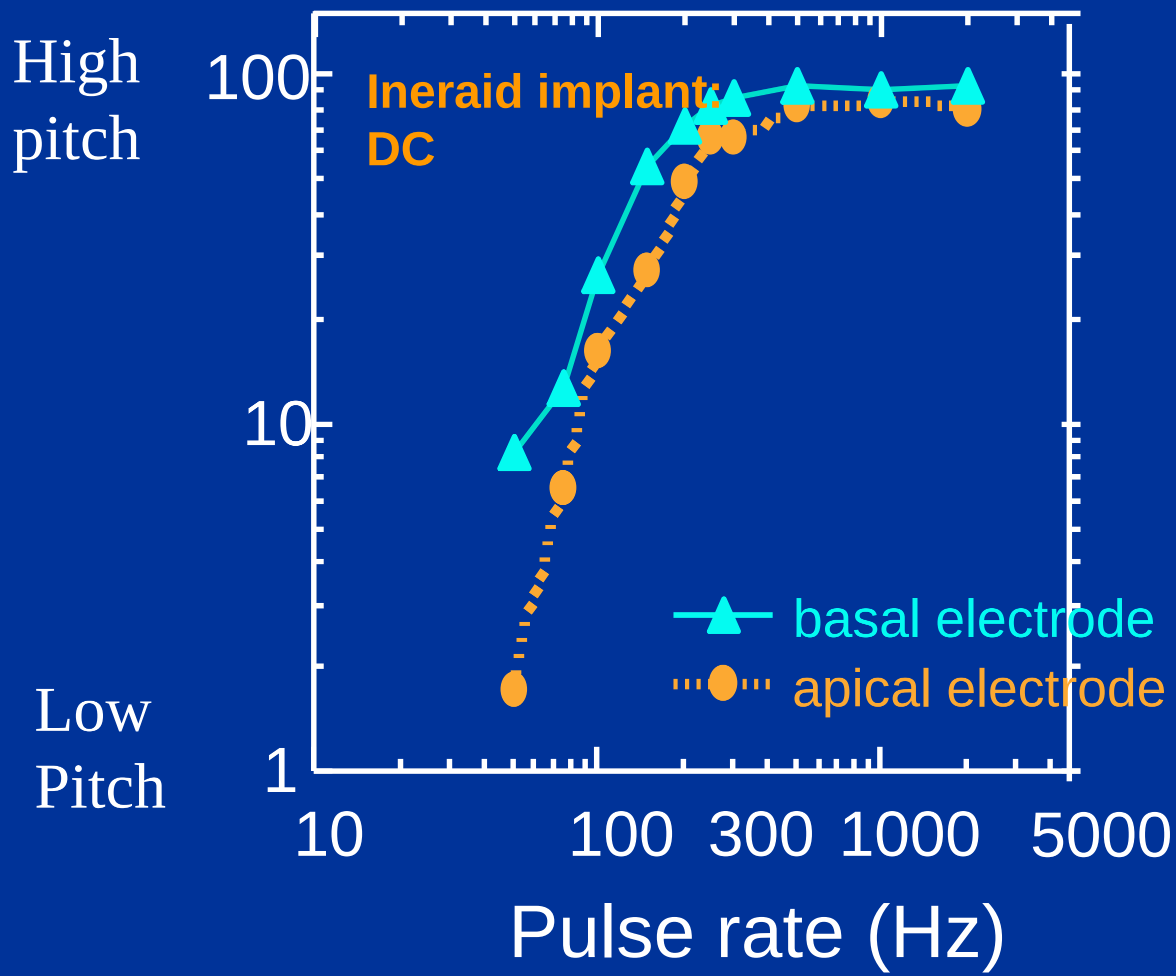
Pitch estimate by place



Electrode Position (base to apex of cochlea)

As CI user does not have a fine tuned cochlea
(because the hair cells are non-functional)
➔ place pitch resolution is very poor
(& there is a great deal of variability between subjects)

Pitch estimate by rate



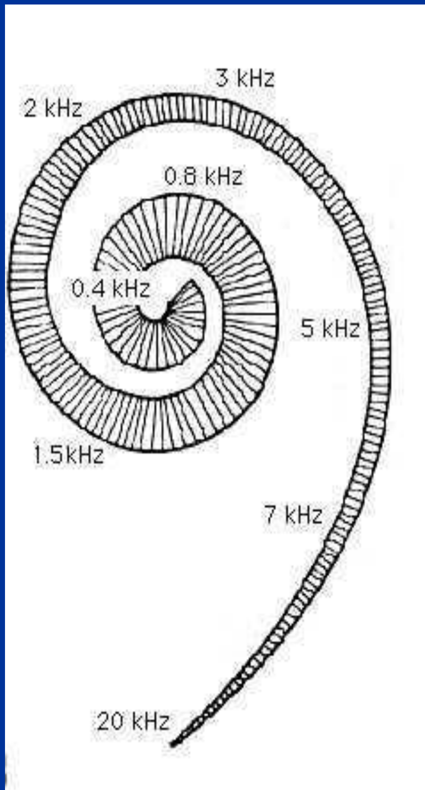
Temporal coding for pitch upto 300 Hz

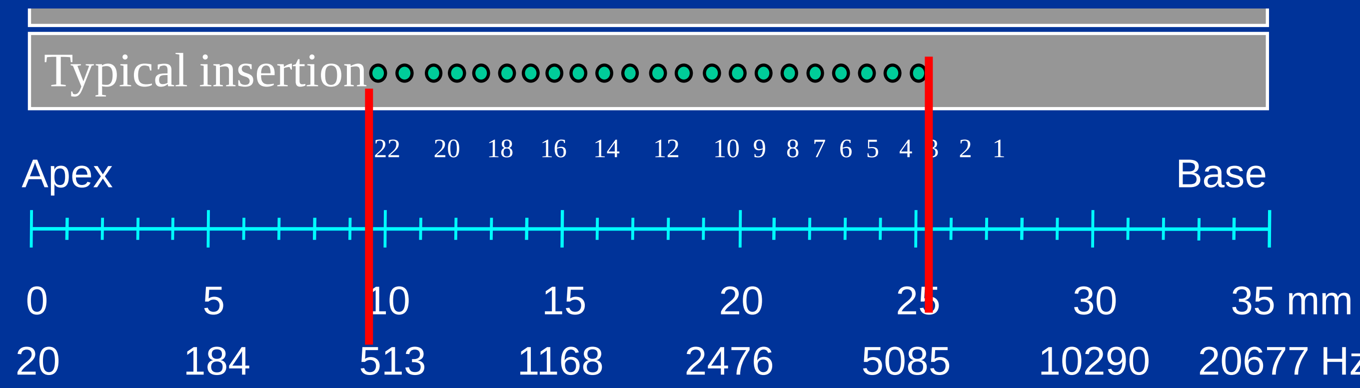
But no matter how finely the pulse rate is varied, the implantee experiences pitch steps of 20 Hz

(normal hearing (NH) discriminates in steps of 1-2Hz at 100 Hz

➔NH uses tonotopic code to obtain frequency resolution at low frequencies

Sound Image Compression





Cochlea is ~35 mm in length

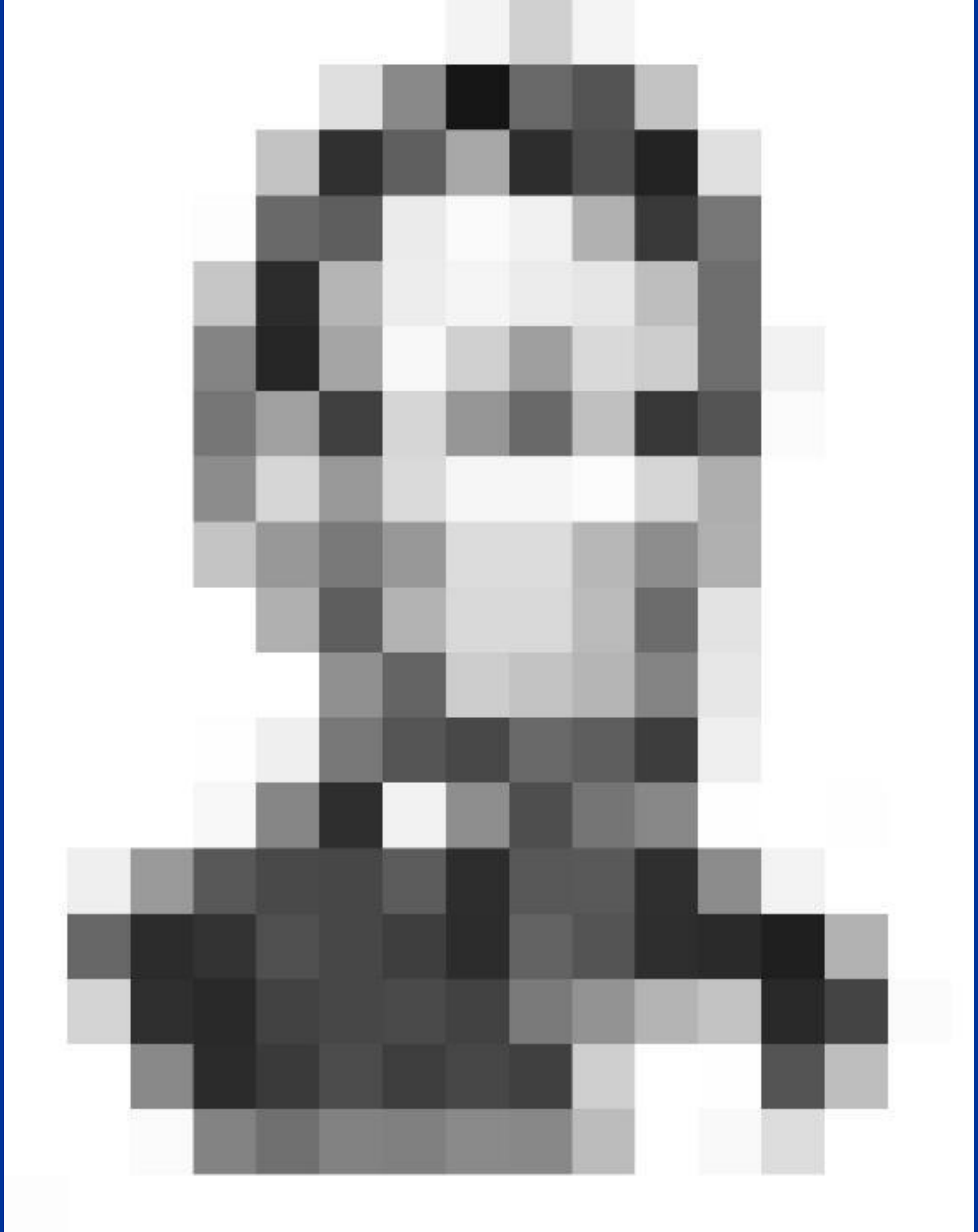
Electrode ~ 15-25 mm

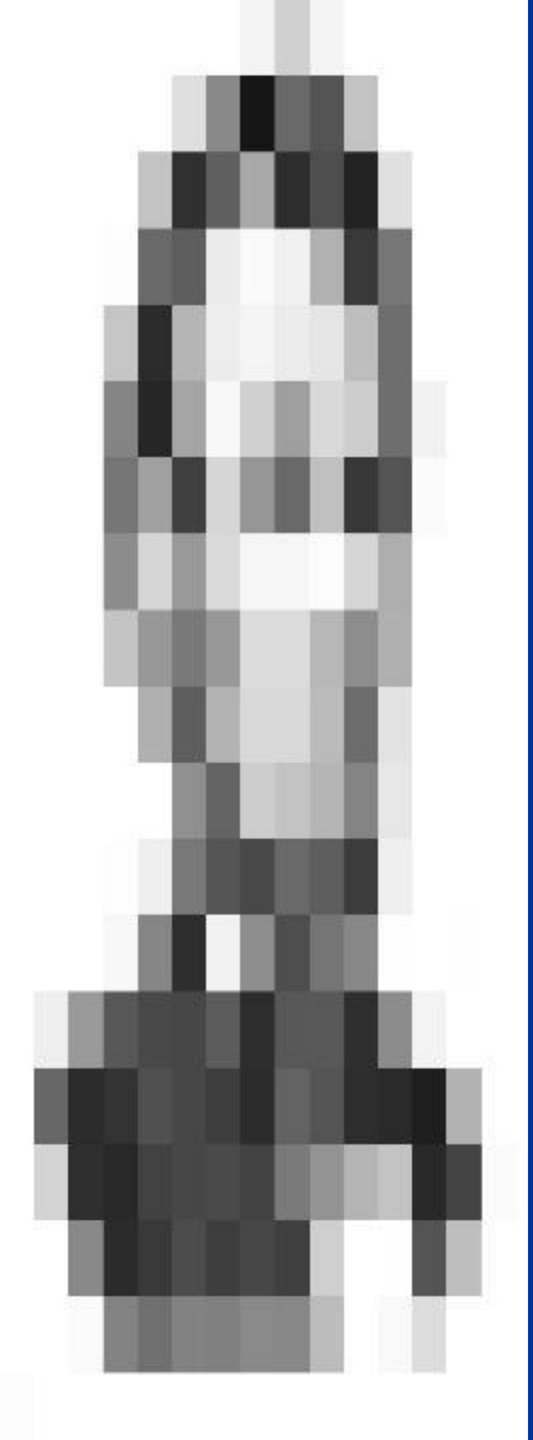
➔Only part of the auditory nerve is stimulated : typically 500- 5000 Hz.

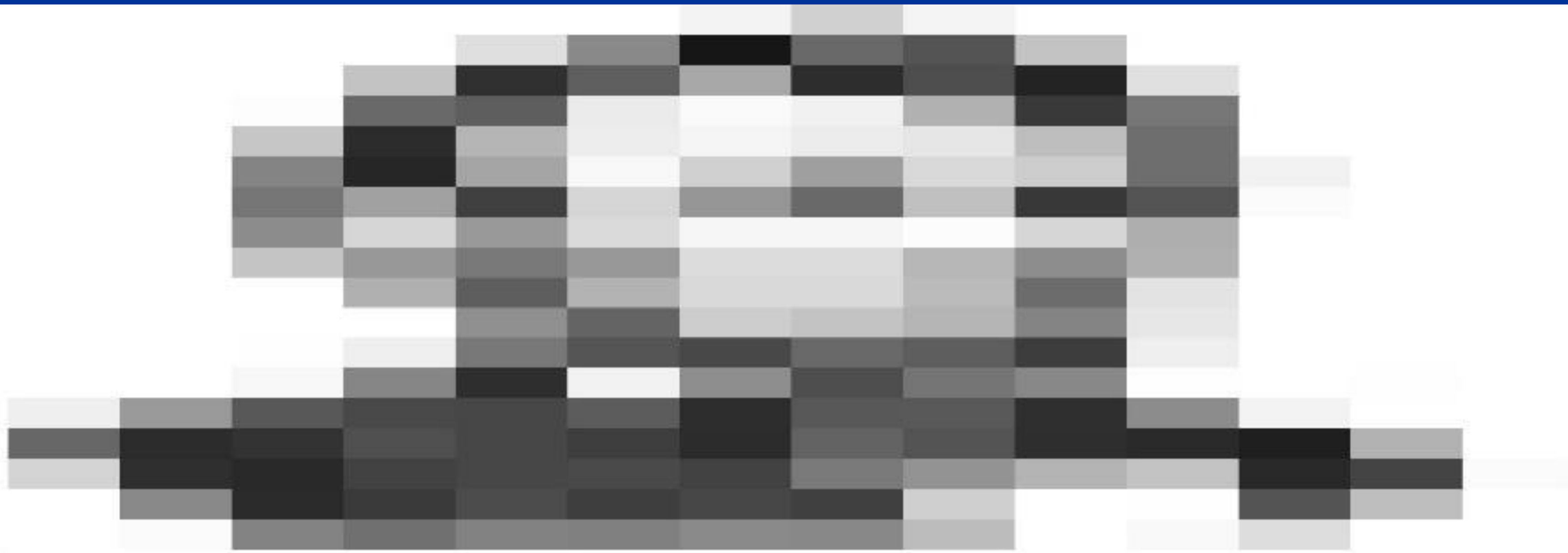
But most speech is 250- 6800 Hz. If we relay all frequencies of speech to the auditory nerve:

➔frequency compression of the sound image.

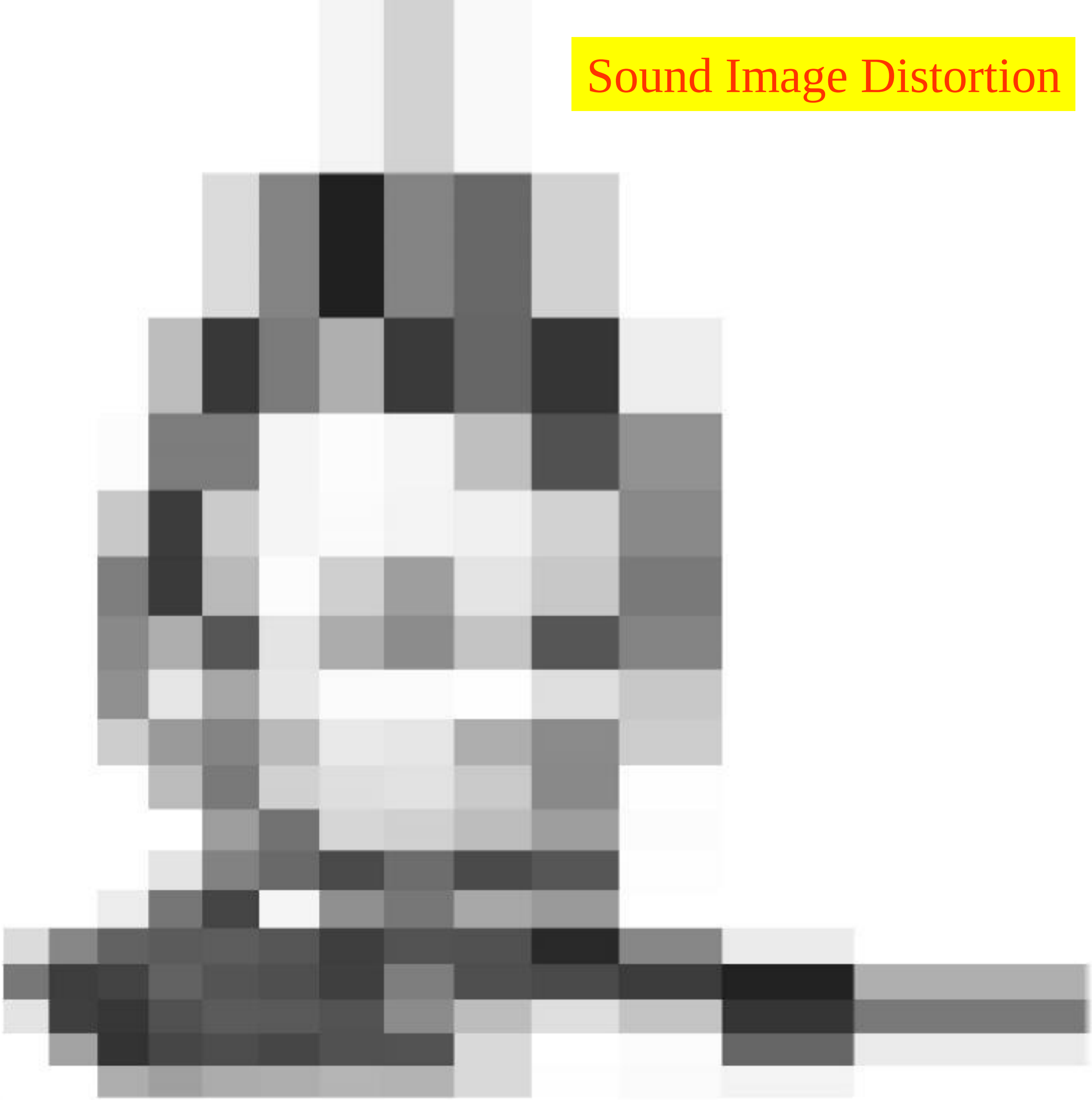
Visual examples







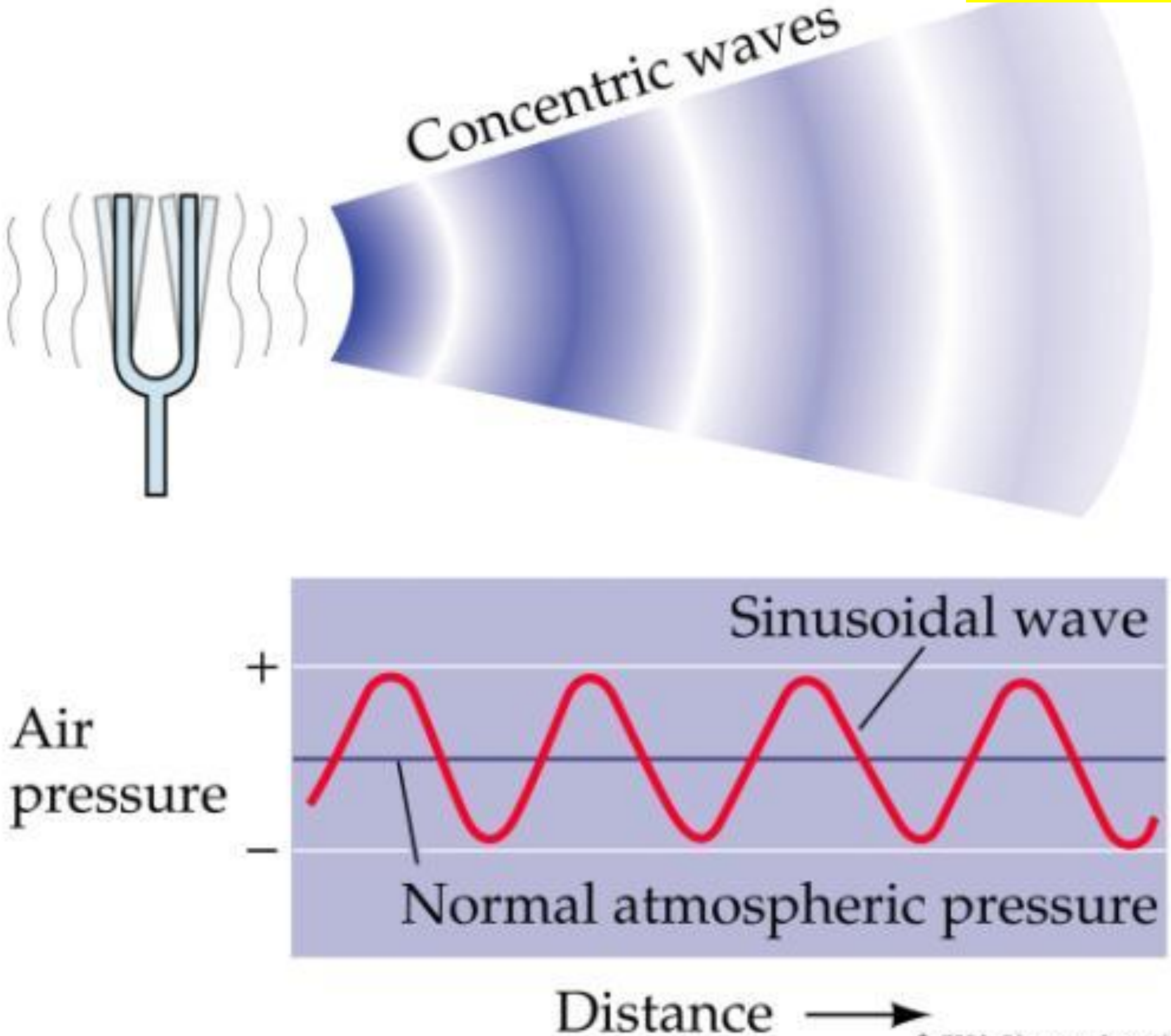
Sound Image Distortion



Sound

ca. 550 B.C.

Pythagoras reasons that sound is a vibration of air.

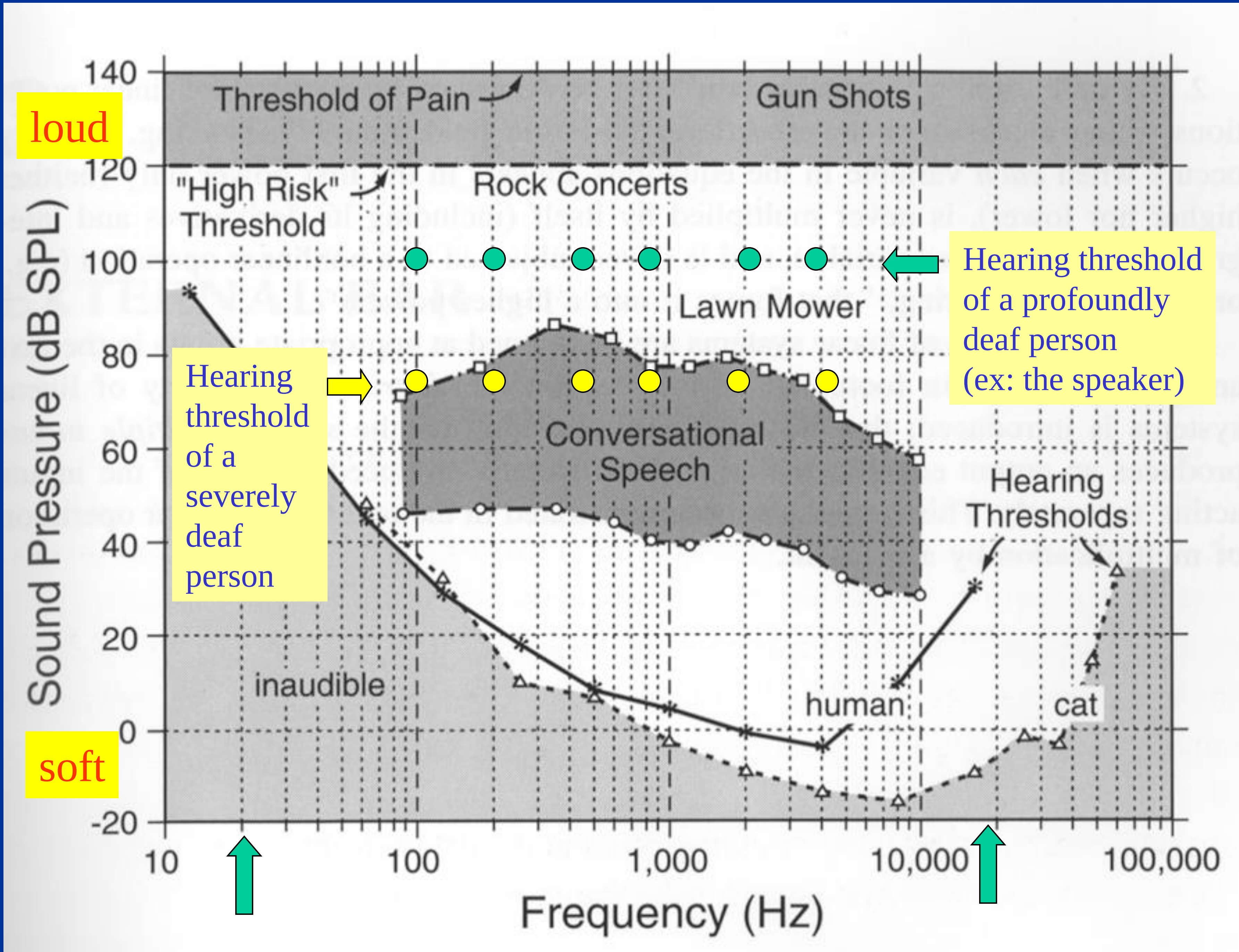


Physical and perceptual characteristics of sound

Physical		Perceptual
• Amplitude	→	• Loudness
• Frequency	→	• Pitch
• Complexity , and phase relationship of constituent frequencies	→	• Timbre

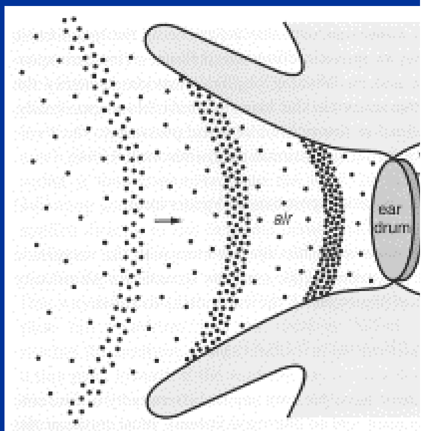
Acoustic Pressure is measured in decibels (dB)

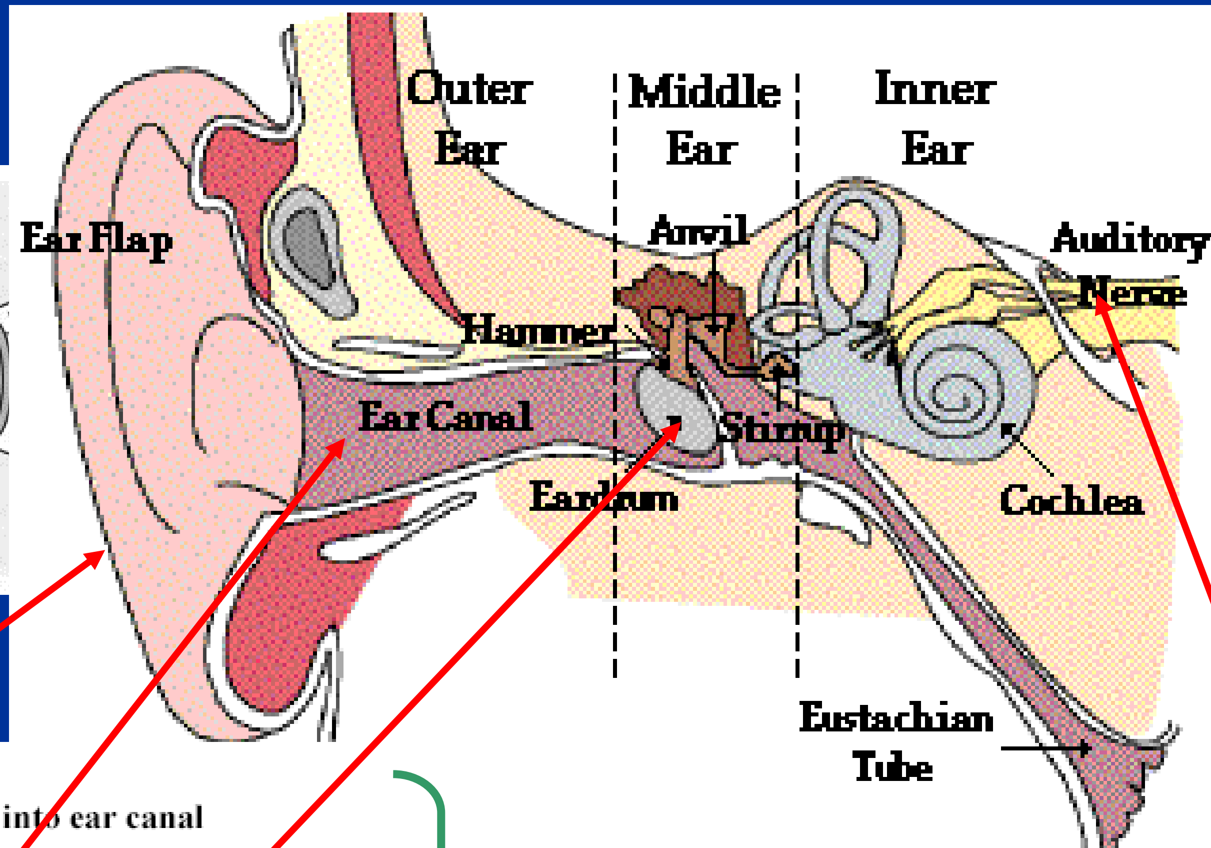
- 1 atm = 100,000 pascals
- Threshold: the softest sound detectable is 20 micropascals (at 1000 Hz). 2 parts in 10 billion of an atmosphere
- We hear sounds 1-10 million times more intense than threshold
- dB are logarithmic units with 0 dB at threshold
- *adding* 20 dB = *factor* of 10 increase in pressure



loud
soft
140
120
100
80
60
40
20
0
-20
Sound Pressure (dB SPL)
Threshold of Pain
Gun Shots
"High Risk" Threshold
Rock Concerts
Lawn Mower
Conversational Speech
Hearing Thresholds
inaudible
human
cat
10
100
1,000
10,000
100,000
Frequency (Hz)
Hearing threshold of a severely deaf person
Hearing threshold of a profoundly deaf person (ex: the speaker)

The Ear Has Three Distinct Regions





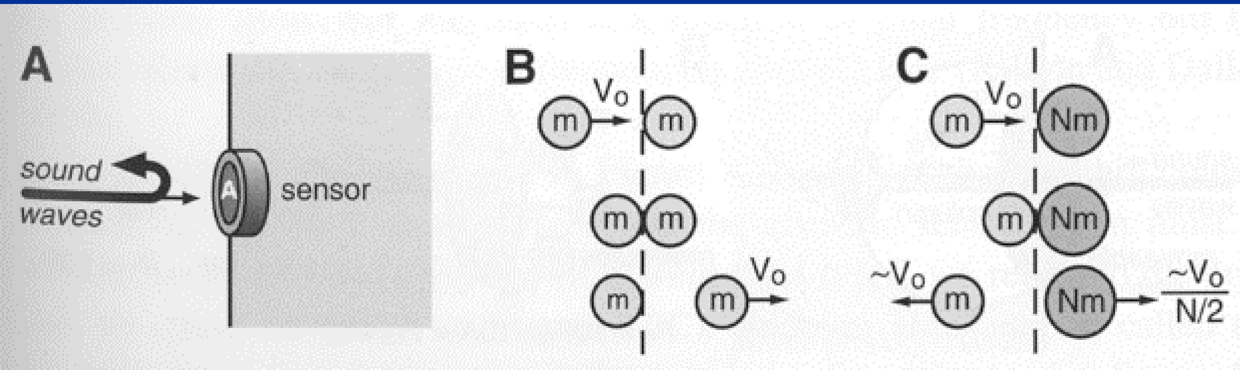
- Pinna
  - Helps direct sound into ear canal
  - Aids in sound localisation
- Auditory canal
  - Funnels and modulates incoming sounds
- Tympanic membrane
  - converts air pressure changes into mechanical vibrations

ca. 550 B.C. Pythagoras & successors

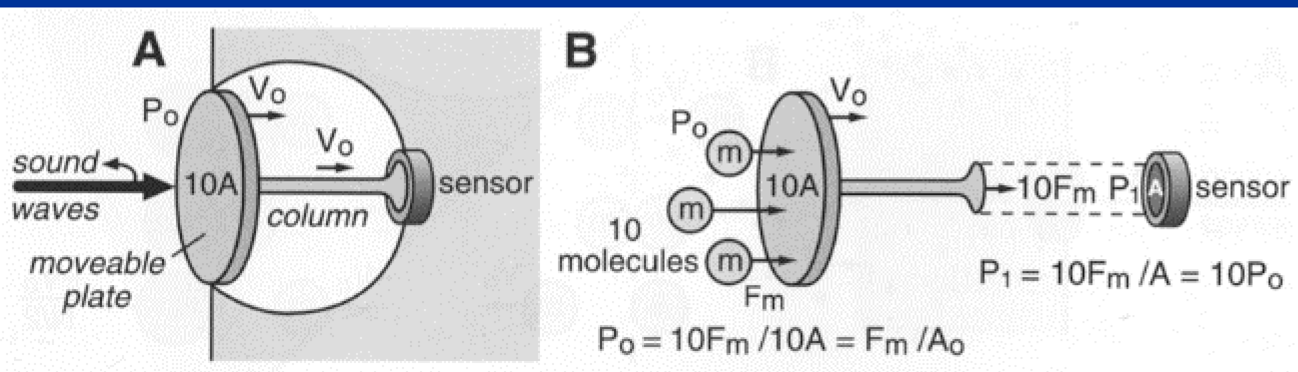
ca. 175 A.D. Galen

Nerve transmits sound to the brain

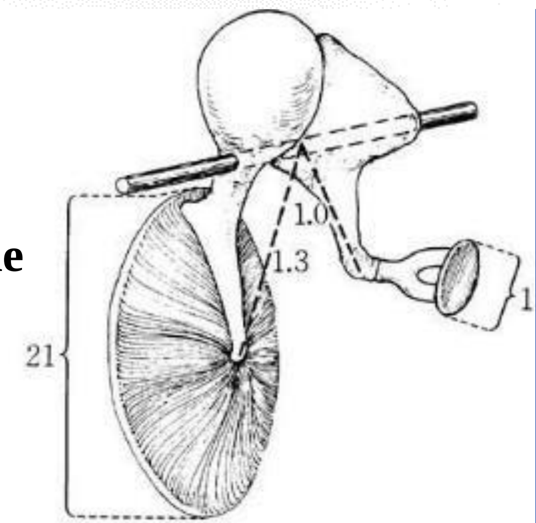
It has taken until the present to unravel the rest



Why is our “sound sensor” not on the outside of our head?

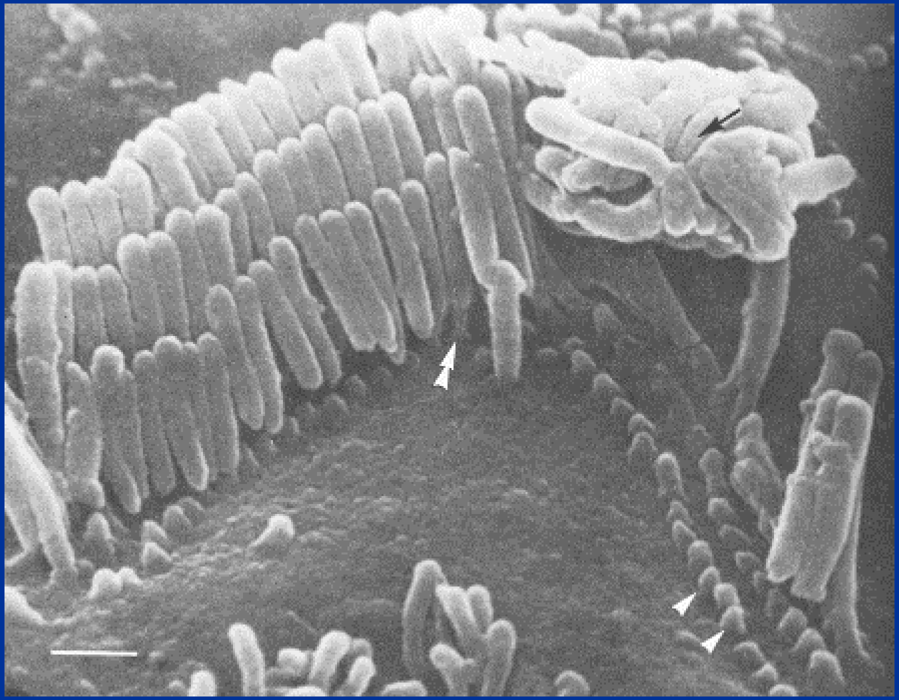


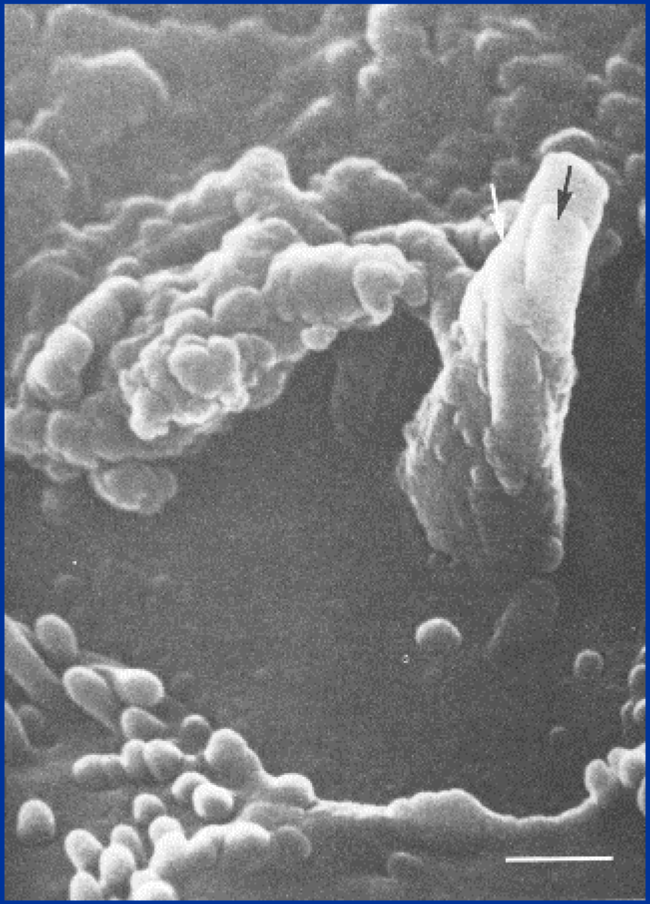
Hermann Ludwig von Helmholtz first to understand the role of the ossicles



Impedance mismatch overcome by ratio of areas and lever action

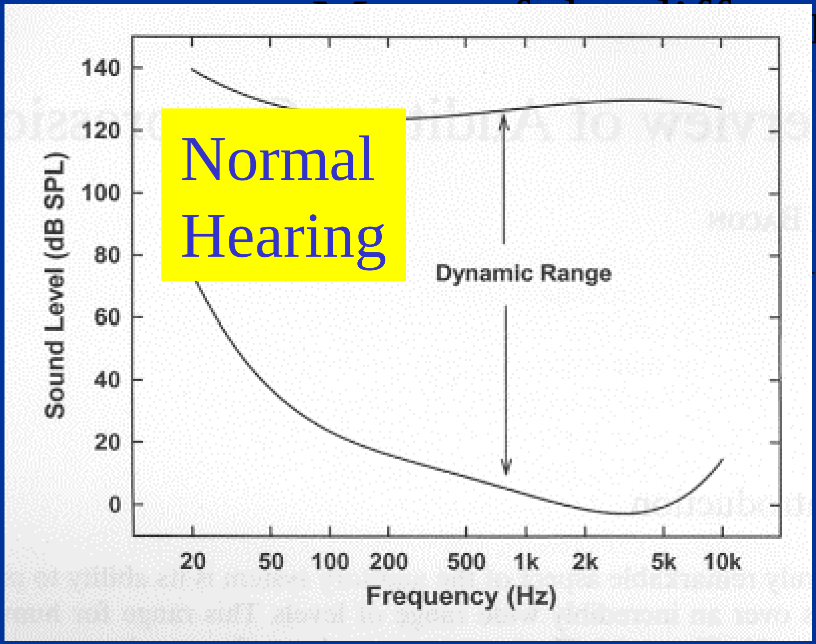
Action of ototoxic antibiotics on hair cells

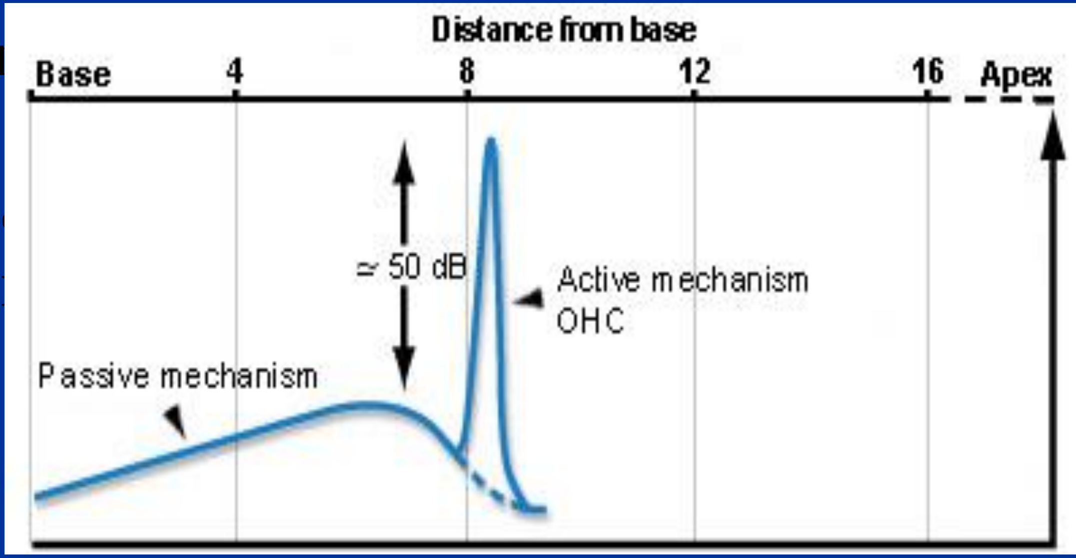


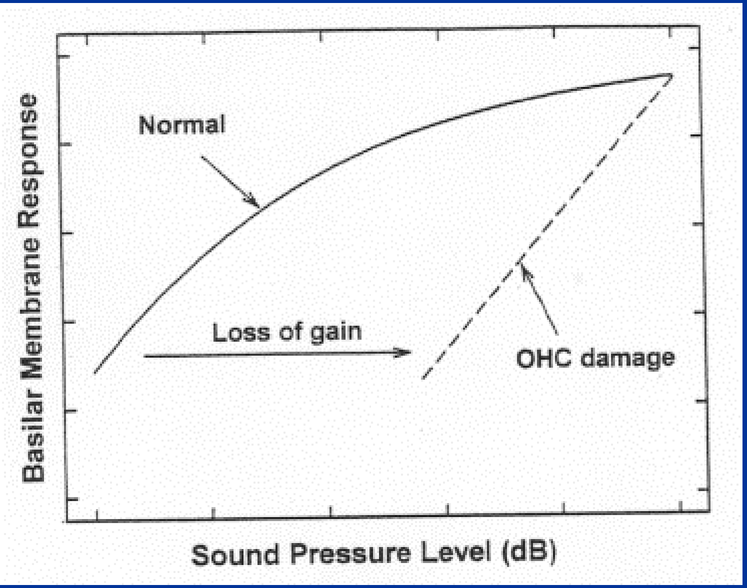


Loud noise also destroys hair cells

Don't lose your hair…. cells

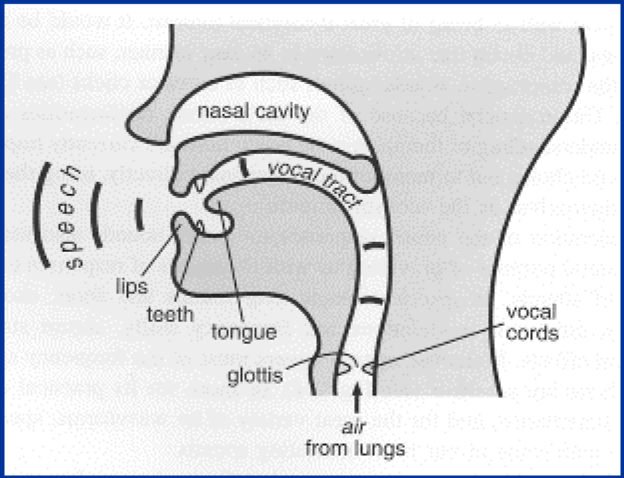






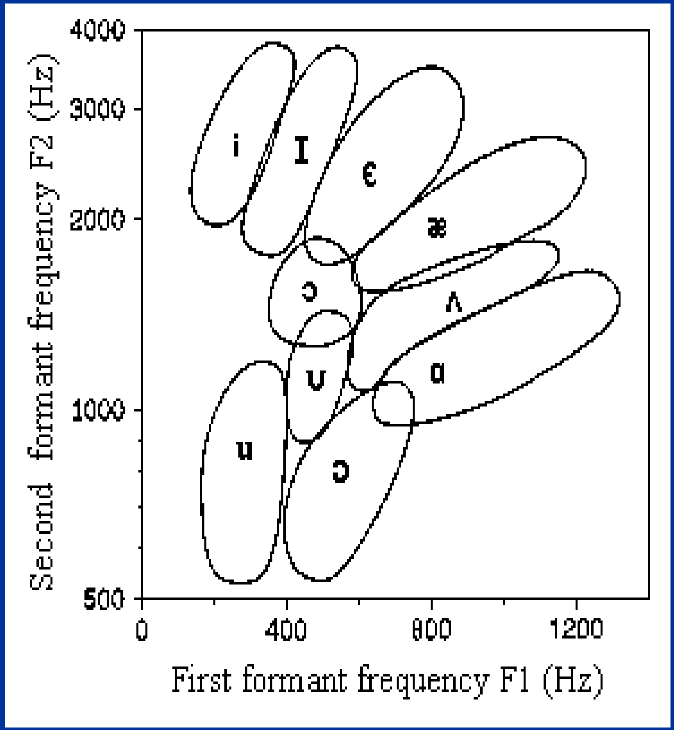
* Loss of gain (can't hear softer sounds)
* Reduced dynamic range
* Loss of frequency sensitivity
* Preferential loss of high frequency sensitivity. (Since hair cells at the base of the cochlea are more prone to damage.)

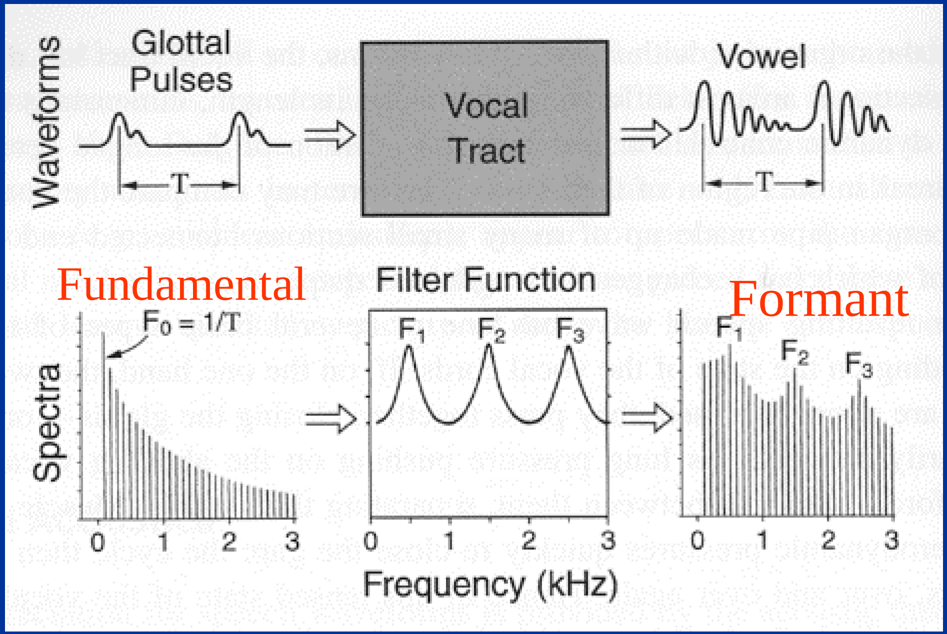
Speech pattern recognition problem



Vowel perception by normal hearing listeners.

F1 and F2 values of English vowels (Peterson and Barney, 1952)

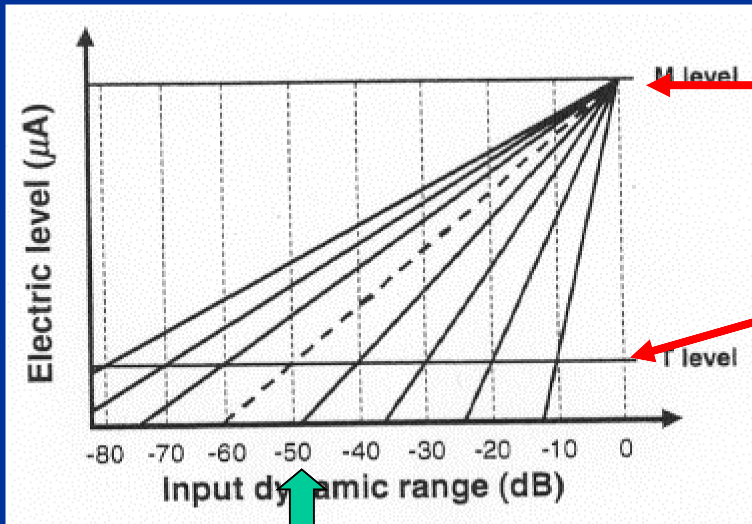




Vowels are quite distinct

- What features of the pattern of neural output from the cochlea
- are most critical? Amplitude? Temporal? Place (frequency)?

Input Dynamic Range



Pain

(20dB)

Just audible

Amplitude Study

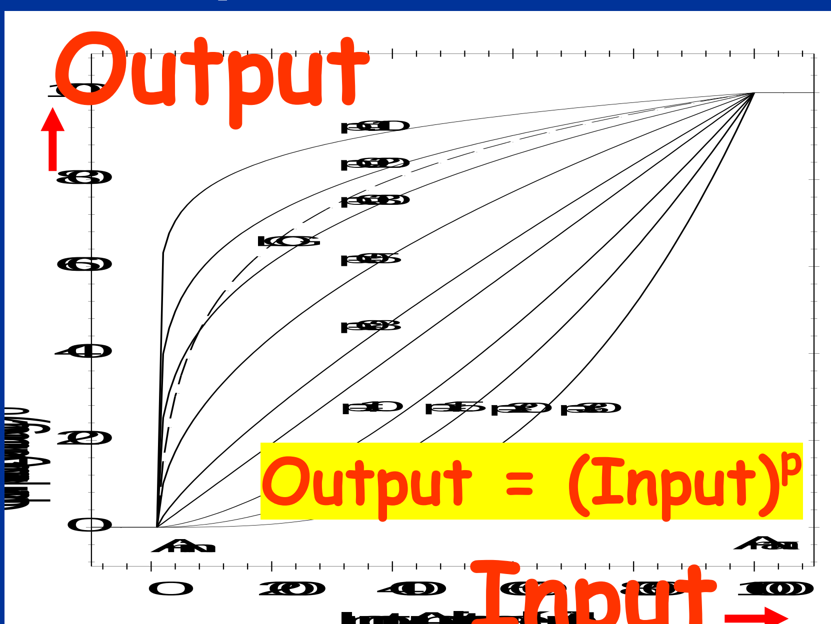
CI electrodes span 20 dB

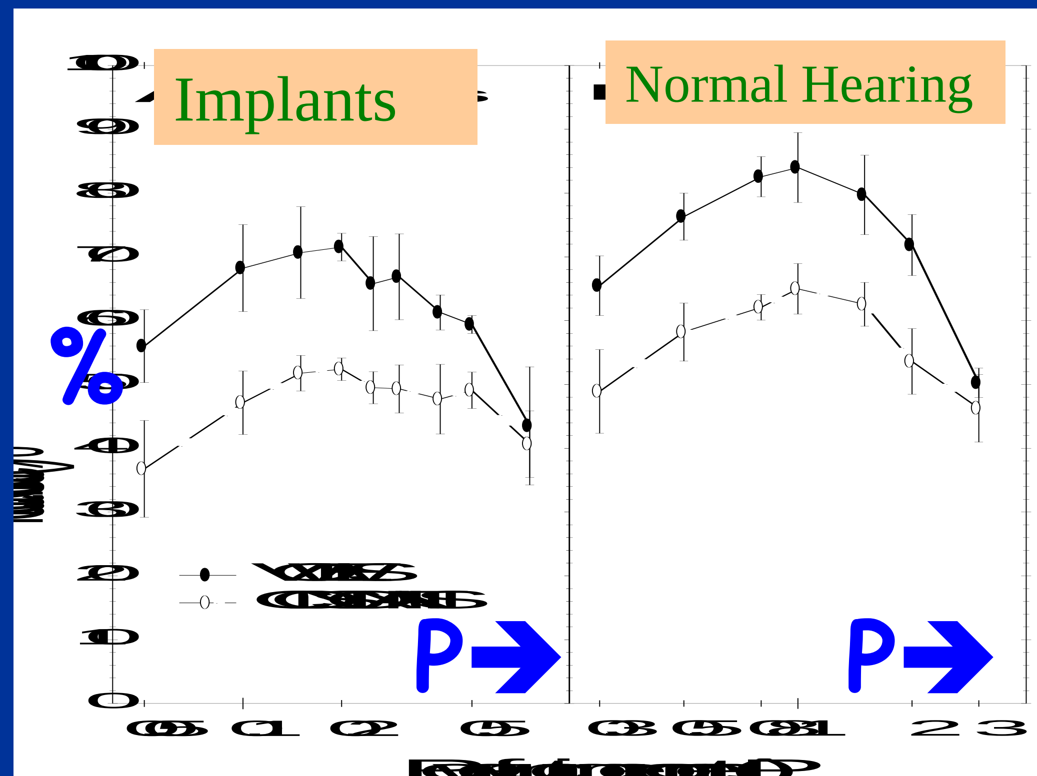
normal hearing: 120 dB

(but speech ~50 dB range)

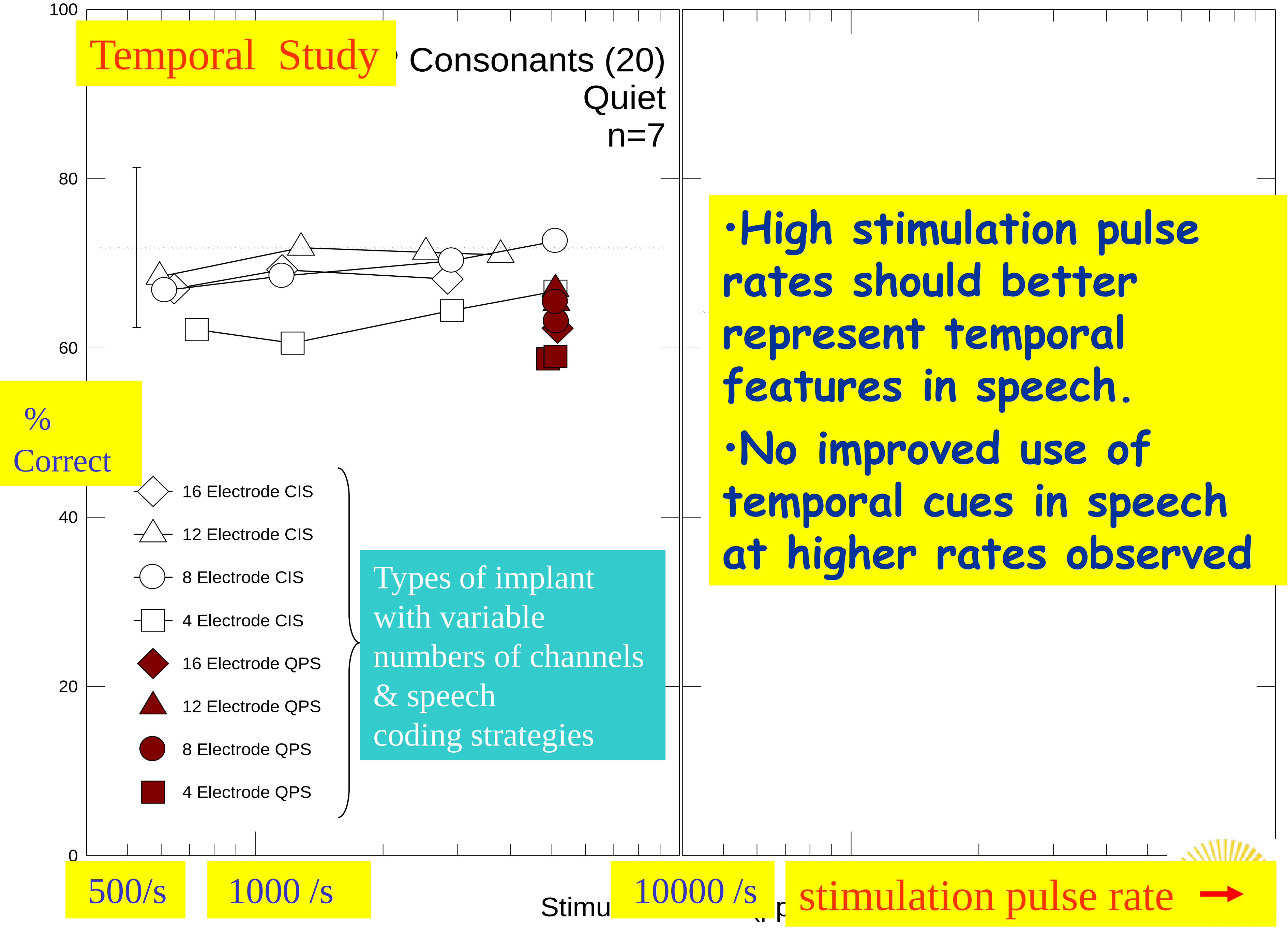
➔ 50 dB input gives best result

Compression

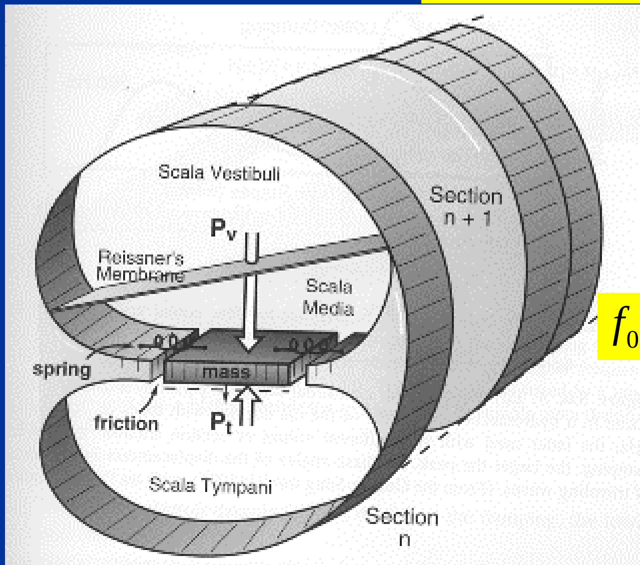




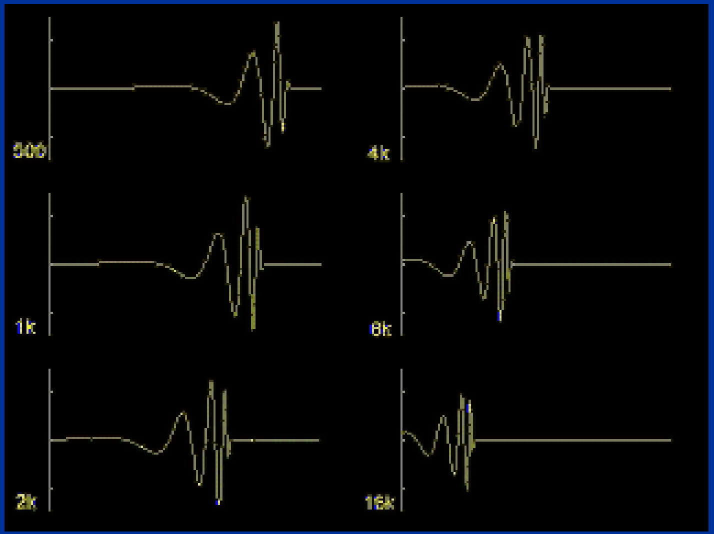
•Speech recognition is only mildly affected by large distortions in amplitude


Temporal Study
Consonants (20)
Quiet
n=7
100
80
60
40
20
0
% Correct
16 Electrode CIS
12 Electrode CIS
8 Electrode CIS
4 Electrode CIS
16 Electrode QPS
12 Electrode QPS
8 Electrode QPS
4 Electrode QPS
Types of implant with variable numbers of channels & speech coding strategies
•High stimulation pulse rates should better represent temporal features in speech.
•No improved use of temporal cues in speech at higher rates observed
500/s
1000 /s
Stimu
10000 /s
stimulation pulse rate →

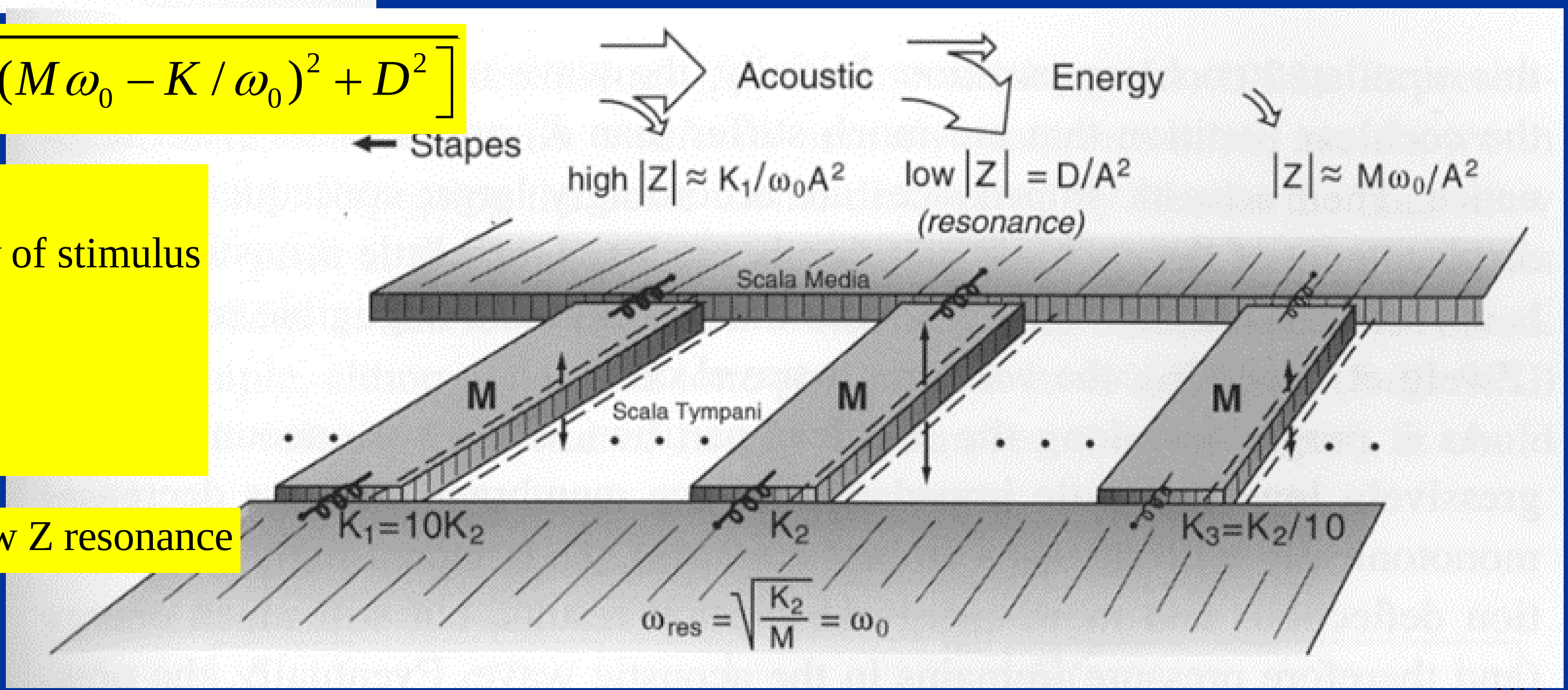
Hydrodynanic Model of the Basilar Membrane



f_0=frequency of stimulus



$$Z = (1/A^2)\sqrt{\left[(M\omega_0 - K/\omega_0)^2 + D^2\right]}$$



M = mass

ω_0=frequency of stimulus

D = damping

K = stiffness

A = area

$\omega_0 = k_2/m$ low Z resonance

Say what? A cartoon depicting two conversations occurring on different "wavelengths" at a cocktail party.
The brains of listeners are able to ignore the nearby voices of others while homing in on just one speaker.
Credit: Zion-Golumbic et al., Neuron

CLOSE ✕