Part 1: Hearing disorders

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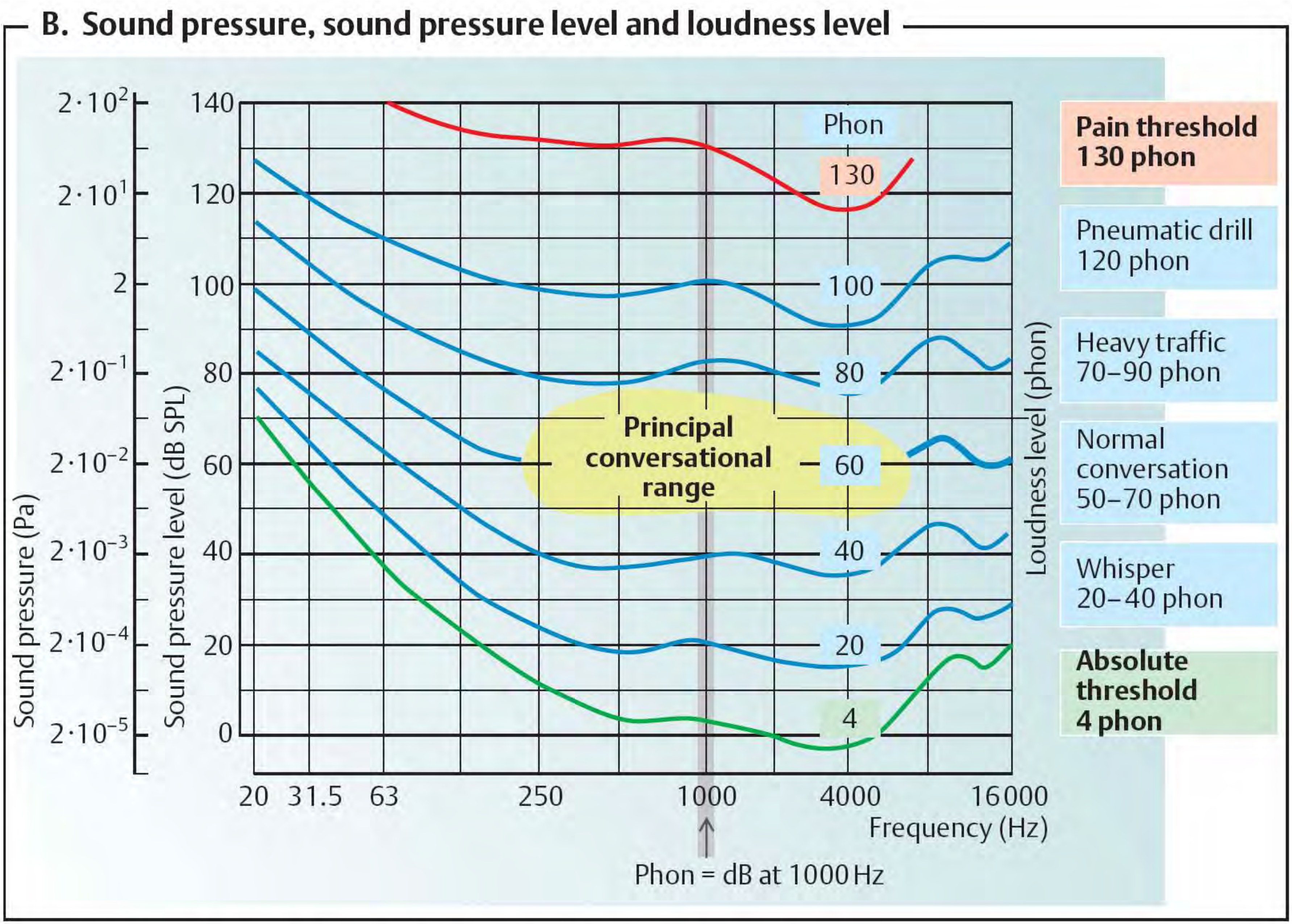
Outline of part 1

- **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**



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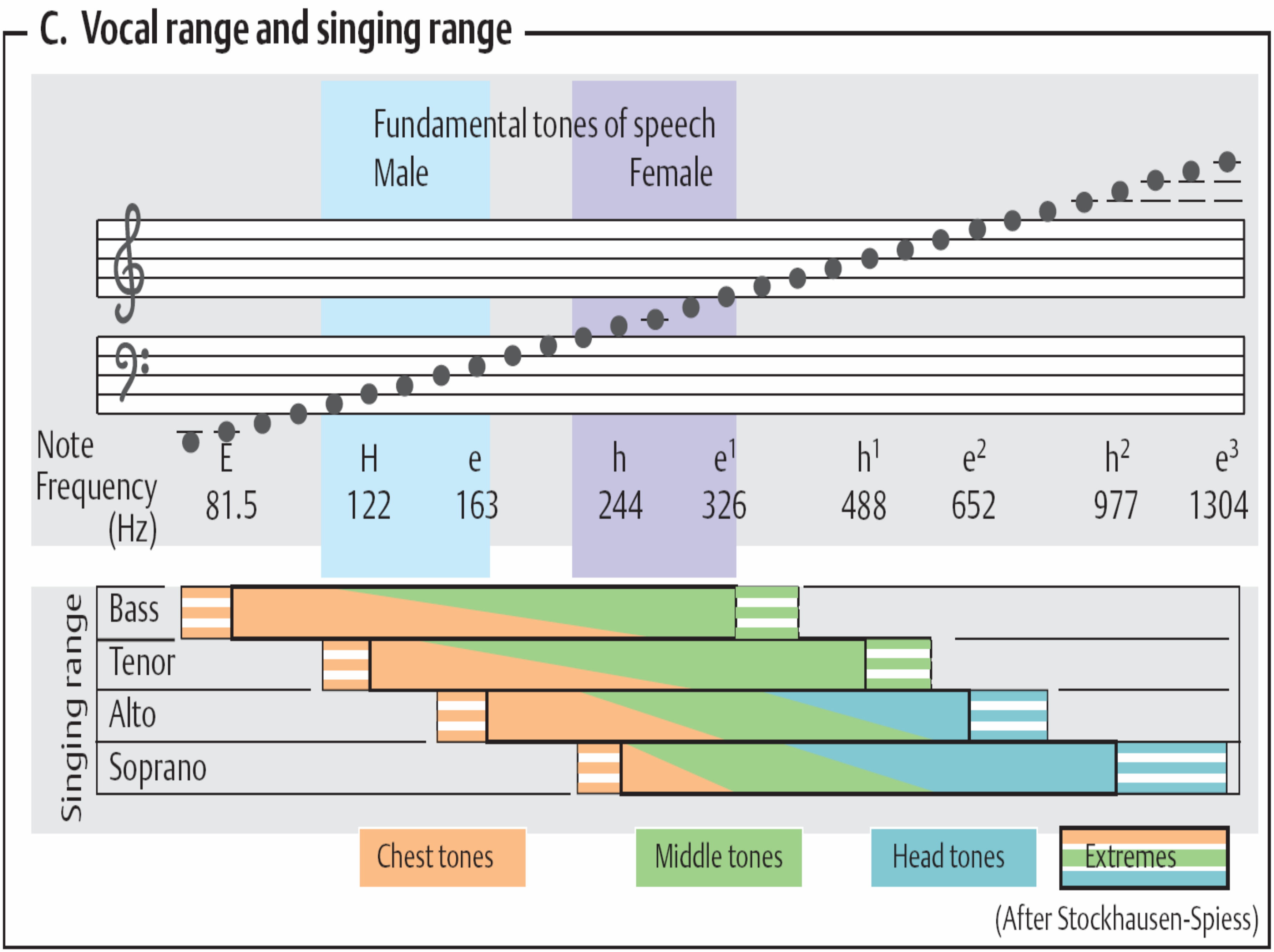
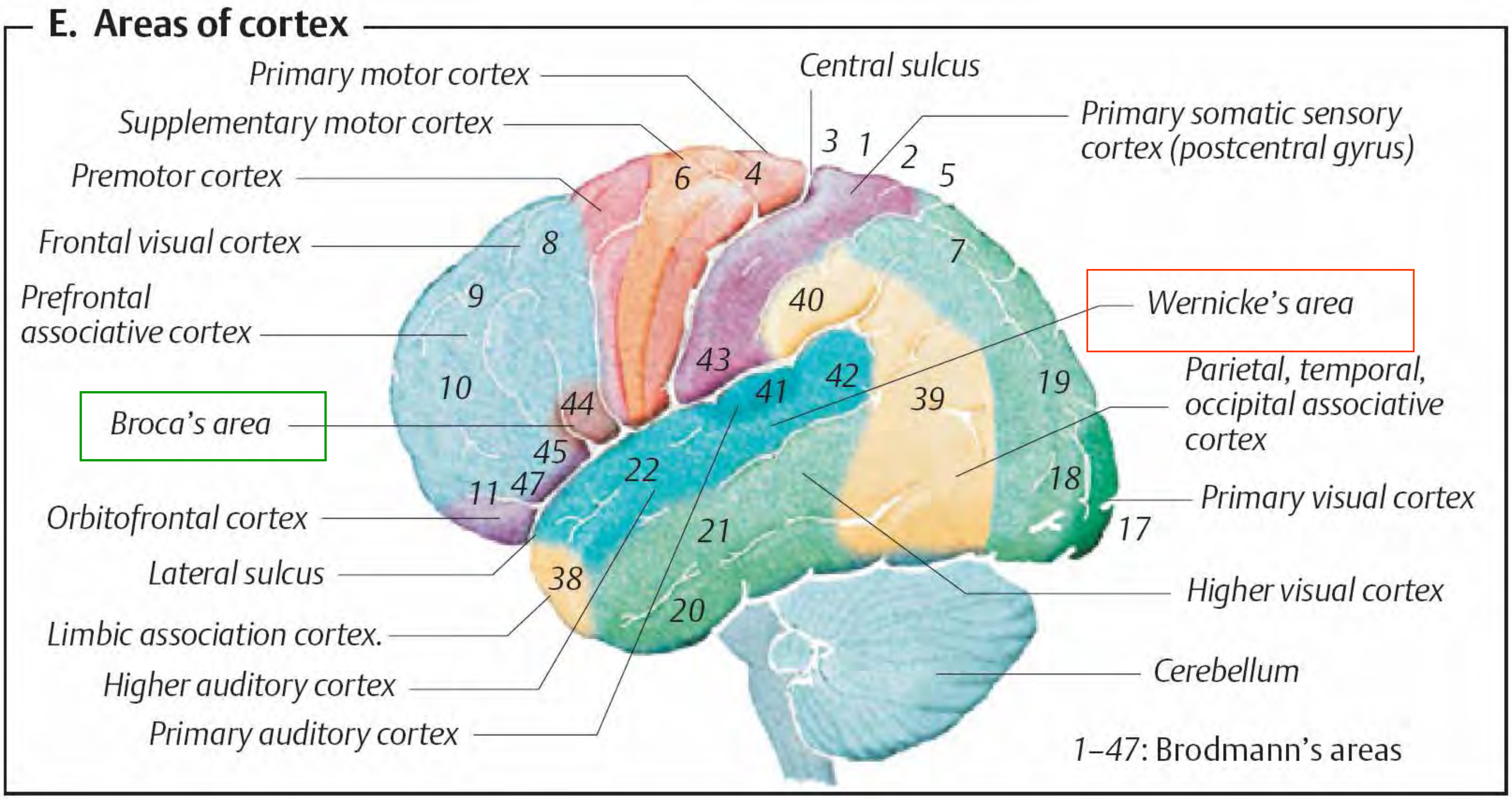
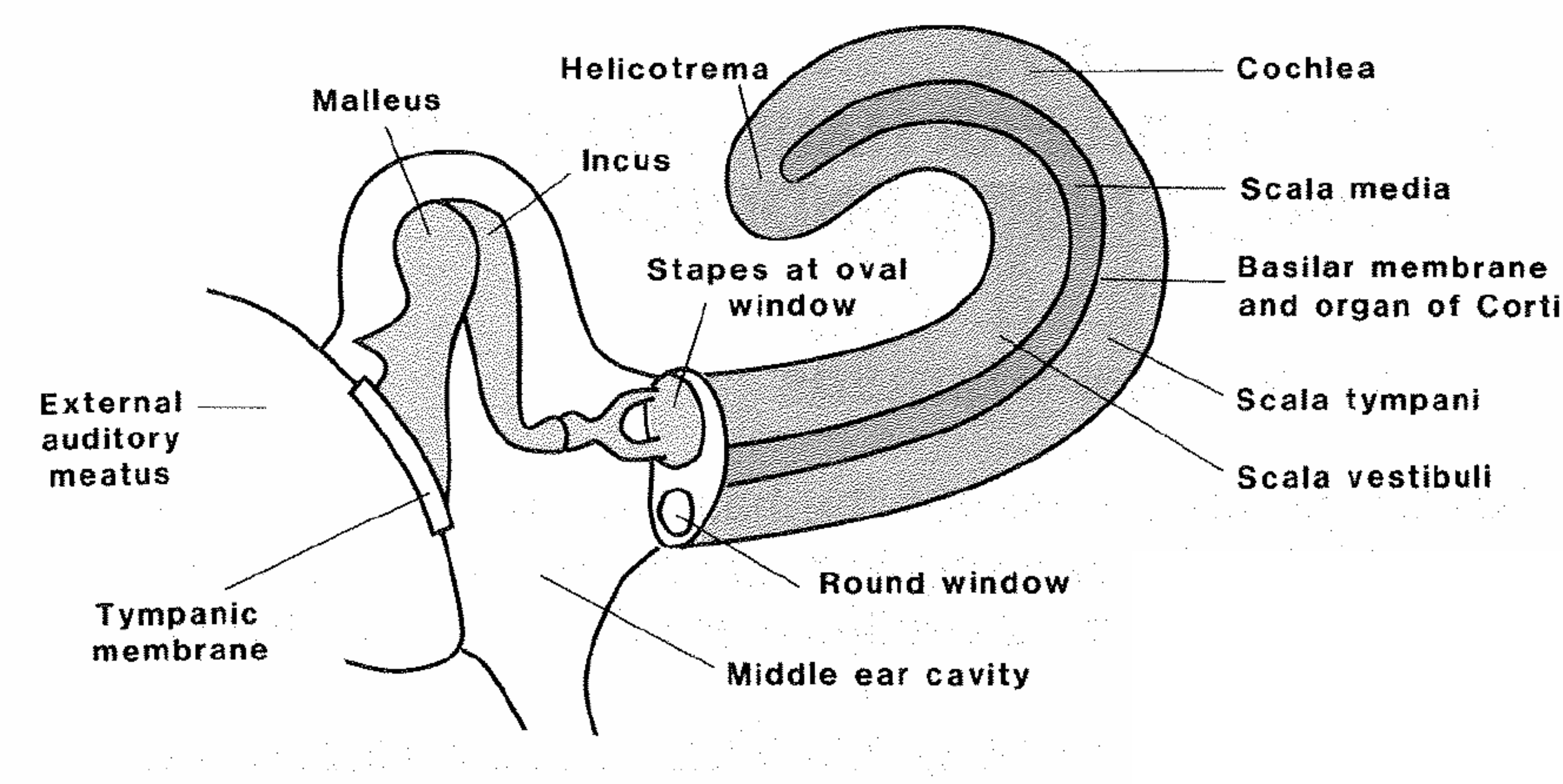
Hearing range: frequencies and intensities



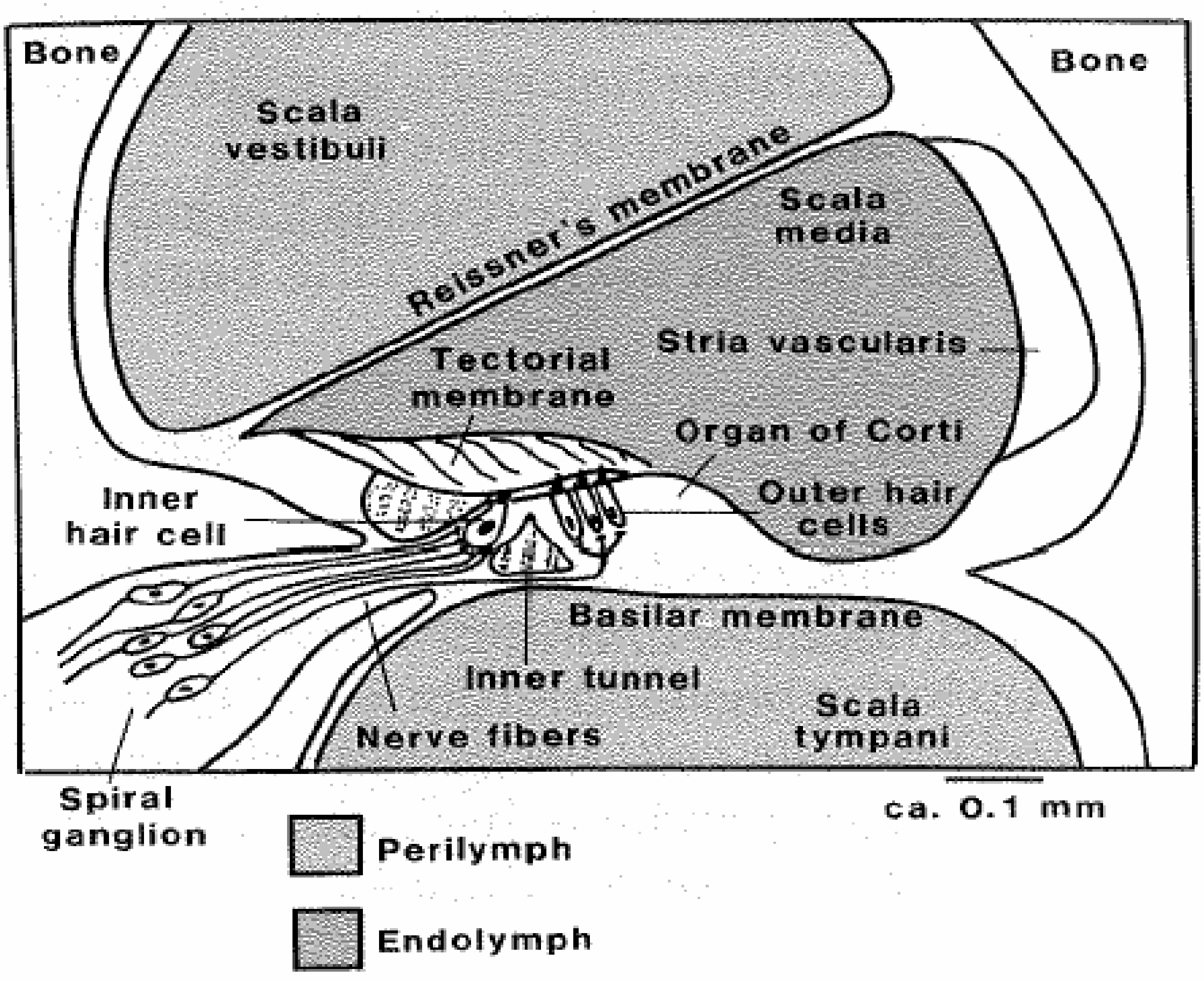
Vocal range and singing range



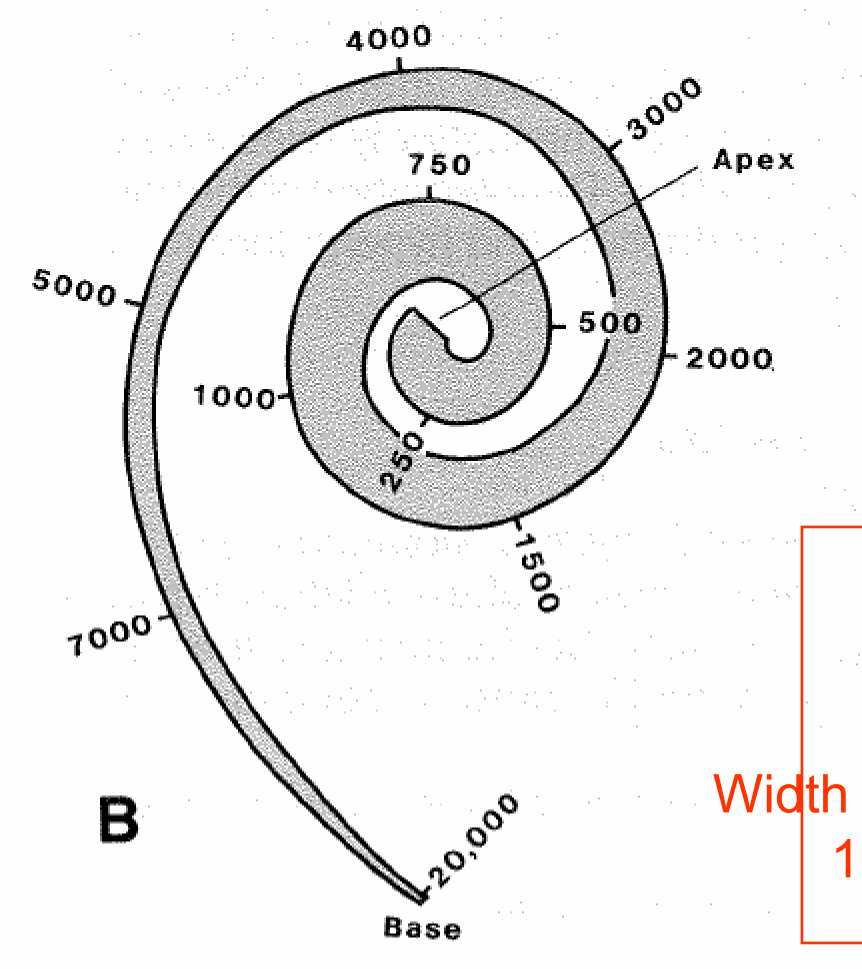
Two main speech centers within the Brodman areas

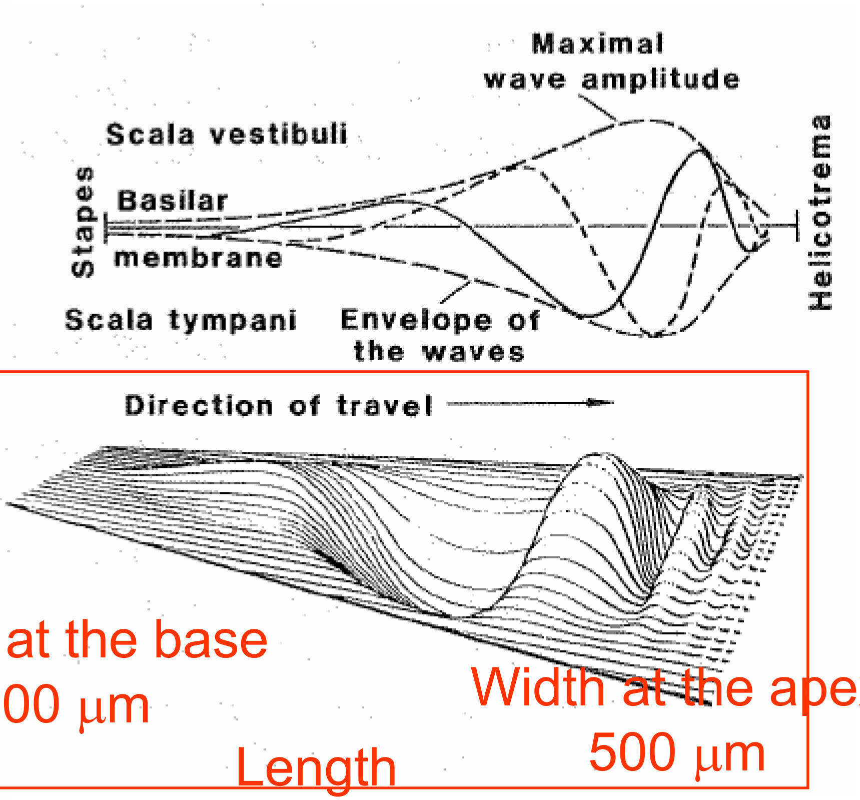


Outer, middle and inner ear



Organ of Corti



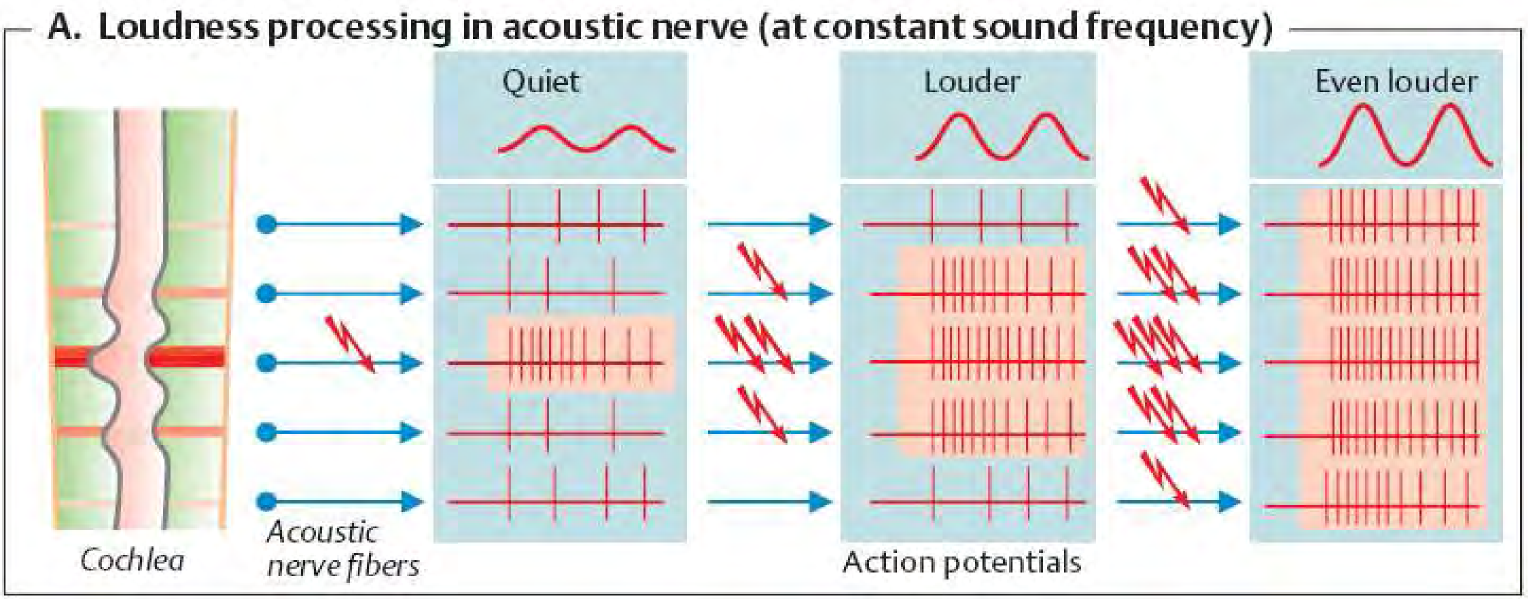


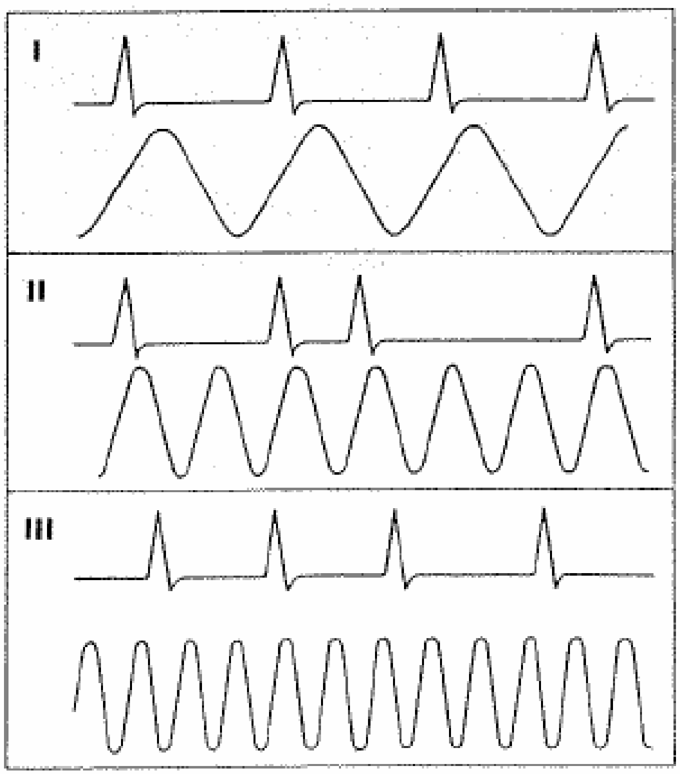
Width at the base
100 μm

Width at the apex
500 μm

Length
33 mm

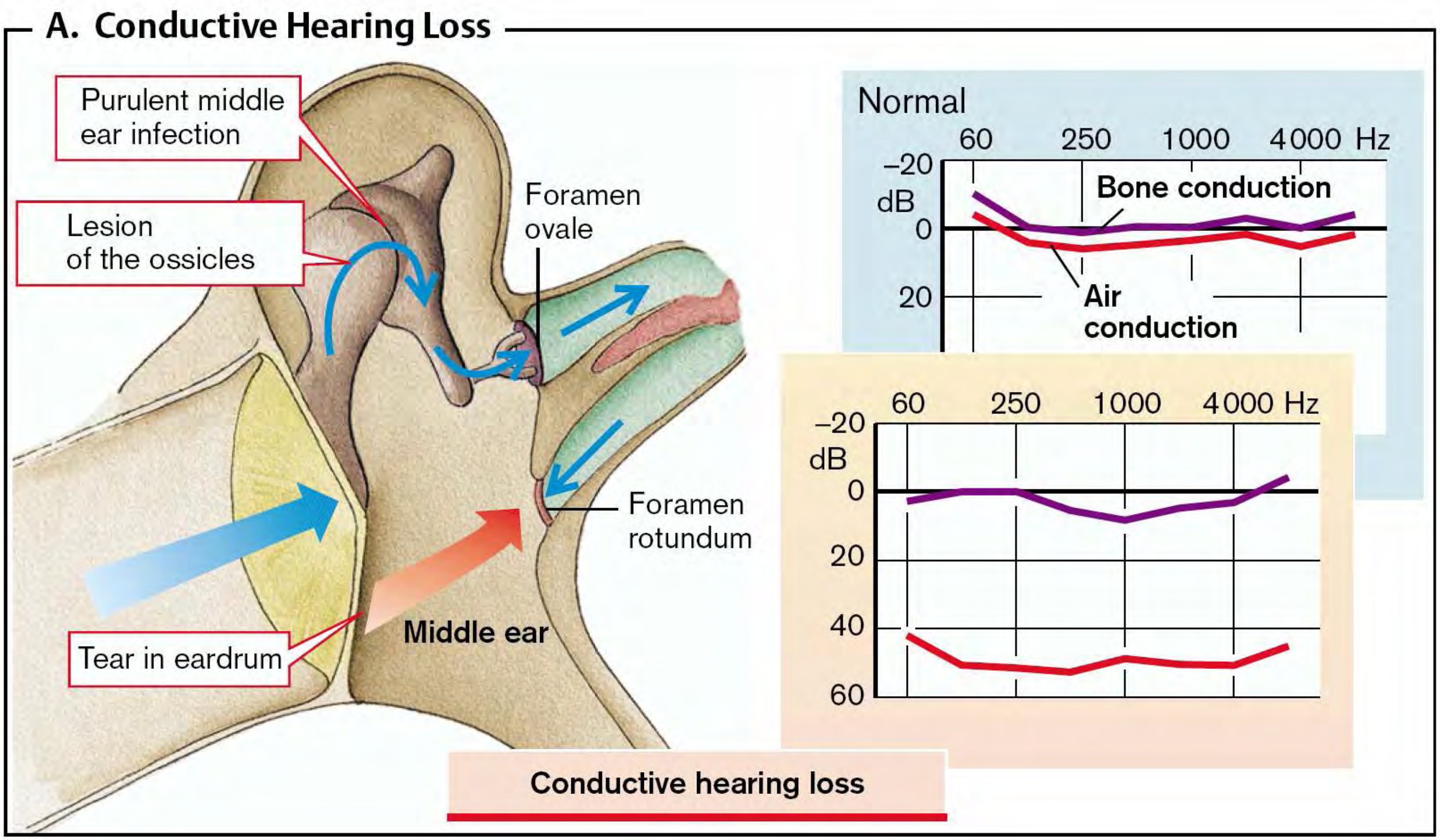
Basilar membrane – from above and unfolded into trapezoid plane



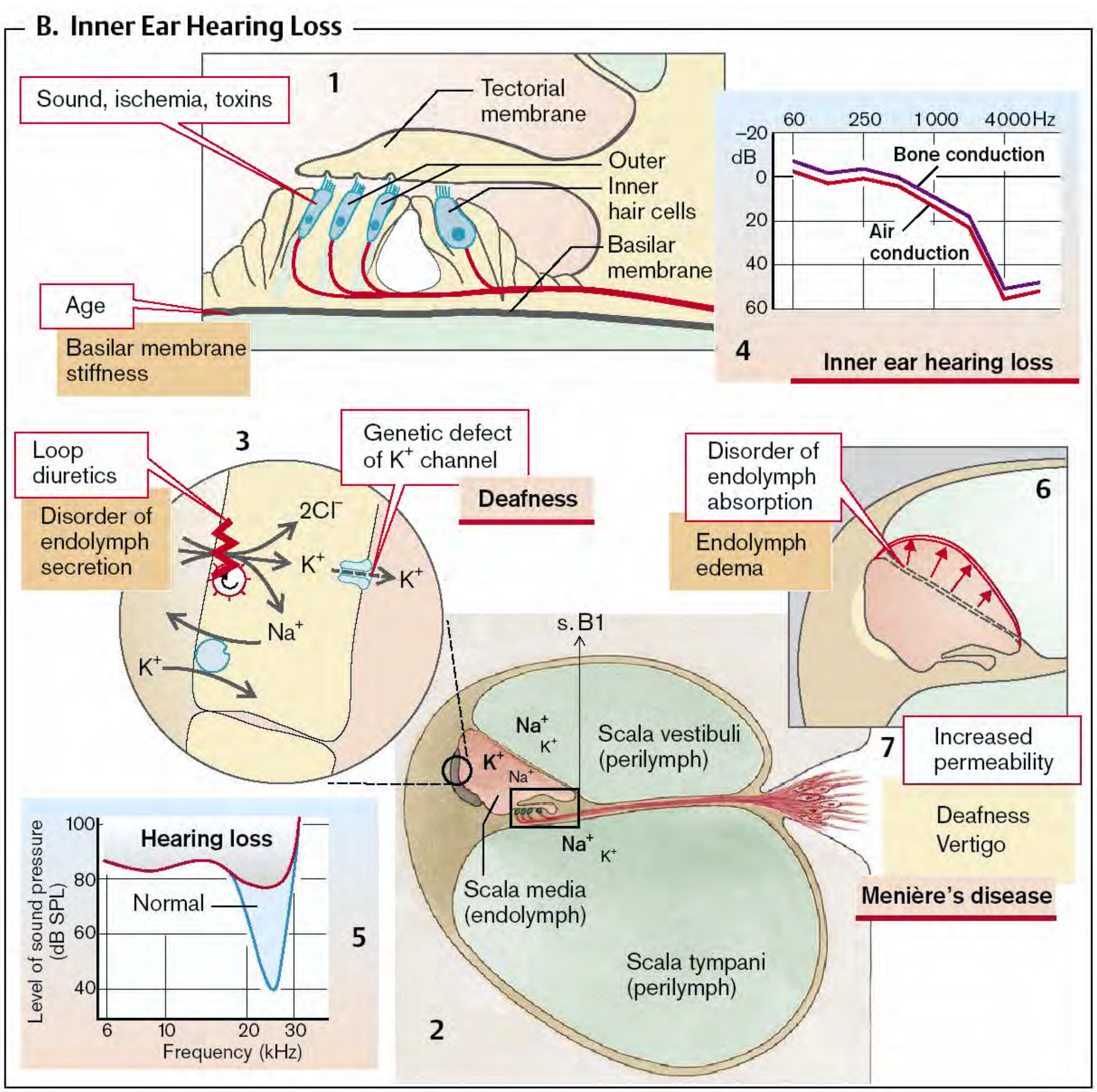


Encoding of sound loudness and frequency

Conduction: through air and bone
Hearing loss: A. conductive, B. sensorineural



Hearing loss: A. conductive, B. sensorineural



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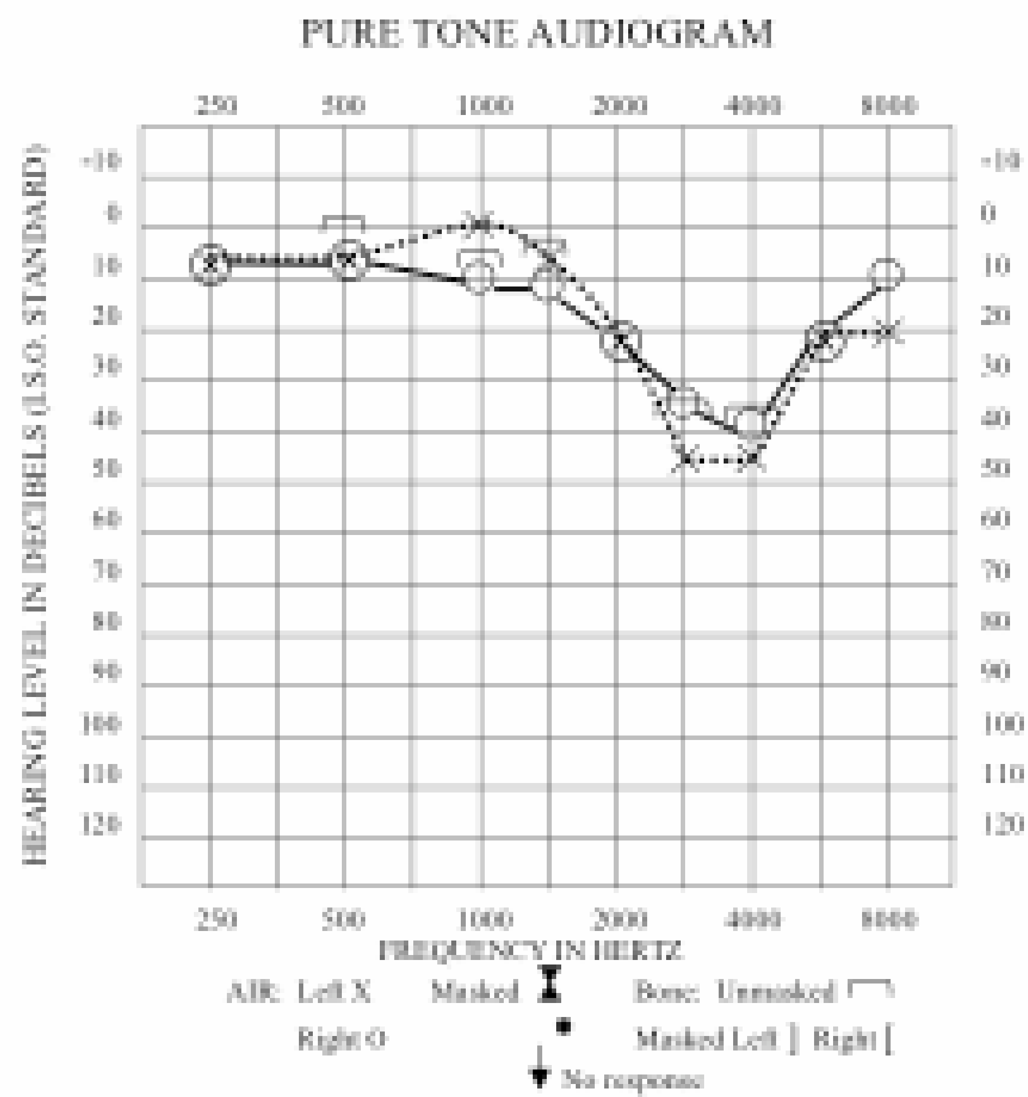
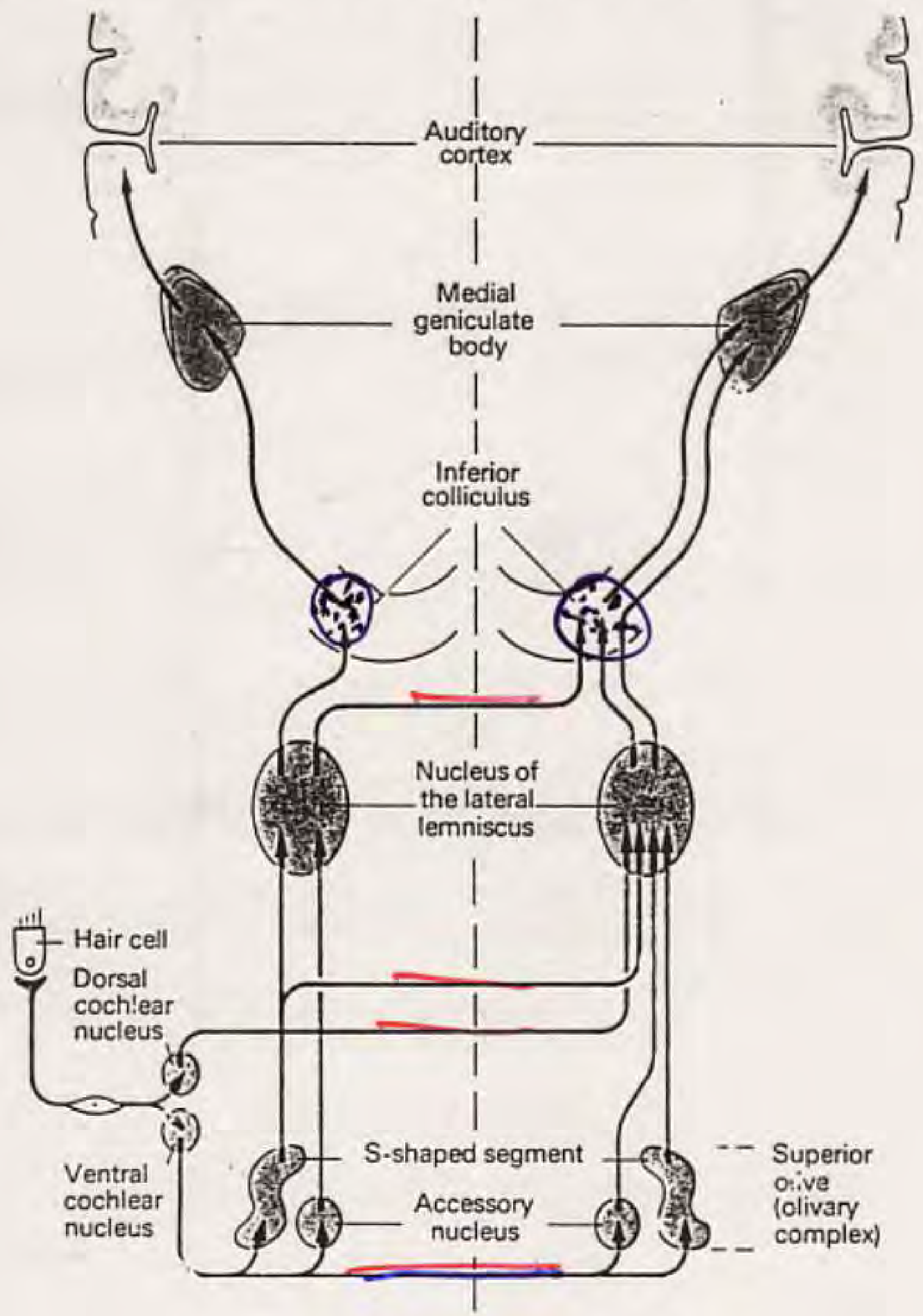
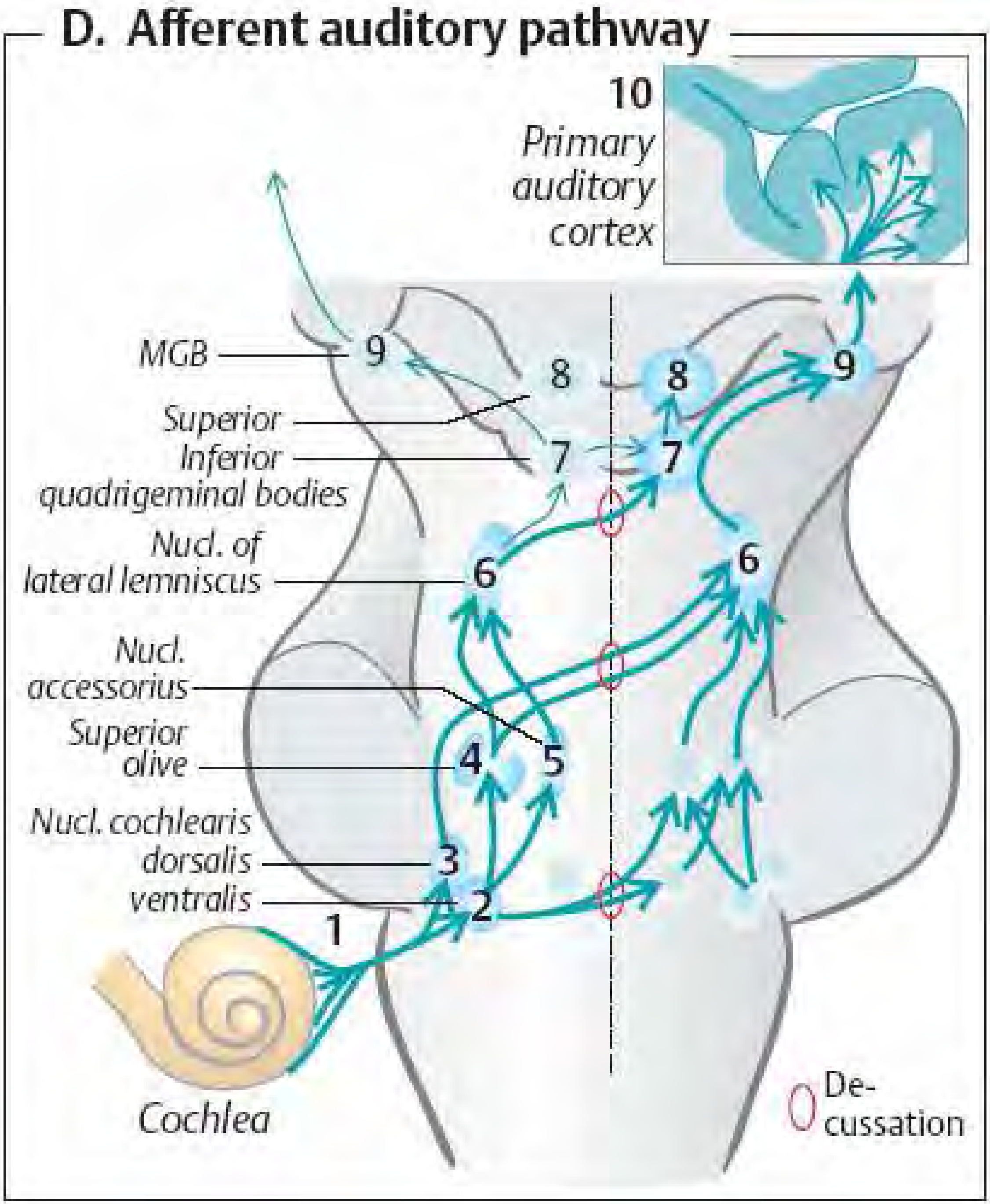

PURE TONE AUDIOGRAM
250
500
1000
2000
4000
8000
HEARING LEVEL IN DECIBELS (I.S.O. STANDARD)
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
FREQUENCY IN HERTZ
AIR: Left X
Right O
Masked
No response
Bone: Unmasked
Masked Left] Right [

Pitchfork tests

Test	Principle	Norm	Conductive	Sensory-neural
Weber	PF on the vertex of the head	Non-lateral	Lateral to blocked side	Lateral to healthy side
Rinne	First on bone, then in the air	Positive	Indifferent	Positive
Schwabach	(subjective) Patient compared to examiner	Normal	Longer	Shorter


Auditory cortex
Medial geniculate body
Inferior colliculus
Nucleus of the lateral lemniscus
Hair cell
Dorsal cochlear nucleus
Ventral cochlear nucleus
S-shaped segment
Accessory nucleus
Superior olive (olivary complex)



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 assymetric (due to probable functional purpose)

>Difference between the left and the right ear is used in sound localization

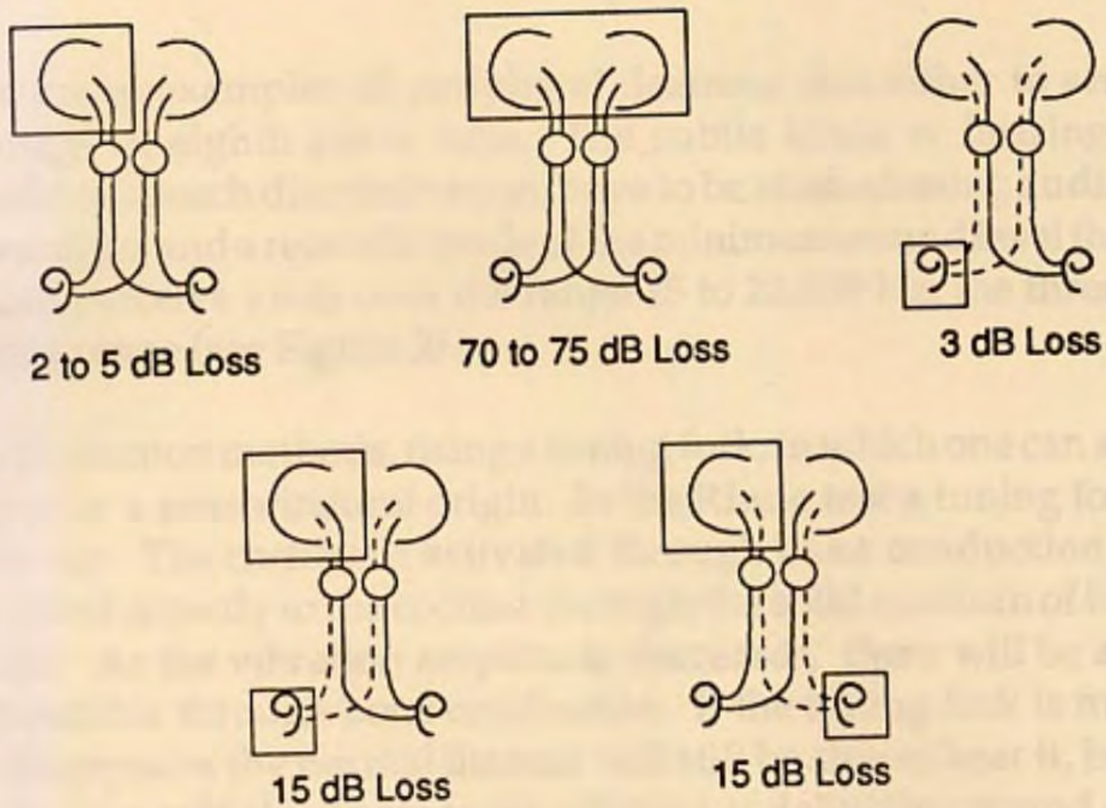


Figure 18. Summary of experiments demonstrating bilaterality of auditory pathways in dog. Number below each diagram is hearing loss in decibels; box around symbol for cerebral cortex or cochlea indicates destruction of it. In D, hearing depends on uncrossed fibers of left lateral lemniscus, whereas in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

(speech was not rehabilitated after inborn deafness)

Causes of hearing loss

- otosclerosis (in 0,5 - 1 % of elderly)
- conductive disorders
- hereditary and inborn disorders
- toxic damage
- meningoencefalitis
- profesional damage
- presbyakusia
- Menier’s disease

"You have an inner ear disorder."

Part 2: Psychophysics

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Outline of part 2

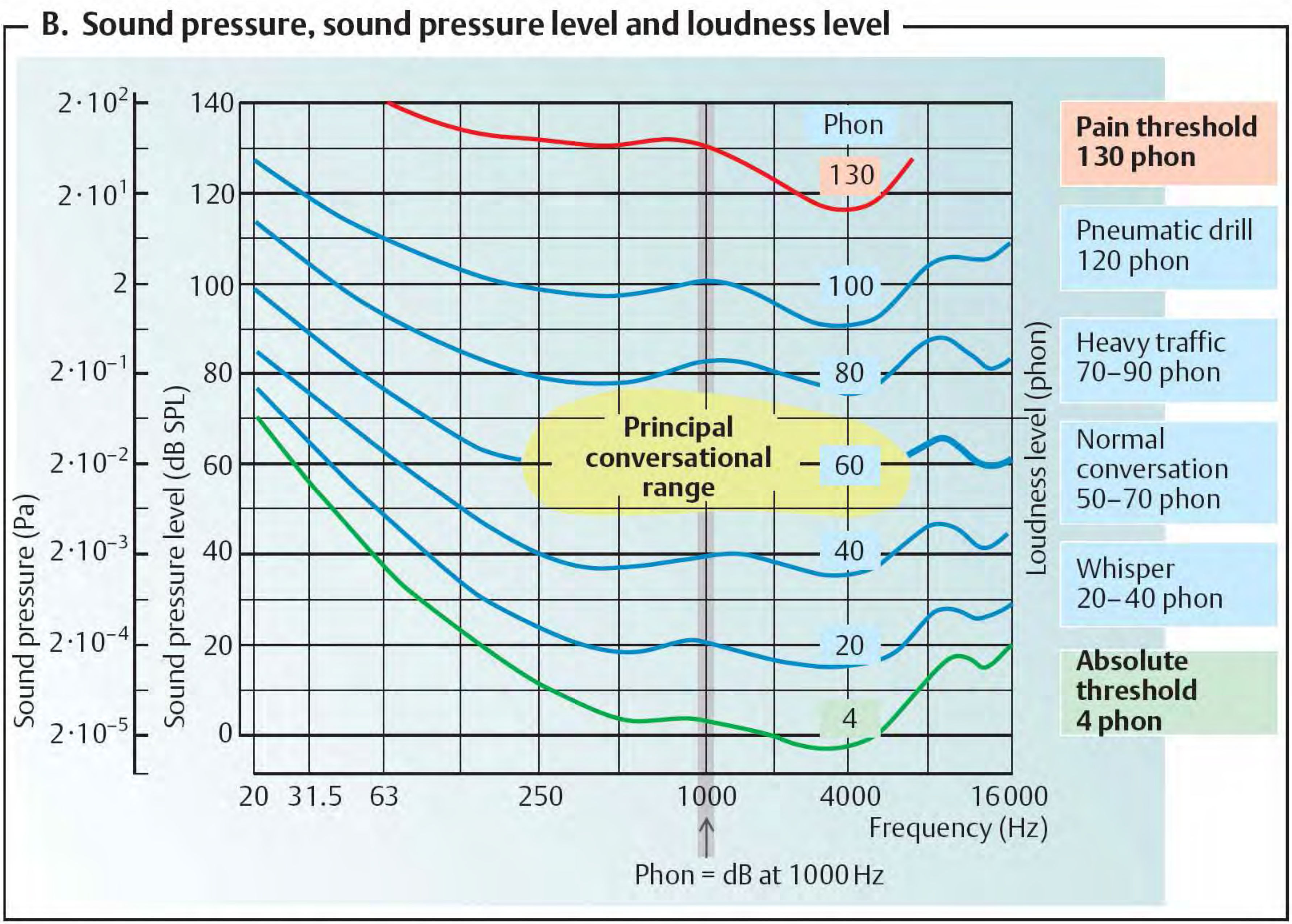
- Introduction: what is psychophysics

- Laws of psychophysics

- Logarithms and other functions – quantitative relations between stimulus and response

- Weber - Fechner logarithmic law

- Stevens's law enables comparison between modalities



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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 (→ 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:

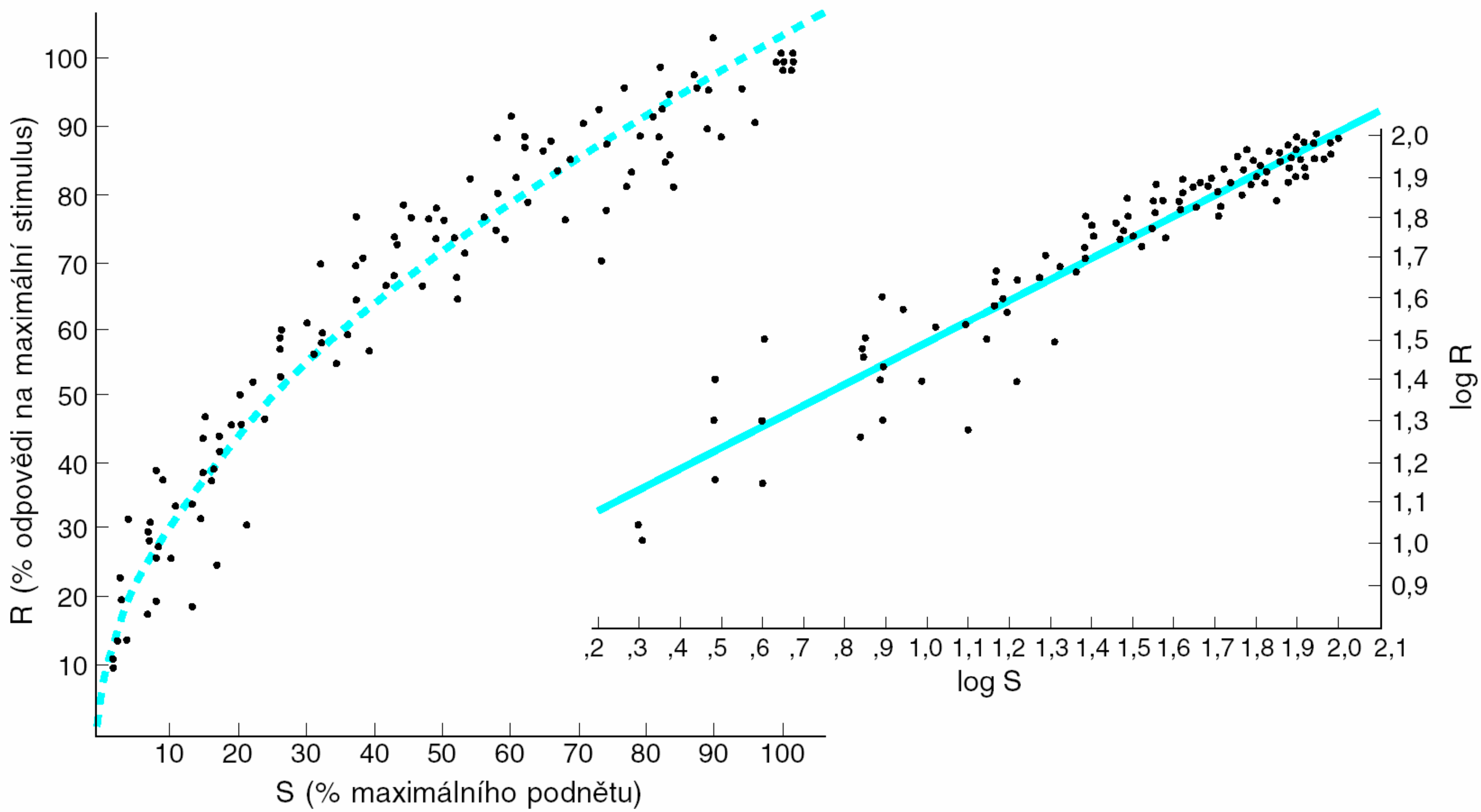
$\log 10 = \ln e = 1$

$\log 1 = \ln 1 = 0$

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

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

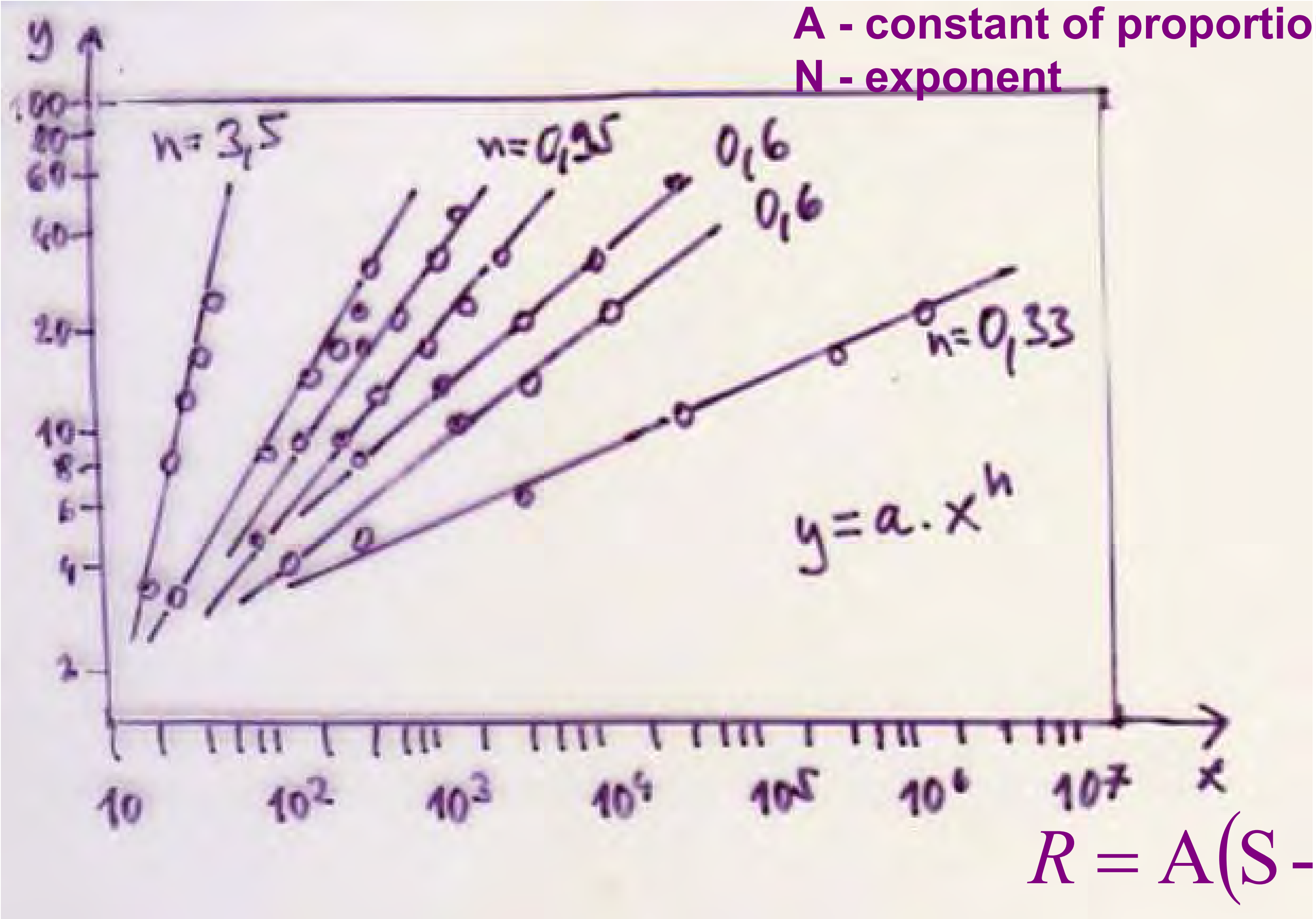
$$R = 10 \log(S / S_0)$$



Obr. 5-5. Vztah mezi intenzitou dotykového podnětu (S) a frekvencí akčních potenciálů v senzorických 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.)

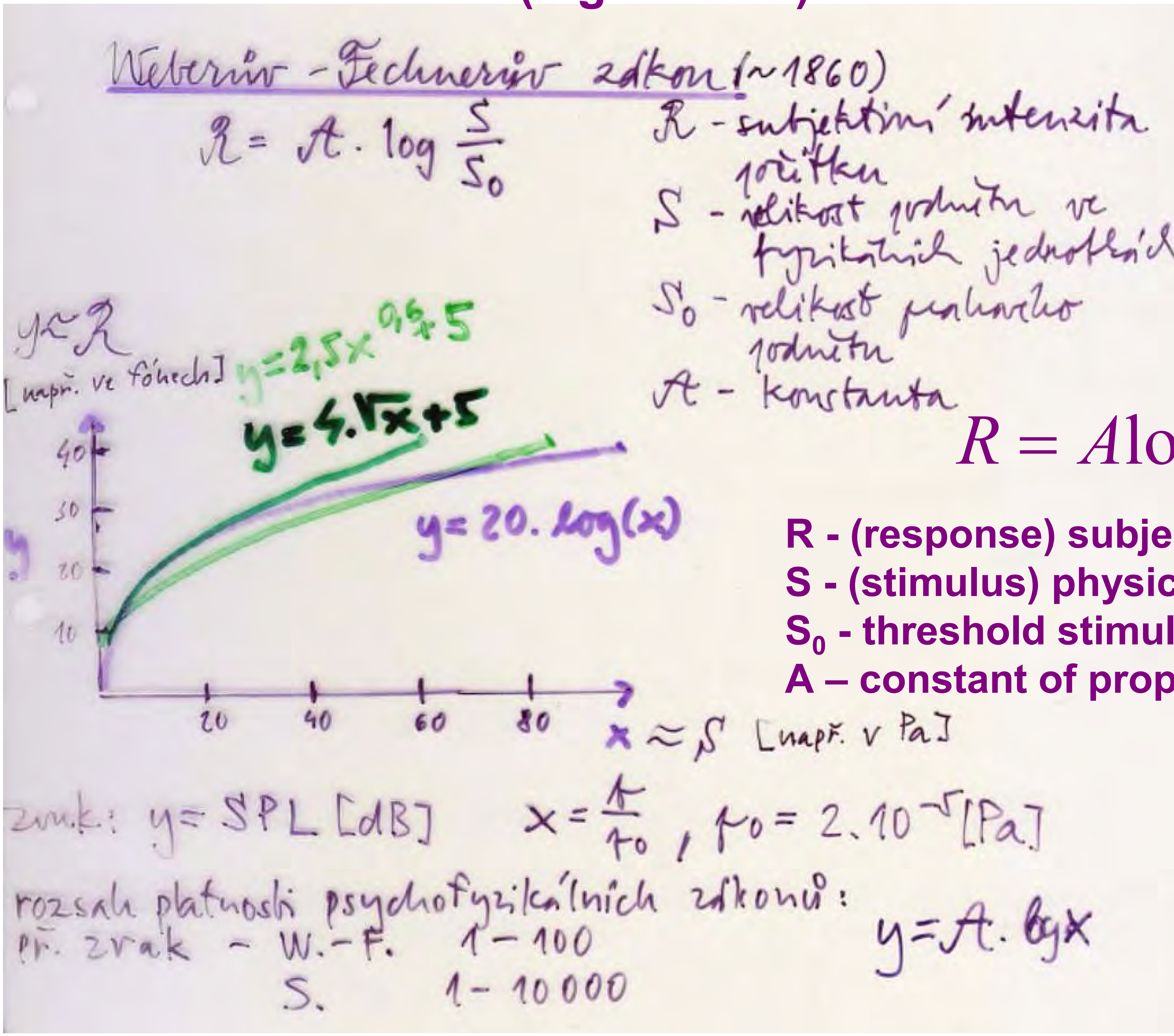
Stevens (power) law

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



$$R = A\left(S - S_0\right)^N$$

Weber – Fechner (logarithmic) law



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

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

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]

Exponents in the Stevens (power) law

$$R = A\left(S - S_0\right)^N$$

Electrophysiology: non-invasive and invasive

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

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**

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 hunderd 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…

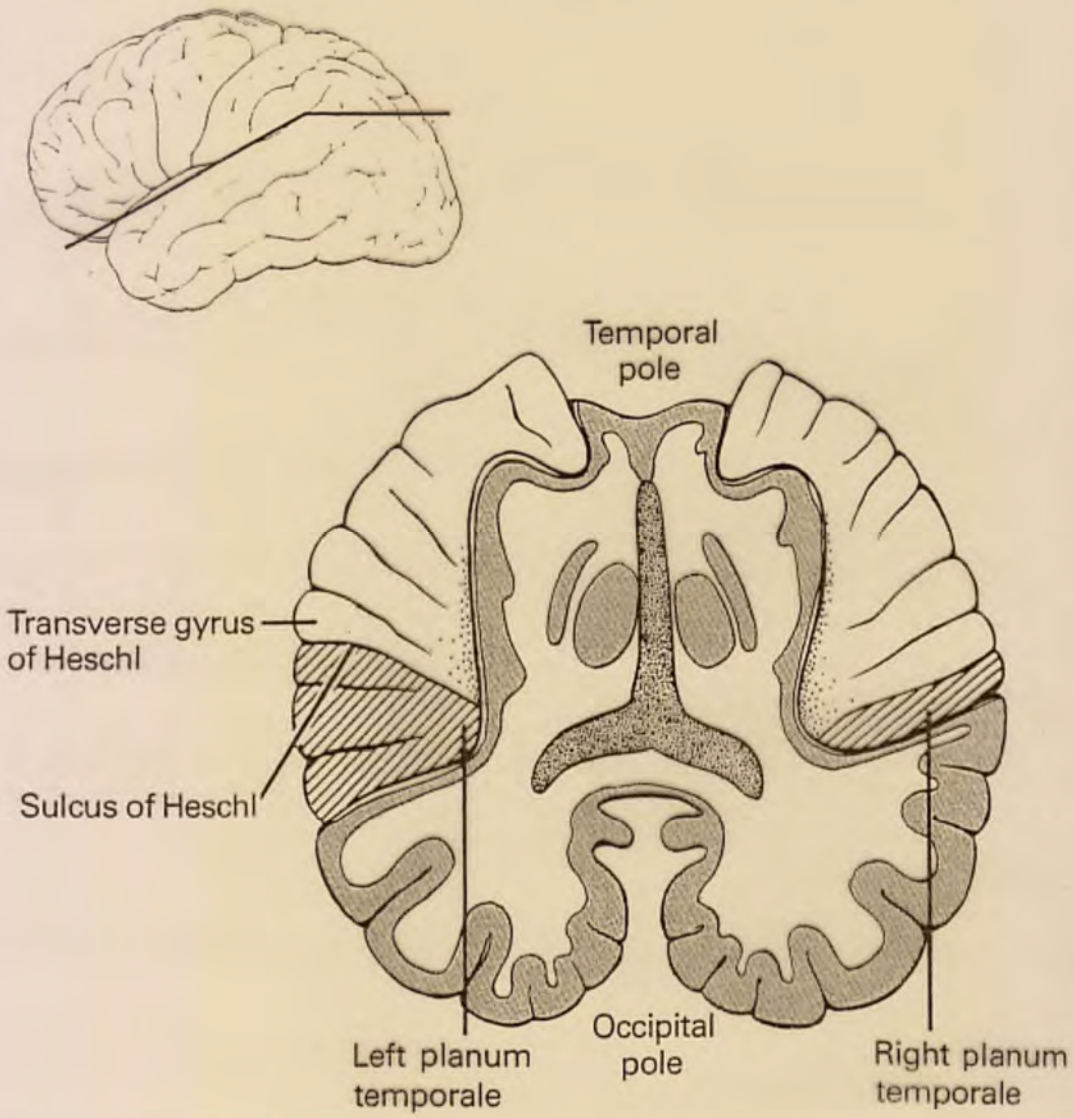


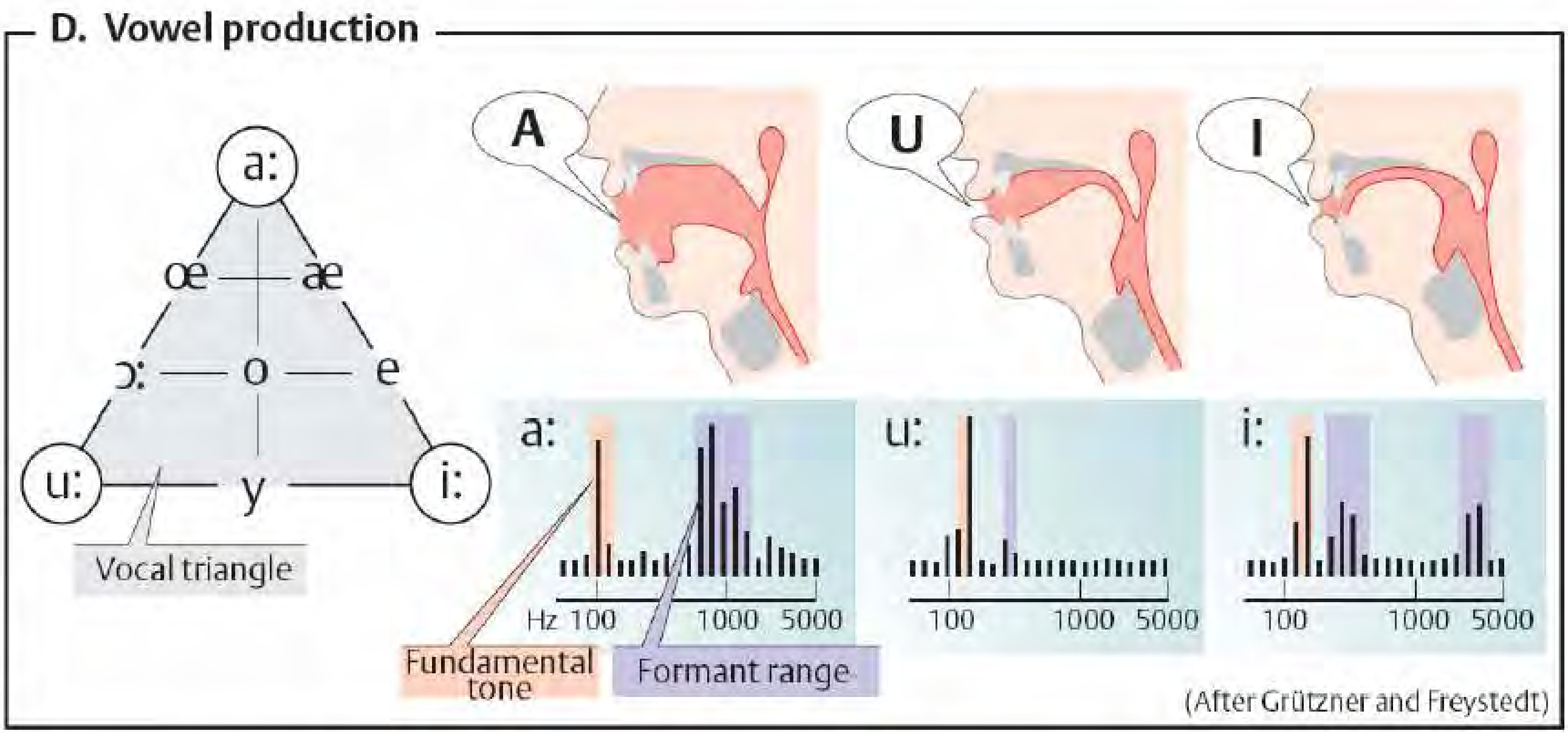
FIGURE 53–8
The planum temporale is larger in the left hemisphere than in the right in the majority of human brains (horizontal section in the plane of the Sylvian fissure). (Adapted from Geschwind and Levitsky, 1968.)

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



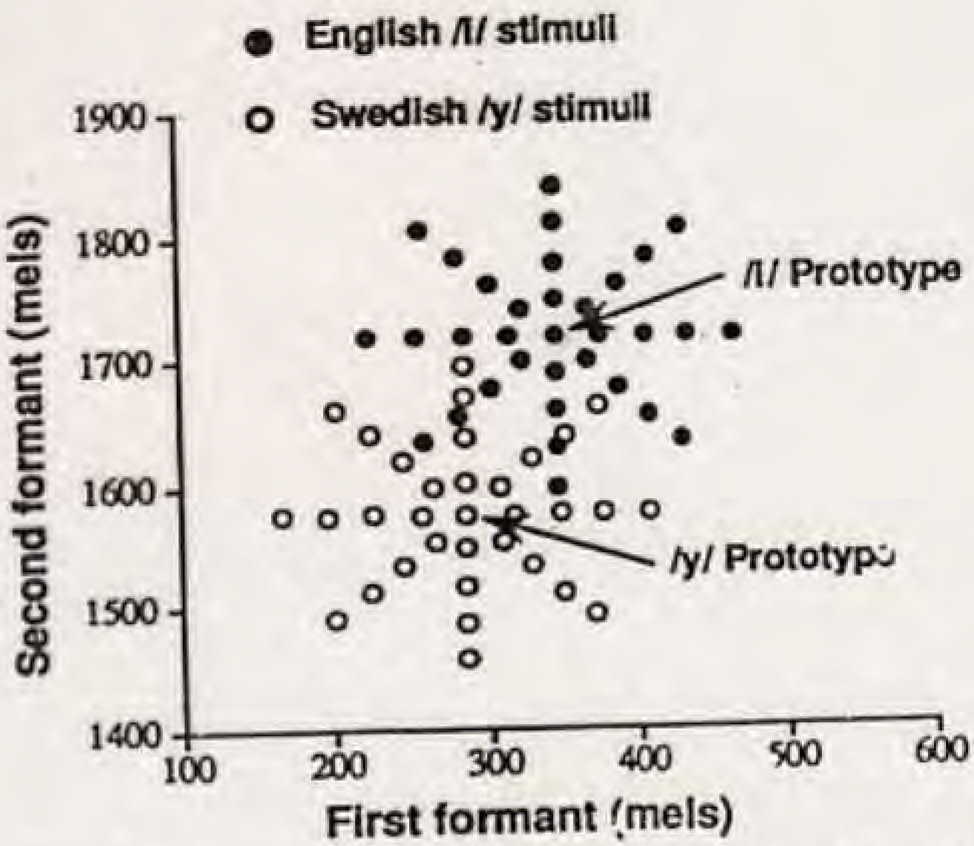


Fig. 1. Six-month-old infants from America and Sweden were tested with two sets of vowel stimuli, American English /i/ and Swedish /y/. Each set included an exceptionally good instance of the vowel (the prototype) and 32 variants that formed four rings (eight stimuli each) around the prototype (*8*).

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

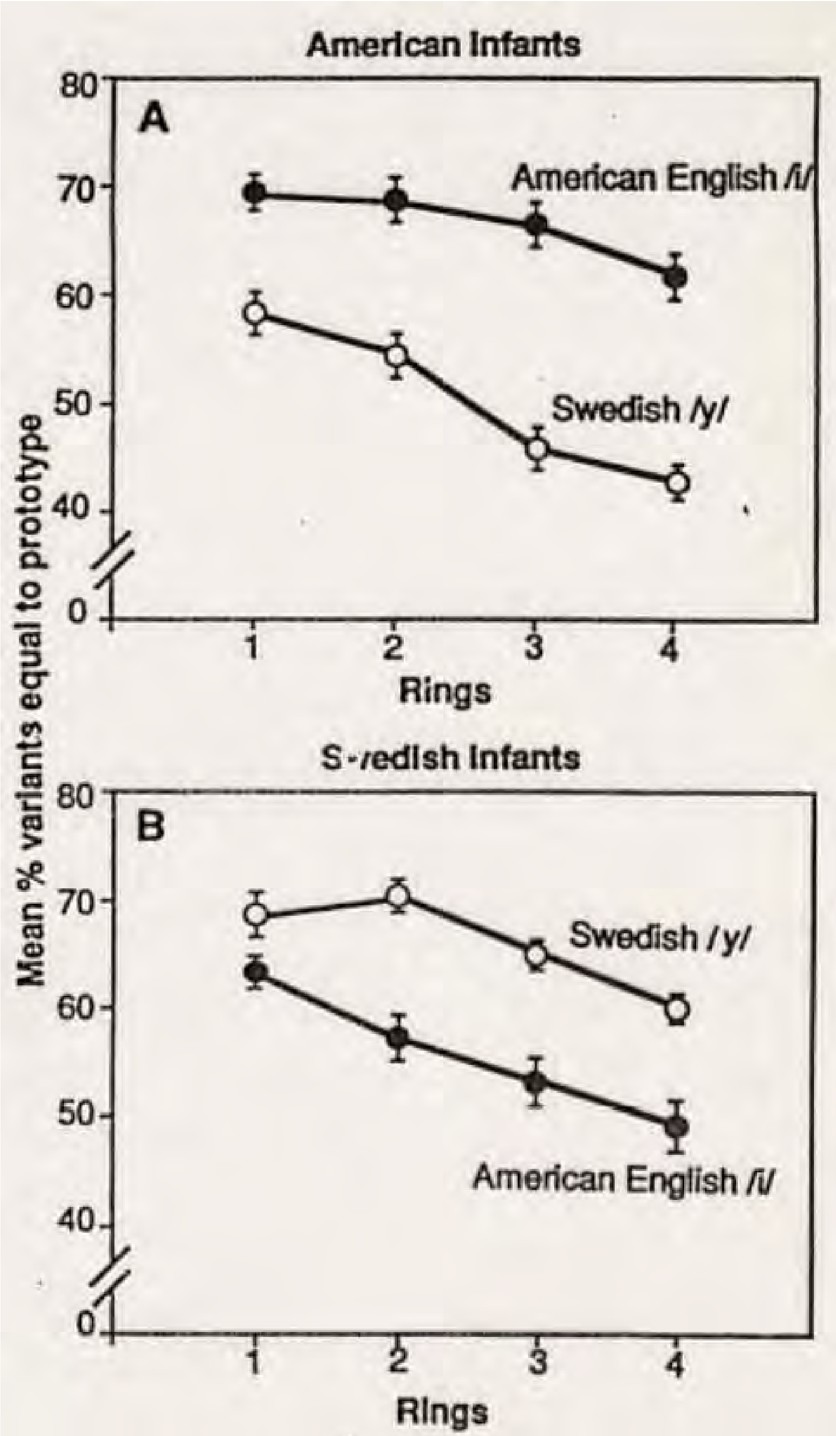
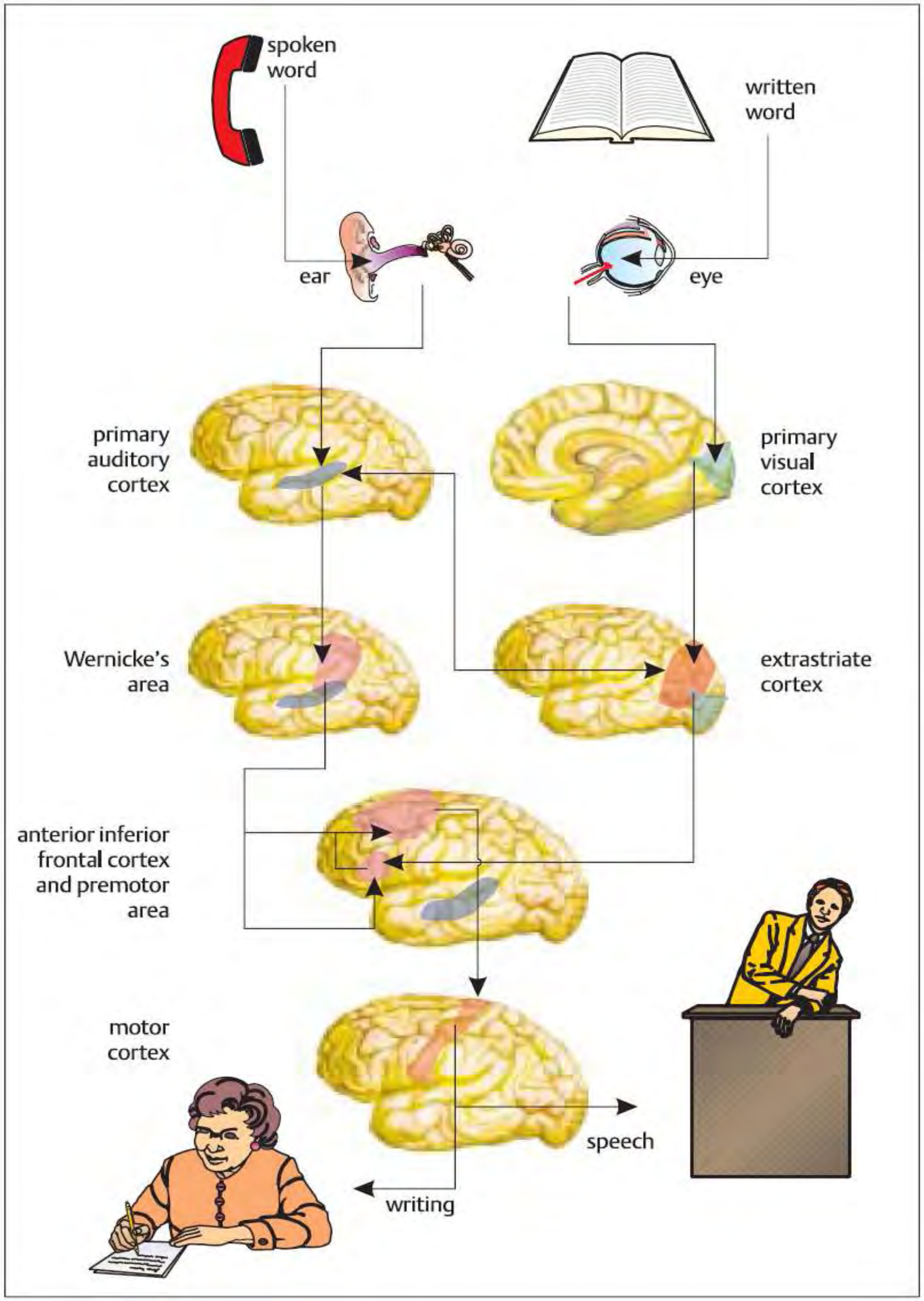


Fig. 2. Results showing an effect of language experience on young infants' perception of speech. Two groups of 6-month-old infants, (**A**) American and (**B**) Swedish, were tested with two different vowel prototypes, American English /i/ and Swedish /y/. The mean percentage of trials in which infants 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.)

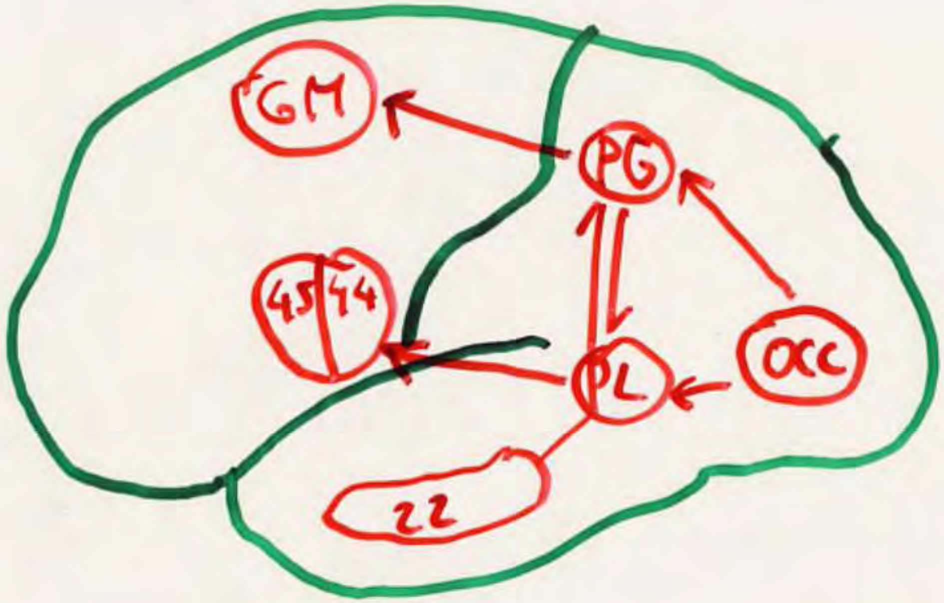
„Psycho-physical“ responses of 6 month old infants to vowels of native and foreign language
[P. Kuhl et al., 1992]



Speech processing in cerebral cortex

APHASIAS (acc. Hrbek, Tichý)

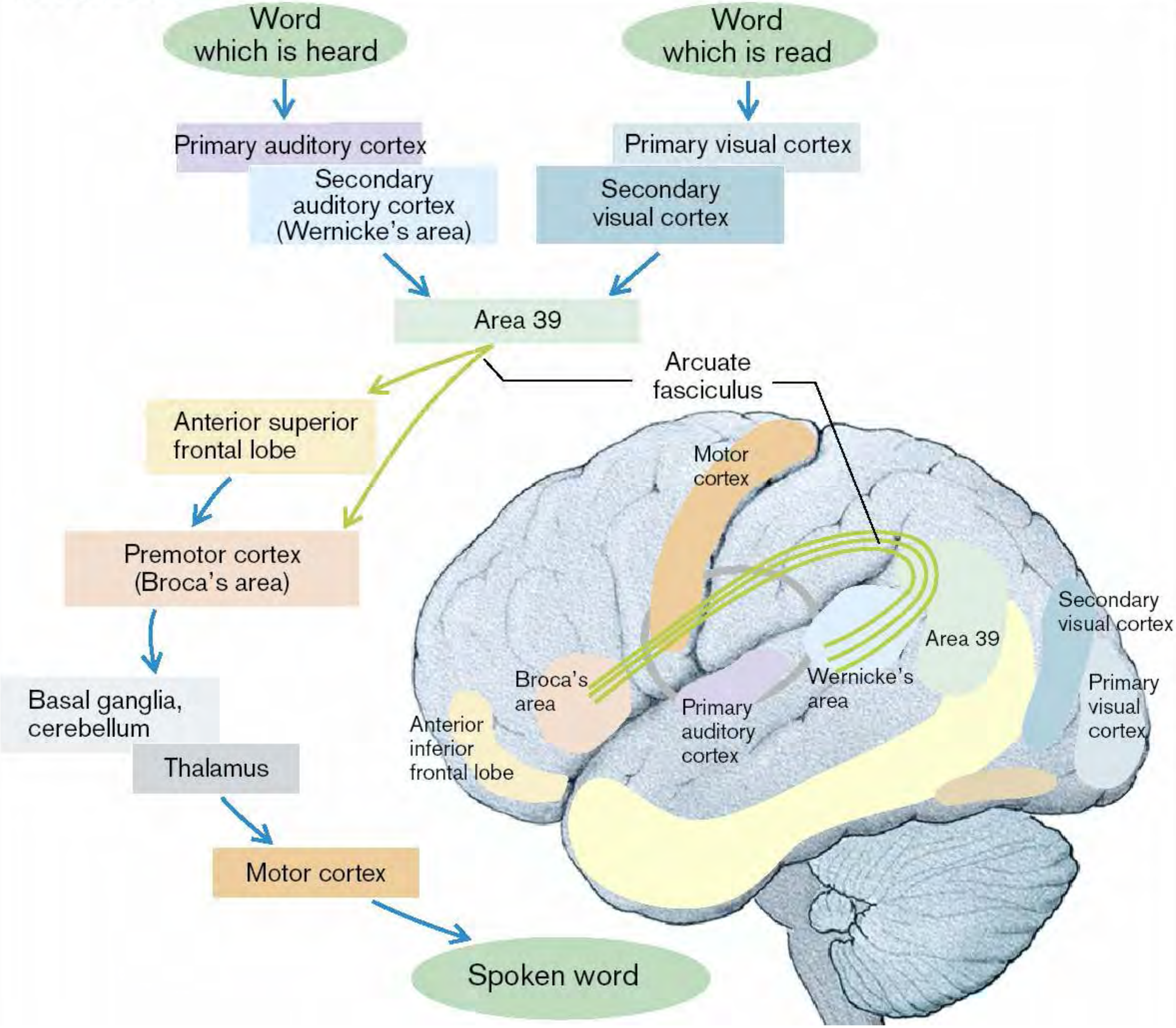
BARTKO, 1985



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

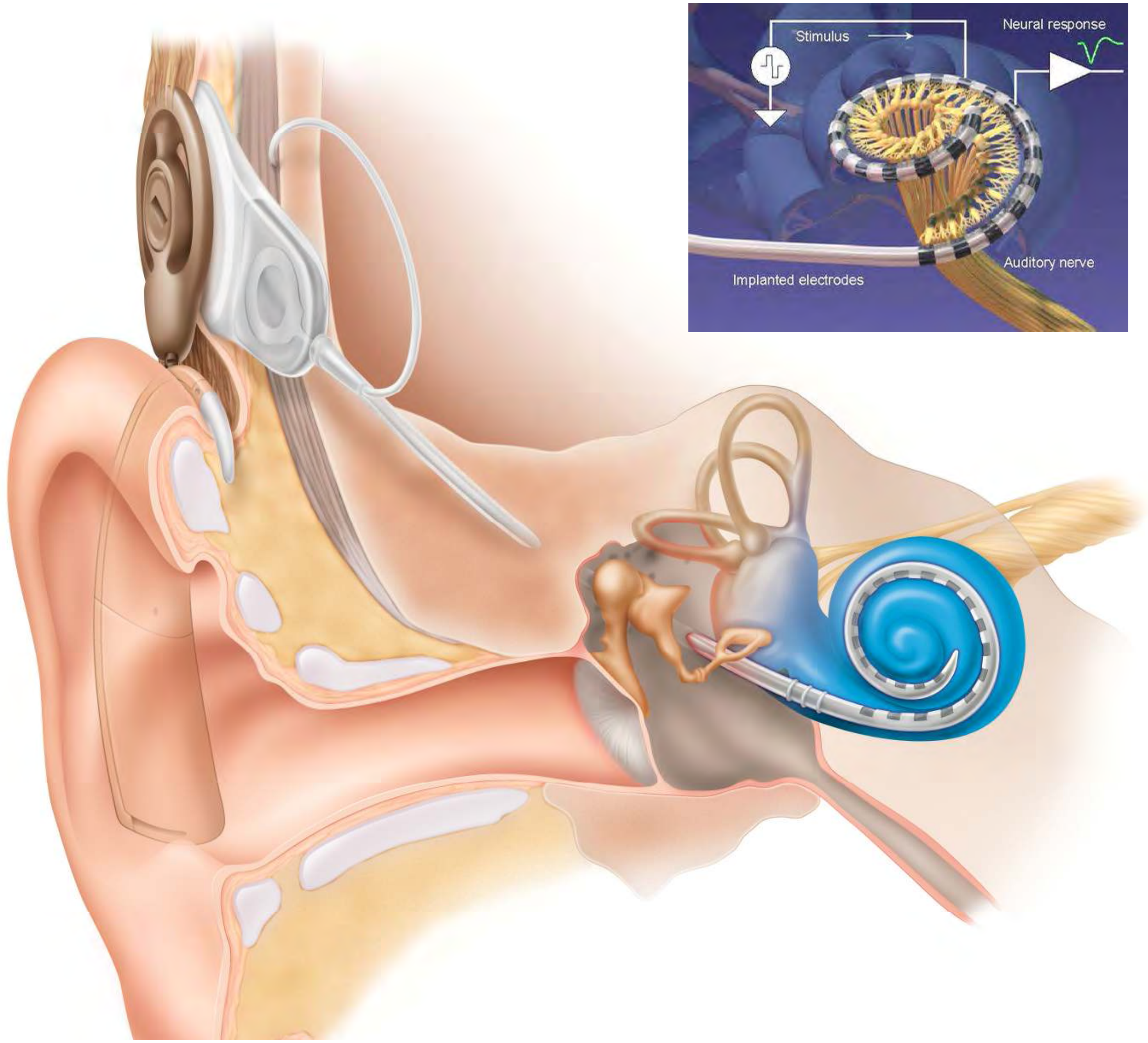


Word which is heard
Word which is read
Primary auditory cortex
Primary visual cortex
Secondary auditory cortex (Wernicke's area)
Secondary visual cortex
Area 39
Arcuate fasciculus
Anterior superior frontal lobe
Premotor cortex (Broca's area)
Basal ganglia, cerebellum
Thalamus
Motor cortex
Spoken word
Motor cortex
Secondary visual cortex
Area 39
Broca's area
Wernicke's area
Primary visual cortex
Anterior inferior frontal lobe
Primary auditory cortex

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)

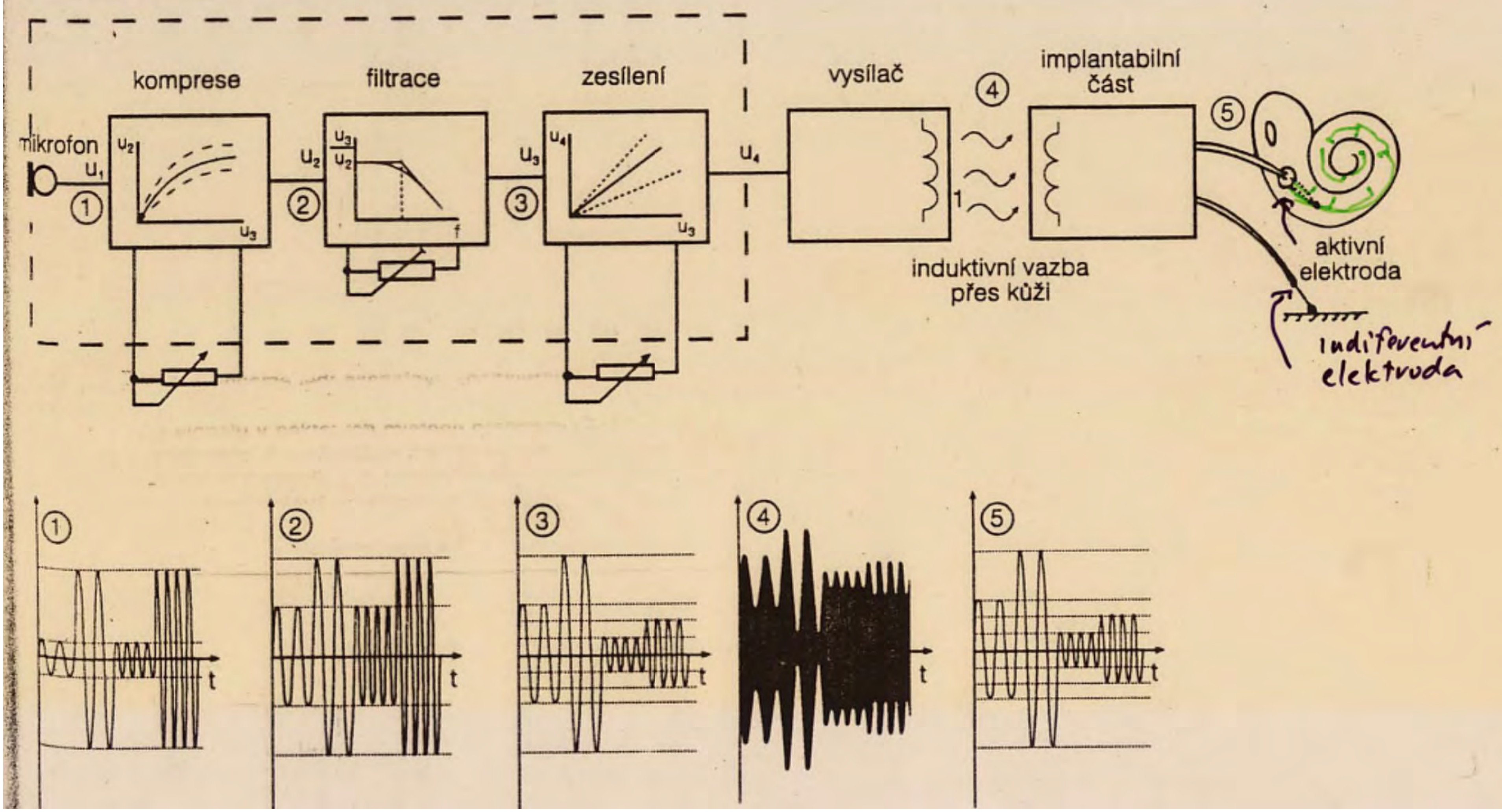
Cochlear implants and sound encoding

In some hearing losses higher than 50 dB the cochlear implant can restore hearing function. The technical design of cochlear implant uses several sound and speech encoding strategies. Most of the encodings are based on the tono-topic organisation of cochlea.

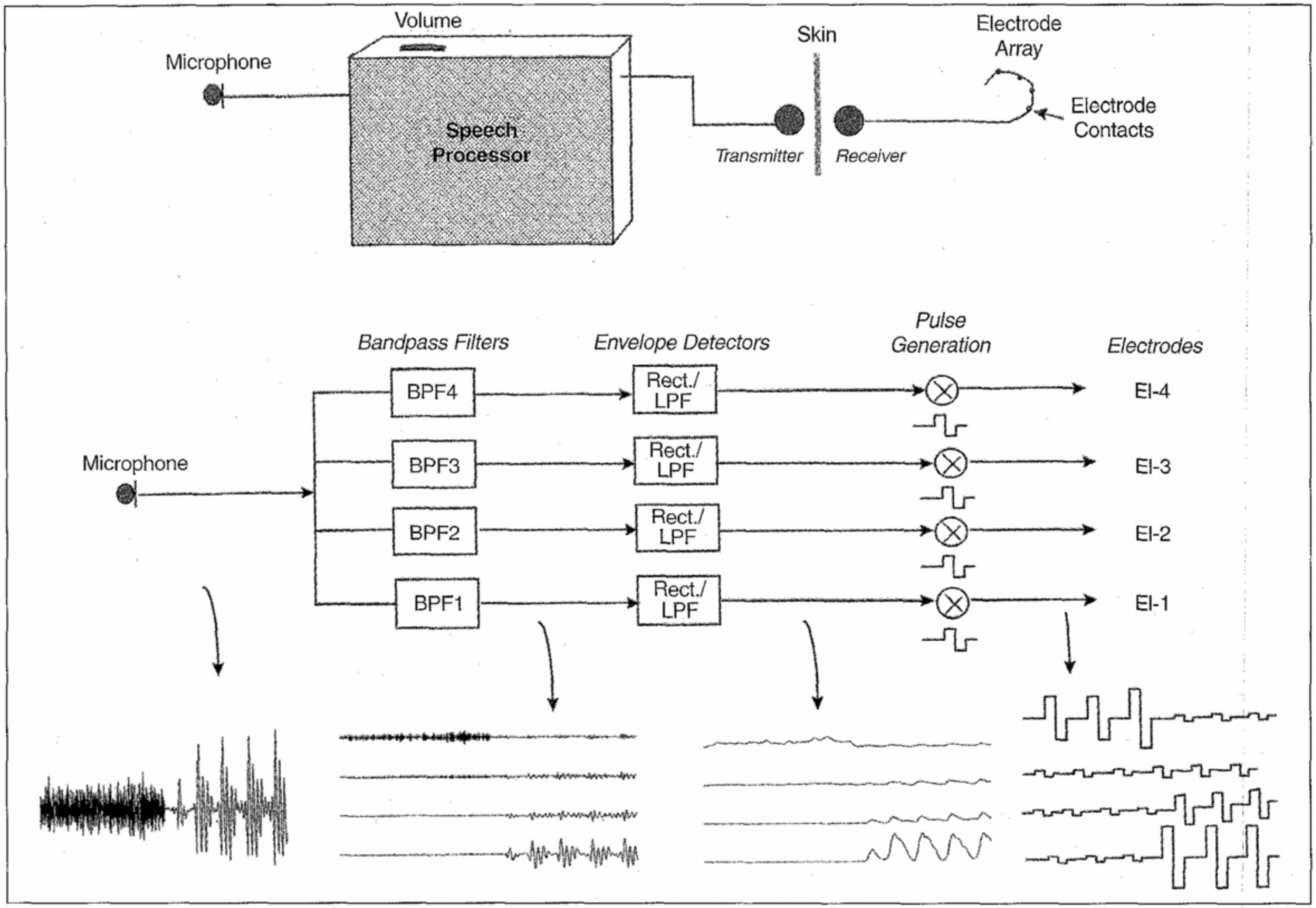


Cochlear implant – single channel

2. Nahoře – Blokové schéma jednokanálové kochleární neuroprotézy
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 – 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 – performance in time

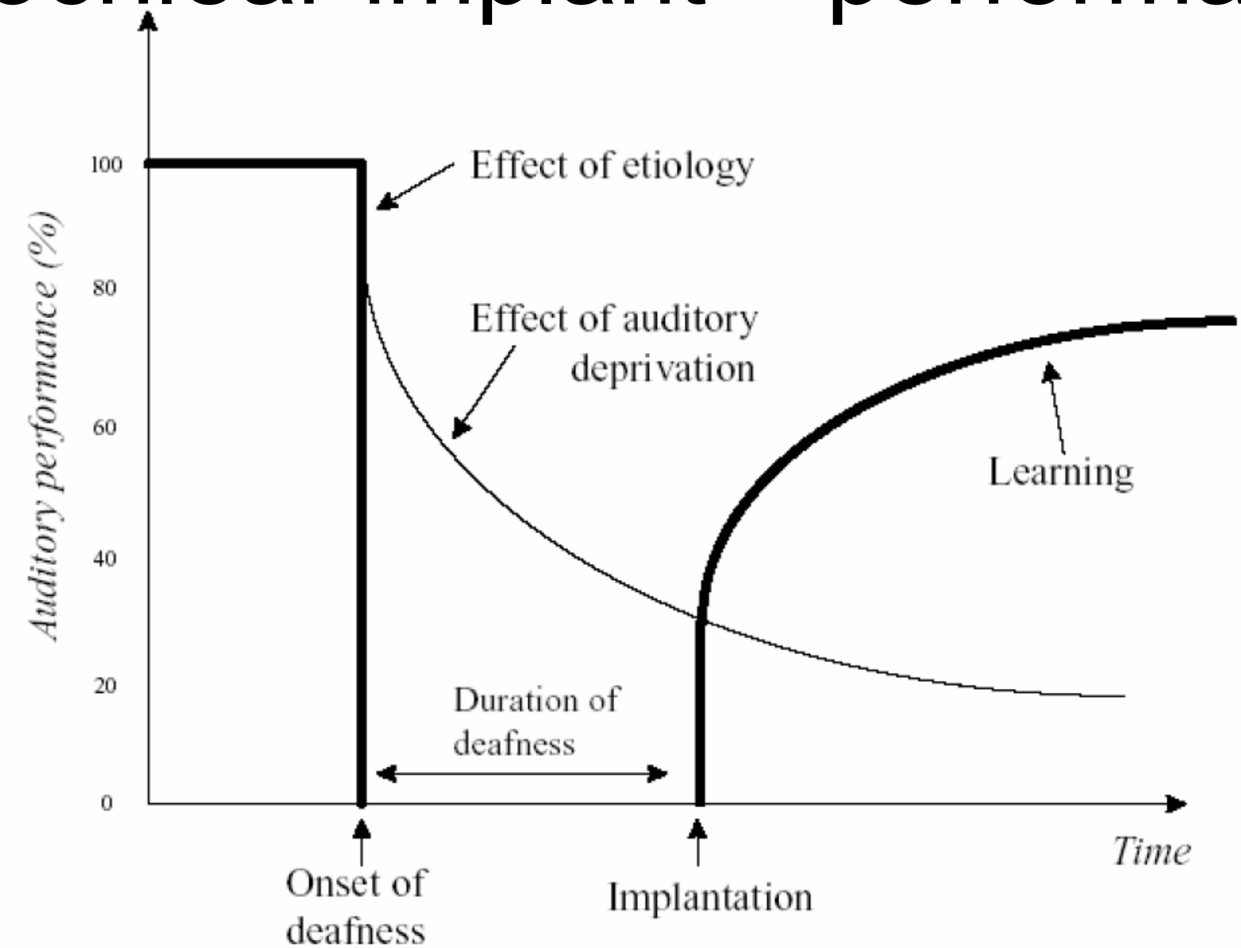


Figure 35. A three-stage model of auditory performance for postlingually deafened adults (Blamey et al. [80]). The thick lines show measurable auditory performance, and the thin line shows potential auditory performance.