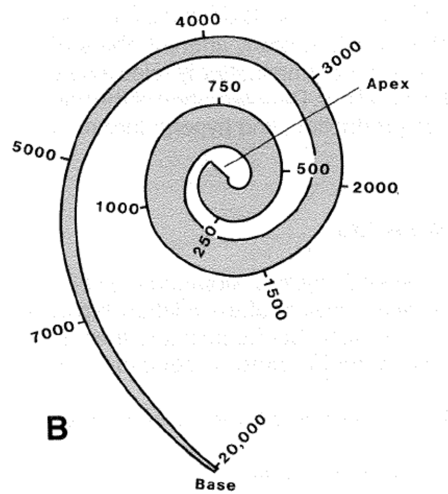
FAV,
Auditory pathway

https://dec52.lf1.cuni.cz/~pmar/ftp/REST/PPT-FEL-older/



Petr Maršálek

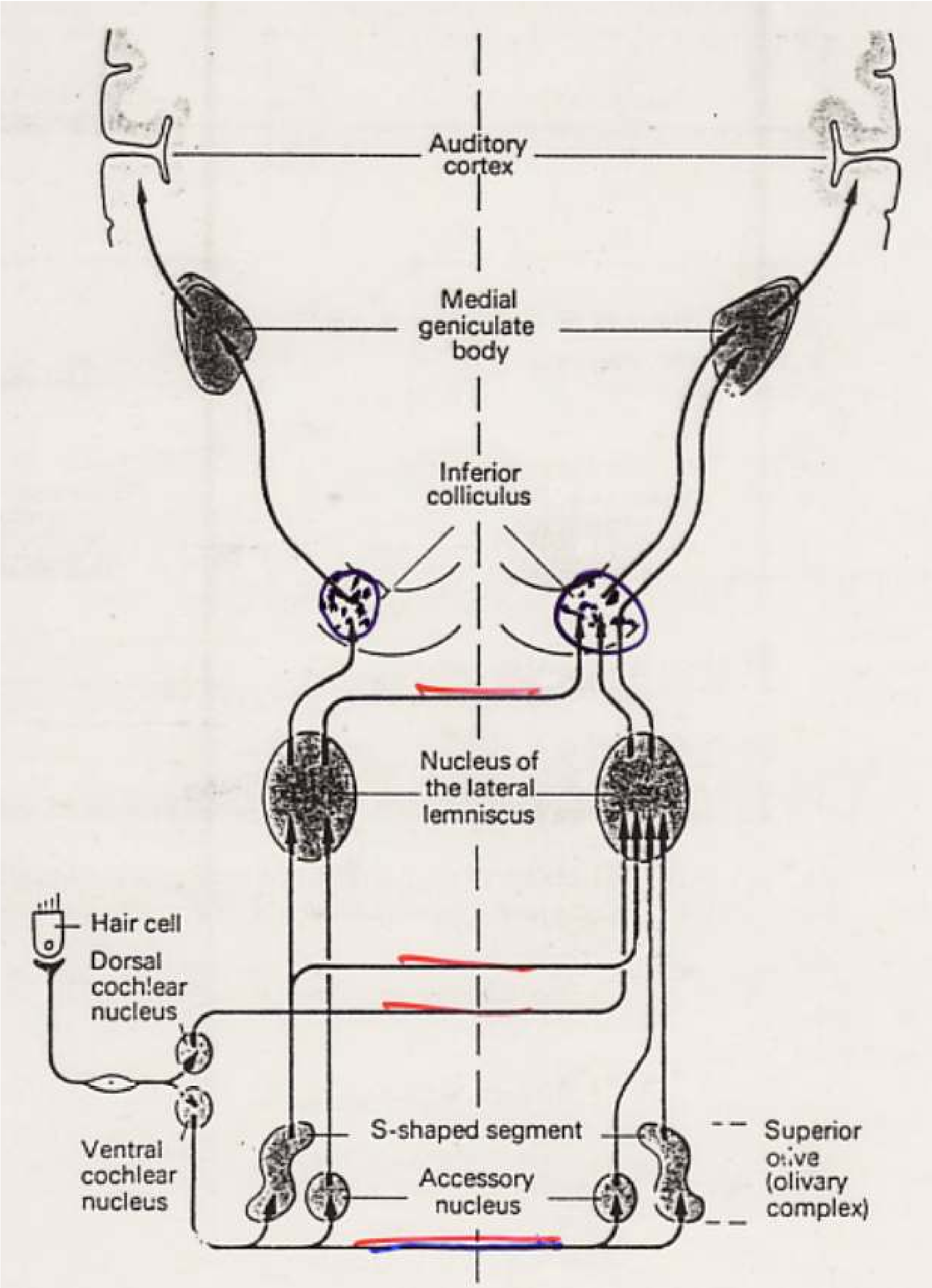
- presentation update -

Outline

- Auditory pathway consists of mono-aural and binaural part.
- Neurons encode signals by trains of action potentials, spike trains.
- Several sound processing stages are attributed to different nuclei in the auditory pathway.
- Binaural hearing uses two cues, Interaural Time Difference (ITD) and Interaural Level Difference. ILD (Level) difference is more important.
- Ultimate processing stage is sound representation in Auditory Cortex.

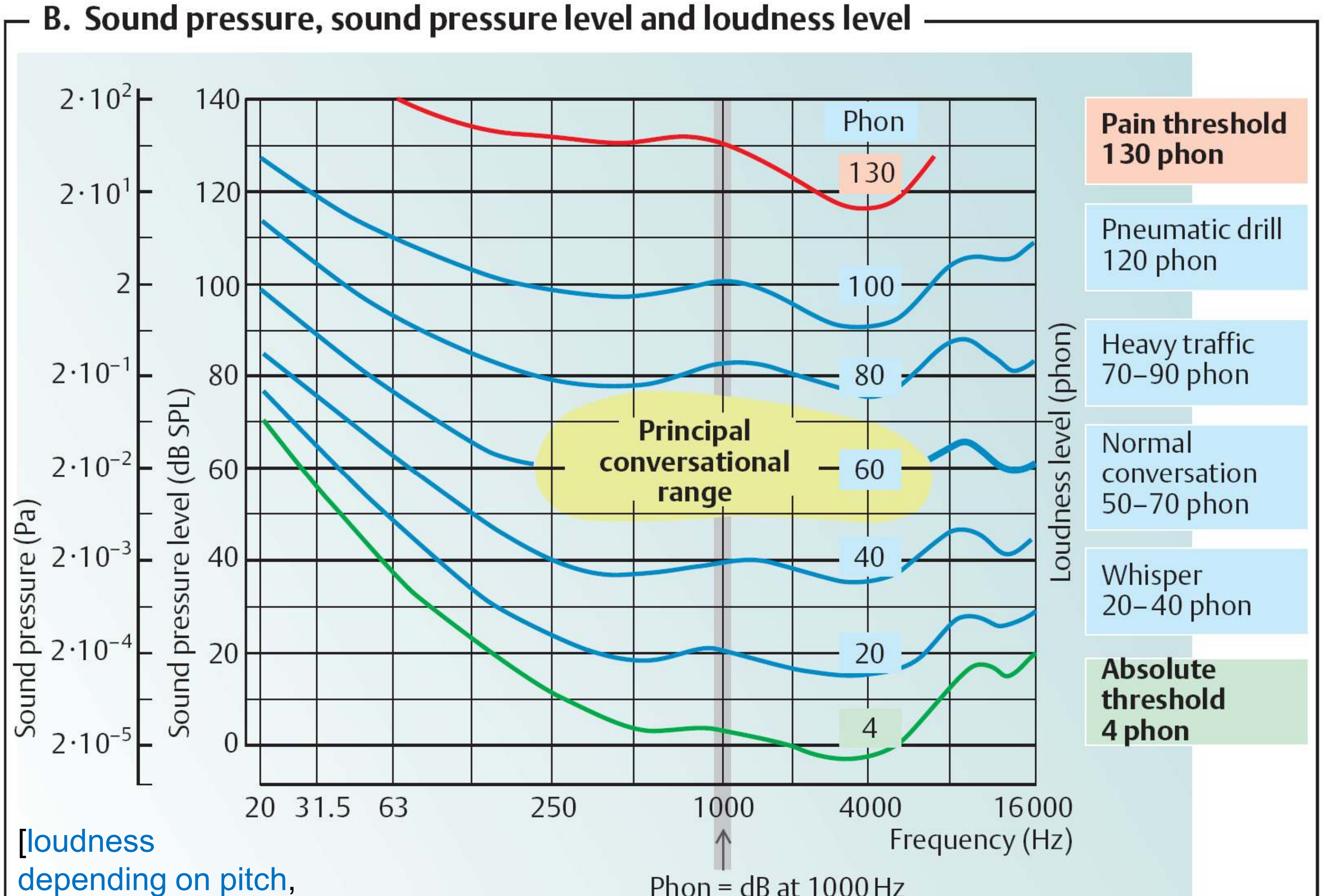
Outline – Review of the auditory pathway anatomy is here

- Auditory nerve encodes sound in 'digital' format – using trains of action potentials (spike trains) composed of binary (all-or-none) pulses.
- Auditory pathway branches into two anatomically and functionally distinct (sub)-pathways: 1 (ascending) mono-aural pathway and 2 binaural pathway.
- Between cochlea and auditory cortex, signal is relayed through circa 10 neuronal relays (=nuclei). Some pathway parts have fewer and some have more neurons in between. We highlight 7 here. Functions of some neurons are not known.
- This (3rd) talk deals with sub-cortical processing, while next (4th) deals with thalamo-cortical (in short cortical) processing and binaural/ =spatial hearing.
- Distinct mono aural nuclei are: 1 spiral ganglion = auditory nerve center, 2 cochlear nuclei, 3 superior olivary complex. These are medial and lateral superior olives (MSO and LSO) and 4 lamina quadrigemina nuclei, one of whose is inferior colliculus.
- Then as numbers 5, 5A, 5B, 5C/ and variable number inbetween/ the pathway intertwines through the bundle of lemniscus lateralis to 6 medial geniculate nucleus, which is in fact thalamic nucleus.
- Last stage is 7: auditory part of cerebral cortex. It consists od several auditory areas, one called primary and the rest is dubbed secondary.
- Binaural pathway starts with the 3rd neuron of medial or lateral superior olive.
- While it is easy to dissect these pathways into anatomical parts, we would like to know, what are neural functions, and they are mostly unknown to date.
- Majority of this talk deals with spikes, so let us start over with the spikes (= action potentials).



Auditory pathway Mono-aural (1) pathway overview

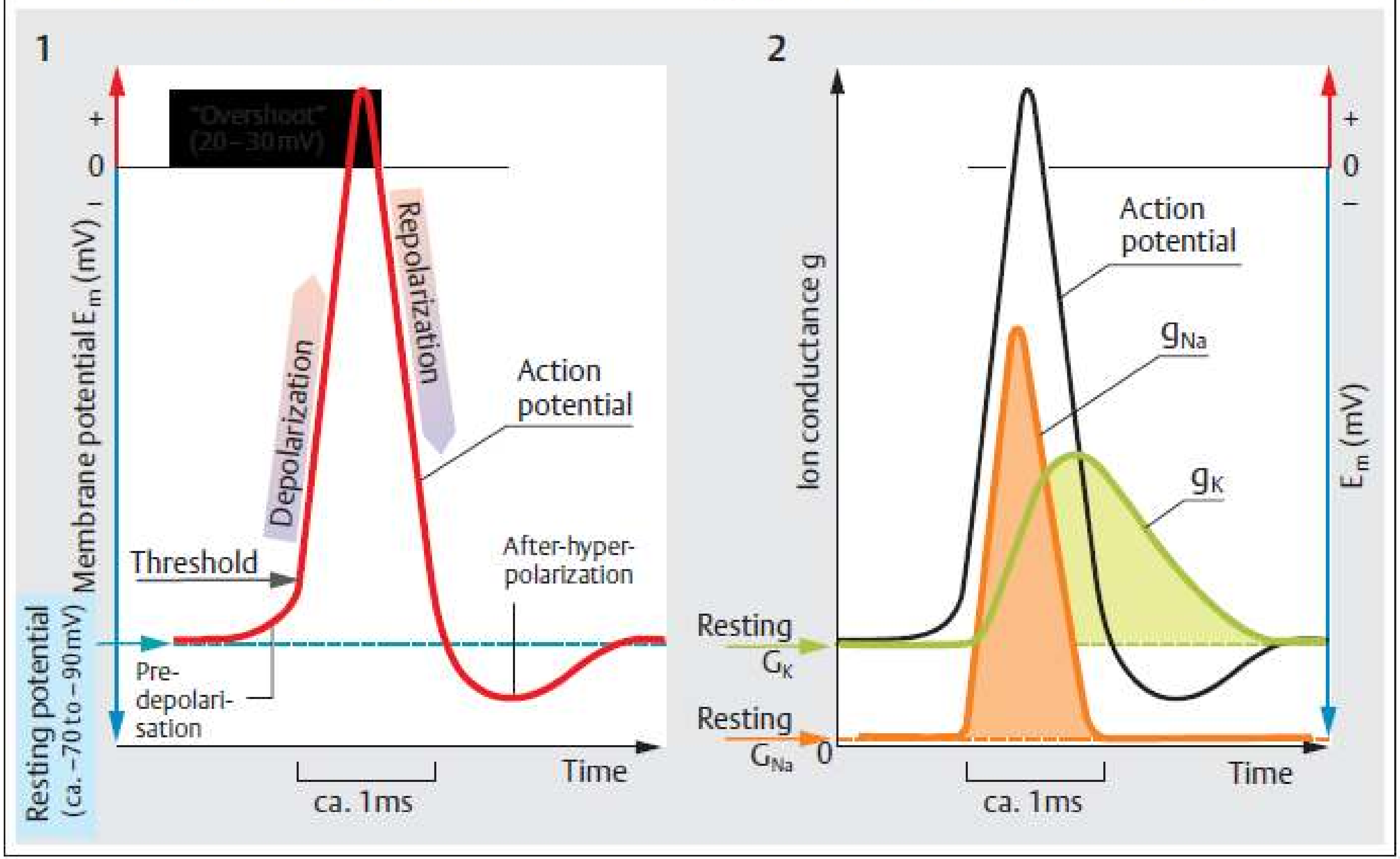
Before starting with spikes, recall Normal audiogram: x-axis, sound frequency (Hz), y-axis, sound pressure (Pa). Red top curve is pain threshold. Hearing threshold is Green bottom curve. Blue are curves of *subjectively* equivalent loudness level. dB SPL is *objective* unit, Phon is *subjective* unit. Yellow blob is speech region.
Gray line is reference frequency 1000 Hz.



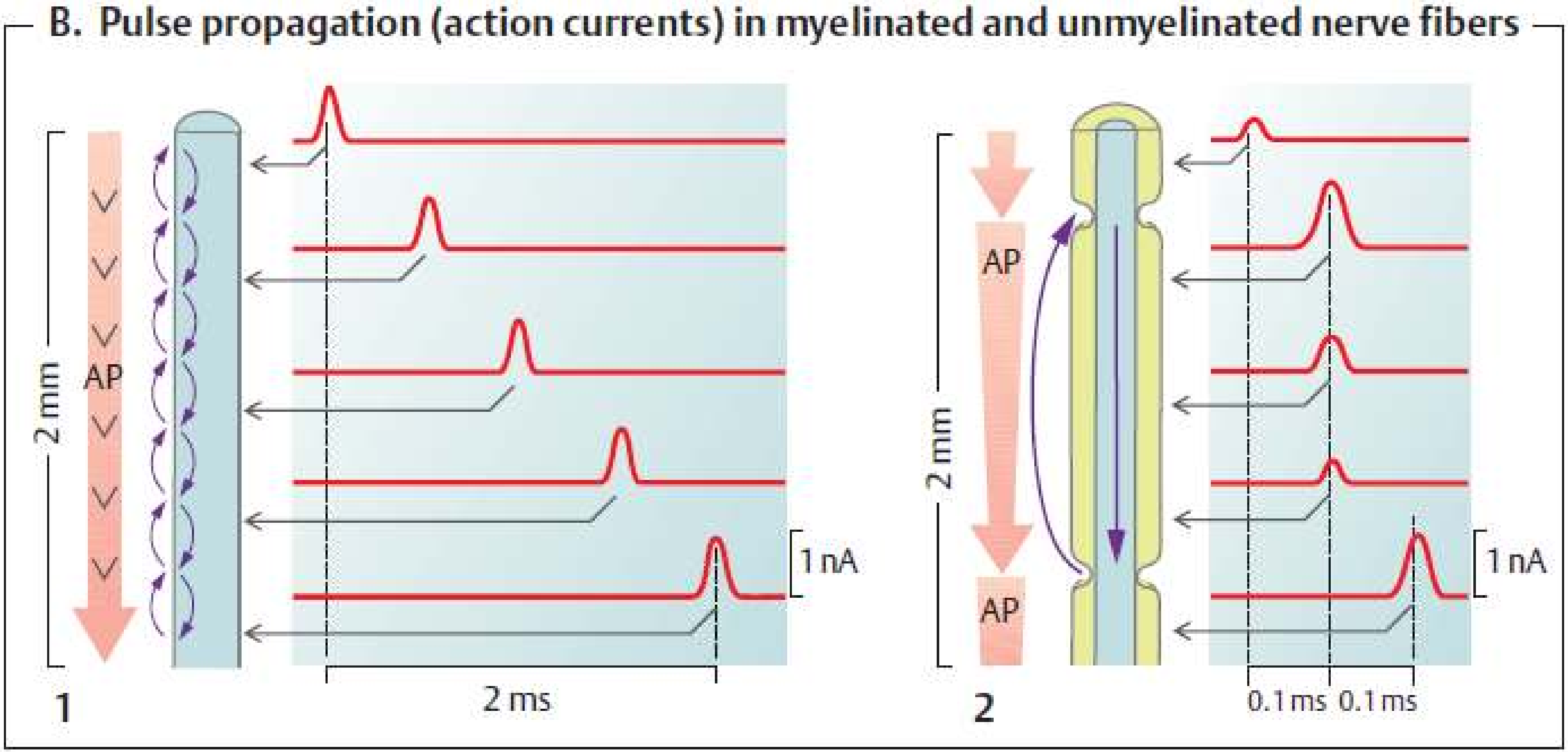
[loudness depending on pitch, in a textbook: Silbernagl, Despopoulos, Thieme, 2000]

Spike, or Action Potential, AP, Is an Unitary Impulse.

A. Action potential (1) and ion conductivity (2) (nerve and skeletal muscle)



AP Conduction in Neural Fiber



RECALLING PSYCHO-PHYSICS:

Objective /to Internal /to Subjective (Barrier)

Physical /to Perceptual Energy

- amplitude
- frequency
- spectrum
- duration
- azimuth

A modulation, etc

- loudness
- pitch
- timbre
- length
- direction

roughness, etc

But: how is this represented/ encoded?

Action Potential (AP) Propagation, and Conduction on a Synapse

Origin: Axon departure from the neuronal body.

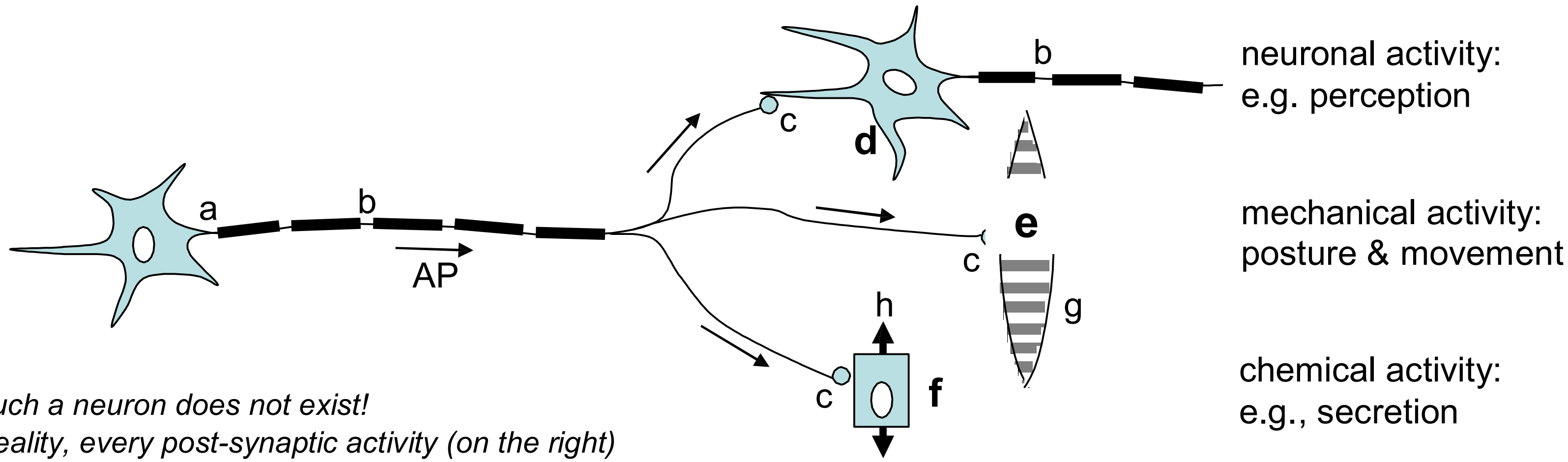
Propagation: By local circuits or, in myelinated axons, by saltatory conduction from one Ranvier node (b) to another.

Termination: In axon terminals: presynaptic buttons (c).

Transmission: To postsynaptic membranes of another neurons (d), or to muscle cells (e), or to epithelial cells (f).

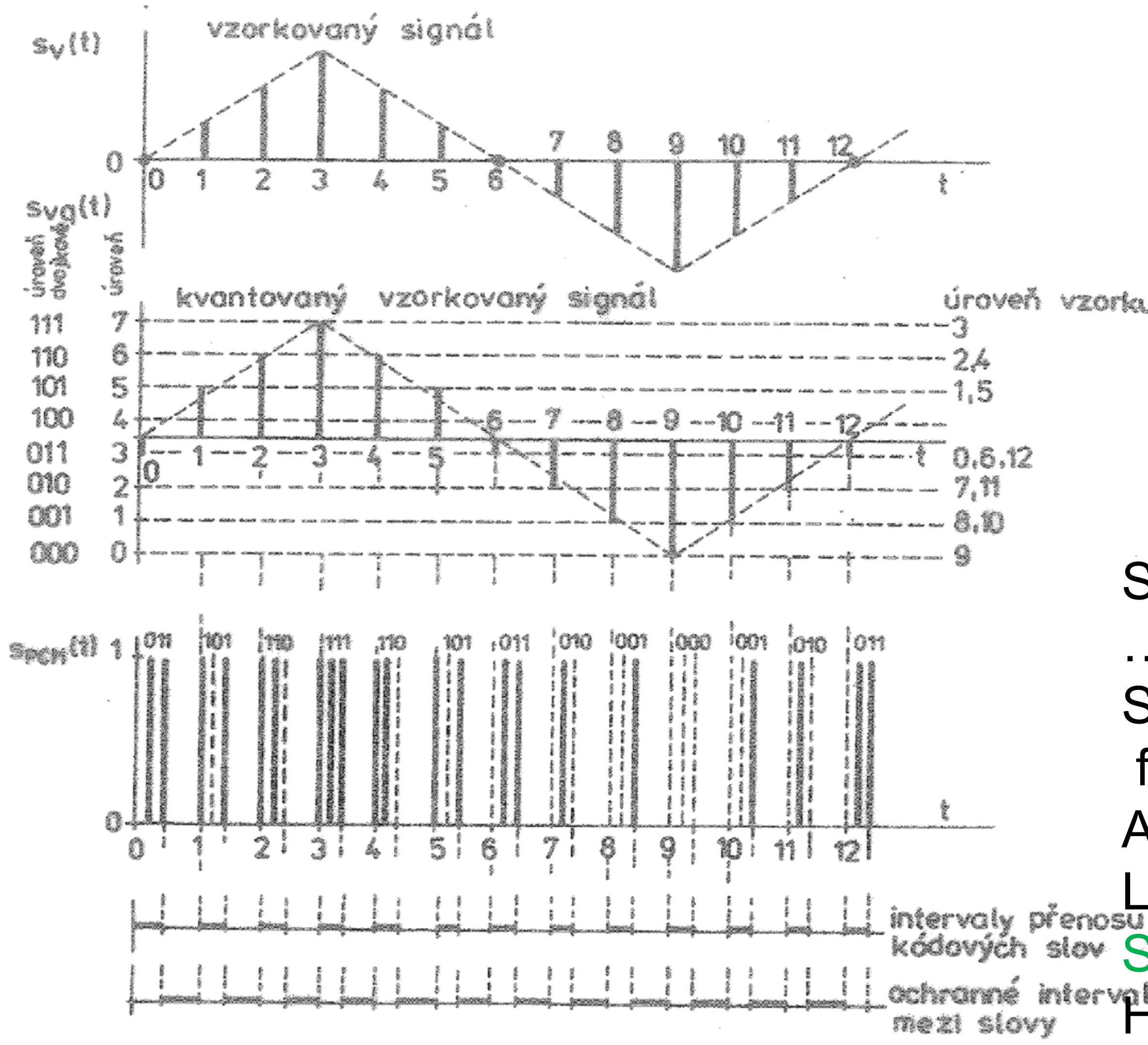
At the synapse, AP leads to secretion of neurotransmitters that bind to and modify the conductance of postsynaptic membrane channels.

Effect: Excitation or inhibition of postsynaptic neuron (d), initiation of muscle contraction (g), modulation of secretion/absorption (h)...



***!** Such a neuron does not exist!*
In reality, every post-synaptic activity (on the right) depends on its own specific pre-synaptic neuron ***!***

Excitatory and Inhibitory Post-Synaptic Potentials, EPSPs and IPSPs. (Plus a Neuromuscular Plate, just for completeness…)



Obr.8.43

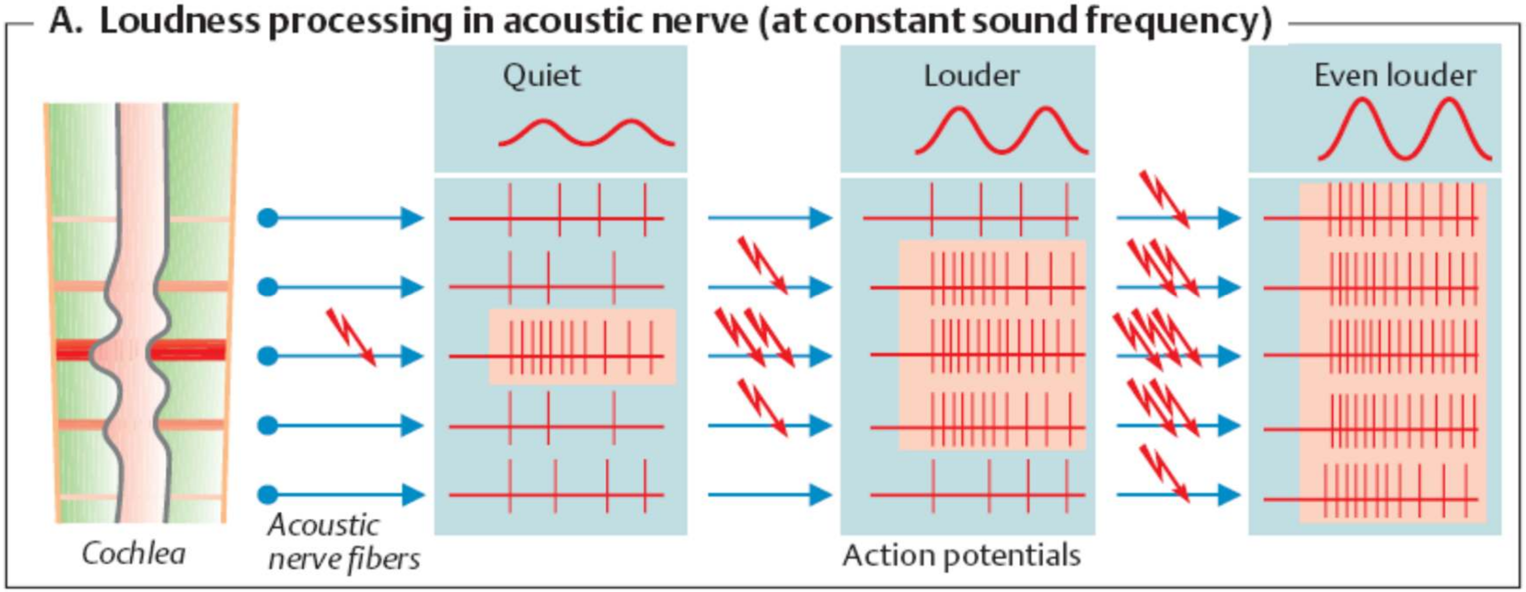
PCM (při osmi kvantovacích úrovních)

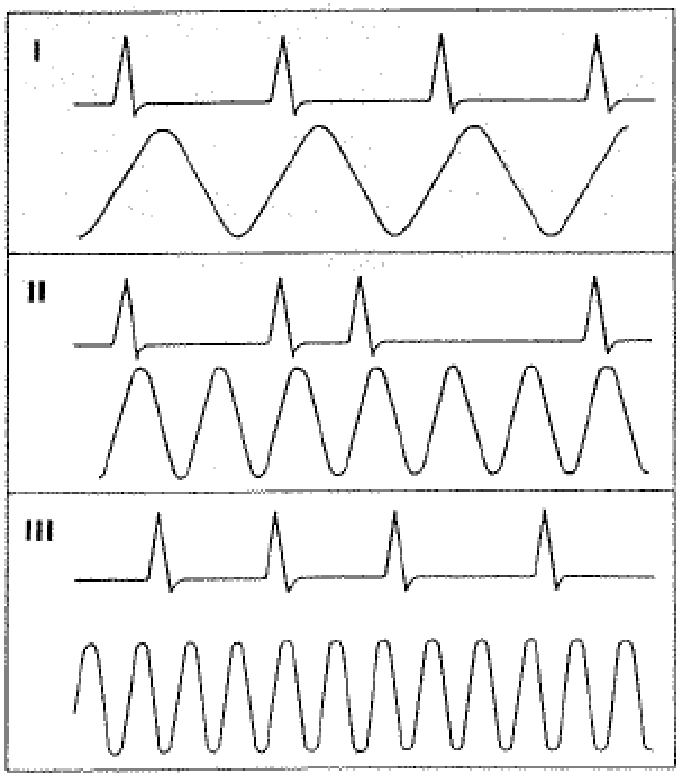
[Vejražka, 1991,Signals and systems]

This is only a methaphor!

Pulse-code modulation (PCM)

Sound file extensions:
…, .WAV, .PCM
Synchronous with sampling frequency,
Auditory pathway:
Low freq. (20-500 Hz)
Synchronous with sound,
High frequency f. (0.5-16 kHz)
Asynchronous, triggered





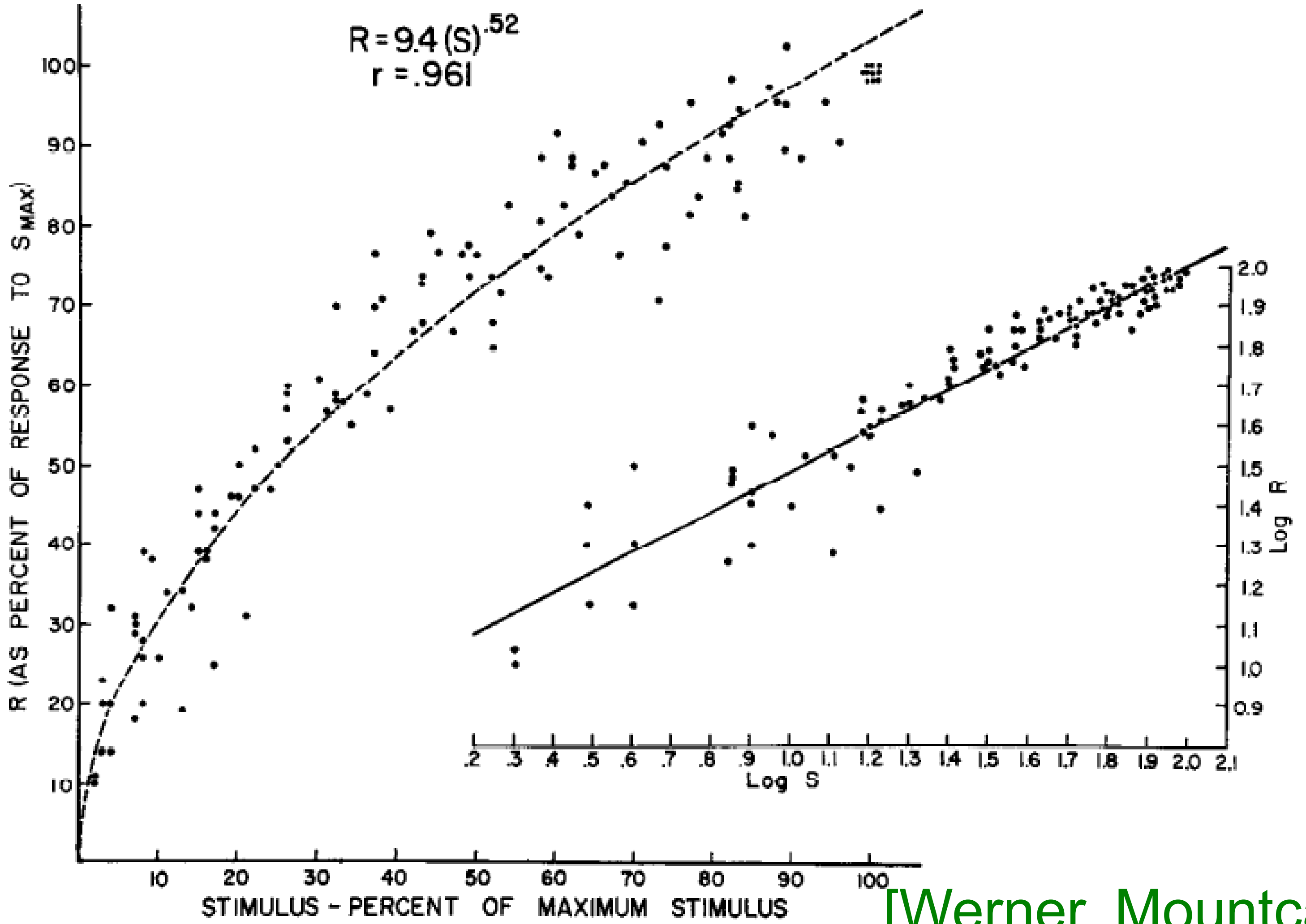
Frequency:

<200 Hz

>2000 Hz

Encoding of Sound Loudness and Frequency by APs (= Spike Trains)

Objective /to Internal /to Subjective; This transform is described as: Psychophysical Law, is also called Psychometric Function, R=f(S)



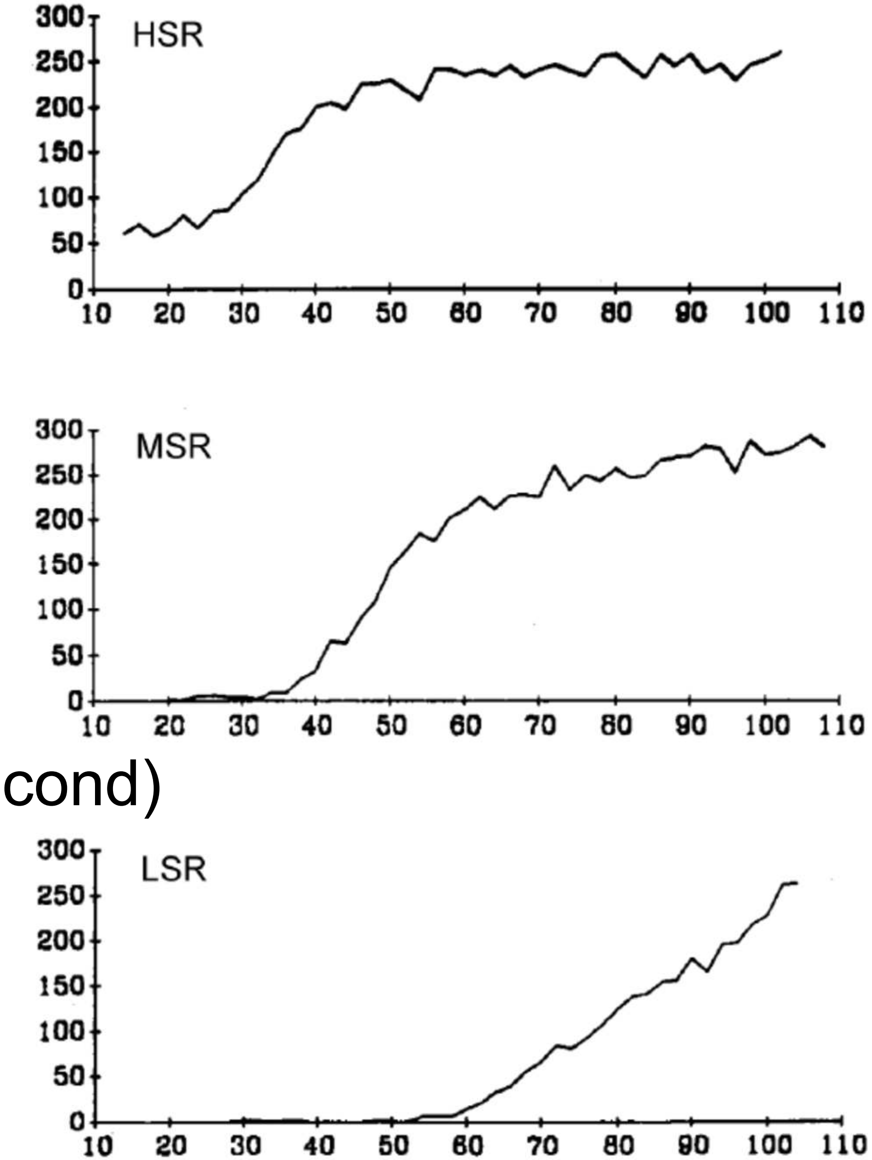
Touch, vibration stimulus: skin indentation stimuli, internal response: spike trains in mechano-receptive fibers, Subjective responses: touch percepts

[Werner, Mountcastle, 1965]

High, Middle and Low Spontaneous Rate Auditory Nerve Fibres

dB SPL,
decibels of sound pressure level (objective units)
spike rate (internal units)

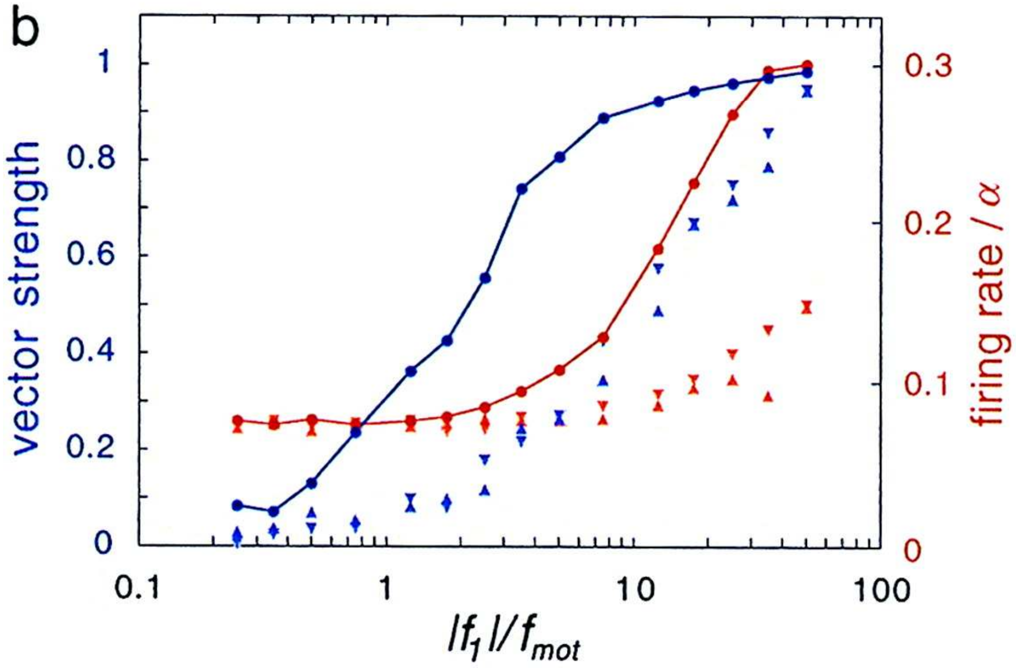
x-axis: stimulus intensity, dB SPL,
y-axis: neuronal spike rate per s(econd)



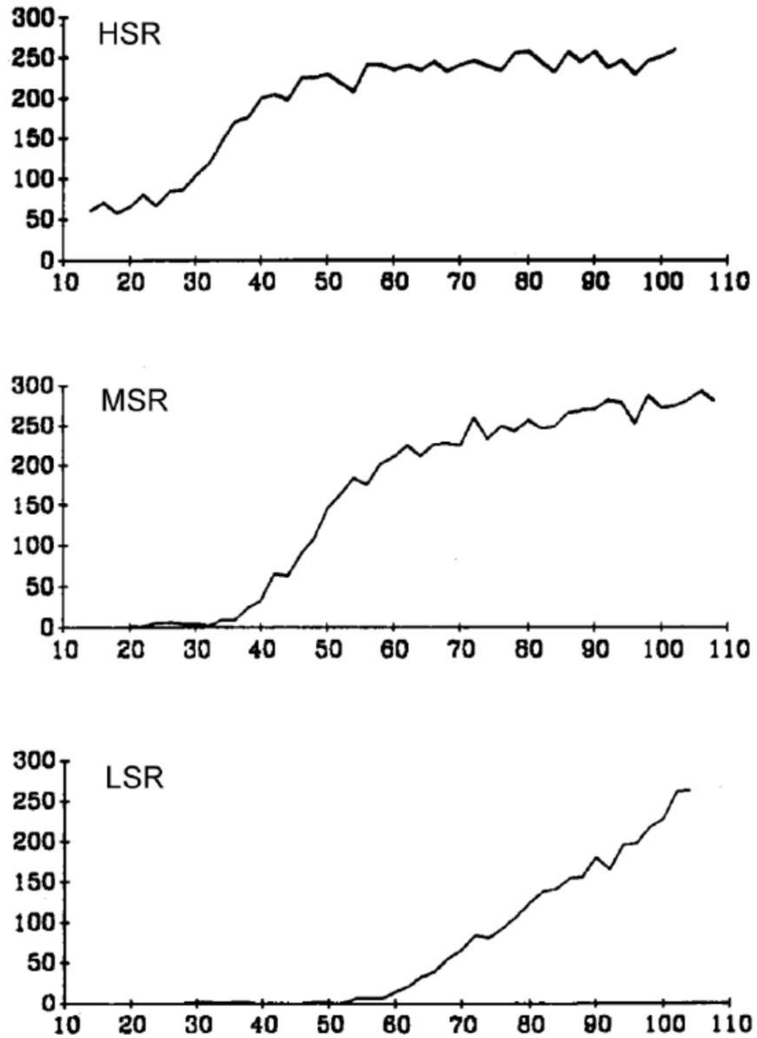
[WINTER I.M., PALMER A.R. Intensity coding in low-frequency auditory-nerve fibres of the guinea pig. J Acoust Soc Am 1991, 90, pp. 1958–1967]

[Winter and Palmer, 1991]

Physical /to Internal Representation of Percept; Modality of Percept; Internal Representation by Spike Trains



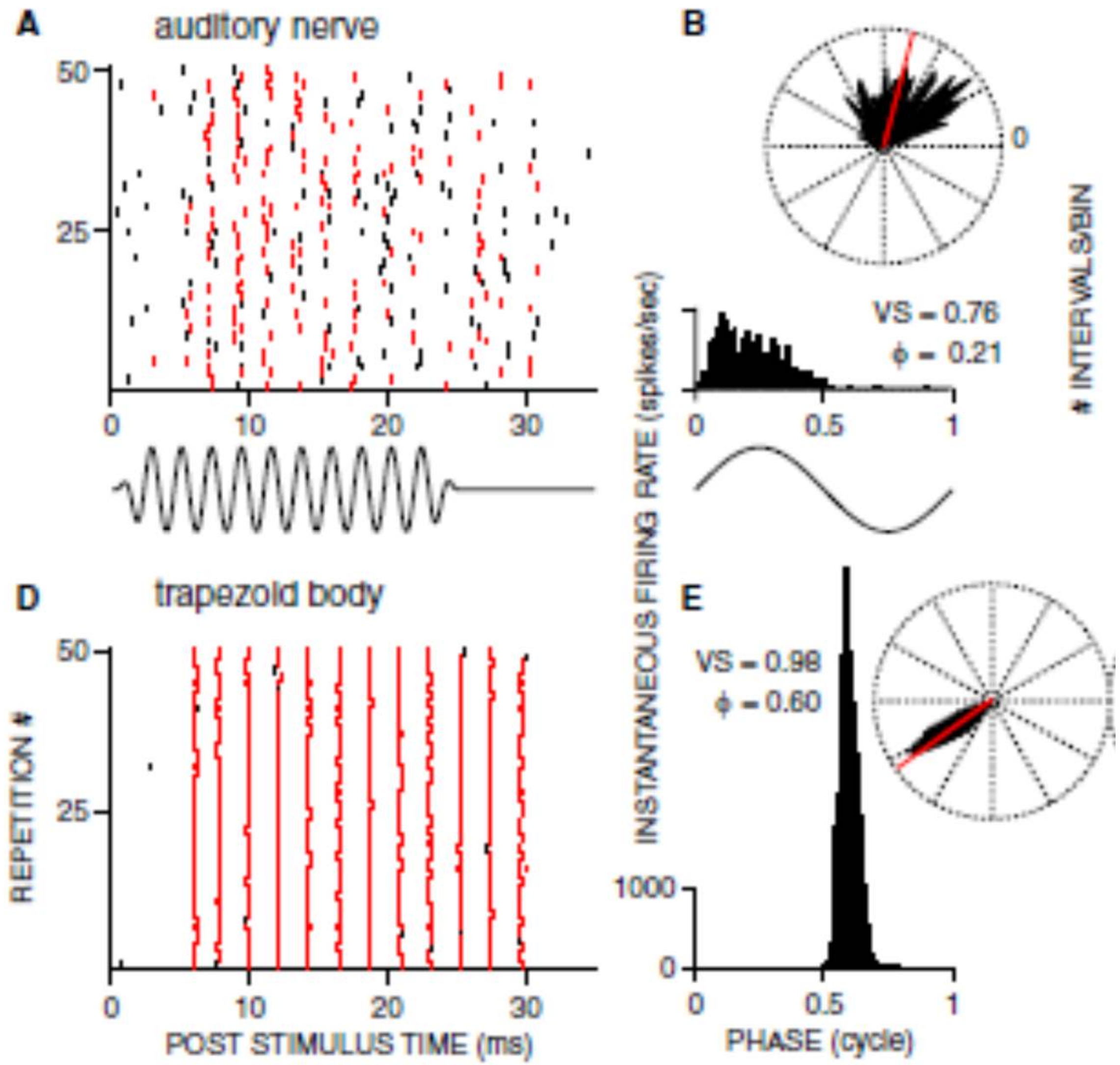
[Camalet, Duke, Julicher, Prost, Proc Natl Acad Sci USA, 2000]



[Winter and Palmer, 1991]

Vector strength,

has values from 0 to 1.
Is similar to correlation coefficient
(which has values from –1 to 1).

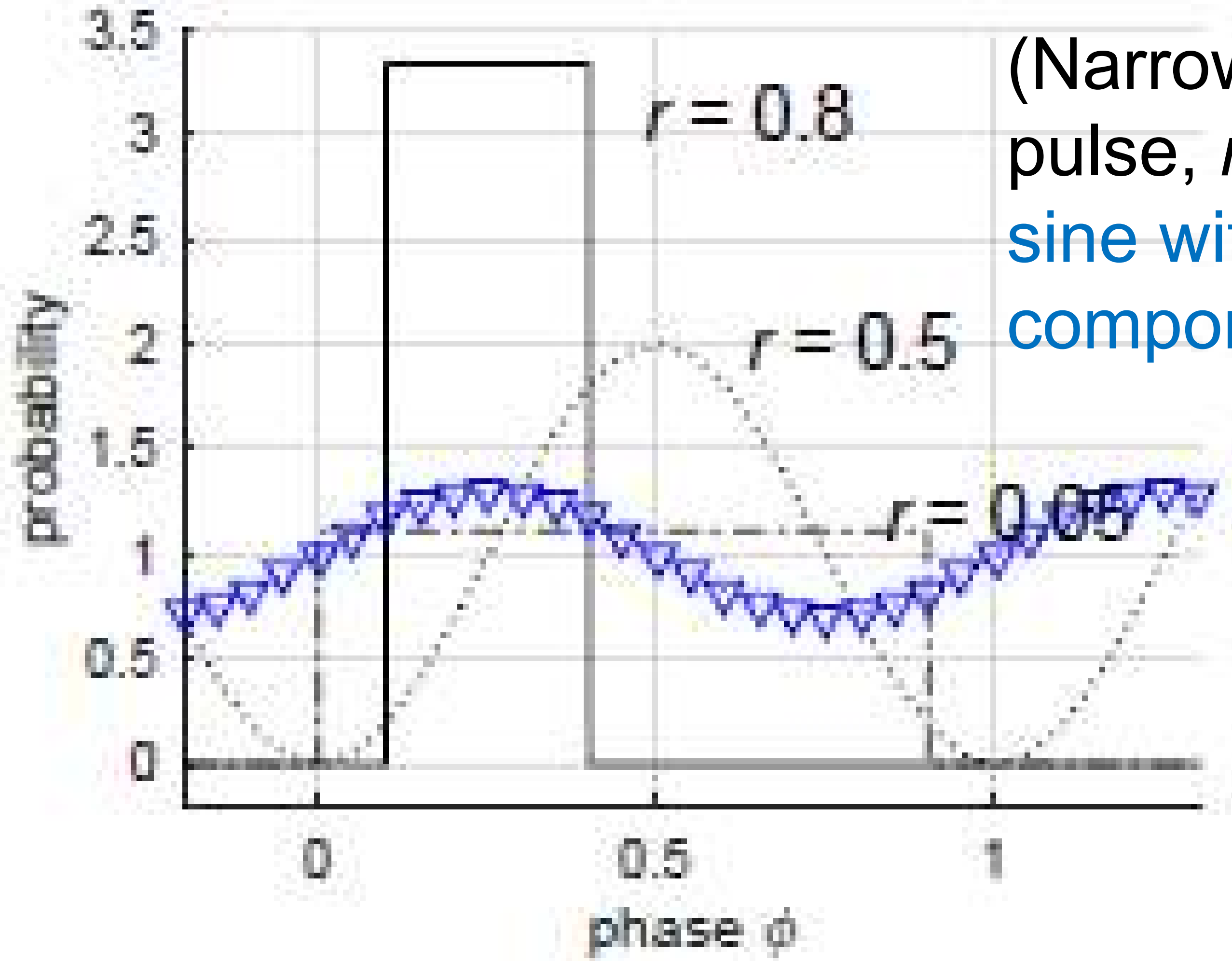


$$r(\varphi)=\frac{1}{N}\sqrt{\left(\sum_{i=1}^{n}\cos\varphi_i\right)^2+\left(\sum_{i=1}^{n}\sin\varphi_i\right)^2}$$

[Joris et al, 2006]

[Goldberg and Brown, 1969]

Examples of variable
Vector strengths r



Examples with
values r = 0.5, 0.8, 0.05

$$1 + \sin\phi, r = 0.5$$

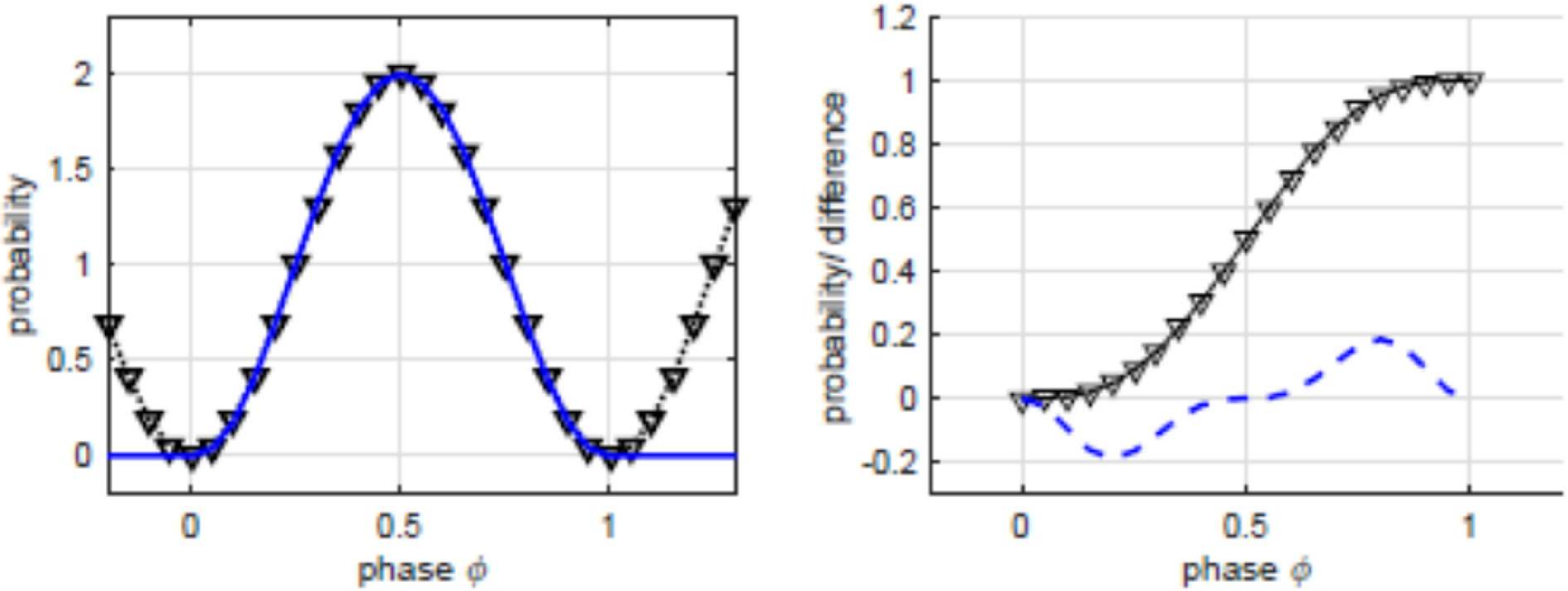
(Narrow) rectangular
pulse, r = 0.8

sine with DC
component, r = 0.05

[Toth, Marsalek, Pokora, Biol Cybern, 2018]

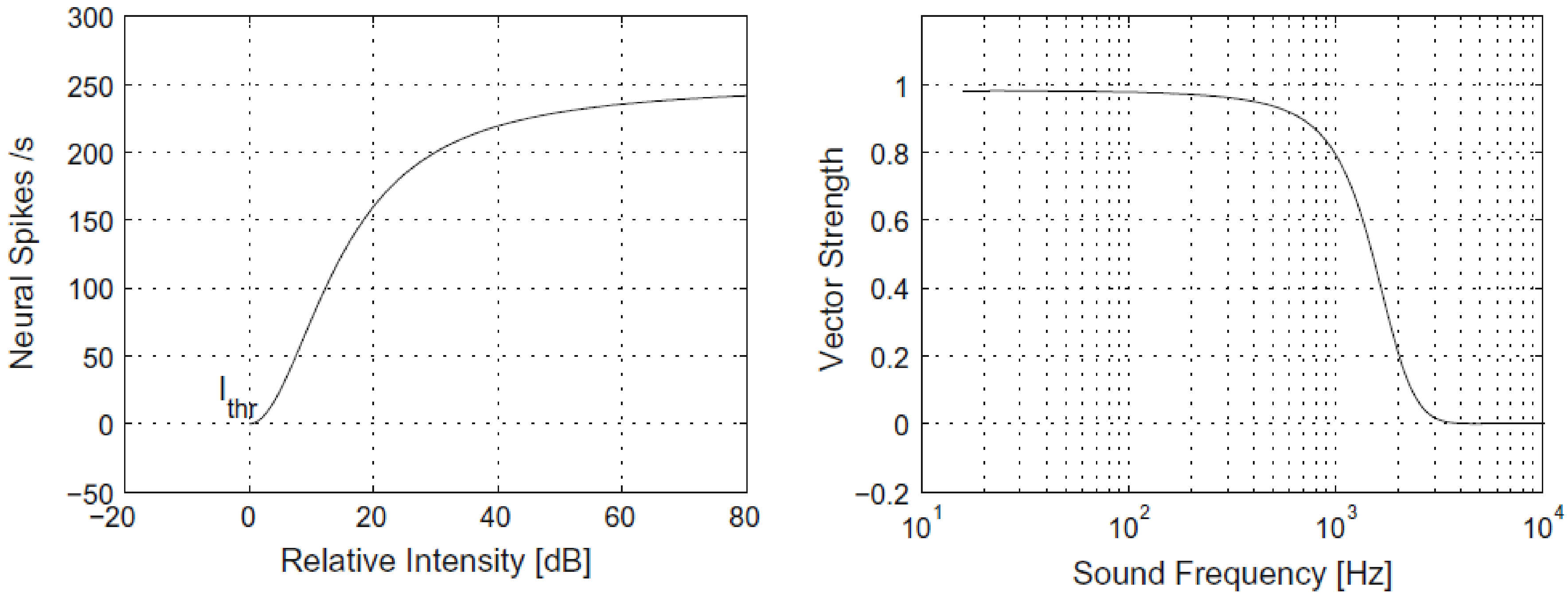
Circular statistics

Circular statistics is used in description of repetitive events (time domain).
It can cover time repetition on different time scales.
(Examples: sound period, time gap in sound.)
Can be used in description of horizontal sound localization (for different quantities: time period, or space).



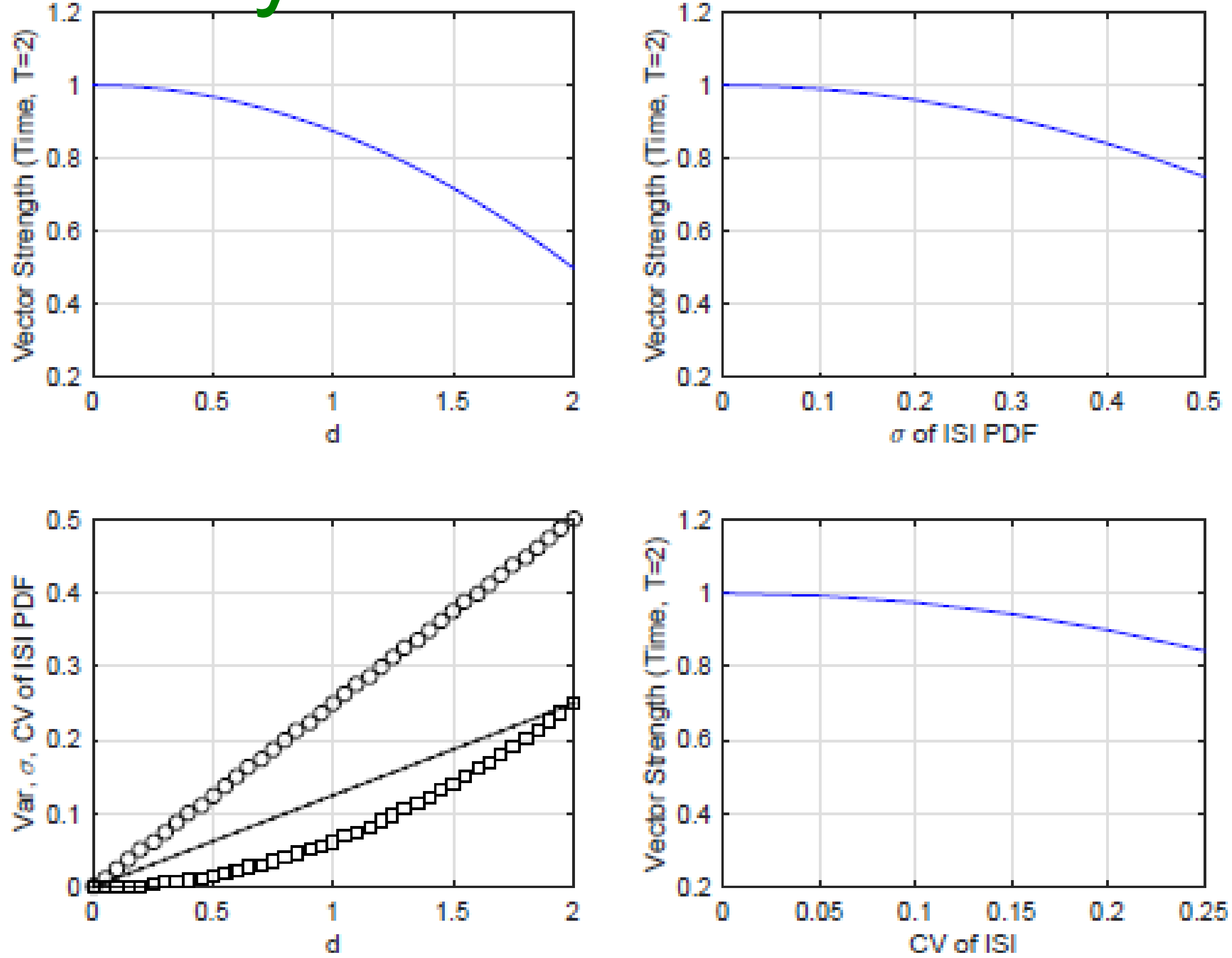
[Toth, Marsalek, Pokora, Biol Cybern, 2018]

“Canonical” spiking auditory model



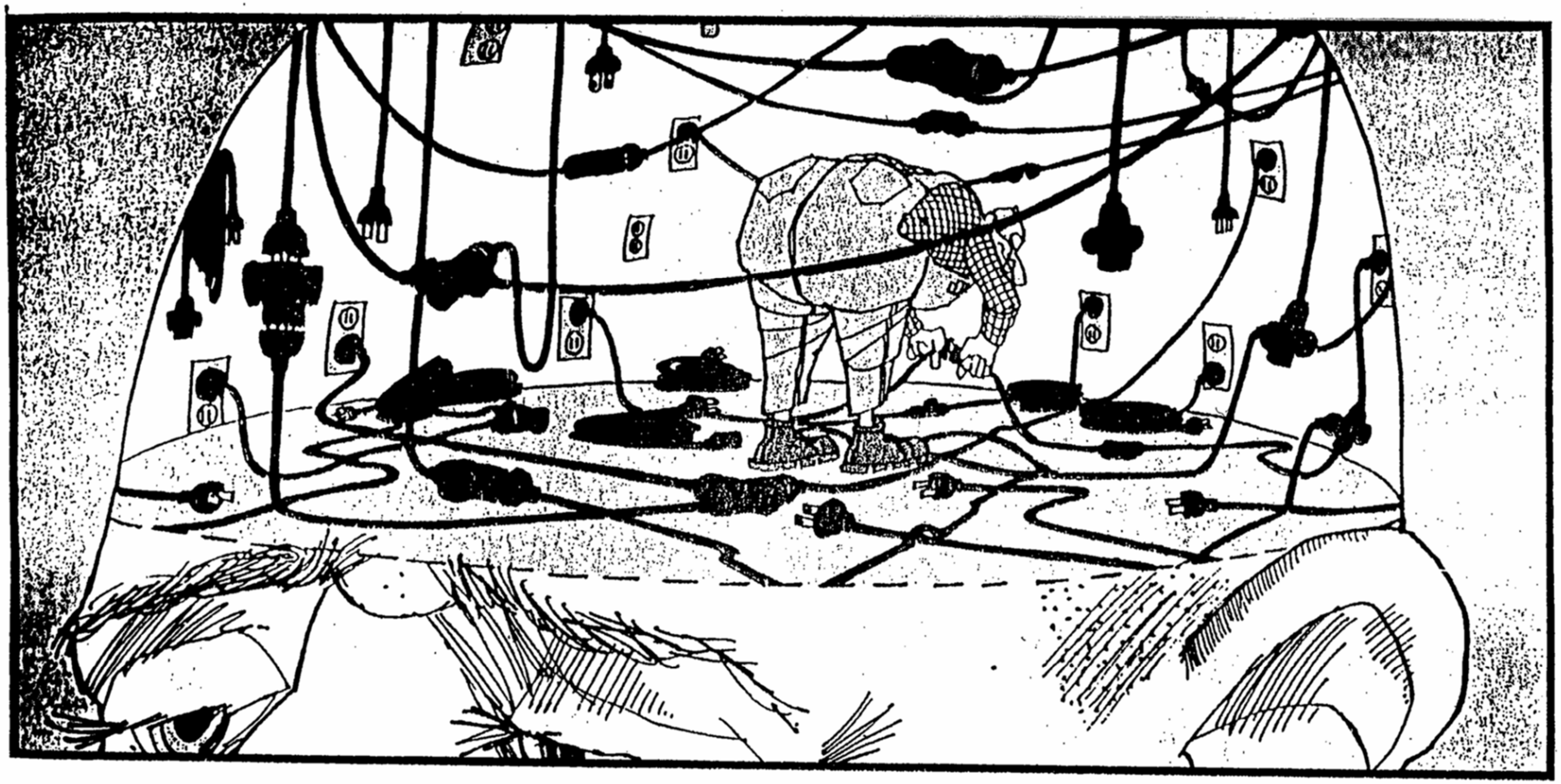
[Heinz MG, Zhang X, Bruce IC, Carney LH, 2001]
[Toth, Marsalek, Pokora, Biol Cybern, 2018]

Vector strength, spike timing jitter and other variability measures

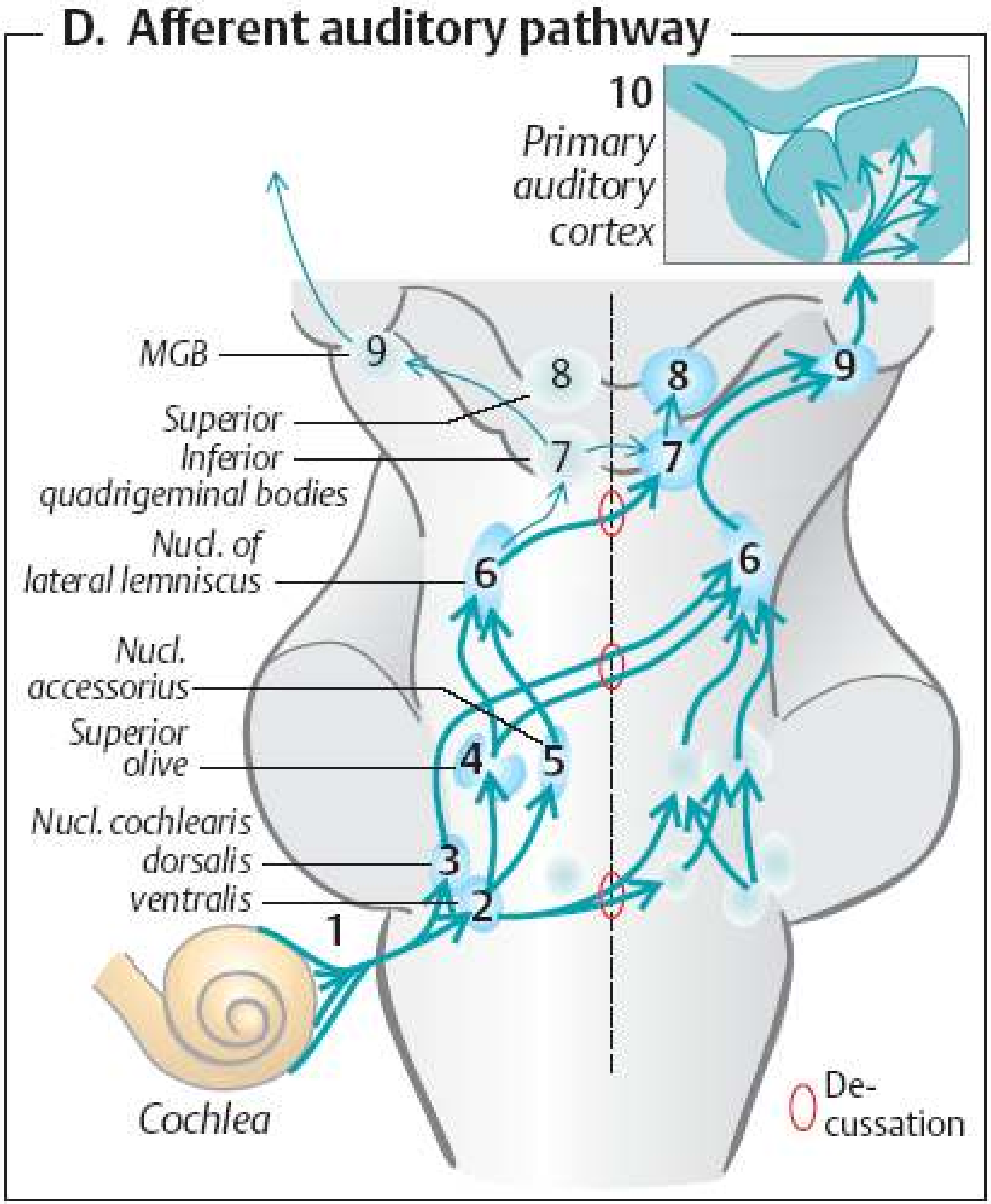


[Toth, Marsalek, Pokora, Biol Cybern, 2018]

Auditory Pathway, Parts: Monoaural (1) and Binaural (2)



How the brain works.



Auditory pathway Binaural part (2)

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

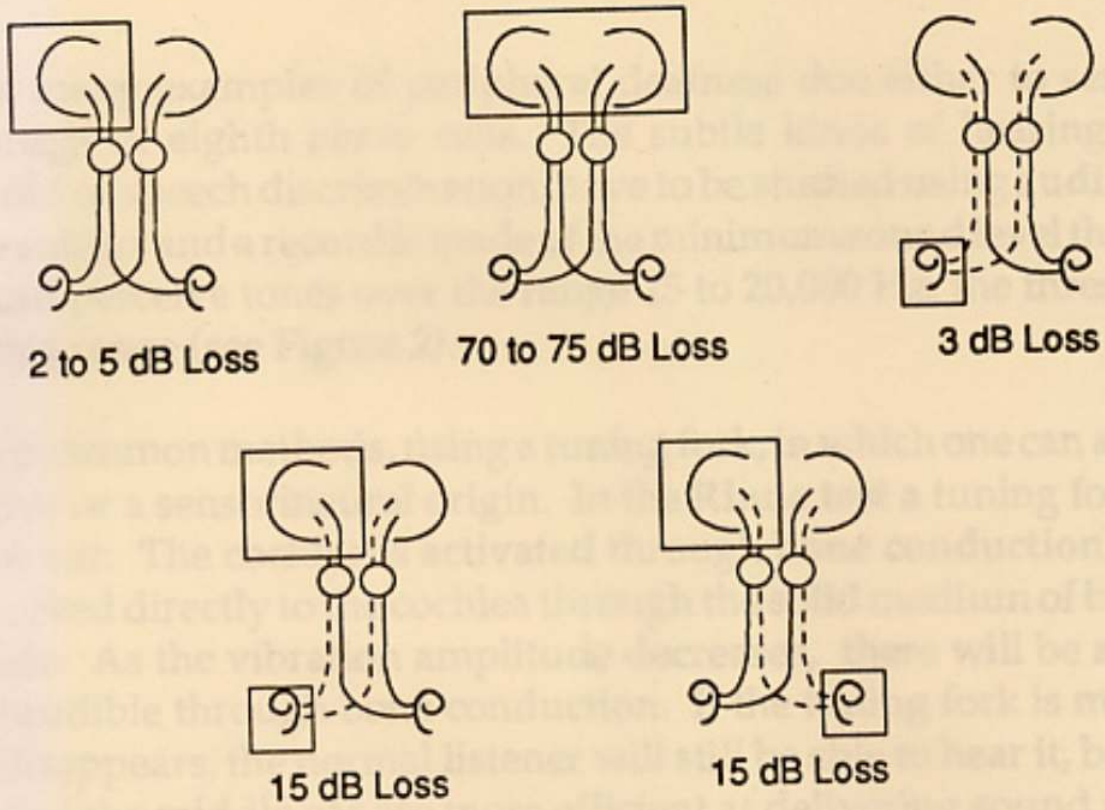
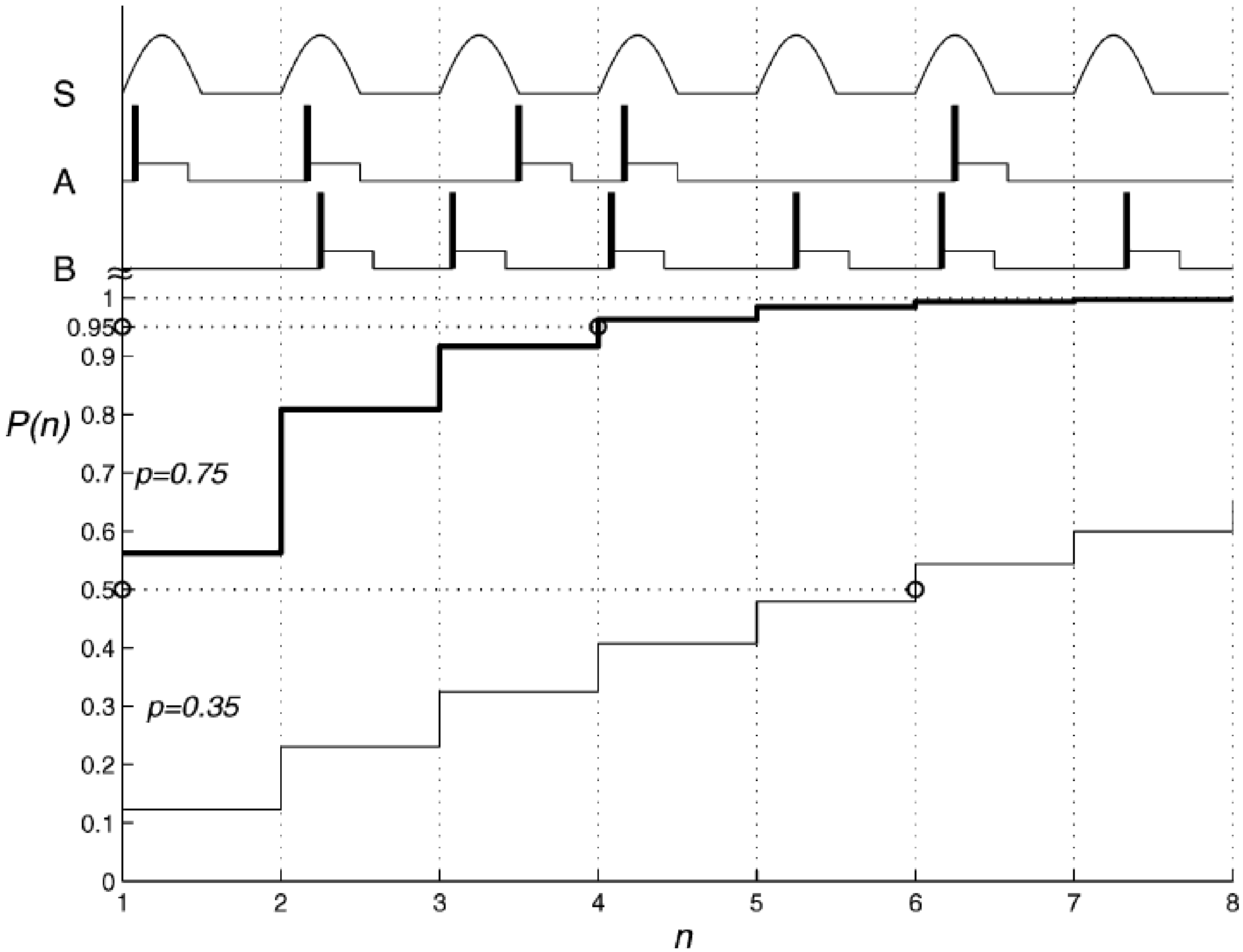


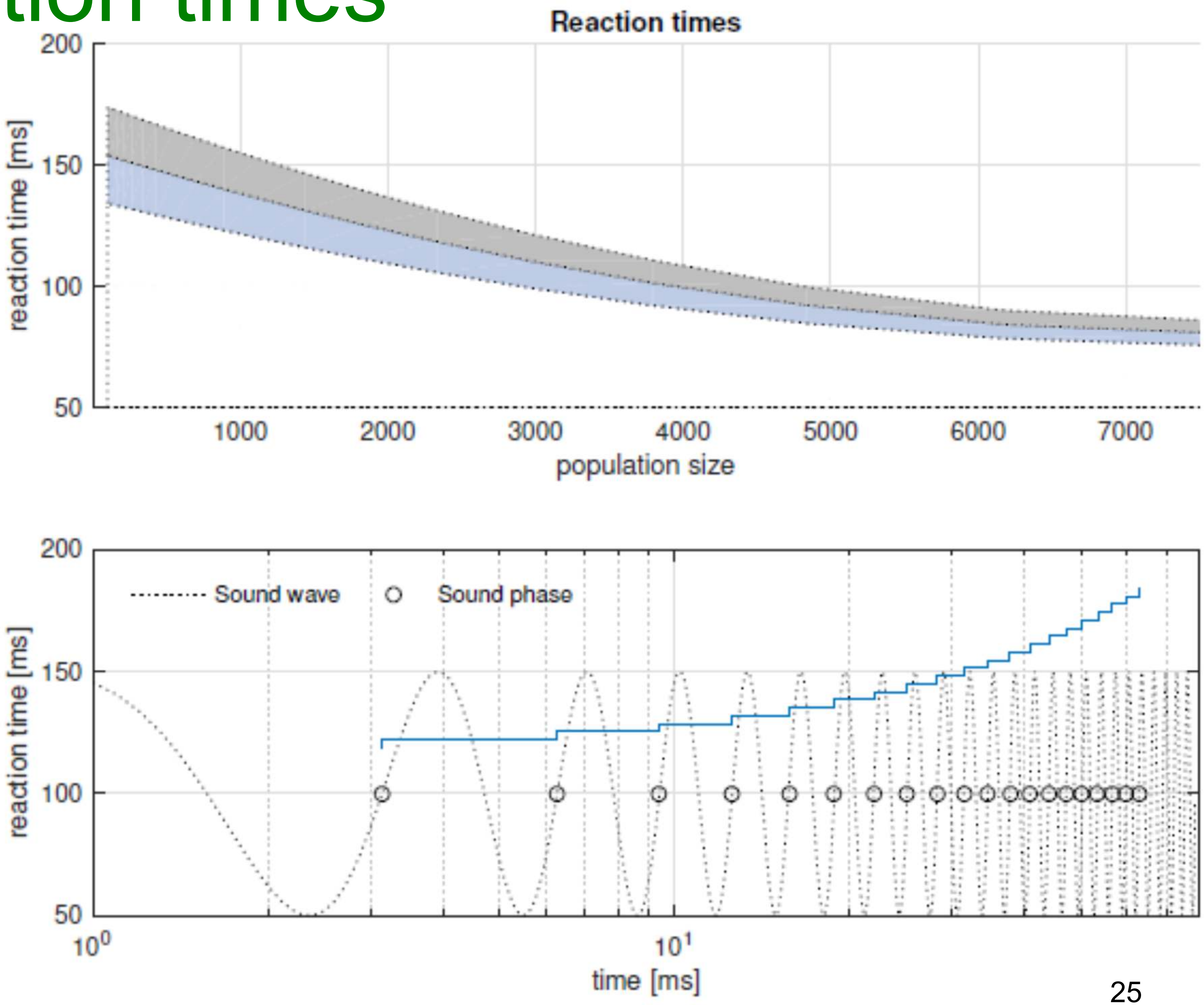
Figure 18. Summary of experiments demonstrating bilaterality of auditory pathways in dog. Number below each diagram is hearing loss in decibels; box around symbol for cerebral cortex or cochlea indicates destruction of it. In D, hearing depends on uncrossed fibers of left lateral lemniscus, whereas in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

(Coincidence) Detection Probability of Two Spikes Converging on Medial Superior Olive Neuron



[Marsalek, Lansky, Biol Cybern, 2005]

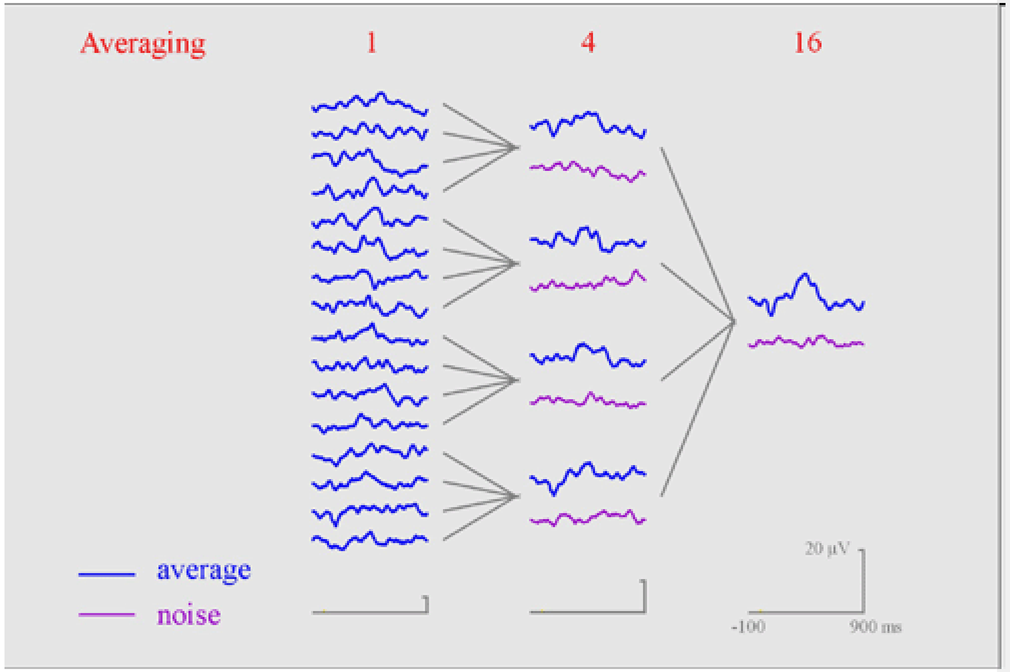
Reaction times

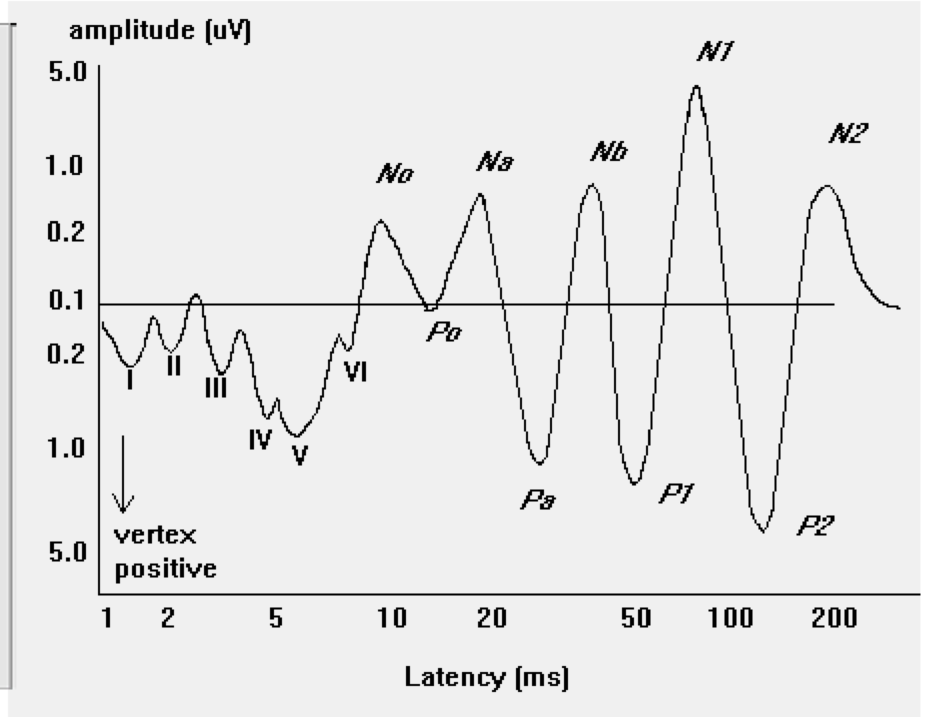


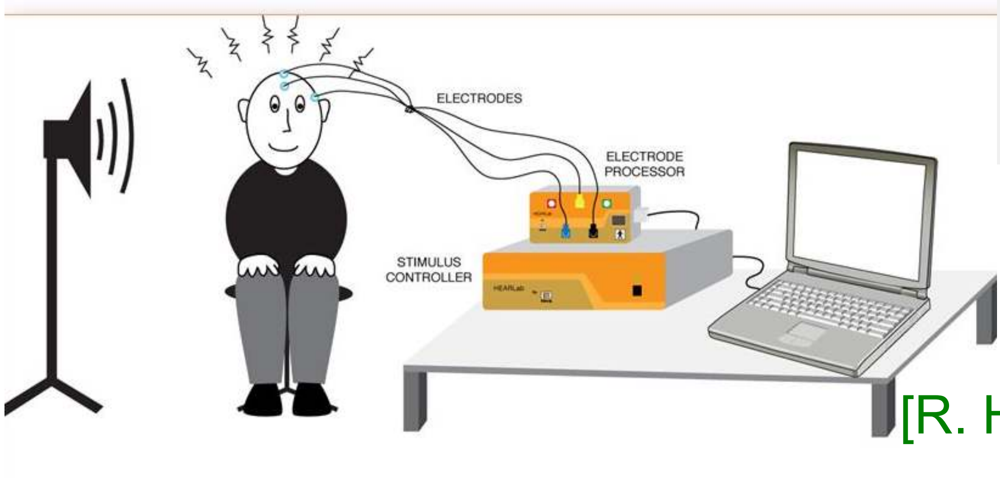
[Toth, Marsalek, Pokora, Biol Cybern, 2018]

Objective Signal From Lower Auditory Relays Is Recorded As: Evoked Potentials

AEP – auditory EP
VEP – visual EP







Repetition rate in brainstem ER audiometry
Can be of low freq. sound (40 Hz).

[R. Hari et al, Exp Brain Res, 1980]

Literary references

[Werner, Mountcastle,
J Physiology, 1965],
[Goldberg and Brown,
J Physiology 1969],
[R. Hari et al, Exp Brain Res, 1980]
[C. Koeppl, J Neuroscience, 1997],
[Camalet, Duke, Julicher, Prost, Proc Natl Acad Sci USA, 2000],
[Joris, et al, Hear Res, 2006],
[Koeppl C, Biol Cybern, 1997]
(on vector. strength in barn owl)
etc

our colleagues
[Marsalek, Lansky,
Biol Cybern, 2005],
[Toth, Marsalek, Pokora,
Biol Cybern, 2017]
[Bouse, Vencovsky, Rund, Marsalek, JASA, 2019]
etc

Conclusions

1 Auditory pathway consists of mono-aural and binaural part.

2 Neurons encode signals by trains of action potentials, spike trains.

3 Several sound processing stages are attributed to different nuclei in the auditory pathway.

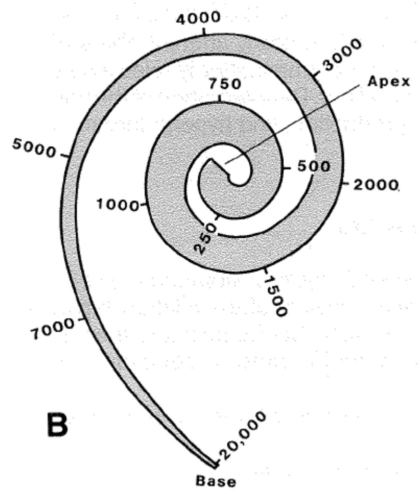
4 Binaural hearing uses two cues, Interaural Time Difference (ITD) and Interaural Level Difference. ILD (Level) difference is more important.

5 Ultimate processing stage is sound representation in Auditory Cortex.

Summary

- Auditory nerve encodes sound in digital format – using trains of action potentials (spike trains) composed from binary (all-or-none) pulses.
- Auditory pathway branches into two anatomically and functionally distinct neural pathways: 1 ascending mono-aural pathway and 2 binaural pathway.
- Between cochlea and auditory cortex, signal is relayed through circa 10 neuronal relays (we highlight 7 here). Not all of them have known functions.
- This (3rd) talk deals with sub-cortical processing, while next (4th) deals with thalamo- cortical, in short cortical processing.
- Distinct mono aural nuclei are: 1 spiral ganglion (auditory nerve center), 2_cochlear nuclei, 3 superior olivary complex (MSO, LSO) and 4 lamina quadri-gemina nuclei, one of whose is inferior colliculus.
- Then as numbers 5, 5A, 5B, 5C the pathway intertwins through the bundle of lemniscus lateralis to 6 medial geniculate nucleus, which is in fact thalamic nucleus.
- Last stage is 7 auditory part of cerebral cortex consisting od several auditory areas, one called primary and the rest is dubbed secondary.
- Binaural pathway starts with the 3rd neuron of medial or lateral superior olive.
- While it is easy to dissect these pathways into anatomical parts, it is relevant what are functions of these, and they are mostly unknown to date.
- Majority of this talk deals with spikes, spikes = action potentials.

END
OF THE LECTURE

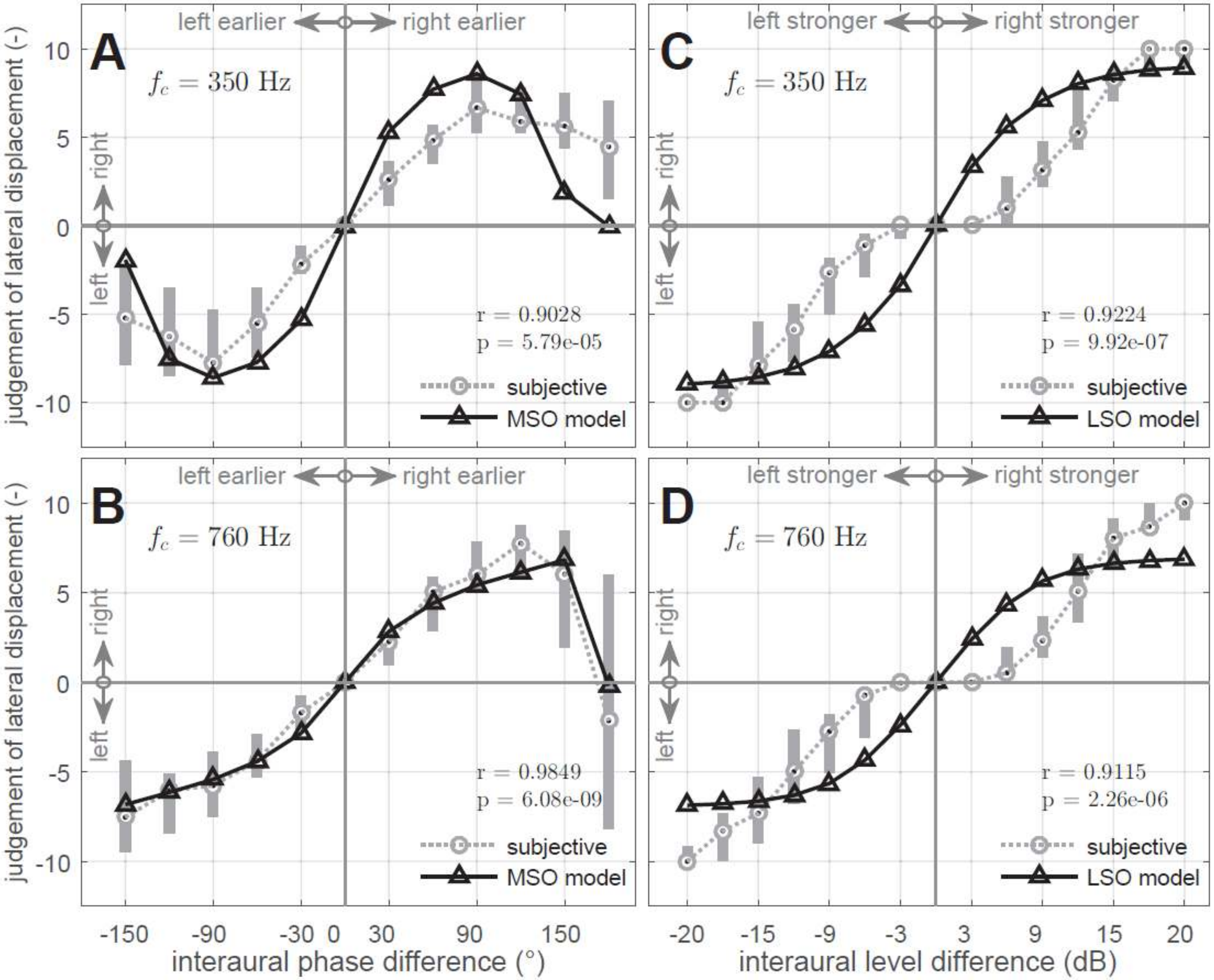


Thanks for your attention

Warning: neither the PDF, nor the PPT, PPTX, etc. versions of this presentation are official study materials. For internal use only. Do not distribute.

Contacts: (Petr.Marsalek@CVUT.CZ)
Petr.Marsalek@LF1.CUNI.CZ

sound azimuth, model and subjective response



[Bouse, Vencovsky, Rund, Marsalek, JASA, 2019]

Group: Audiology, Acoustics and Computational Neuroscience, CTU and 1stMF CUni (year 2015)