

Part 1: Hearing disorders

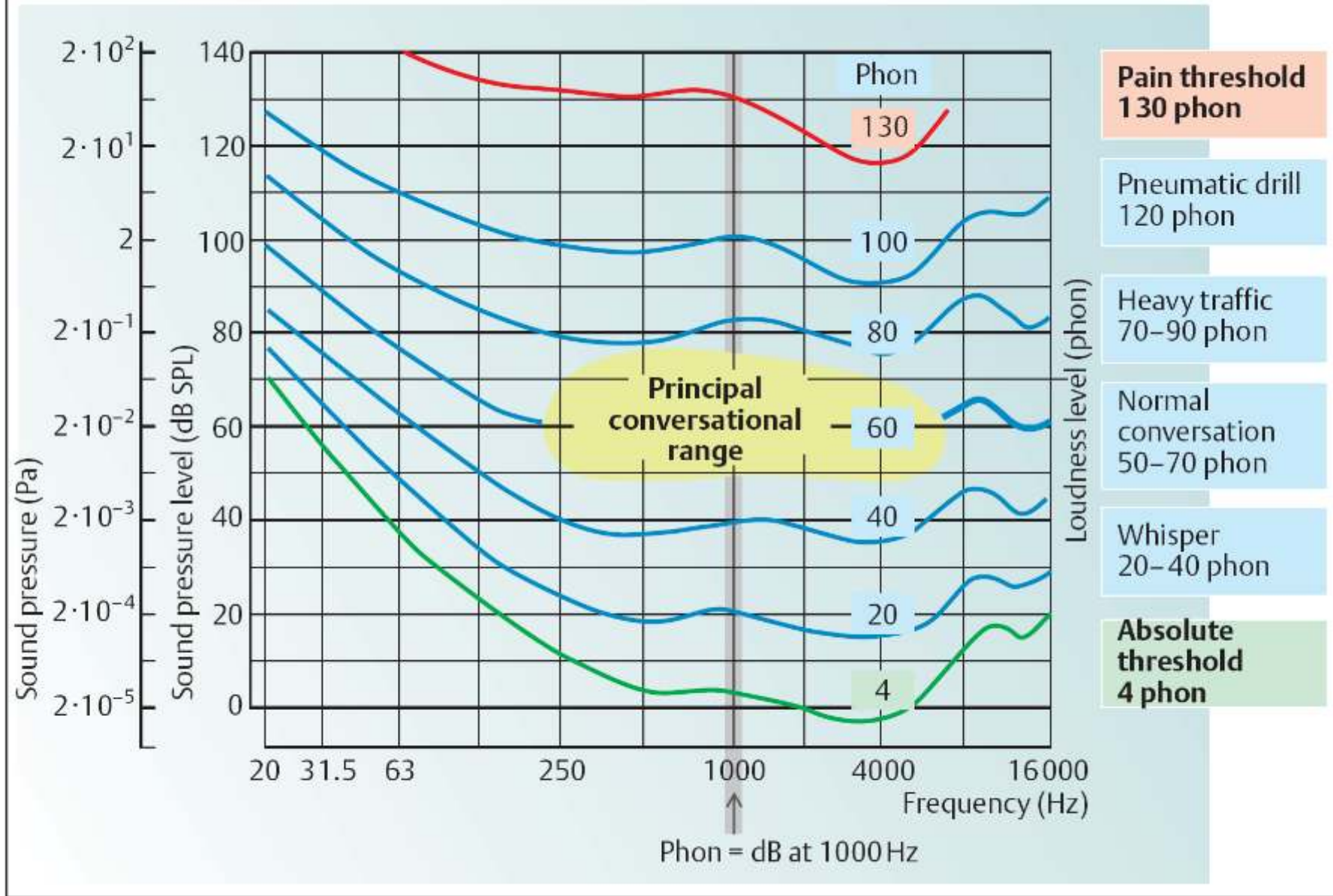


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Outline of part 1

- **Intro: normal hearing, speech production and understanding**
- **Basics of anatomy of the ear -> for understanding the function**
- **Bone and air conduction**
- **Hearing disorders**
- **Functional classification of hearing performance**

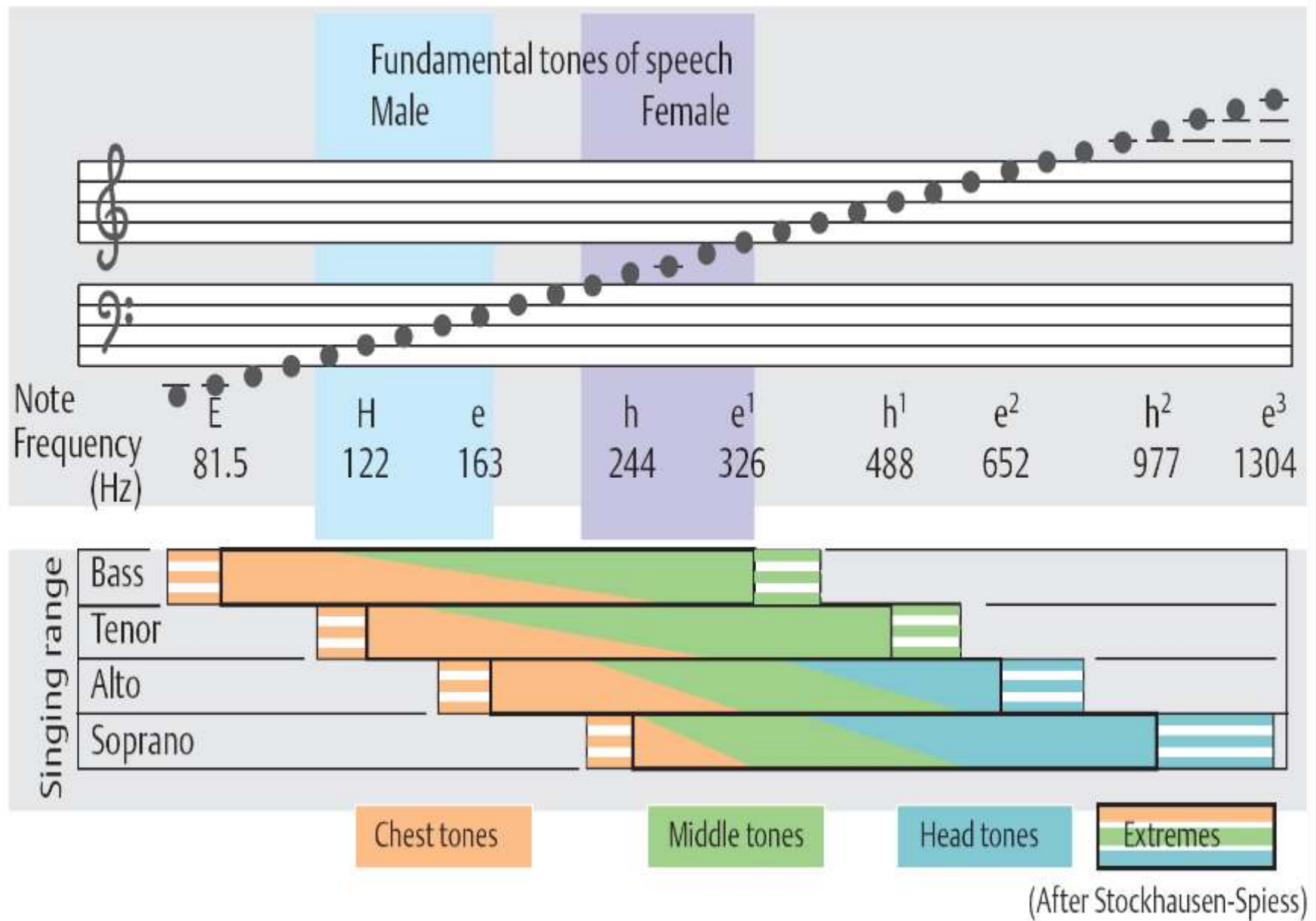
B. Sound pressure, sound pressure level and loudness level



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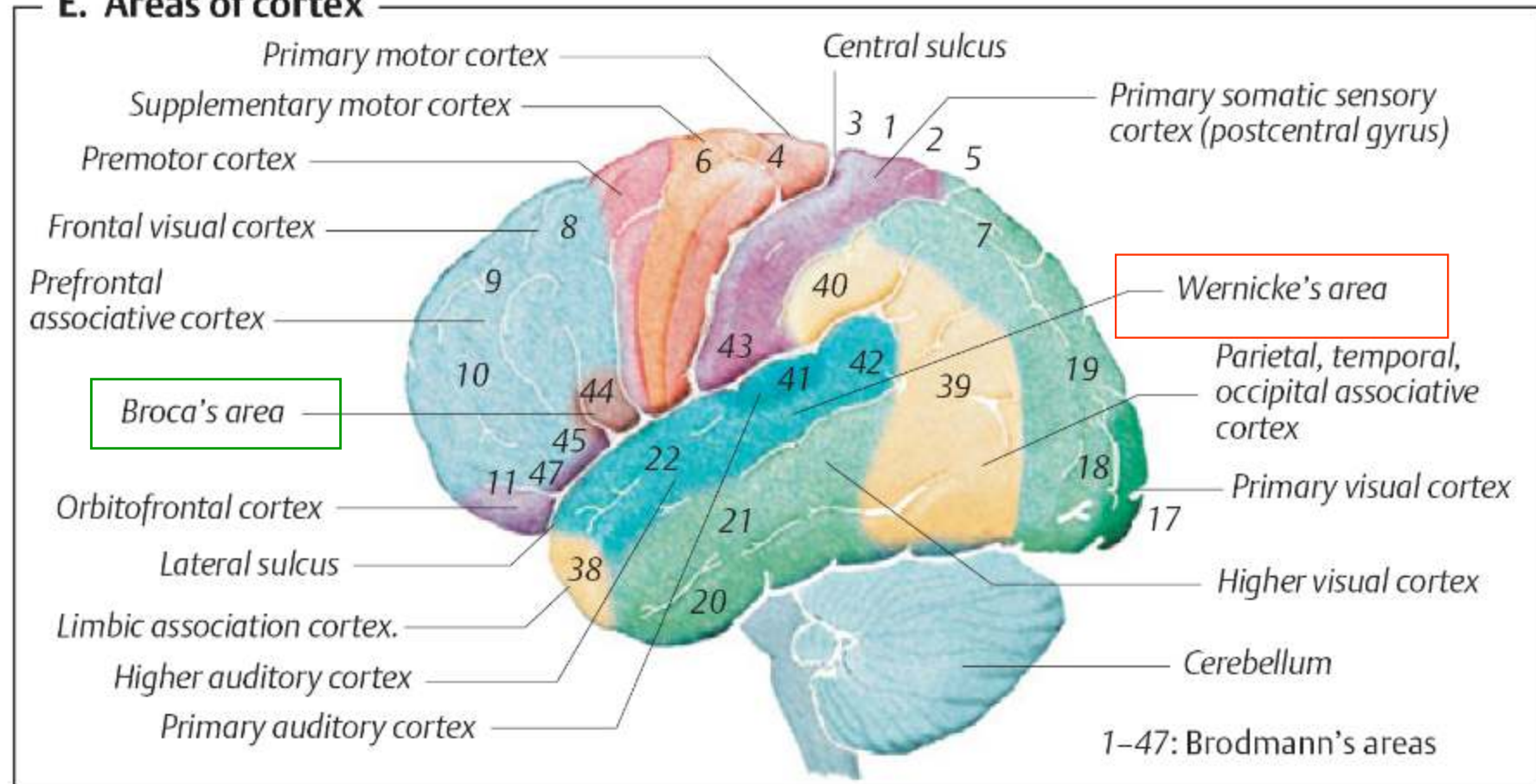
Hearing range: frequencies and intensities

C. Vocal range and singing range



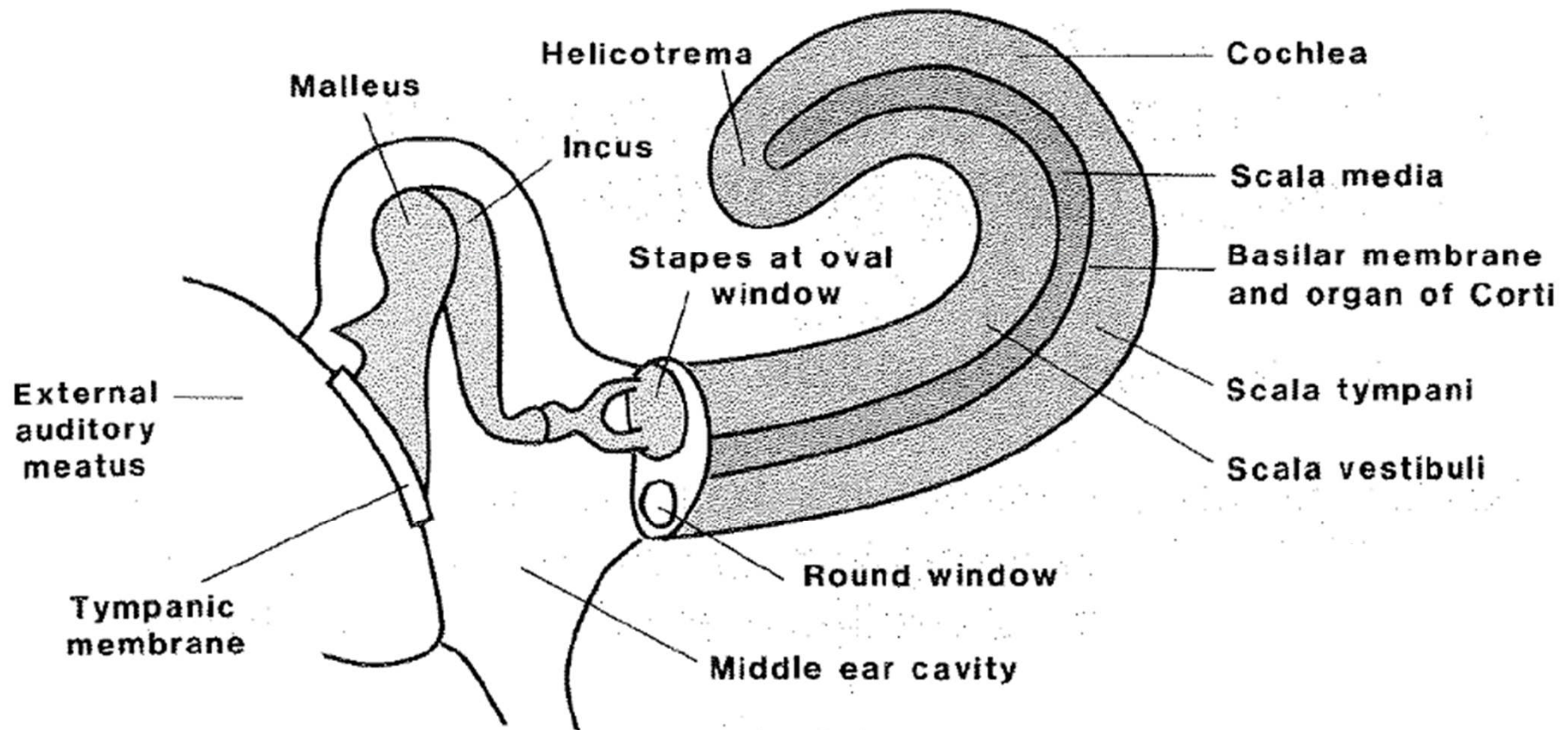
Vocal range and singing range

E. Areas of cortex

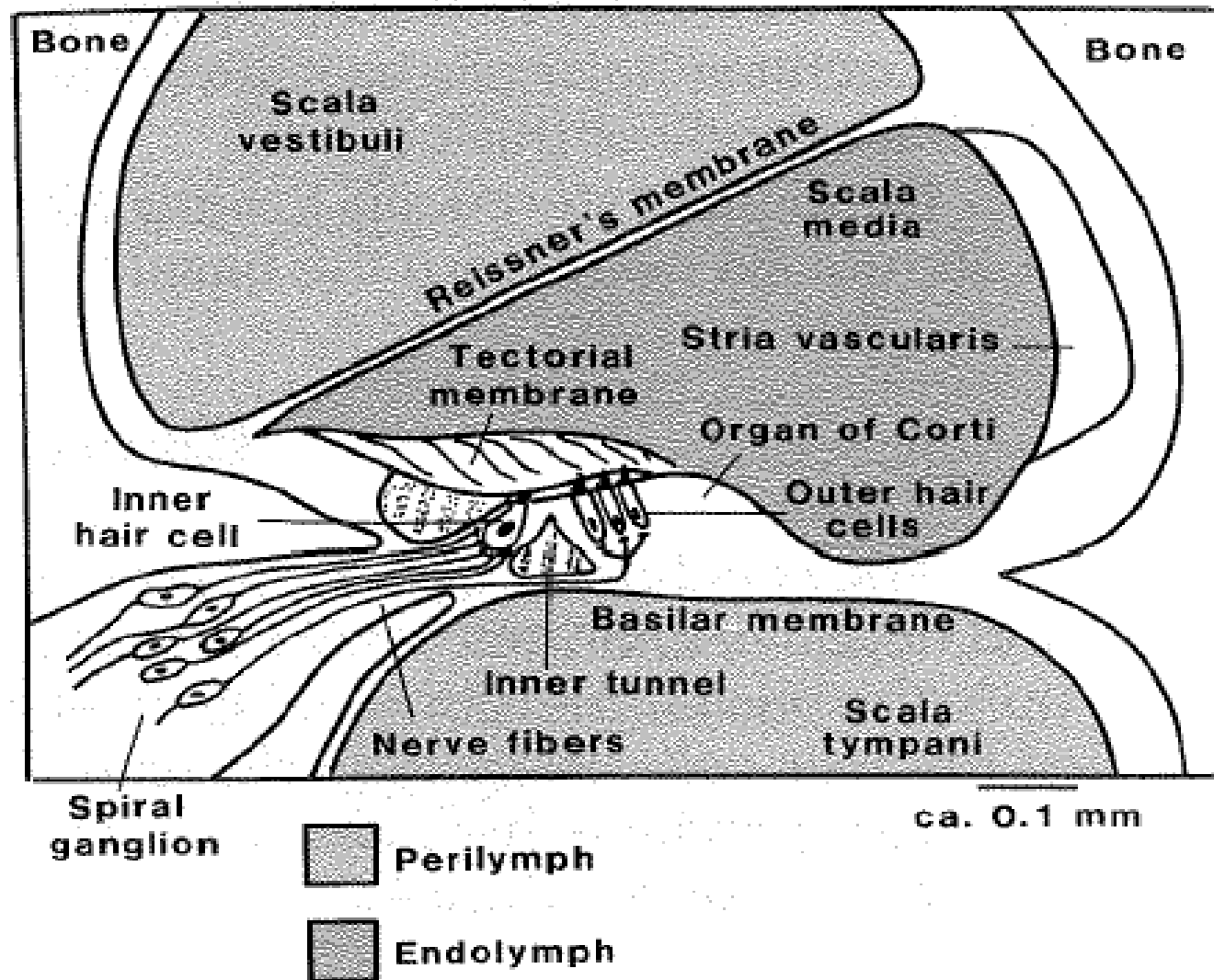


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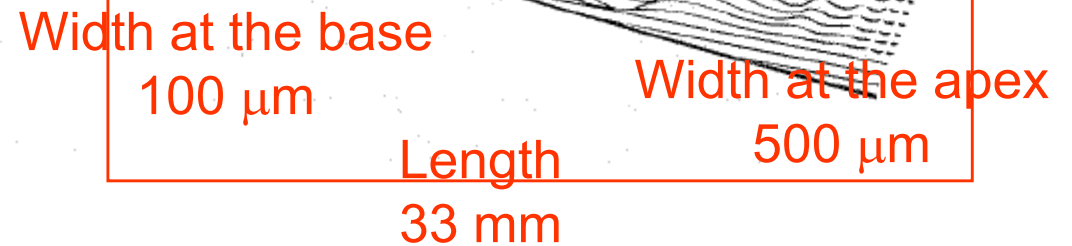
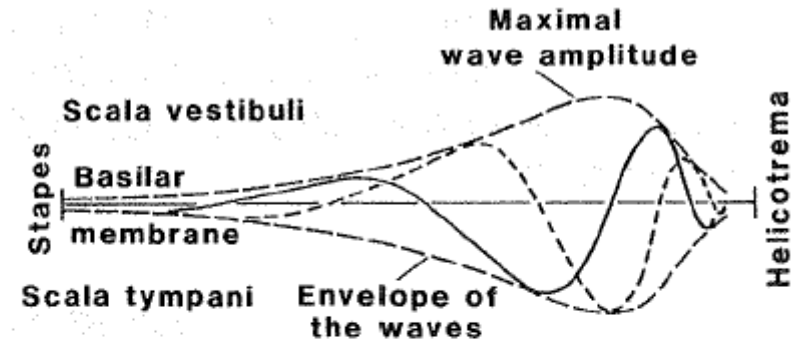
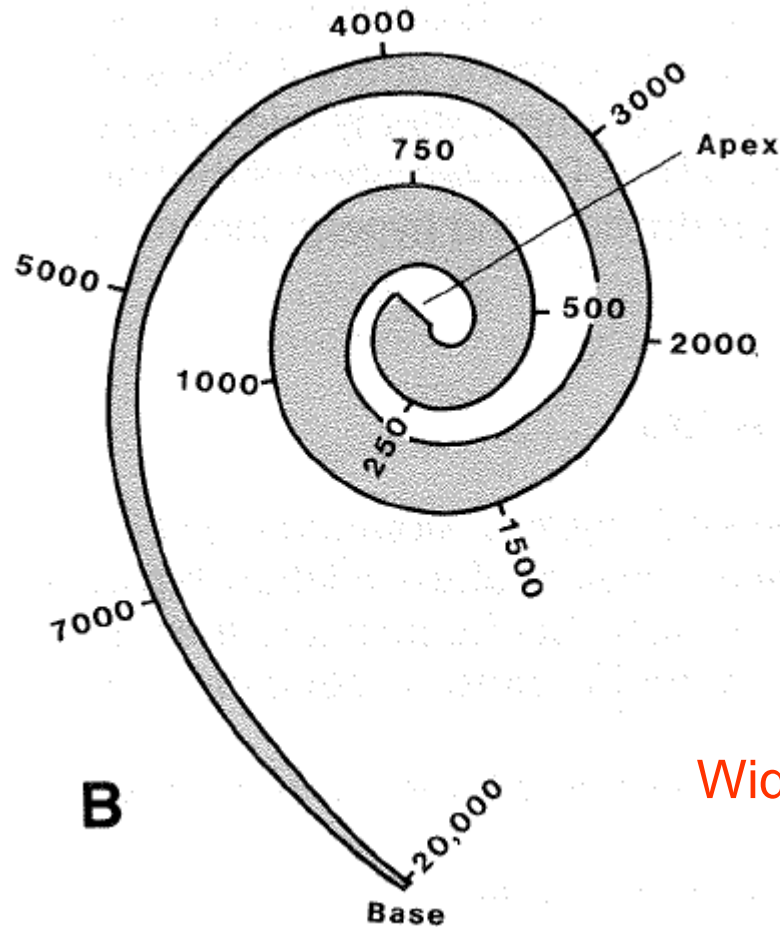
Two main speech centers within the Brodman areas



Outer, middle and inner ear

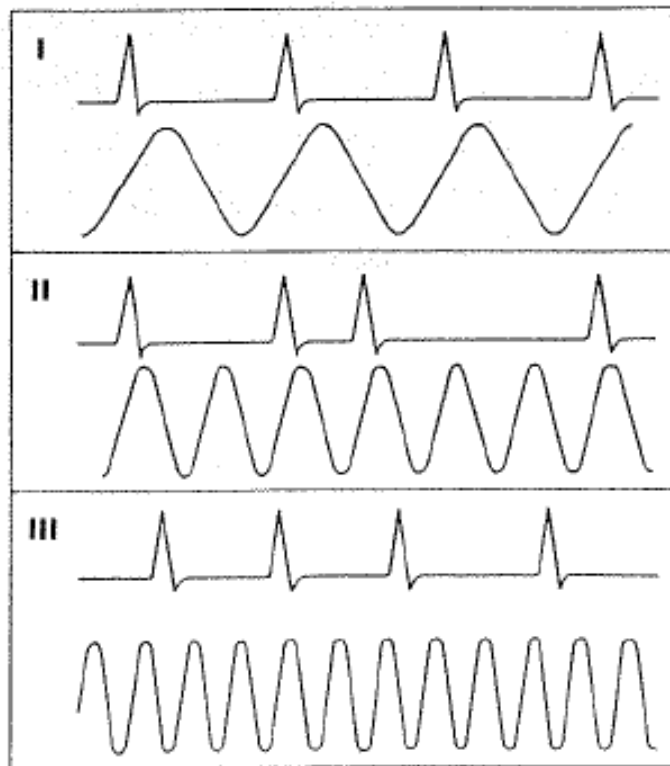
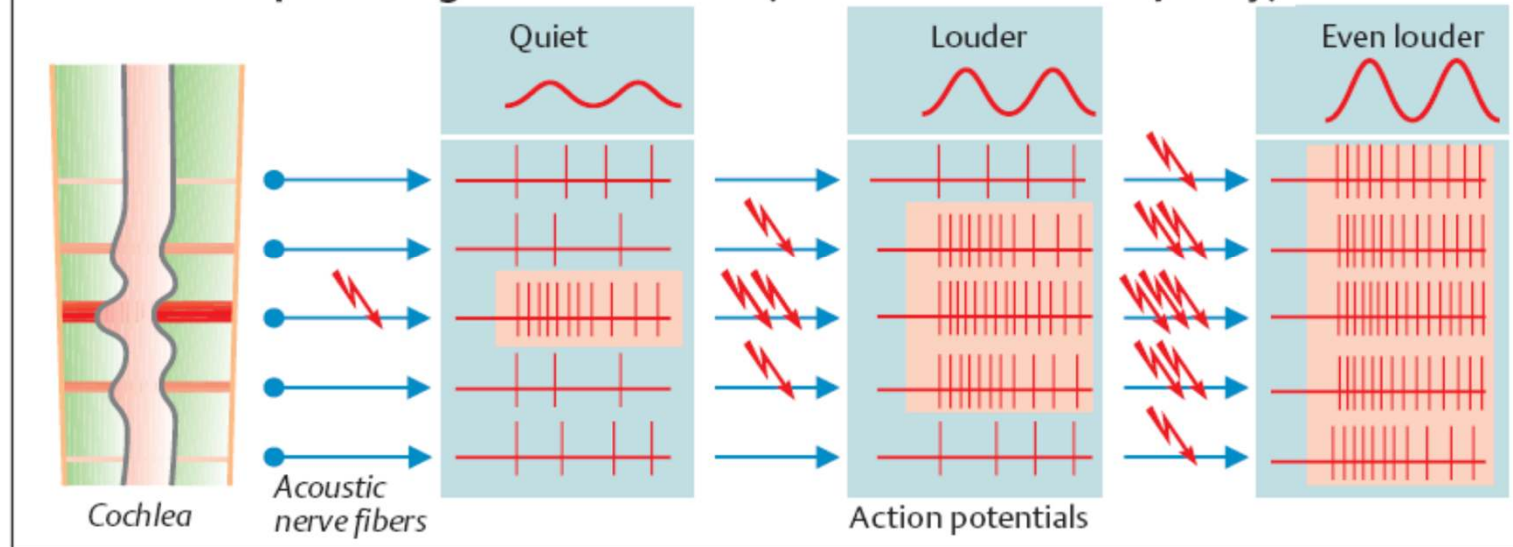


Organ of Corti



Basilar membrane – from above and unfolded into trapezoid plane

A. Loudness processing in acoustic nerve (at constant sound frequency)



Frequency:

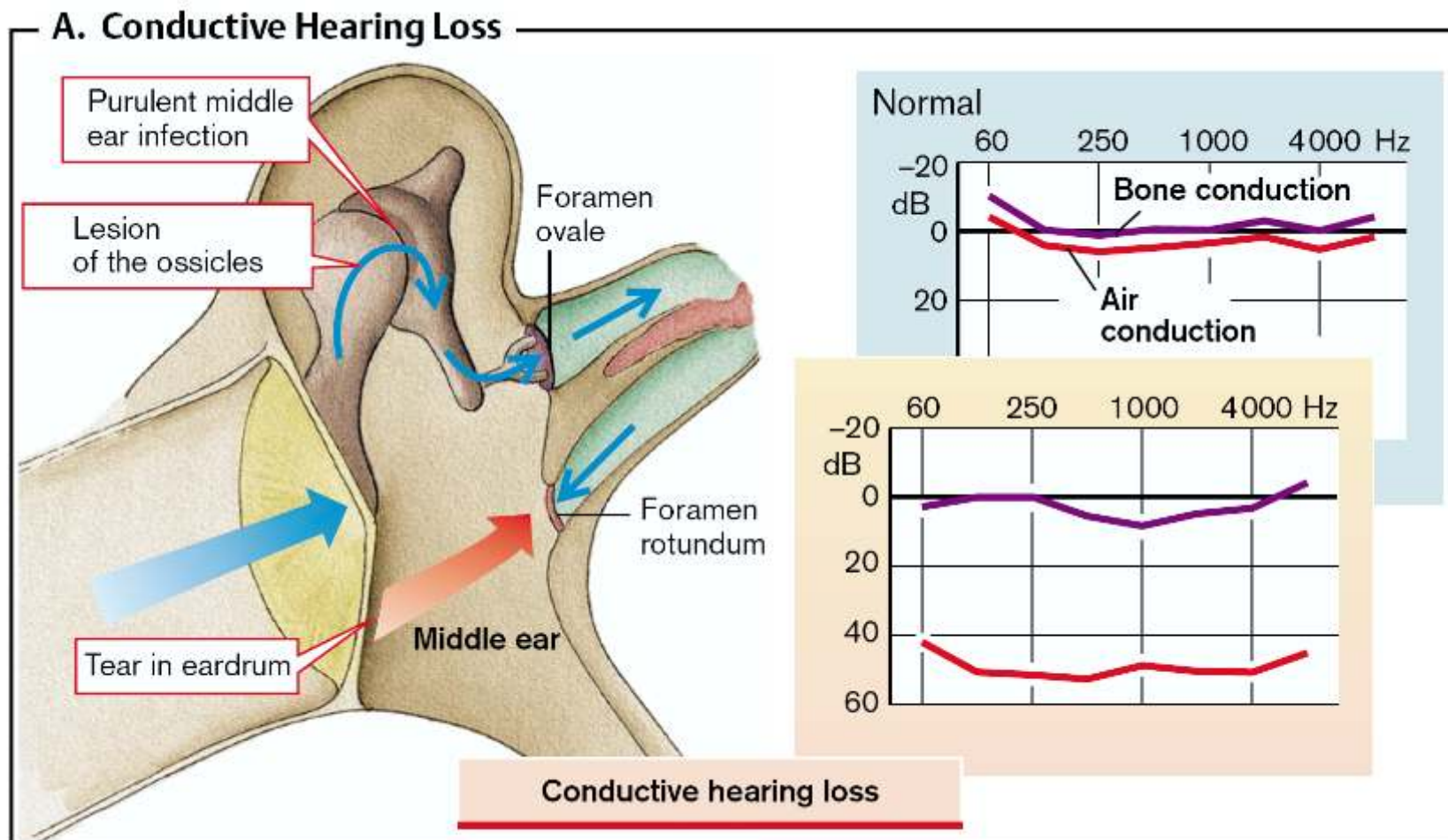
< 200 Hz

> 2000 Hz

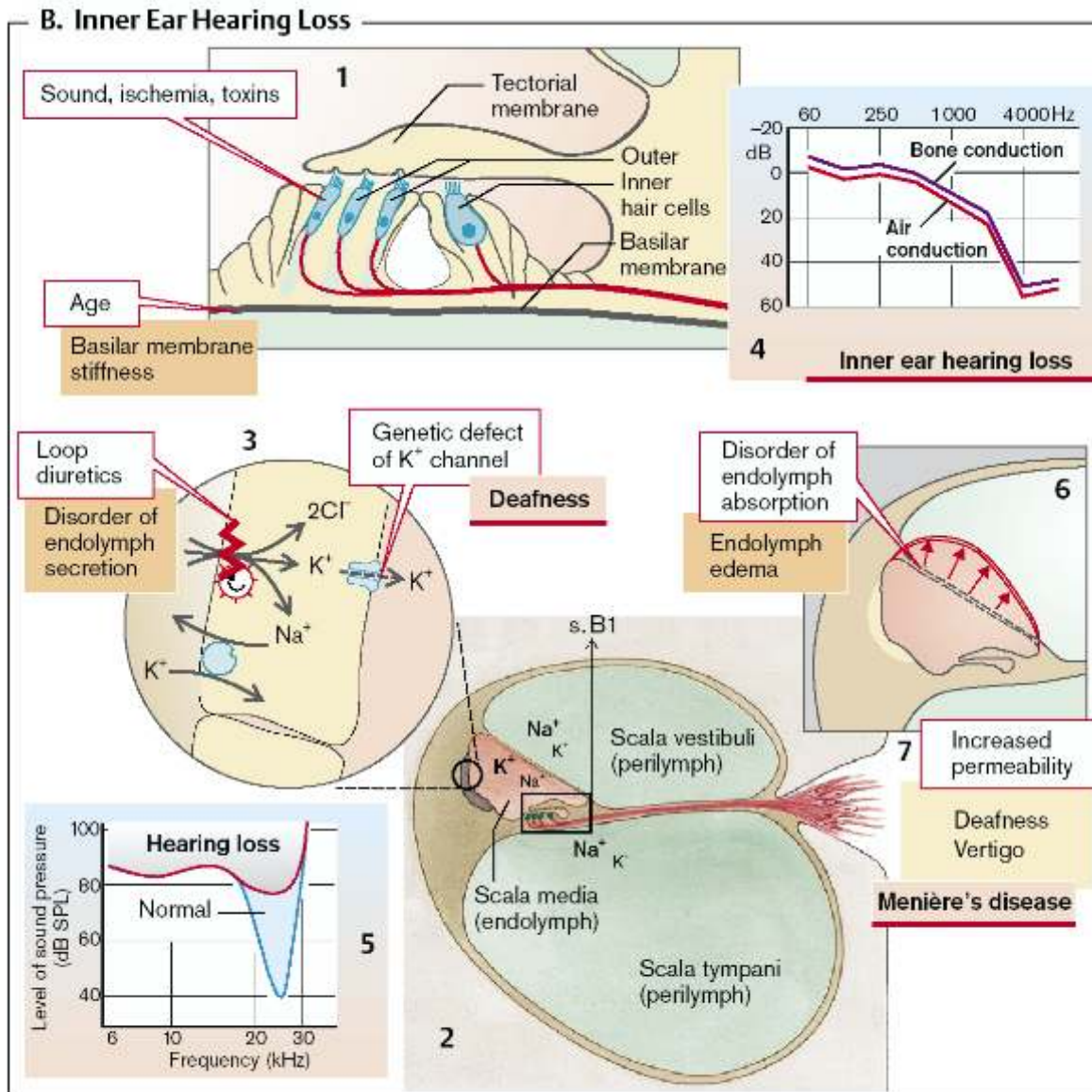
Encoding of sound loudness and frequency

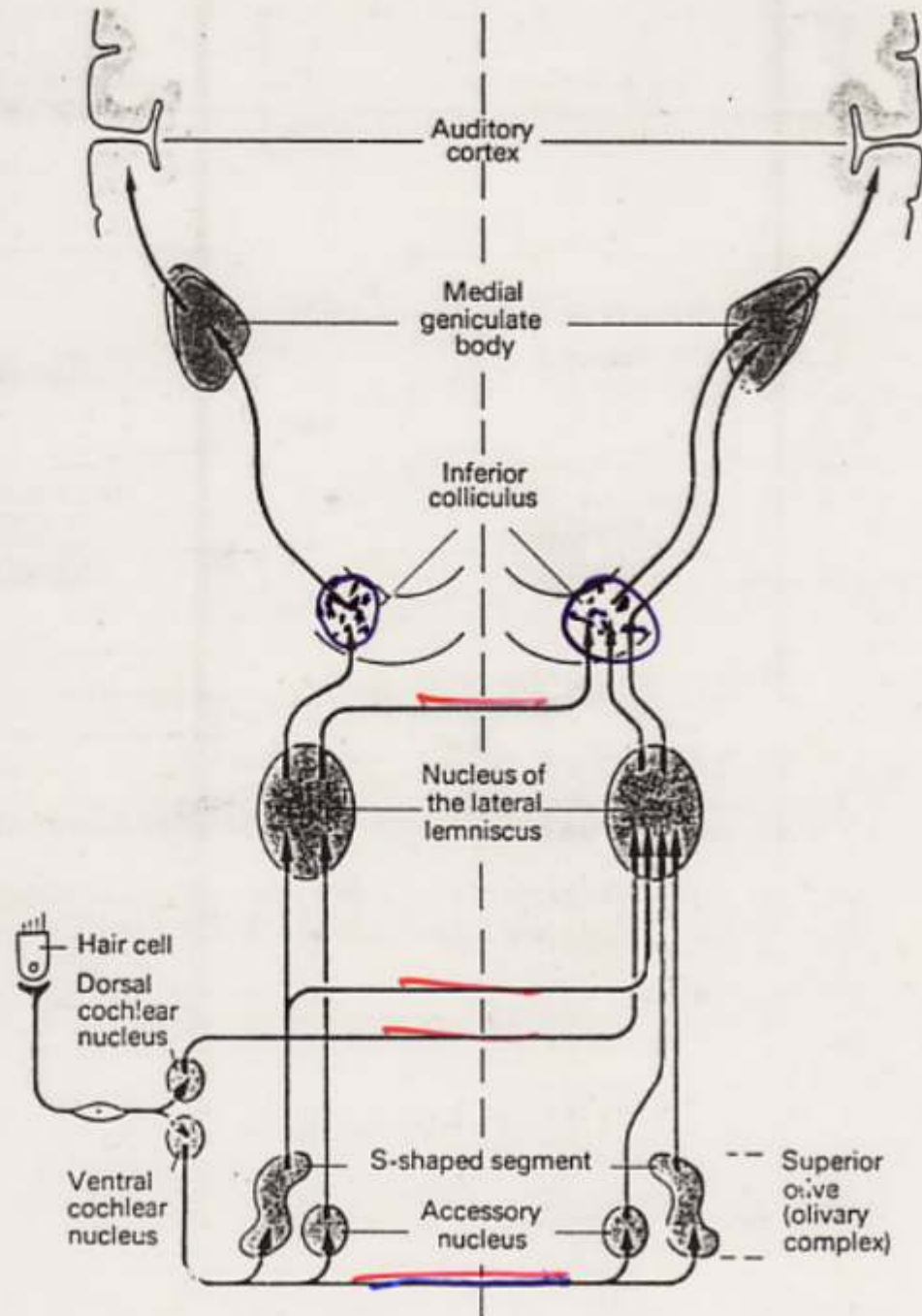
Conduction: through air and bone

Hearing loss: A. conductive, B. sensorineural

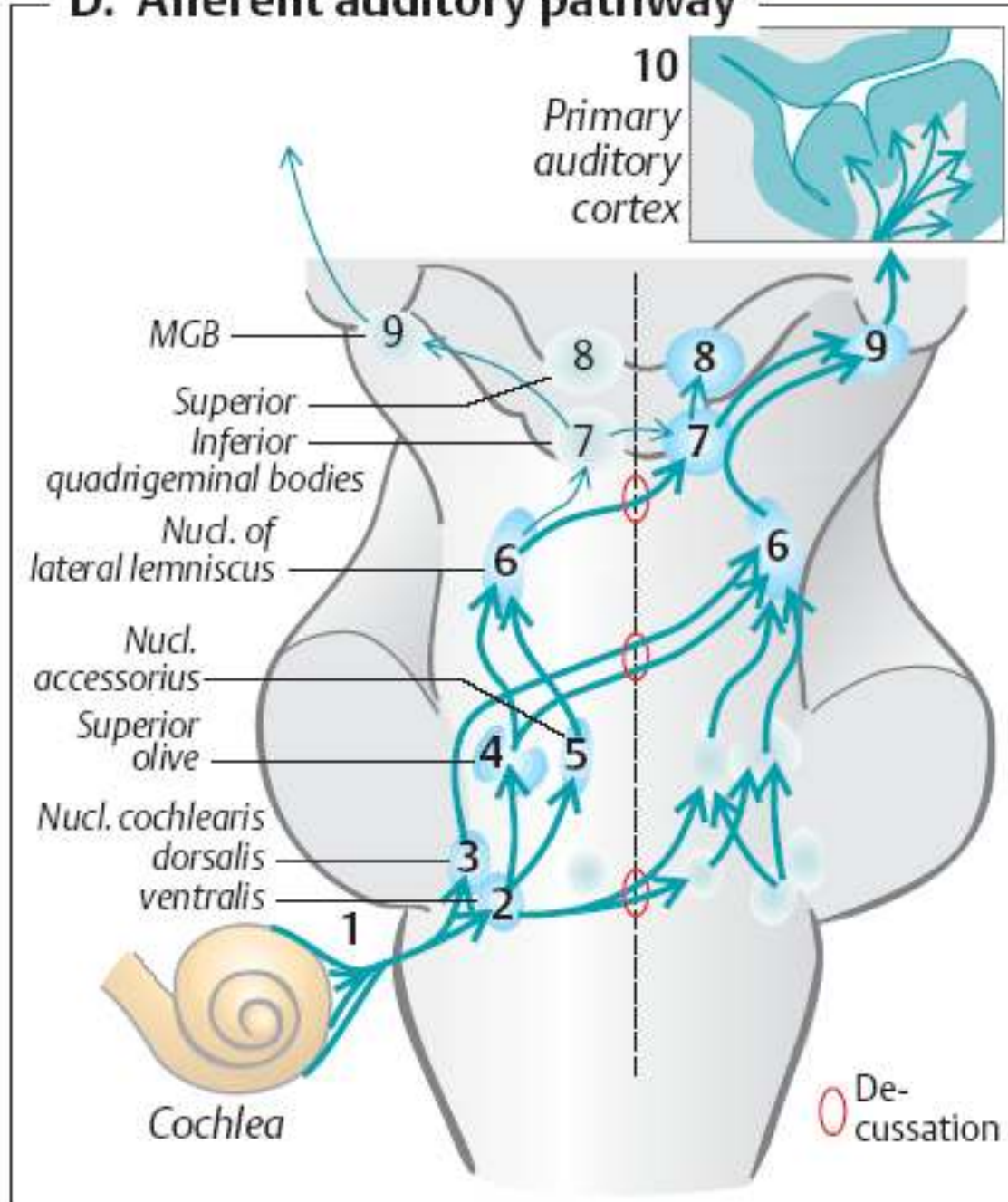


Hearing loss: A. conductive, B. sensorineural





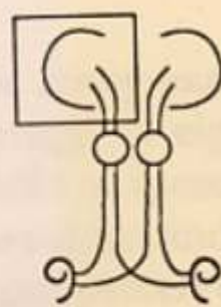
D. Afferent auditory pathway



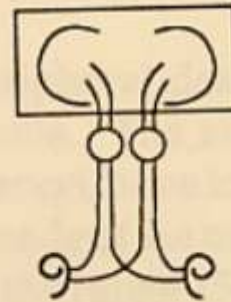
Auditory pathway

Three notes to lateral symmetry of auditory pathway

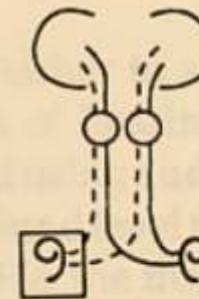
- > Compared to visual pathway, where left and right parts of visual scene only cross, the auditory pathway is from the third (first binaural) neuron on backed up by the crossings
- > Speech centers are laterally asymmetric (due to probable functional purpose)
- > Difference between the left and the right ear is used in sound localization



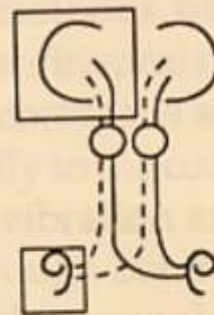
2 to 5 dB Loss



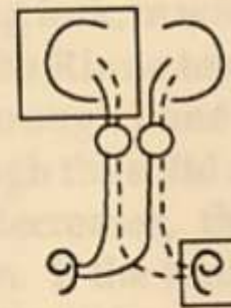
70 to 75 dB Loss



3 dB Loss



15 dB Loss



15 dB Loss

Figure 18. Summary of experiments demonstrating bilaterality of auditory pathways in dog. Number below each diagram is hearing loss in decibels; box around symbol for cerebral cortex or cochlea indicates destruction of it. In D, hearing depends on uncrossed fibers of left lateral lemniscus, whereas in E hearing depends upon crossed fibers of right lateral lemniscus. Hearing loss is equal in the 2 cases.

Functional classification of hearing loss

(measured without hearing aid)

1 normal hearing (threshold about 4 phon)

2 hardness of hearing

(hearing aid may be indicated:

at the band 500 Hz - 2 kHz bilaterally

threshold rise of 35 - 40 dB,

speech audiometry –threshold rise of more than 35 dB

low comprehension of loud speech at less than 4 m)

3 (practical) deafness

(does not hear loud voice at the ear, own voice,

threshold rise of 75 - 80 dB)

4 *deaf-and-dumbness*

(when the speech is not rehabilitated with inborn deafness)

Causes of hearing loss

- otosclerosis (in 0,5 - 1 % of elderly)
- conductive disorders
- hereditary and inborn disorders
- toxic damage
- meningoencephalitis
- professional damage
- presbycusis
- Menier's disease

What and Where in auditory cortex

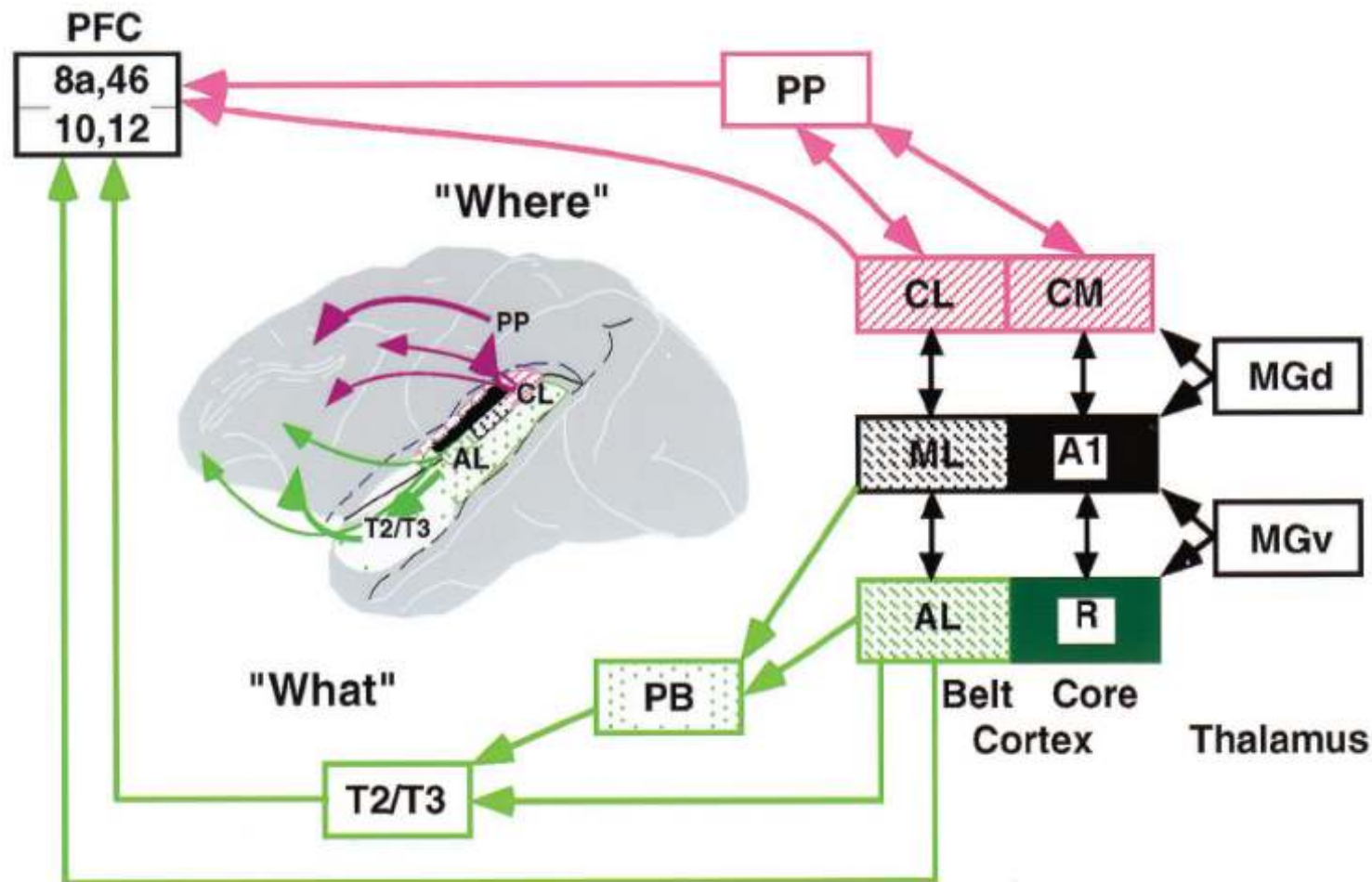


Fig. 6. Schematic flow diagram of "what" and "where" streams in the auditory cortical system of primates. The ventral "what"-stream is shown in green, the dorsal "where"-stream, in red. [Modified and extended from Rauschecker (35); prefrontal connections (PFC) based on Romanski et al. (46).] PP, posterior parietal cortex; PB, parabelt cortex; MGd and MGv, dorsal and ventral parts of the MGN.



"You have an inner ear disorder."

Part 2: Psychophysics

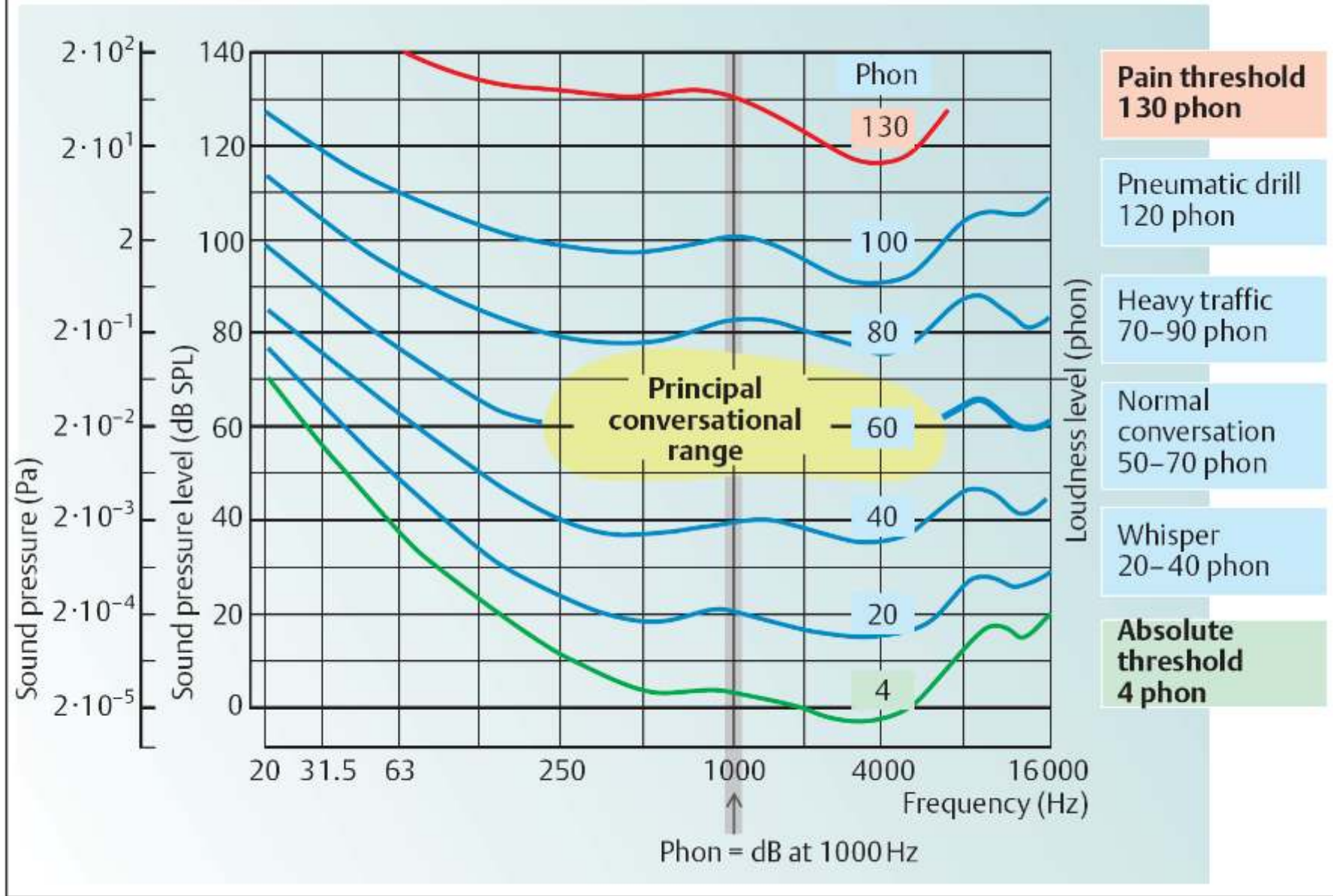


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Outline of part 2

- **Introduction: what is psychophysics**
- **Laws of psychophysics**
- **Logarithms and other functions – quantitative relations between stimulus and response**
- **Weber - Fechner logarithmic law**
- **Stevens's law enables comparison between modalities**

B. Sound pressure, sound pressure level and loudness level



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Let us remind the hearing range again

Logarithms. There are two kinds of logarithms: common and natural. Logarithmic calculations are performed using exponents alone. The **common (decimal) logarithm** (\log or \lg) is the power or exponent to which 10 must be raised to equal the number in question. The common logarithm of 100 ($\log 100$) is 2, for example, because $10^2 = 100$. Decimal logarithms are commonly used in physiology, e.g., to define pH values (see above) and to plot the pressure of sound on a decibel scale (\rightarrow p. 363).

Natural logarithms (\ln) have a natural base of 2.71828..., also called *base e*. The common logarithm ($\log x$) equals the natural logarithm of x ($\ln x$) divided by the natural logarithm of 10 ($\ln 10$), where $\ln 10 = 2.302585$. The following rules apply when converting between natural and common logarithms:

$$\log x = (\ln x)/2.3$$

$$\ln x = 2.3 \cdot \log x.$$

When performing mathematical operations with logarithms, the type of operation is reduced by one rank—multiplication becomes addition, potentiation becomes multiplication, and so on.

Examples:

$$\log(a \cdot b) = \log a + \log b$$

$$\log(a/b) = \log a - \log b$$

$$\log a^n = n \cdot \log a$$

$$\log \sqrt[n]{a} = (\log a)/n$$

Special cases:

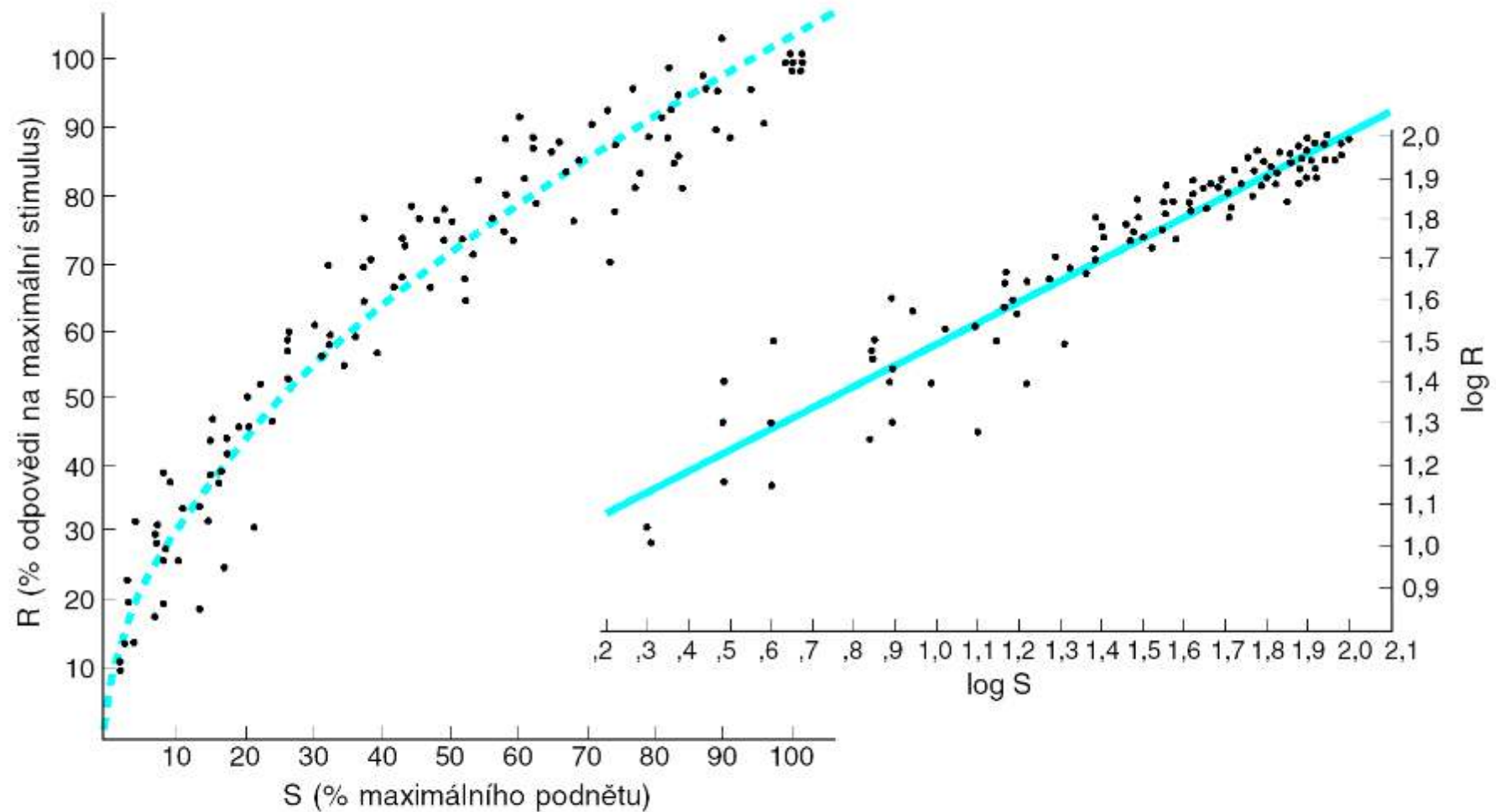
$$\log 10 = \ln e = 1$$

$$\log 1 = \ln 1 = 0$$

$$\log 0 = \ln 0 = \pm \infty$$

Decibel is defined as ten times decimal logarithm of the ration of intensities.

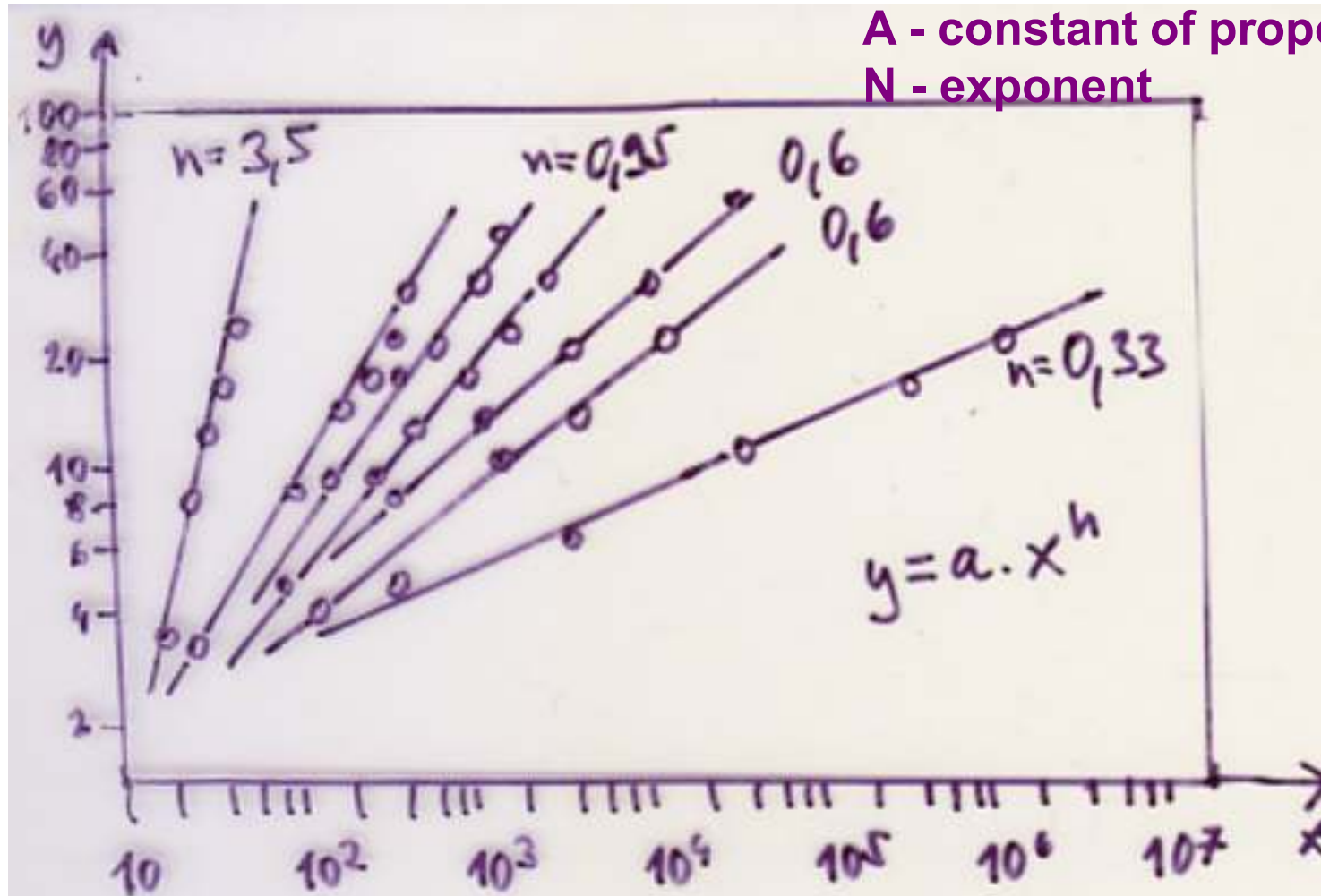
$$R = 10 \log(S / S_0)$$



Obr. 5-5. Vztah mezi intenzitou dotykového podnětu (S) a frekvencí akčních potenciálů v senzických nervových vláknech (R). Tečky znázorňují jednotlivé hodnoty u koček; jsou vyneseny do souřadnic lineárních **(vlevo)** a logaritmických **(vpravo)**. Rovnice vyjadřuje vypočítaný exponenciální vztah mezi R a S. (Reprodukováno se souhlasem z WERNER, G., MOUNTCASTLE, VB. *Neural activity in mechanoreceptive cutaneous afferents. Stimulus-response relations, Weber functions, and information transmission.* J Neurophysiol, 1965, 28, 359.)

Stevens (power) law

R - (response) subjective intensity
S - (stimulus) physical intensity
 S_0 - threshold stimulus intensity
A - constant of proportion
N - exponent



$$R = A(S - S_0)^N$$

Weber – Fechner (logarithmic) law

Weberov - Fechnerov zákon (~1860)

$$R = A \cdot \log \frac{S}{S_0}$$

R - subjektívna intenzita
počítka

S - veľkosť podnetu v
fyzikálnych jednotkách

S_0 - veľkosť prahu podnetu

A - konštanta

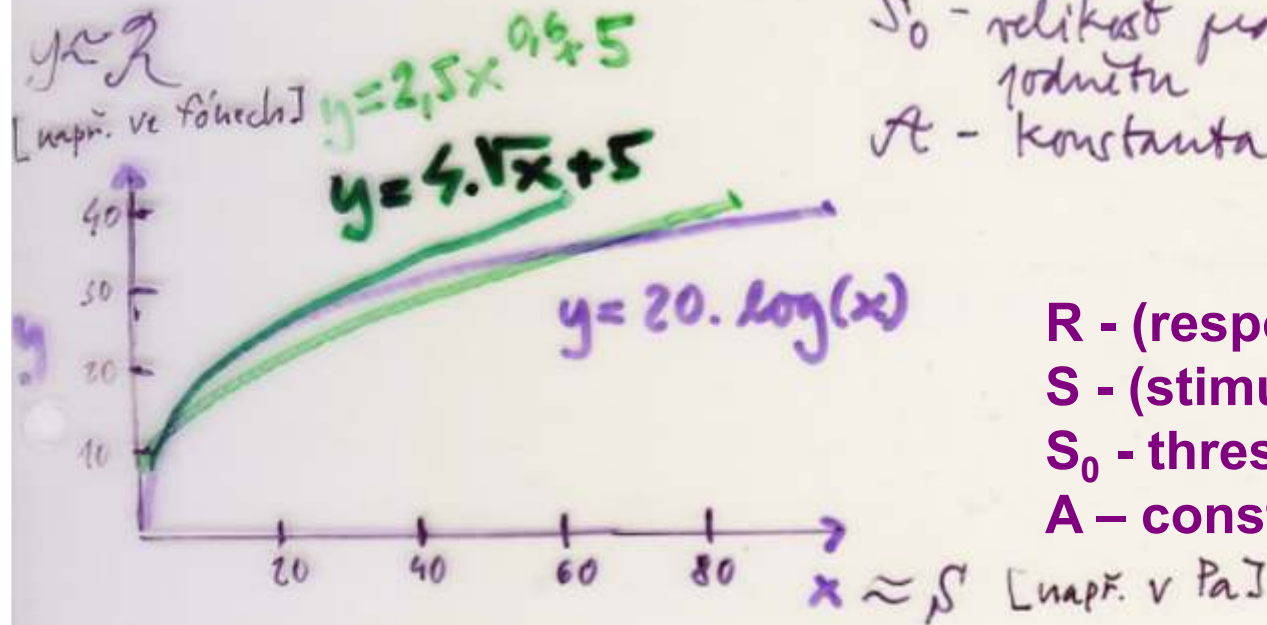
$$R = A \log(S / S_0)$$

R - (response) subjective intensity

S - (stimulus) physical intensity

S_0 - threshold stimulus intensity

A - constant of proportion



zrak: $y = SPL [dB]$ $x = \frac{I}{I_0}$, $I_0 = 2 \cdot 10^{-5} [Pa]$

rozsah platnosti psychofyzikálnych zákonov:

pr. zrak - W.-F. 1 - 100
S. 1 - 10 000

$$y = A \cdot \log x$$

Exponents in the Stevens (power) law

$$R = A(S - S_0)^N$$

Table 18-1. Representative exponents of power functions relating psychophysical magnitude to stimulus magnitude on prothetic continua*

Continuum	Exponent	Stimulus conditions
Loudness	0.60	Binaural
Loudness	0.54	Monaural
Brightness	0.33	5° target—dark-adapted eye
Brightness	0.50	Point source—dark-adapted eye
Lightness	1.20	Reflectance of gray papers
Smell	0.55	Coffee odor
Smell	0.60	Heptane
Taste	0.80	Saccharine
Taste	1.30	Sucrose
Taste	1.30	Salt
Temperature	1.00	Cold—on arm
Temperature	1.60	Warmth—on arm
Vibration	0.95	60 Hz—on finger
Vibration	0.60	250 Hz—on finger
Duration	1.10	White-noise stimulus
Repetition rate	1.00	Light, sound, touch, and shocks
Finger span	1.30	Thickness of wood blocks
Pressure on palm	1.10	Static force on skin
Heaviness	1.45	Lifted weights
Force of hand-grip	1.70	Precision hand dynamometer
Autophonic level	1.10	Sound pressure of vocalization
Electric shock	3.50	60 Hz, through fingers

*From Stevens.^{37a}

Part 3: Speech: development, perception and production. Hearing prosthetics, cochlear implants.



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Outline of part 3

- introduction: speech and development (ontogenesis) of speech
- perception and production of speech
- classical and revised view of speech ontogenesis, based on new experiments with infants
- hearing impairment and speech, cochlear implants

Electrophysiology: non-invasive and invasive





„Psycho-physical“
and electro-
encephalo-graphic
responses
of infants and
small children

Stages of language acquisition

- 6 mo Beginning of distinct babbling.
- 1 y Beginning of language understanding, one word utterances.
- 1.5 y Dictionary of 30 to 50 words.
- 2 y Dictionary of 50 to several hundred words. Two word (telegraphic/ short message) speaker.
- 2.5 y Three or more word sentences. Many grammatical errors and idiosyncratic expressions. Good understanding of language.
- 3 y Dictionary of 1000 words.
- 4 y Dictionary of 2000 words. Speech competence close to adults.

[Kandel, Schwartz, Jessel, Principles of Neural Science, 1991]

EN: babble, CZ: žvatlat, SK: džavotať, GE: plappern,

LAT: balbuties, et cetera...

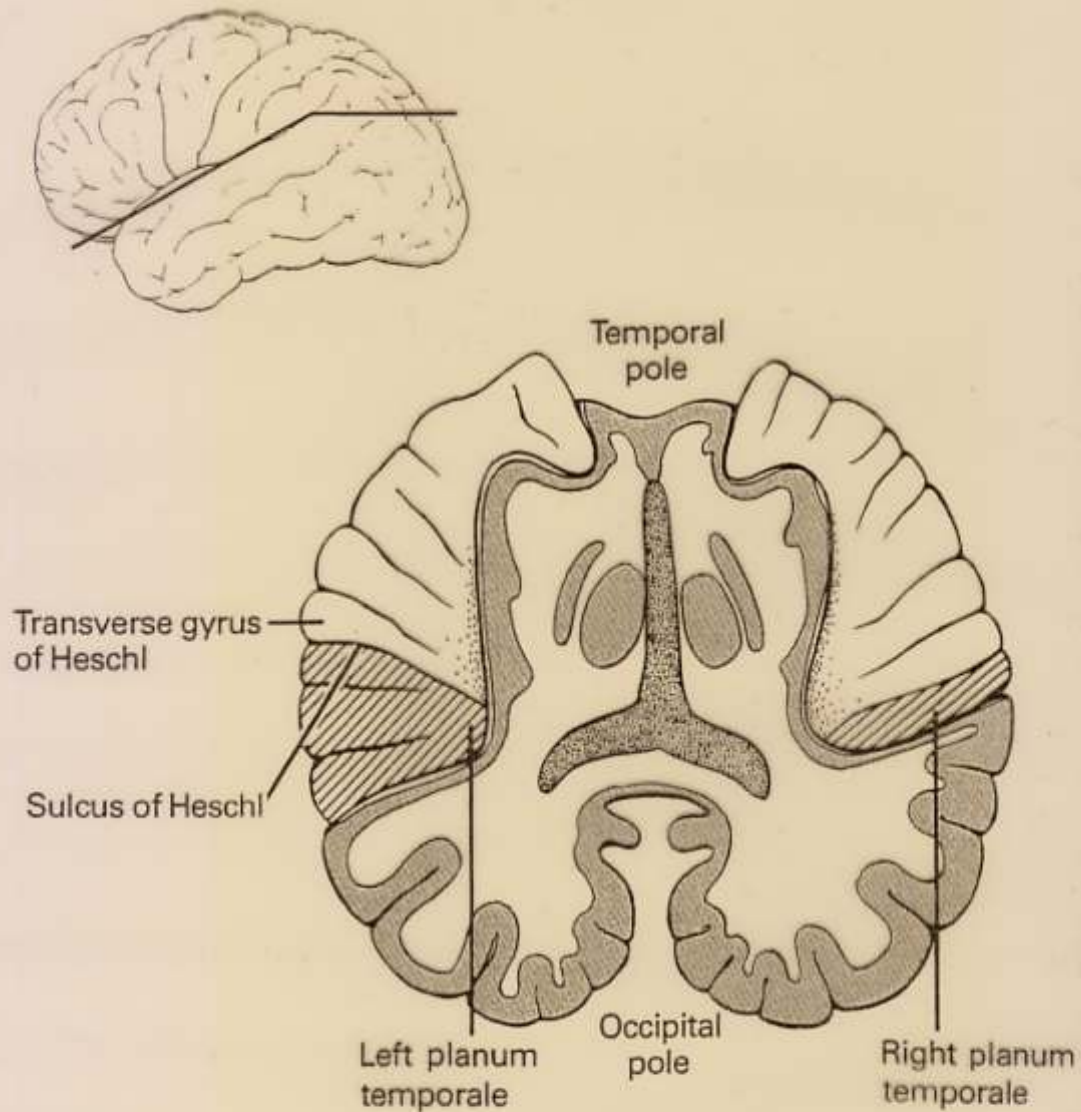


FIGURE 53-8

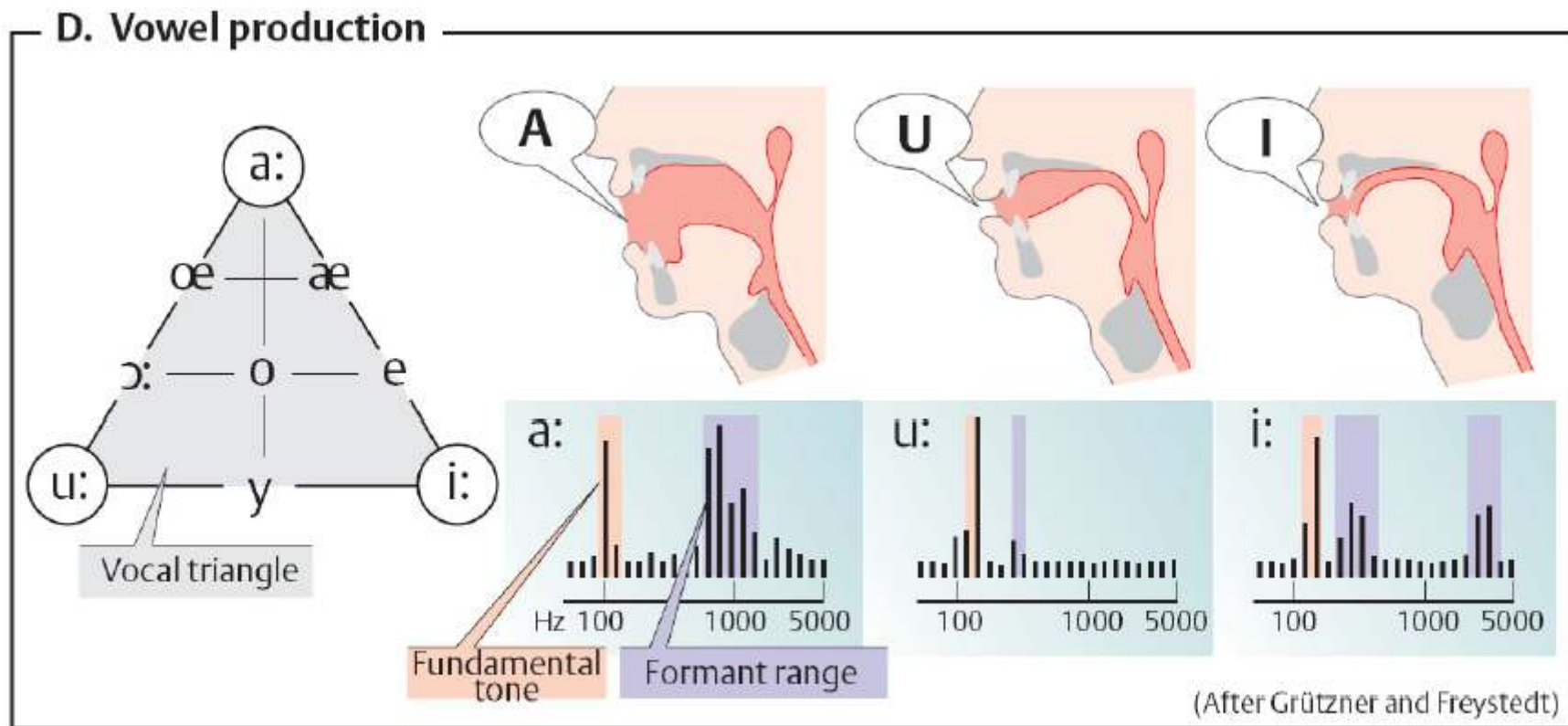
The planum temporale is larger in the left hemisphere than in the right in the majority of human brains (horizontal section in the plane of the Sylvian fissure). (Adapted from Geschwind and Levitsky, 1968.)

TABLE 53-2. Linguistic Dominance and Handedness

Handedness	Dominant hemisphere (%)		
	Left	Right	Both
Left or mixed handed	70	15	15
Right handed	96	4	0

(Data from Rasmussen and Milner, 1977.)

Formants of vowels in English



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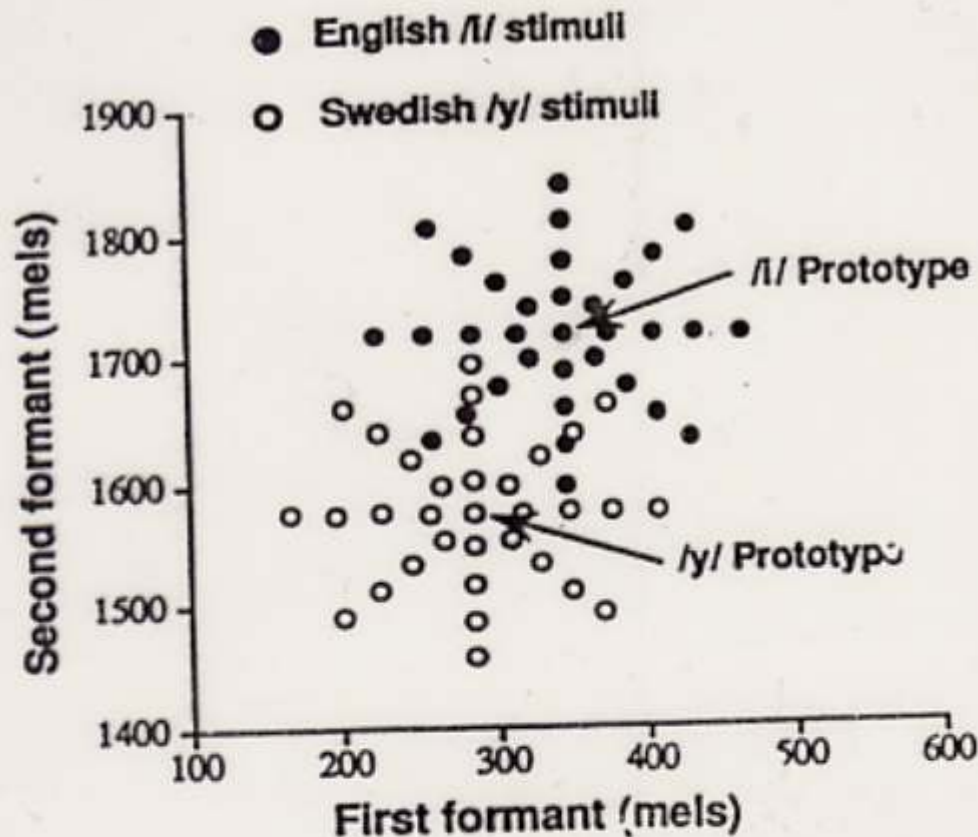


Fig. 1. Six-month-old infants from America and Sweden were tested with two sets of vowel stimuli, American English /ɪ/ and Swedish /y/. Each set included an exceptionally good instance of the vowel (the prototype) and 32 variants that formed four rings (eight stimuli each) around the prototype (8).

Prototypes of vowels
and synthetic vowels
in formant space
[P. Kuhl et al., 1992]

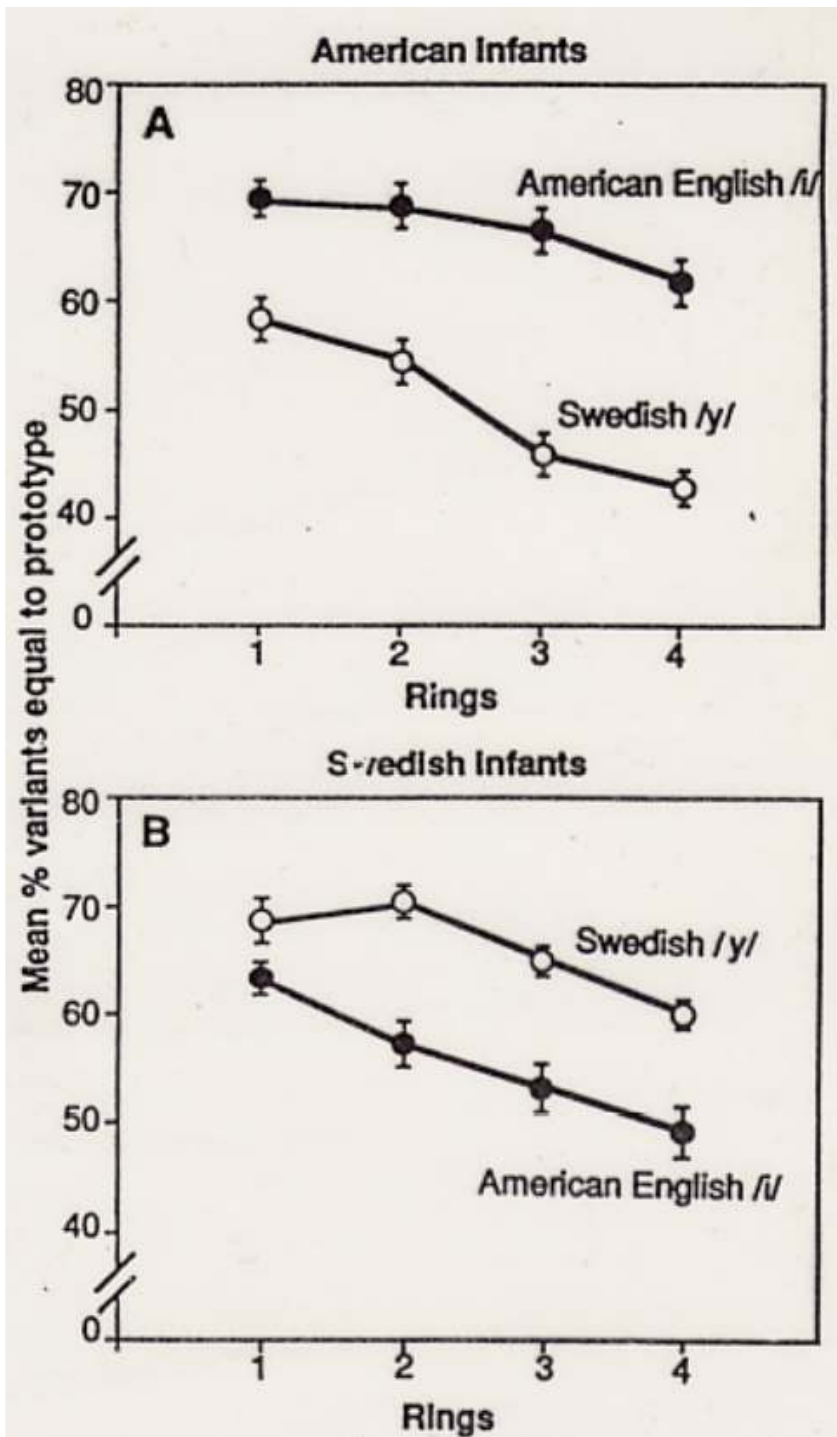
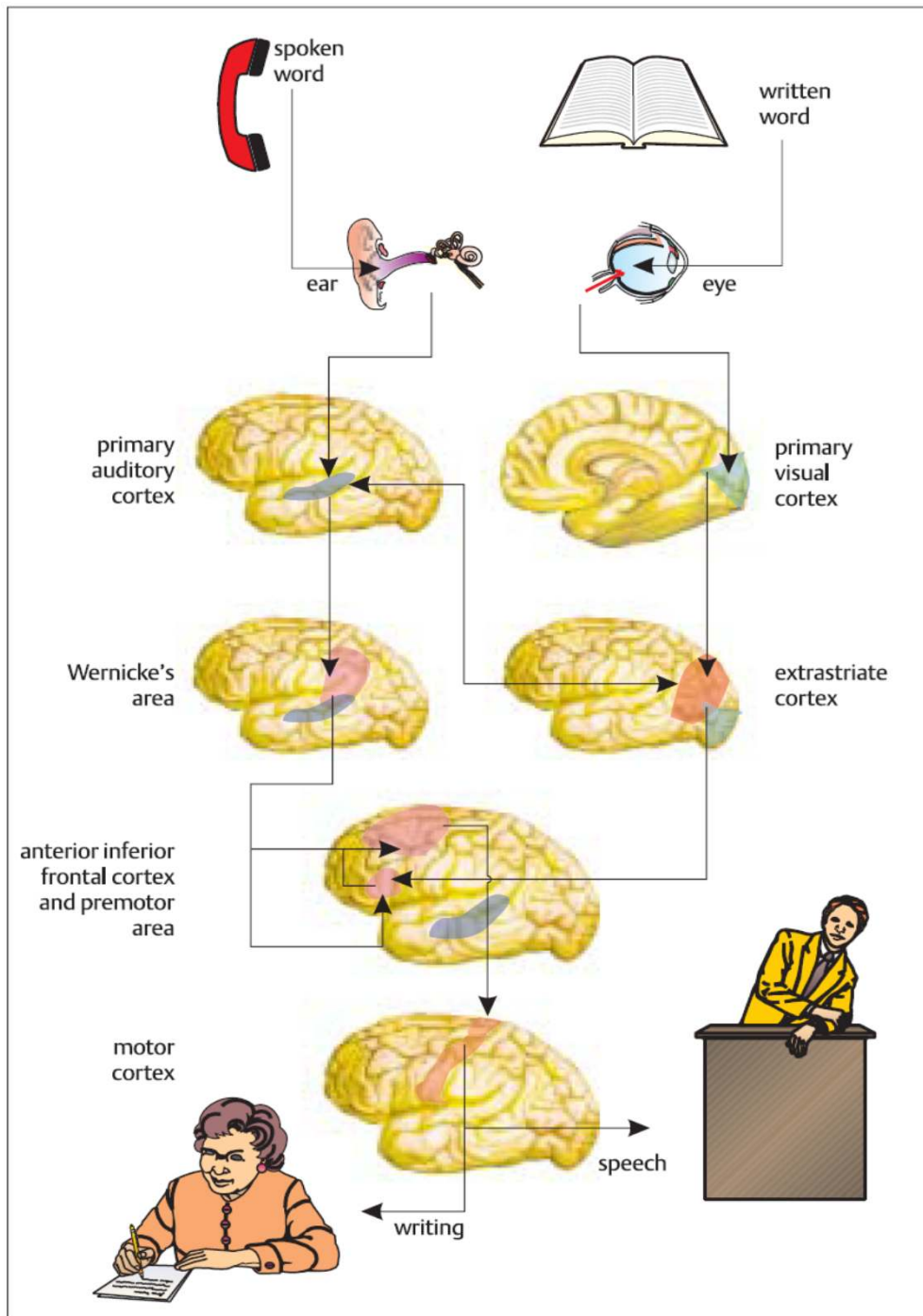


Fig. 2. Results showing an effect of language experience on young infants' perception of speech. Two groups of 6-month-old infants, (A) American and (B) Swedish, were tested with two different vowel prototypes, American English /i/ and Swedish /y/. The mean percentage of trials in which infants equated variants on each of the four rings to the prototype is plotted. Infants from both countries produced a stronger magnet effect (equated variants to the prototype more often) for the native-language vowel prototype when compared to the foreign-language vowel prototype. (Error bars = standard error.)

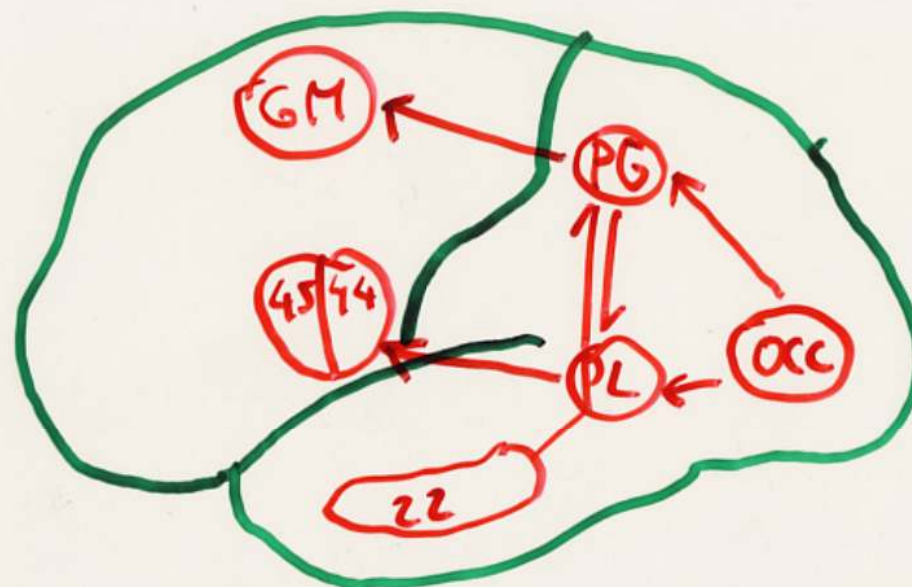
„Psycho-physical“
responses of 6 month
old infants to vowels of
native and foreign
language
[P. Kuhl et al., 1992]

Speech processing in cerebral cortex



APHASIAS (acc. Hrbek, Trichy)

DARFEO, 1985



LEFT OUTER HEMISPHERE

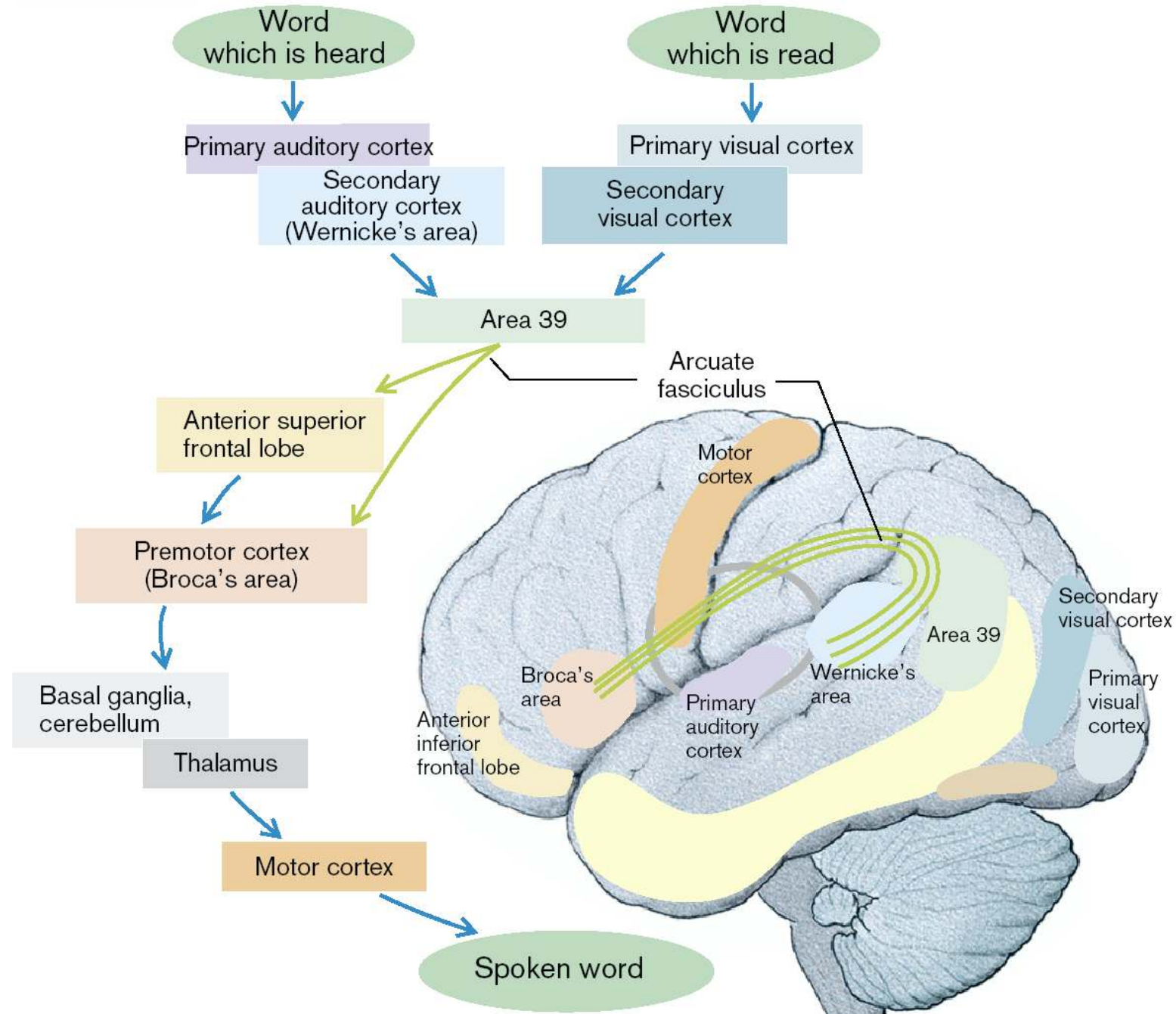
PG - parietal graphesthetic center

PL - parietal logesthetic center

Occ - occipital assoc. center 22 - Wernicke's c. - (logesthetic c.)

GM - graphomotoric center 44, 45 - Broca's c. - (logomotoric c.)

- A. Aphasias

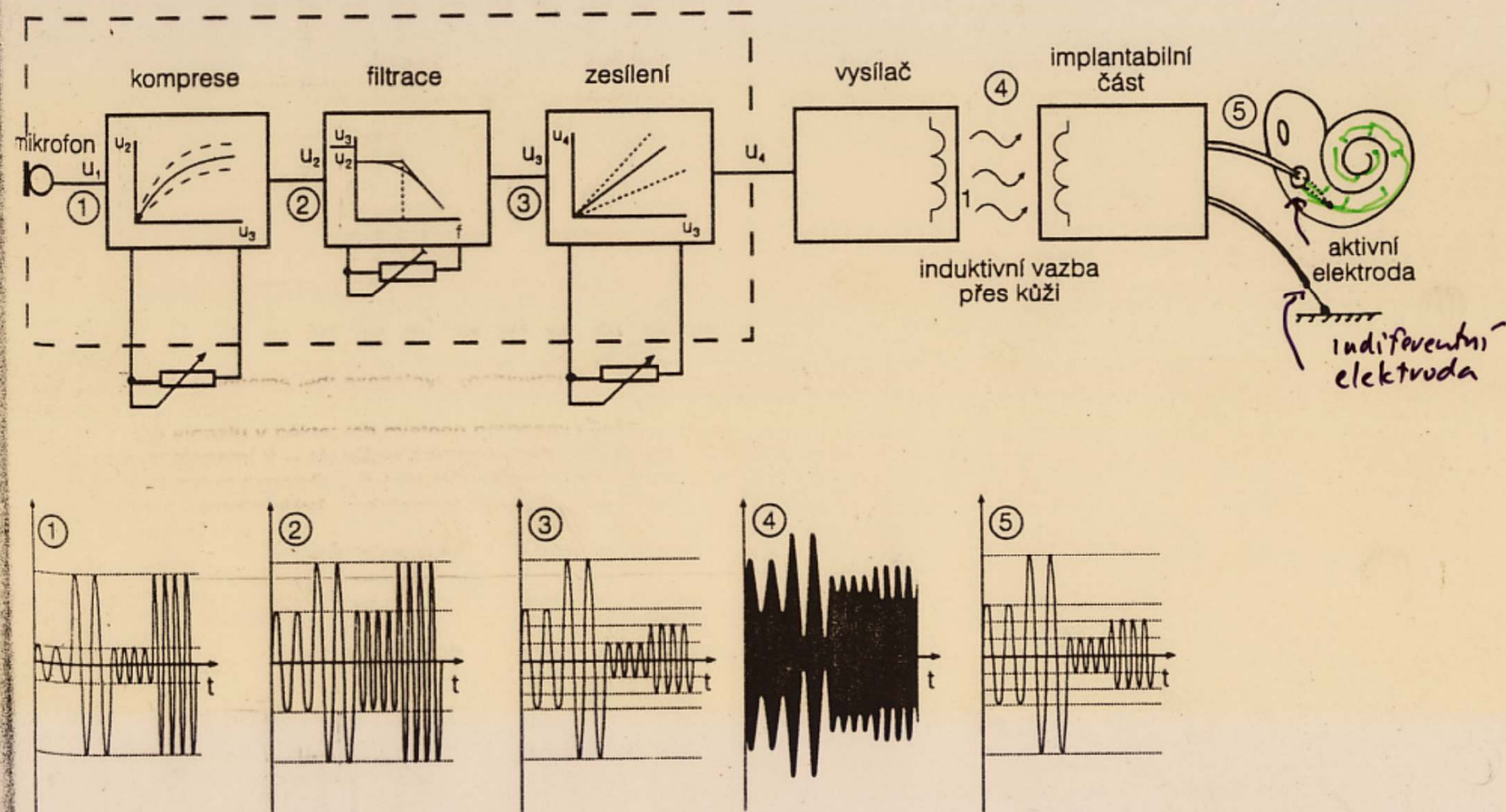


Type	Spontaneous speech	Repetition of words	Language comprehension	Finding words
Broca's aphasia	abnormal	abnormal	normal	impaired
Wernicke's aphasia	fluent (at times logorrhea, paraphasia, neologisms)	abnormal	impaired	impaired
Conduction aphasia	fluent, but paraphasic	markedly impaired	normal	abnormal, paraphasic
Global aphasia	abnormal	abnormal	abnormal	abnormal
Anomic aphasia	fluent	normal, but anomic	normal	impaired
Achromatic aphasia	fluent	normal, but anomic	normal	impaired
Motor transcortical aphasia	abnormal	normal	normal	abnormal
Sensory transcortical aphasia	fluent	fluent	abnormal	abnormal
Subcortical aphasia	fluent	normal	abnormal (transient)	abnormal (transient)

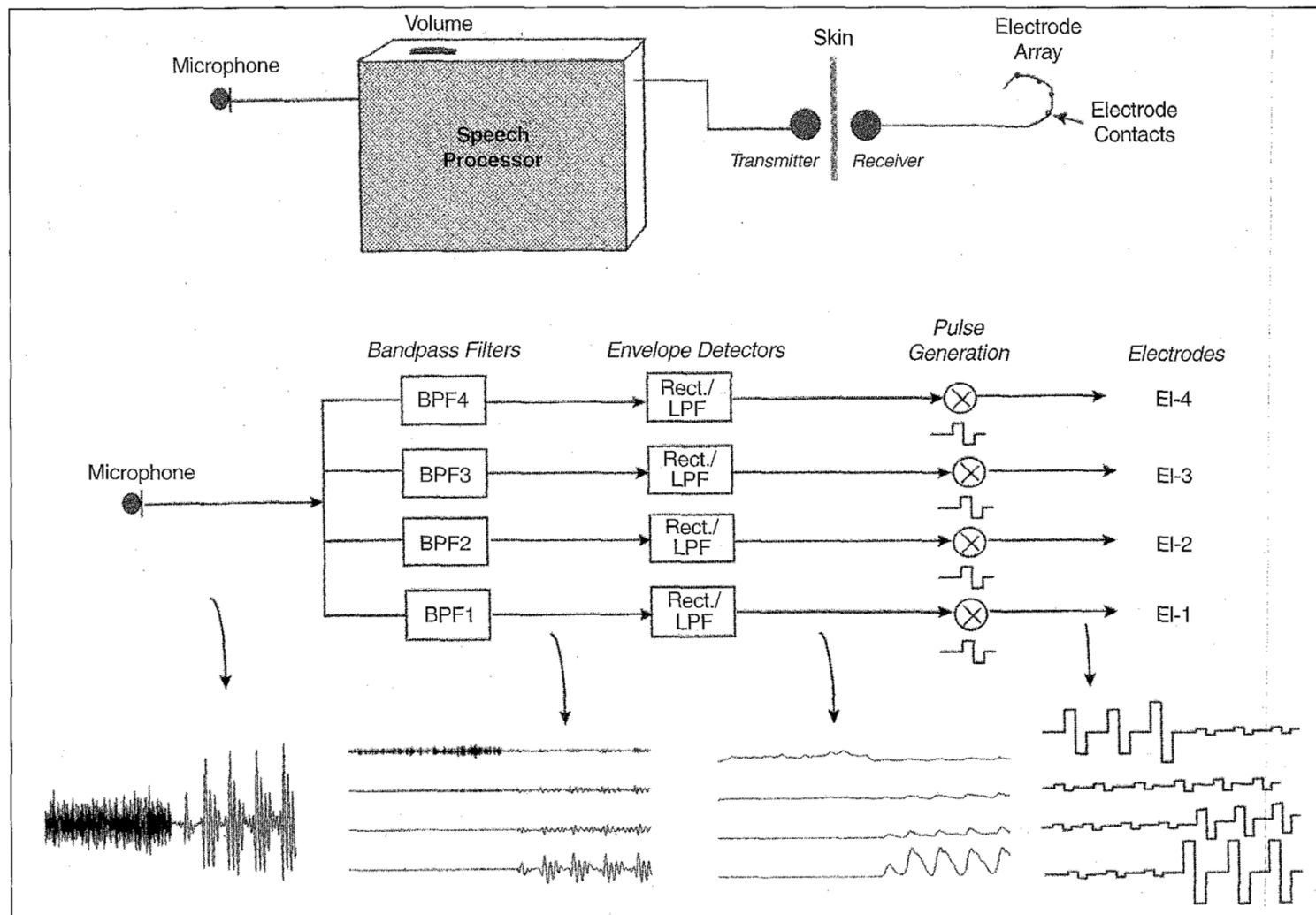
2. Nahoře – Blokové schéma jedнокanálové kochleární neuropro-
tény

Dole – Průběh signálu v některých místech přenosové cesty: 1 –
signál za mikrofonem, 2 – signál za kompresorem (na všech
kmitočtech redukována dynamika), 3 – signál za filtrem (potlačeny
vyšší kmitočty), 4 – amplitudově modulovaný signál, 5 – signál po
demodulaci (totožný s 3)

Cochlear implant – single channel

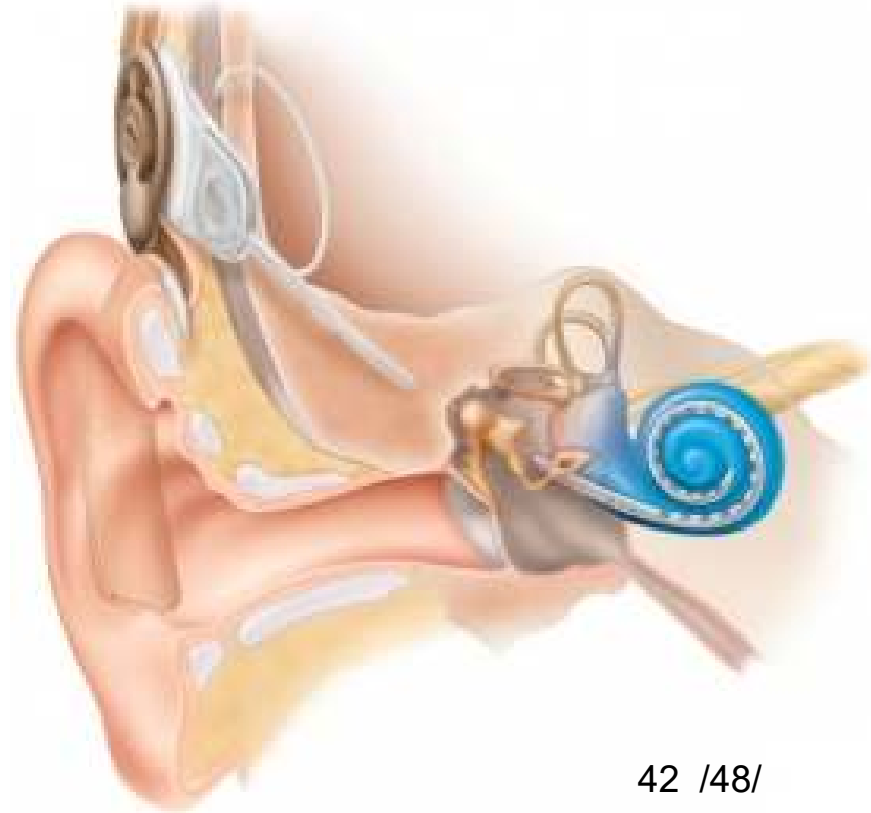


Cochlear implant – multi-channel



▲ 4. Diagram showing the operation of a four-channel cochlear implant. Sound is picked up by a microphone and sent to a speech processor box worn by the patient. The sound is then processed, and electrical stimuli are delivered to the electrodes through a radio-frequency link. Bottom figure shows a simplified implementation of the CIS signal processing strategy using the syllable "sa" as an input signal. The signal first goes through a set of four bandpass filters that divide the acoustic waveform into four channels. The envelopes of the bandpassed waveforms are then detected by rectification and low-pass filtering. Current pulses are generated with amplitudes proportional to the envelopes of each channel and transmitted to the four electrodes through a radio-frequency link. Note that in the actual implementation the envelopes are compressed to fit the patient's electrical dynamic range.

Cochlear implant vs. hearing aid



Cochlear implant – performance in time

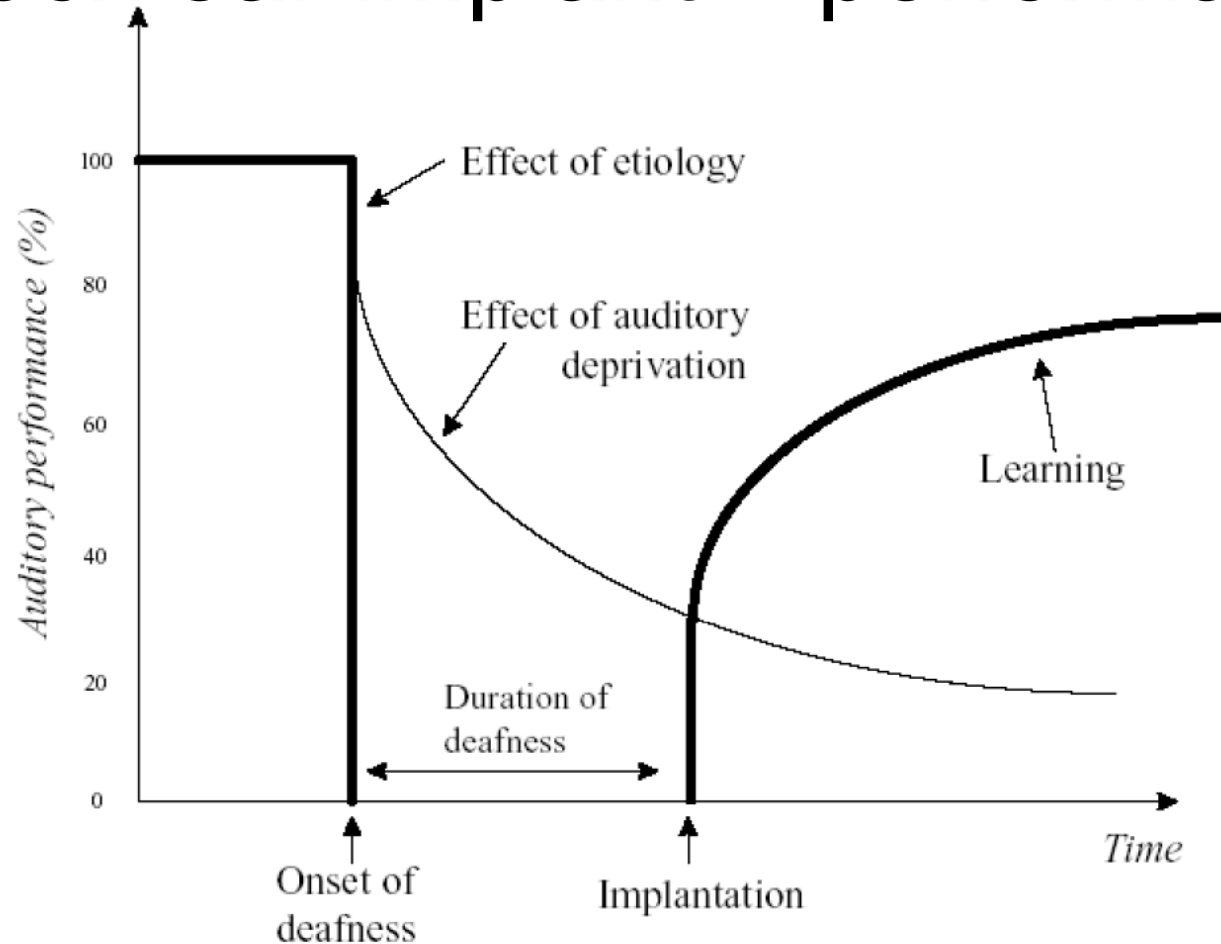


Figure 35. A three-stage model of auditory performance for postlingually deafened adults (Blamey et al. [80]). The thick lines show measurable auditory performance, and the thin line shows potential auditory performance.

END OF THE LECTURE

Thanks for your attention

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First Medical Faculty, Institute of Pathological Physiology