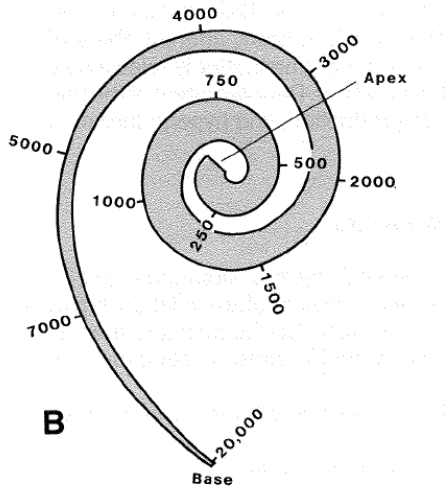
FAV, Talk no. 3,
Auditory pathway

http://nemo.lf1.cuni.cz/mlab/ftp/PPT-CVUT/

Petr Maršálek



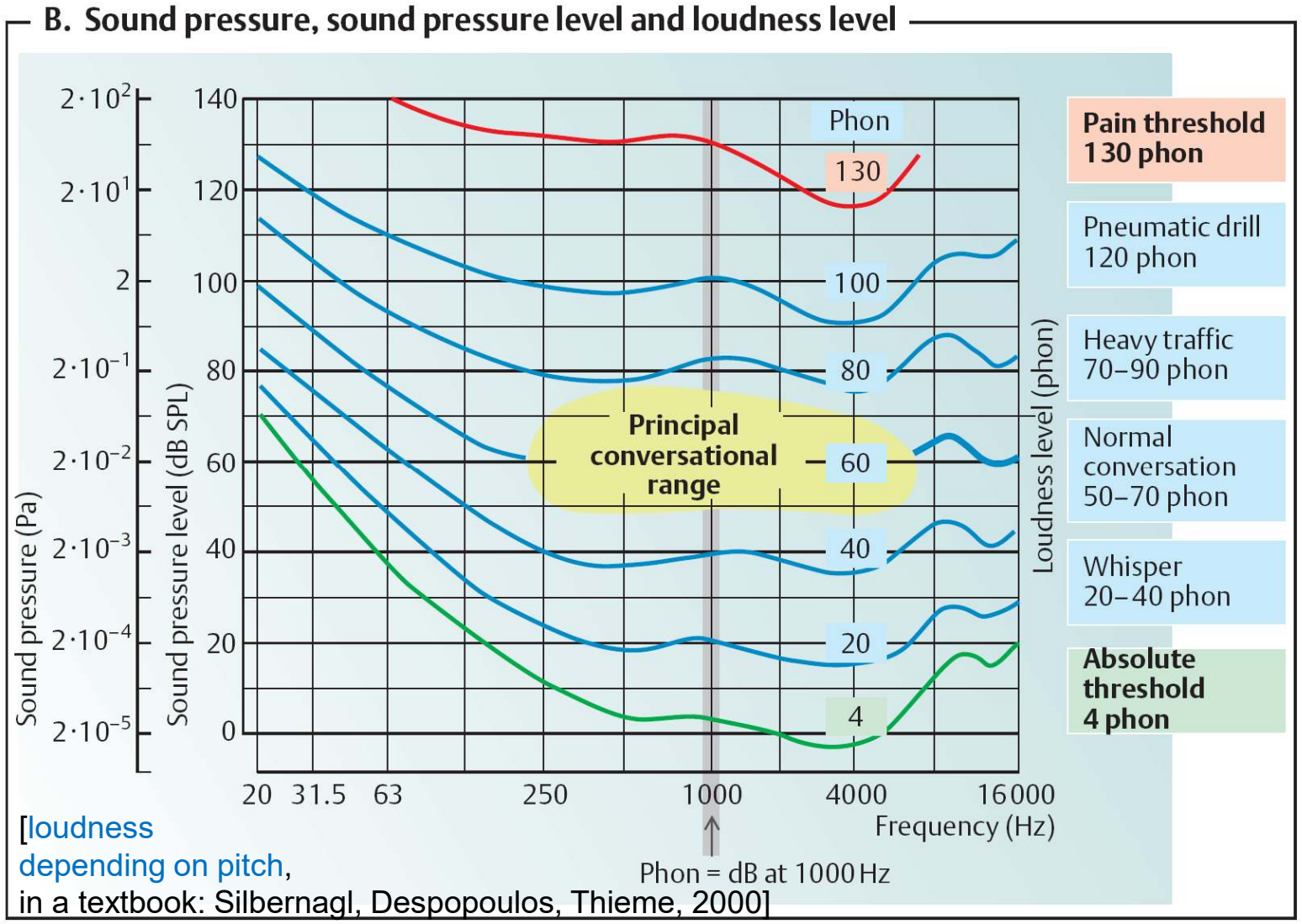
October 2022

Outline

- 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. Some have fewer and some have more neurons inbetween. 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 and with binaural/ spatial hearing.
- Distinct mono aural nuclei are: 1 spiral ganglion= auditory nerve center, 2_cochlear nuclei, 3 superior olivary complex. ie. medial and lateral superior olive, MSO, LSO, and 4 lamina quadri-gemina nuclei, one of whose is inferior colliculus.
- Then as numbers 5, 5A, 5B, 5C/ and variable number enbetween/ 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, we want to know, what are neuronal 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.

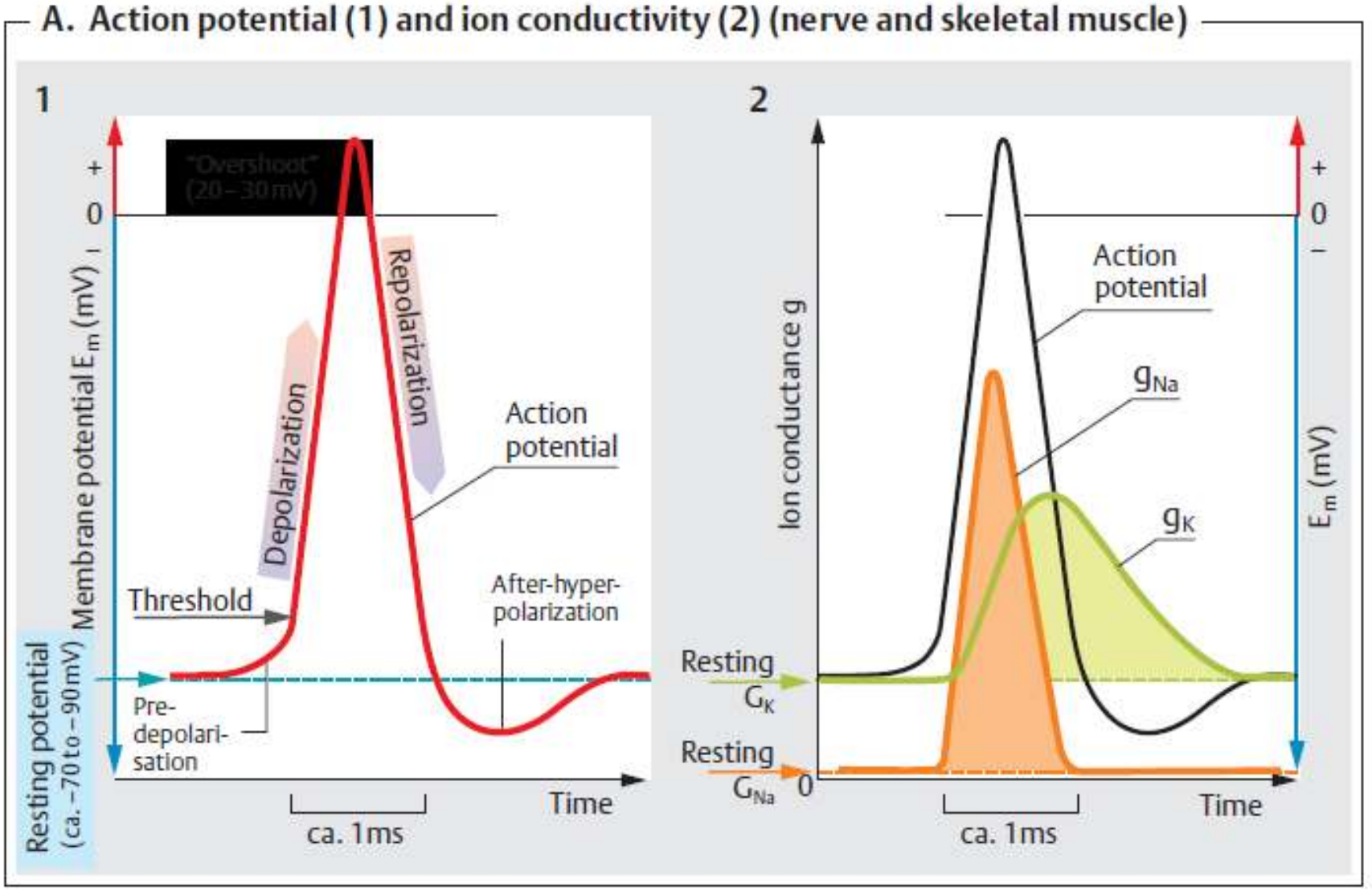
Before starting with spikes, recall Normal audiogram: x-axis, sound frequency (Hz), y-axis, sound pressure (Pa). Red top curve is pain threshold. Hearing threshold is Green bottom curve. Blue are curves of *subjectively* equivalent loudness level. dB SPL is *objective* unit, phone is *subjective* unit.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

Gray line is reference frequency 1000 Hz.

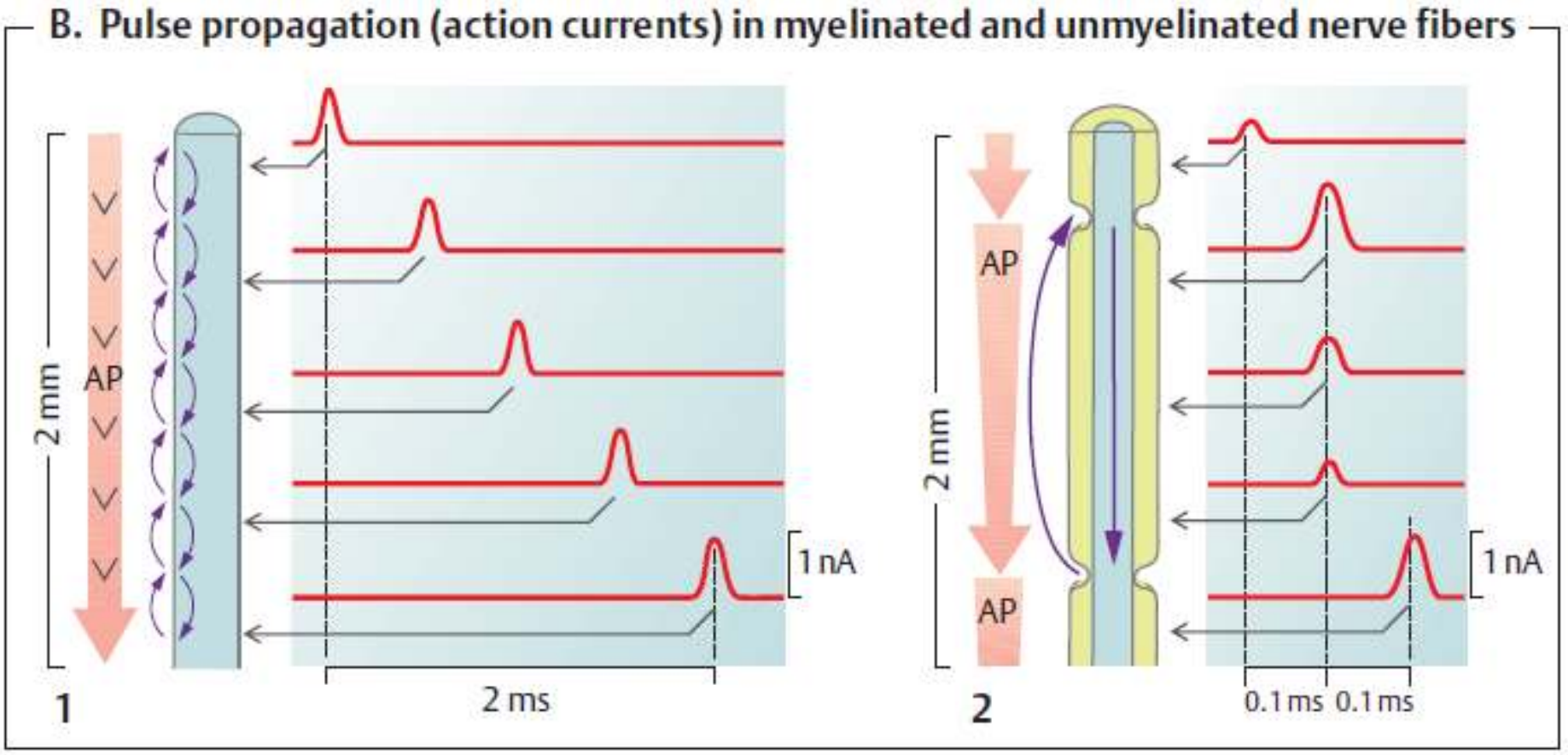


[loudness depending on pitch, in a textbook: Silbernagl, Despopoulos, Thieme, 2000]

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



AP Conduction in Neural Fiber



RECALLING PSYCHO-PHYSICS:
Objective /to Subjective Barrier;
Physical /to Perceptual Energy

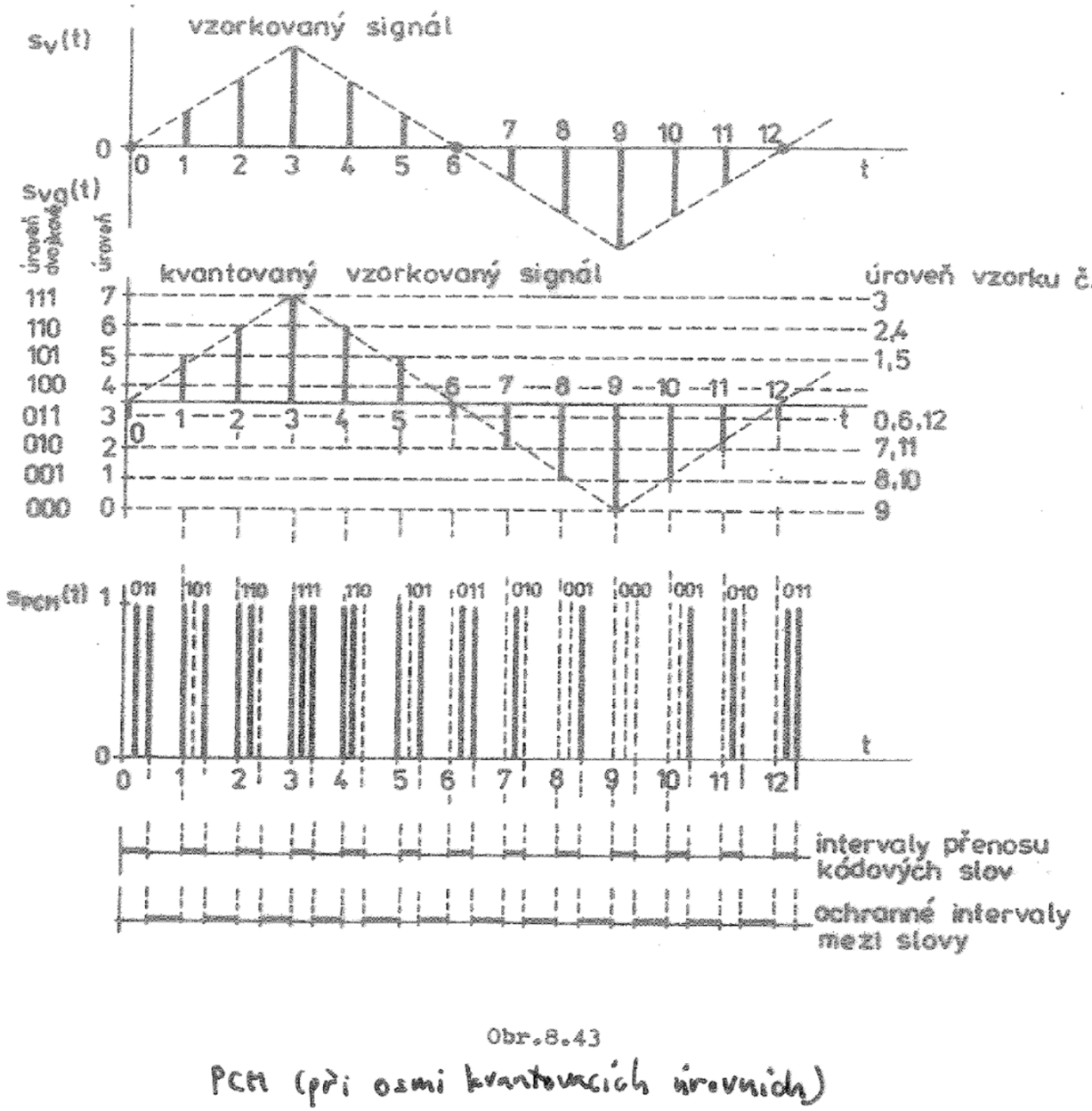
- amplitude
- frequency
- spectrum
- duration
- azimuth

A modulation, etc

- loudness
- pitch
- timbre
- length
- direction

roughness, etc

But: how is this represented/ encoded?



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

Origin: Axon departure from the neuronal body.

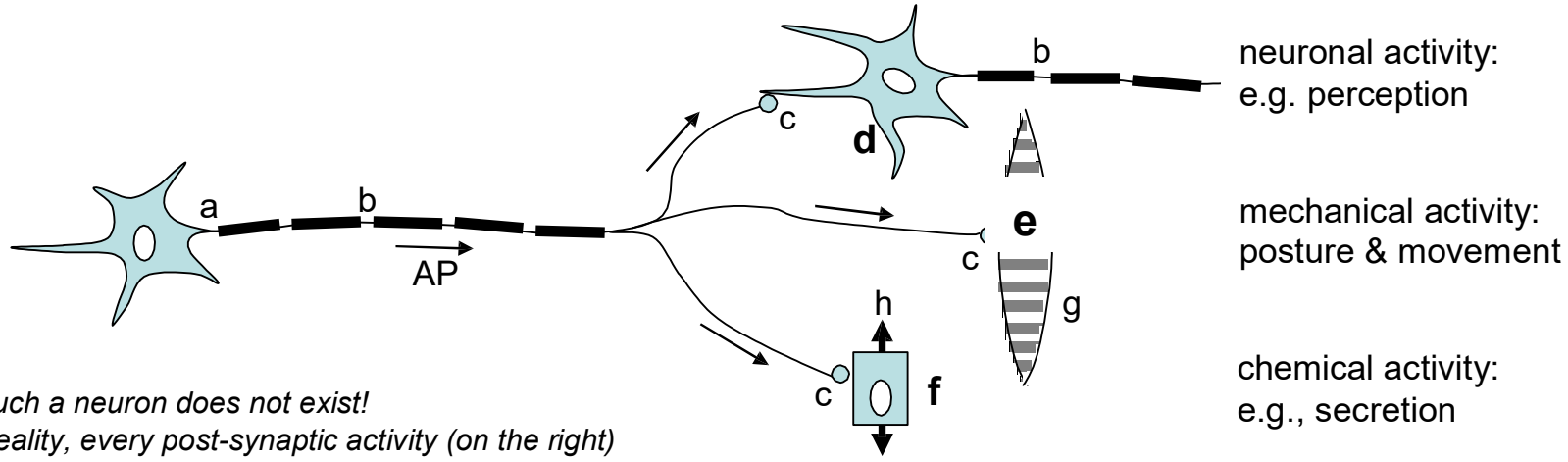
Propagation: By local circuits or, in myelinated axons, by saltatory conduction from one Ranvier node (b) to another.

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.

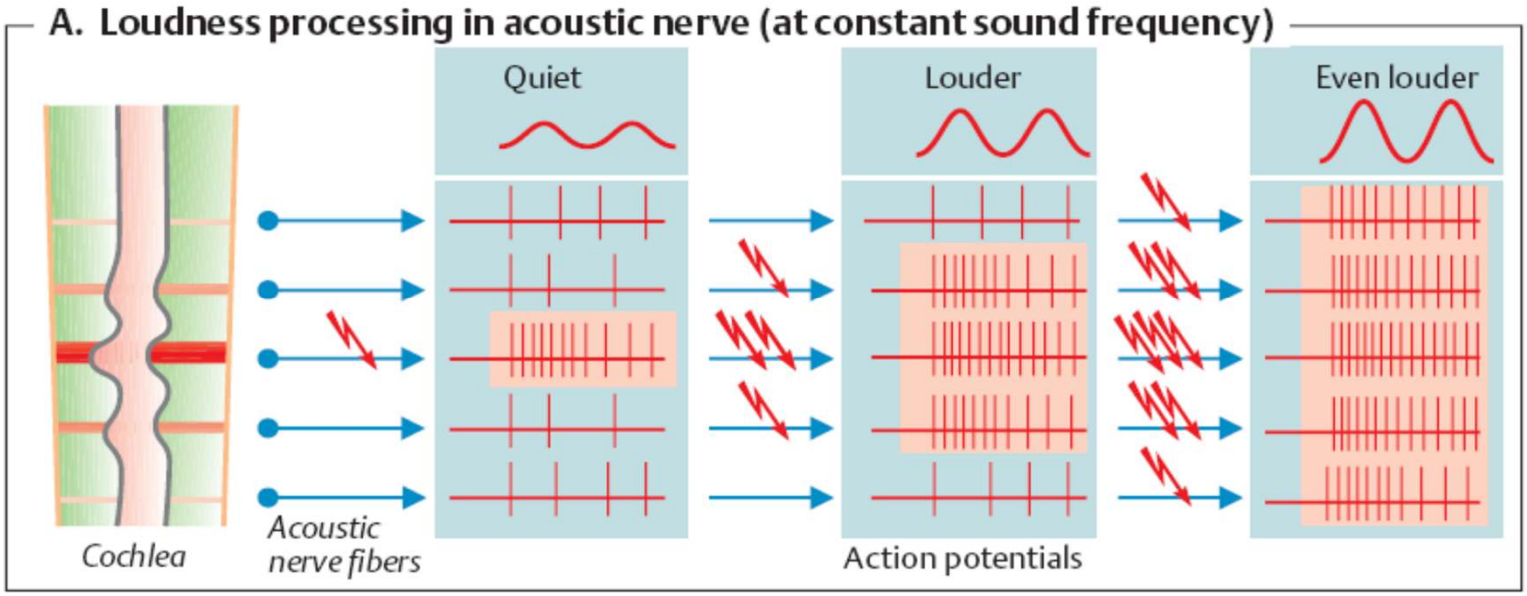
Effect: Excitation or inhibition of postsynaptic neuron (d), initiation of muscle contraction (g), modulation of secretion/absorption (h)...

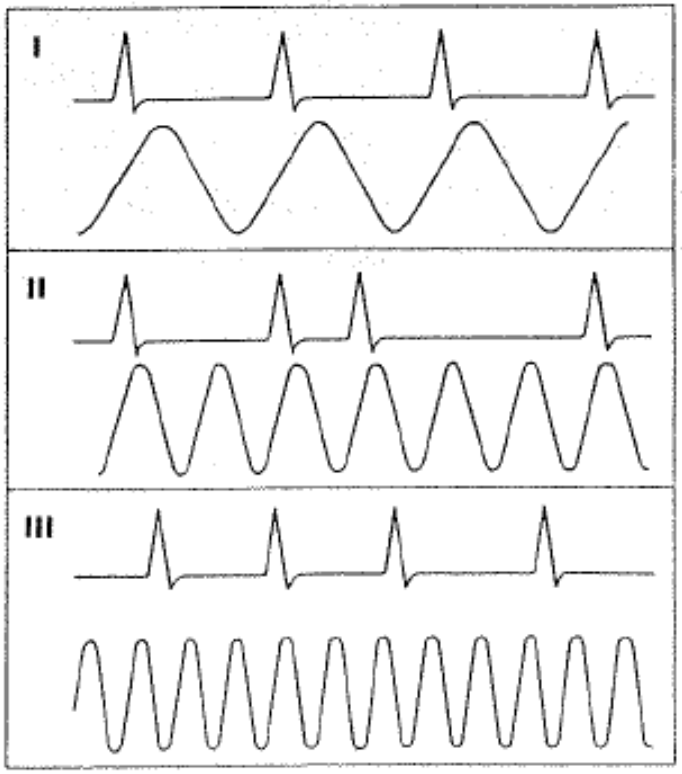


! *Such a neuron does not exist!*
In reality, every post-synaptic activity (on the right) depends on its own specific pre-synaptic neuron ***!***

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

Excitatory and Inhibitory Post-Synaptic Potentials, EPSPs and IPSPs. (Plus neuromuscular plate, just for completeness…)





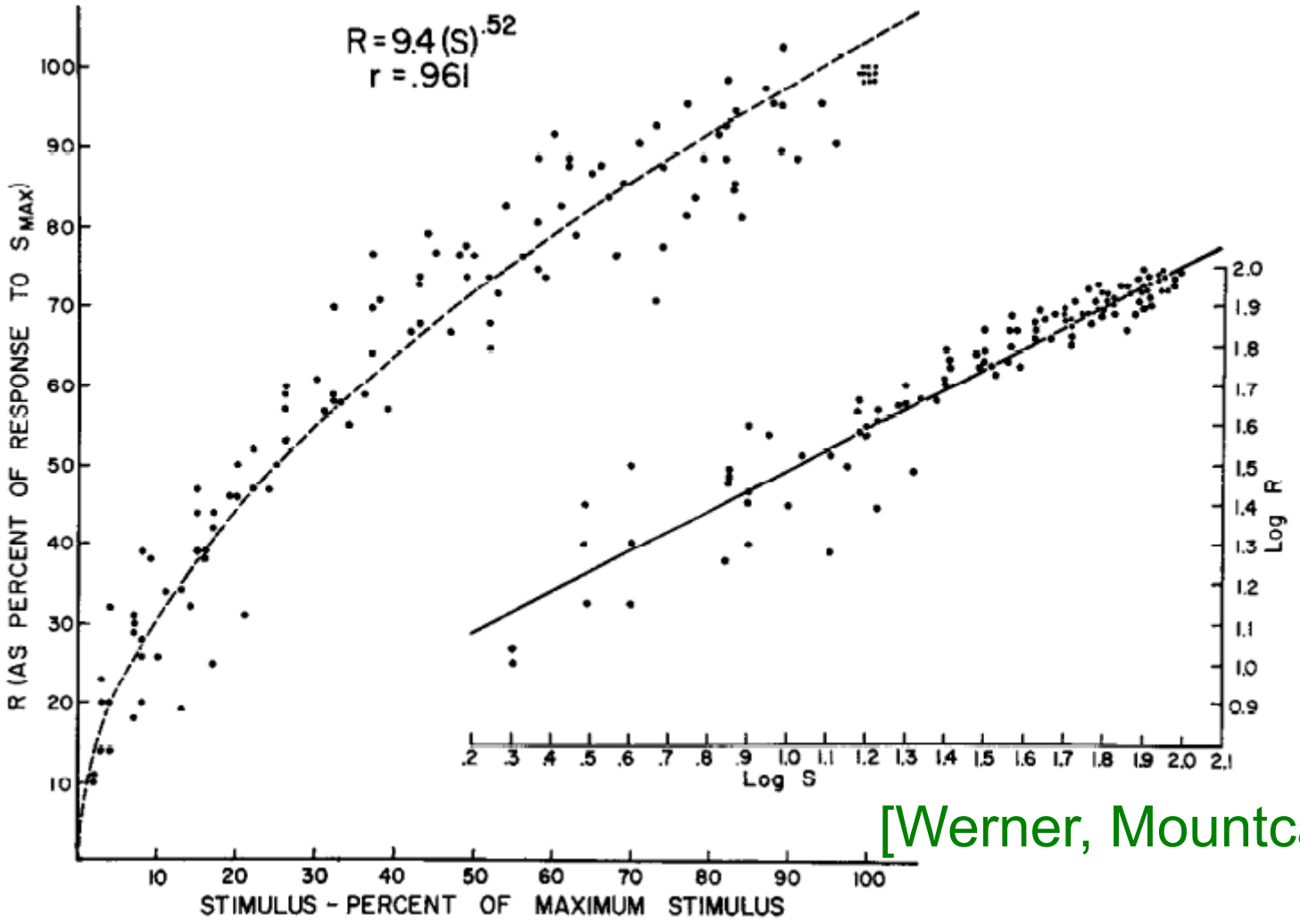
Frequency:

<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 mechanoreceptive fibers, Subjective: touch percept

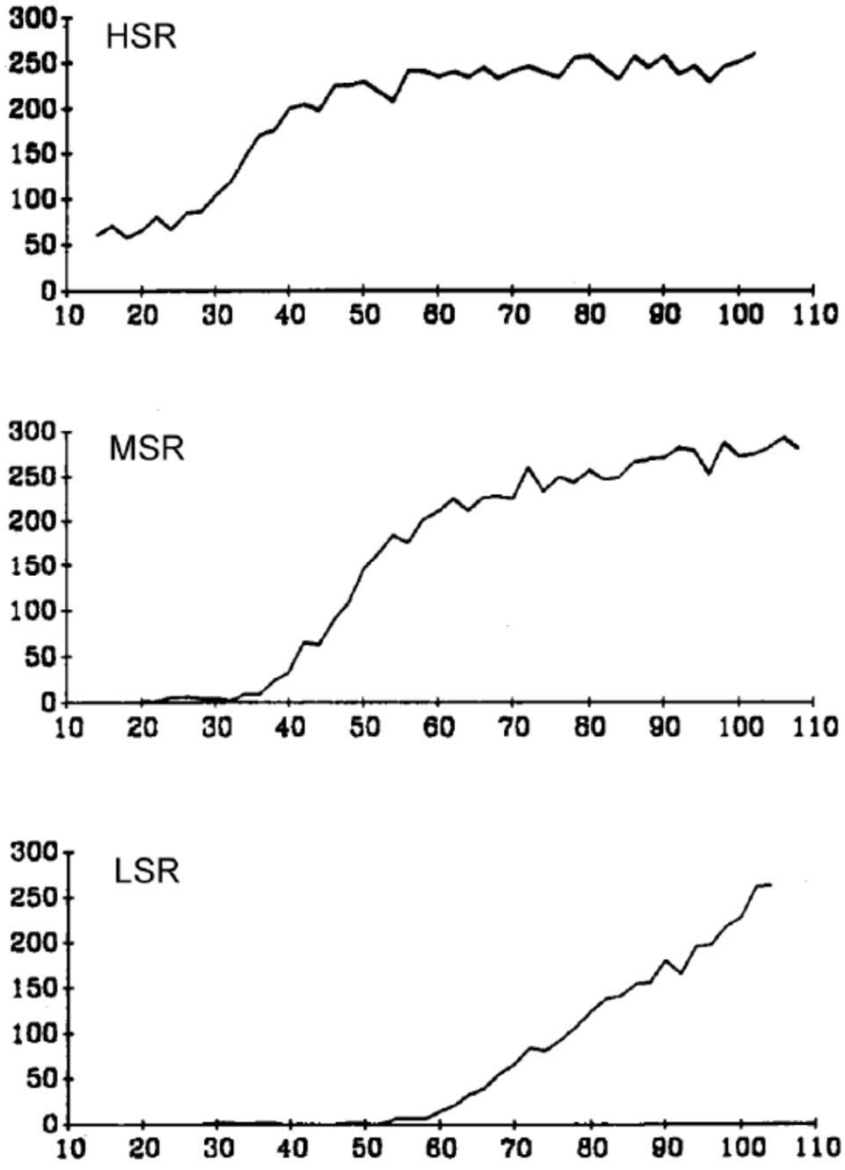
[Werner, Mountcastle, 1965]

High, Middle and Low Spontaneous Rate Auditory Nerve Fibres

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

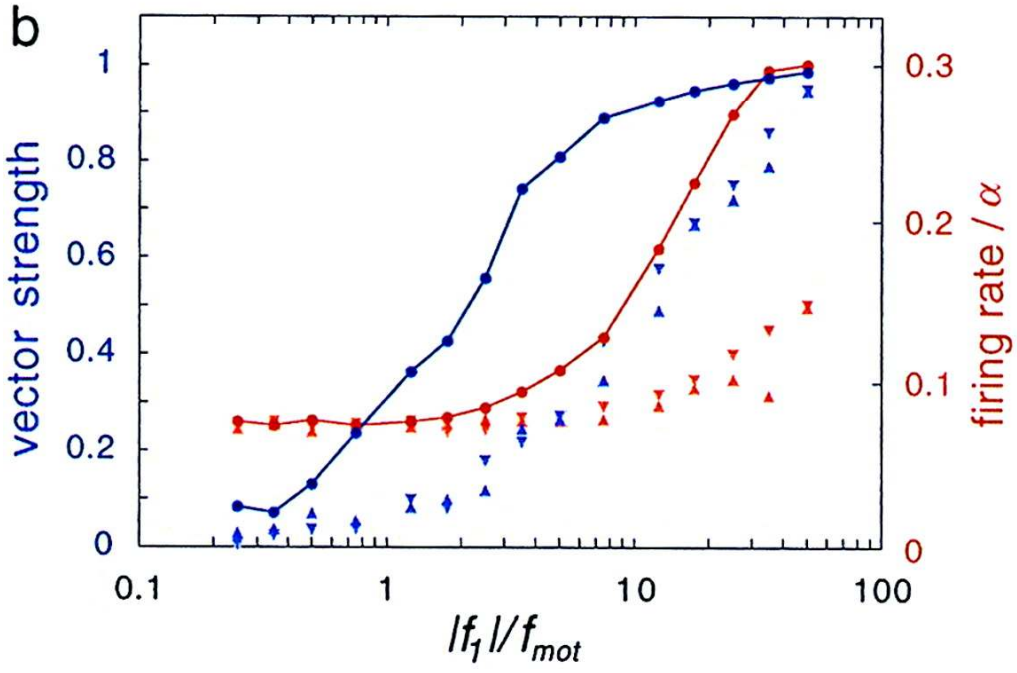
x-axis: stimulus intensity, dB SPL,
y-axis: neuronal spike rate per s

[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]

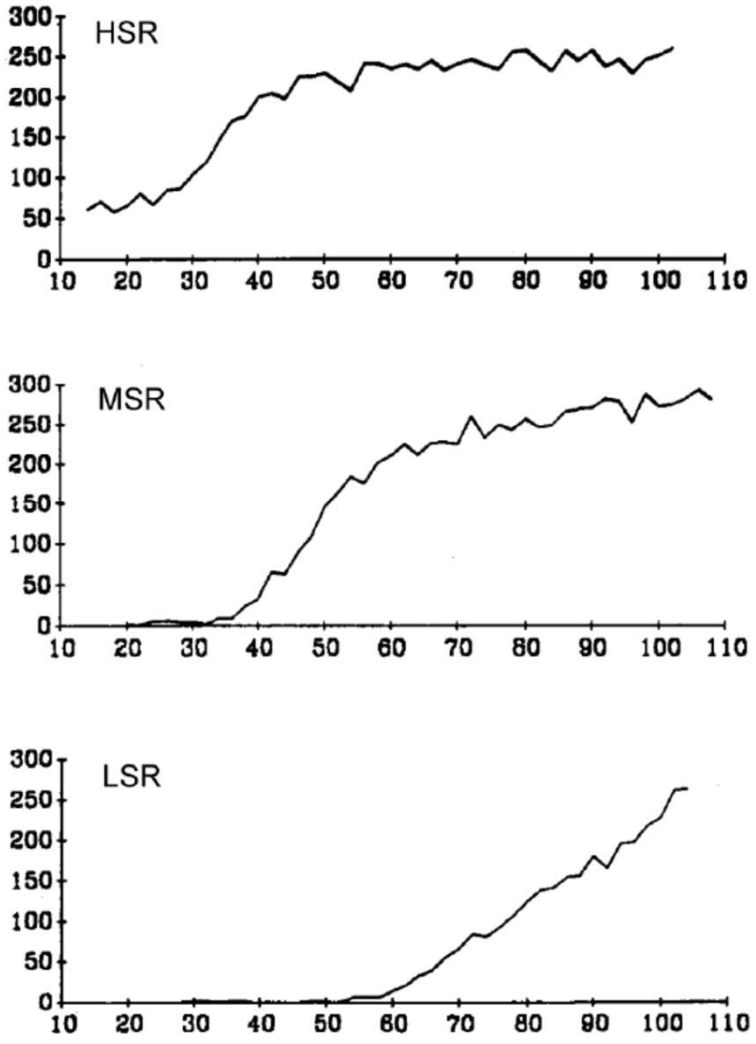


[Winter and Palmer, 1991]

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



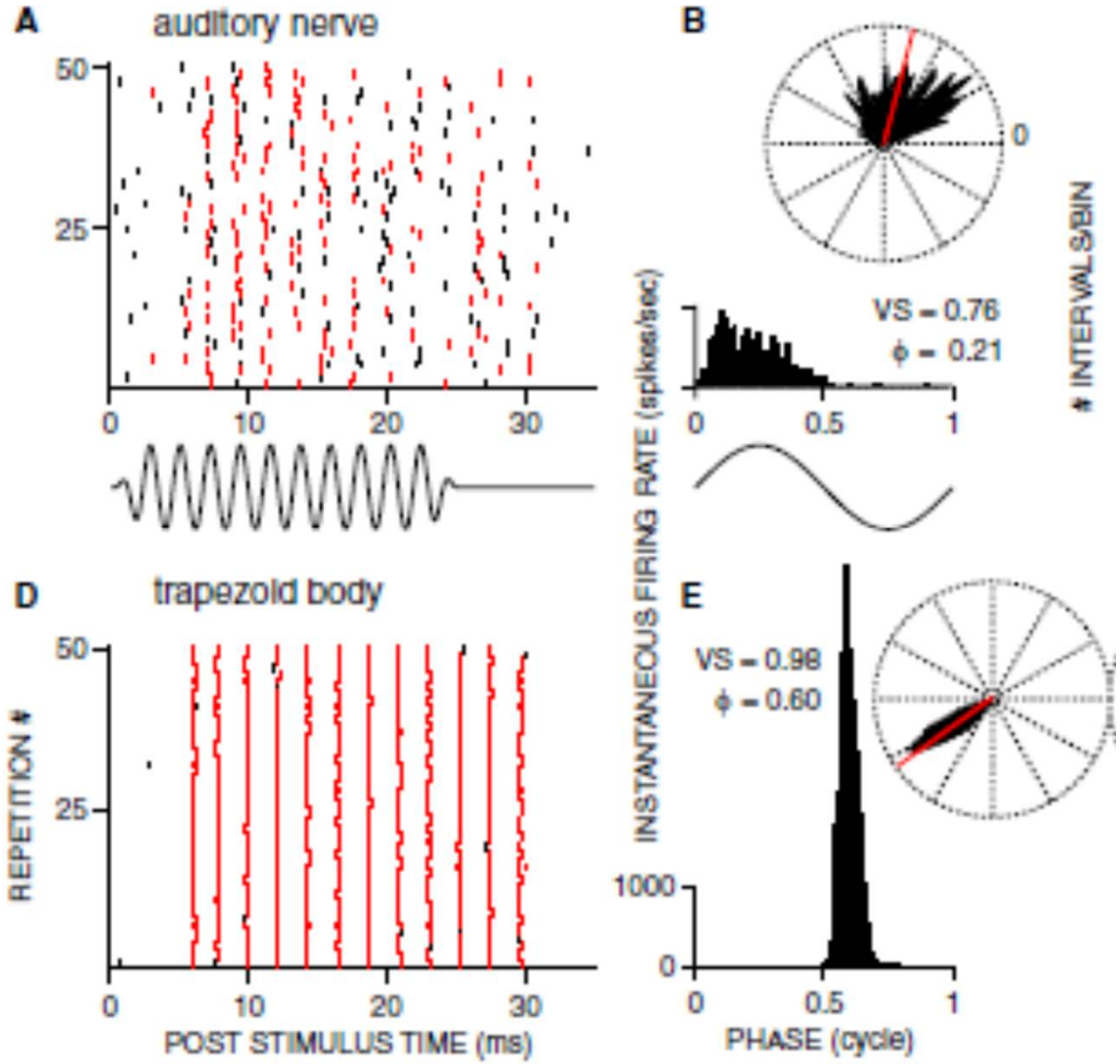
[Camalet, Duke, Julicher, Prost, Proc Natl Acad Sci USA, 2000]



[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]

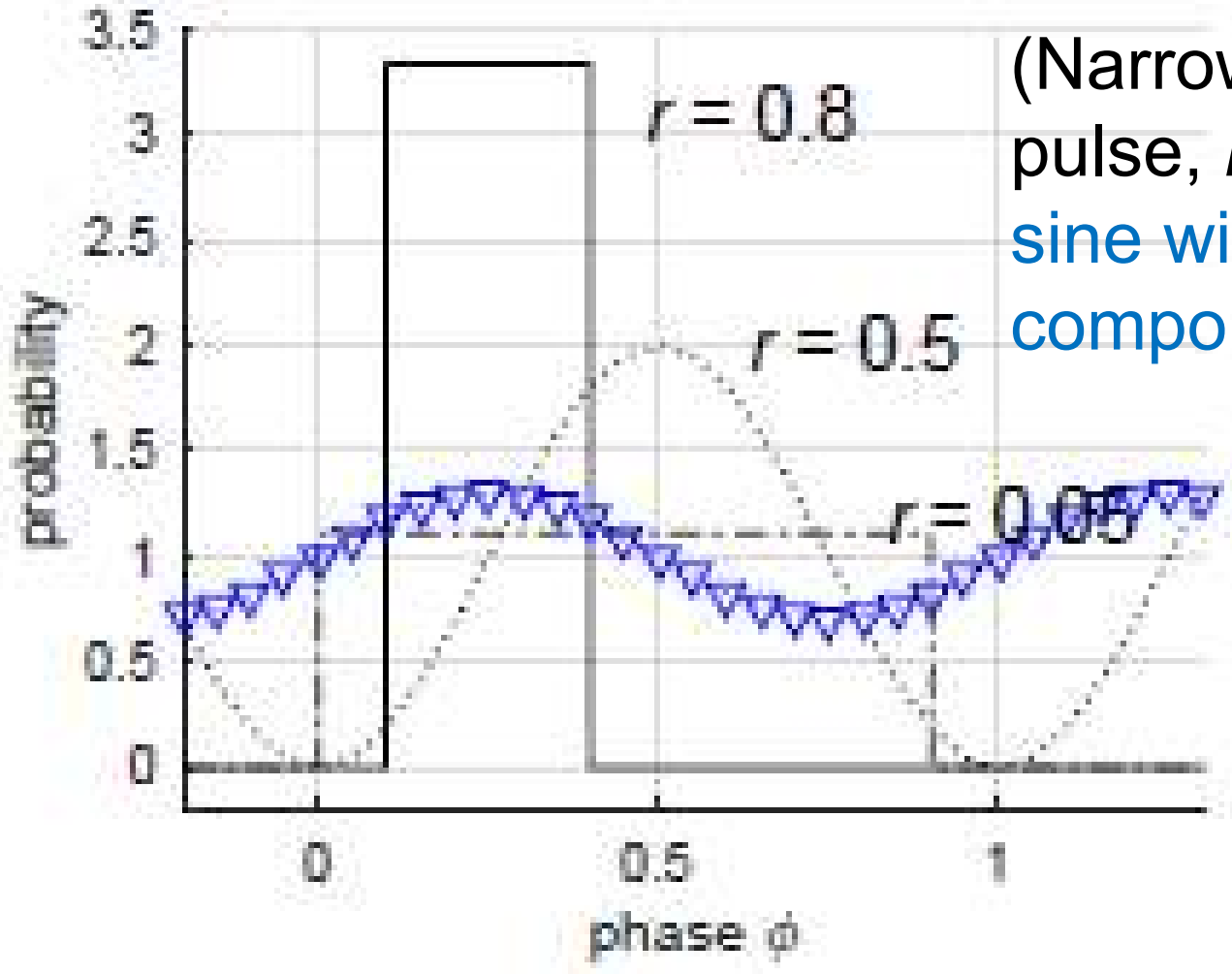
Vector strength r

Examples with values r = 0.5, 0.8, 0.05

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

(Narrow) rectangular pulse, *r* = 0.8

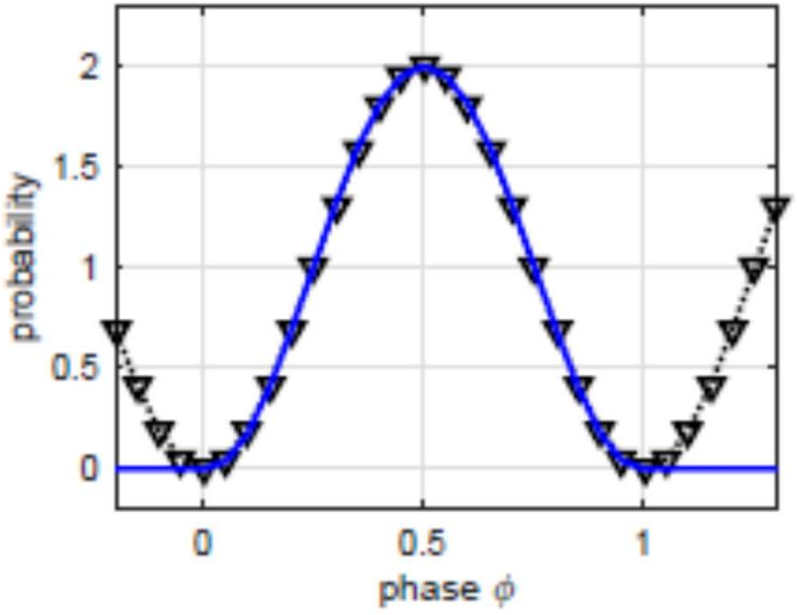
sine with DC component, *r* = 0.05

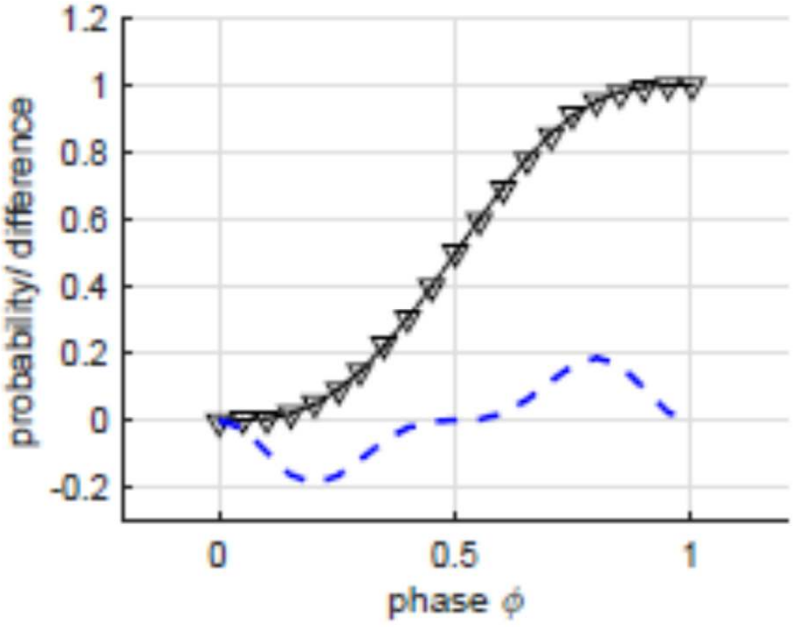


[Toth, Marsalek, Pokora, Biol Cybern, 2017]

Circular statistics

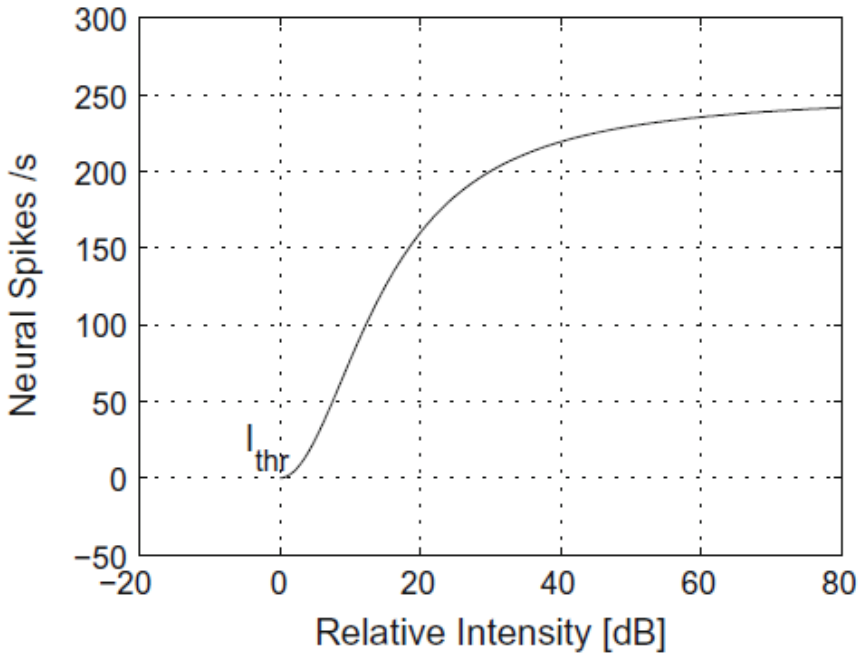
Circular statistics is used in description of repetitive events (time domain).
It can cover time repetition on different time scales. (Examples: sound period, time gap in sound.)
Can be used in description of horizontal sound localization (for different quantities: time or space).

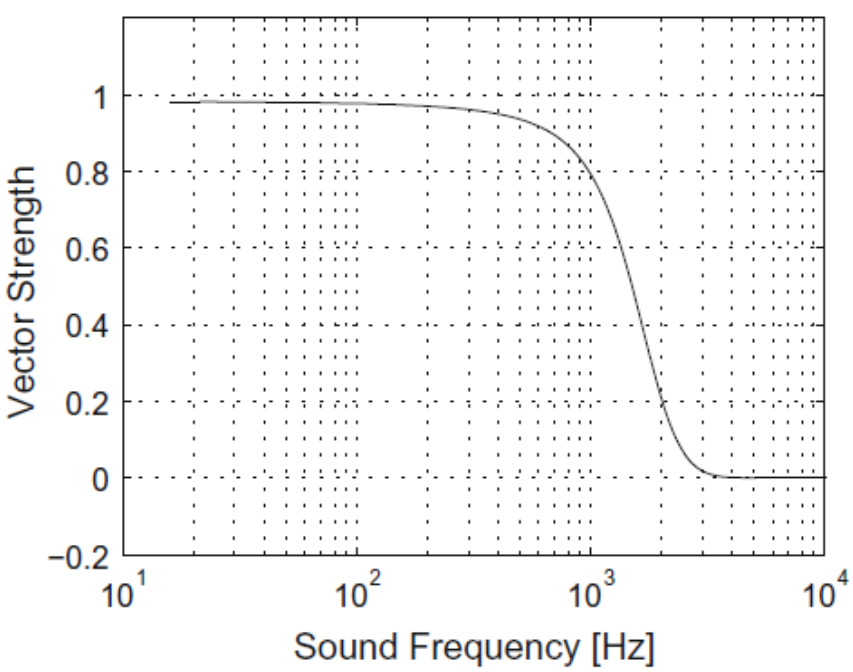




[Toth, Marsalek, Pokora, Biol Cybern, 2017]

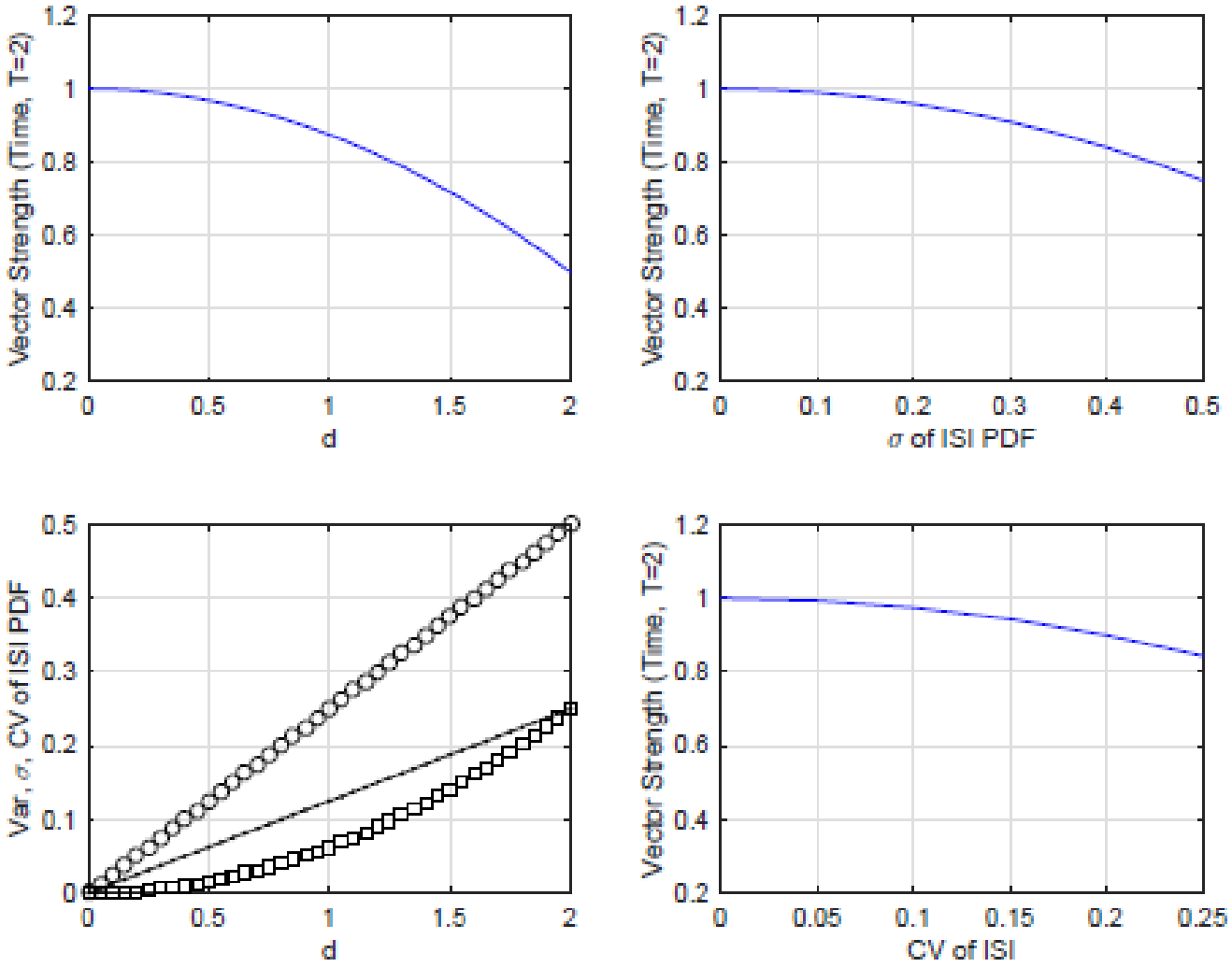
“Canonical” spiking auditory model





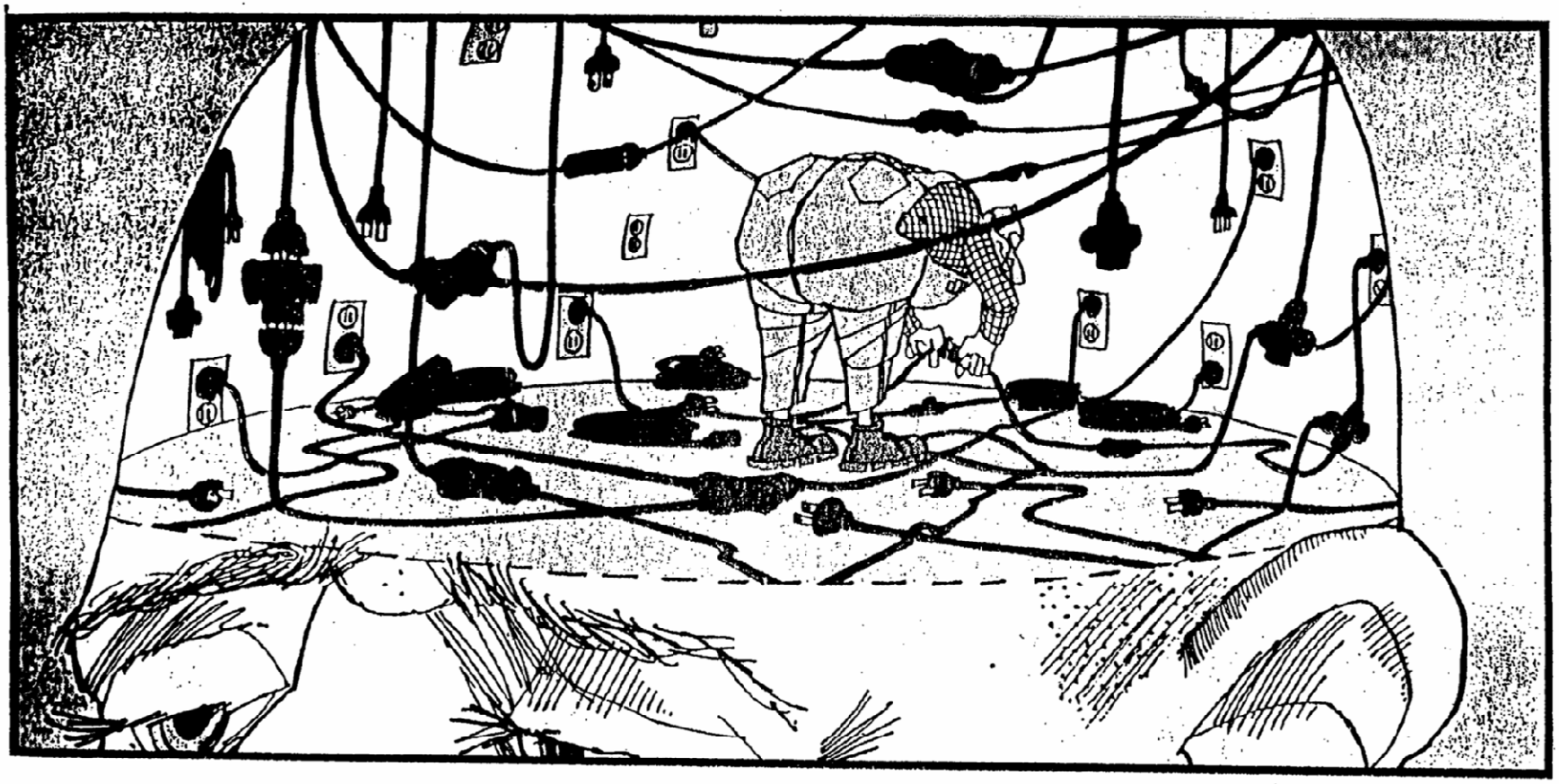
[Toth, Marsalek, Pokora, Biol Cybern, 2017]

Vector strength, spike timing jitter and other variability measures



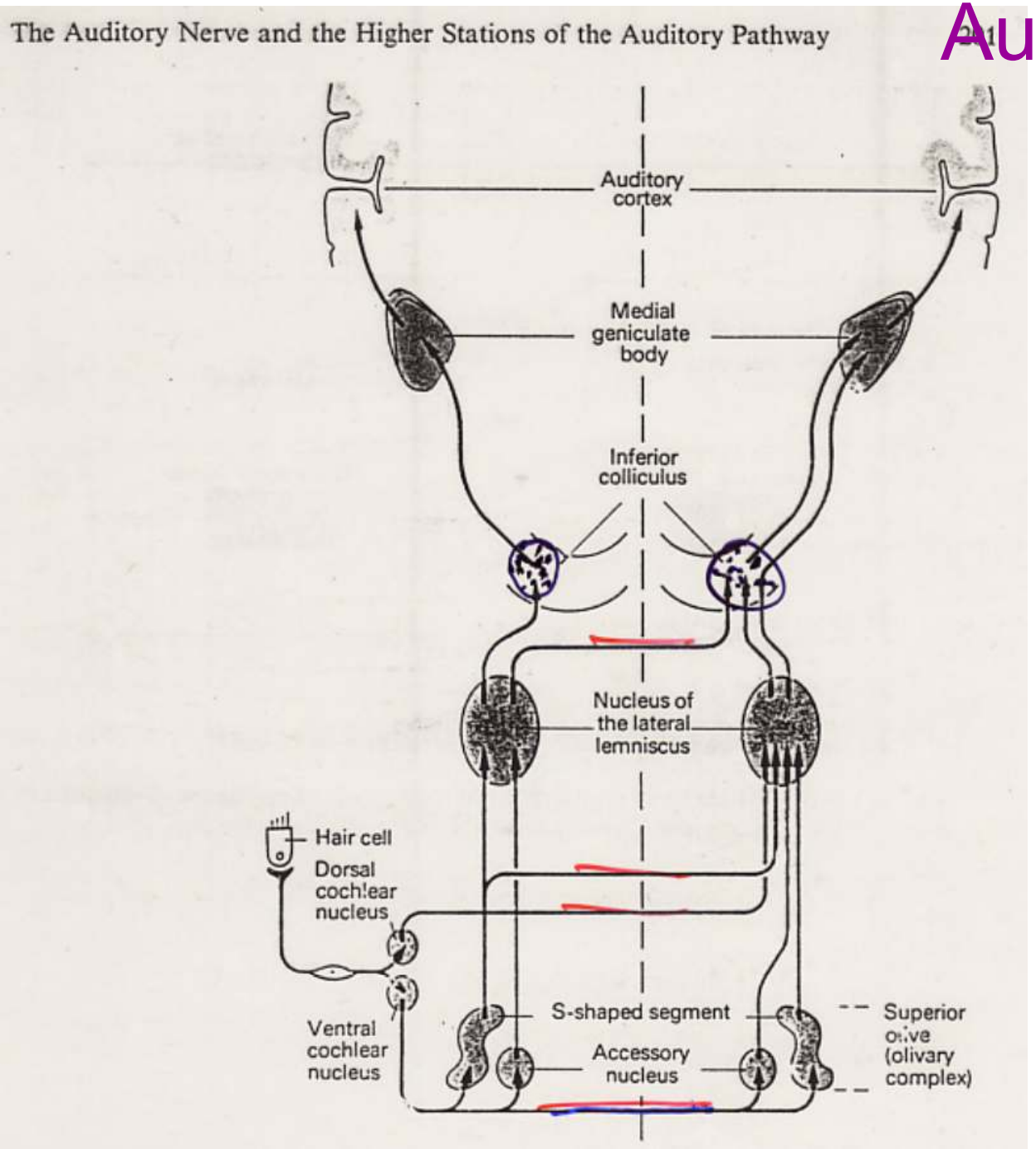
[Toth, Marsalek, Pokora, Biol Cybern, 2017]

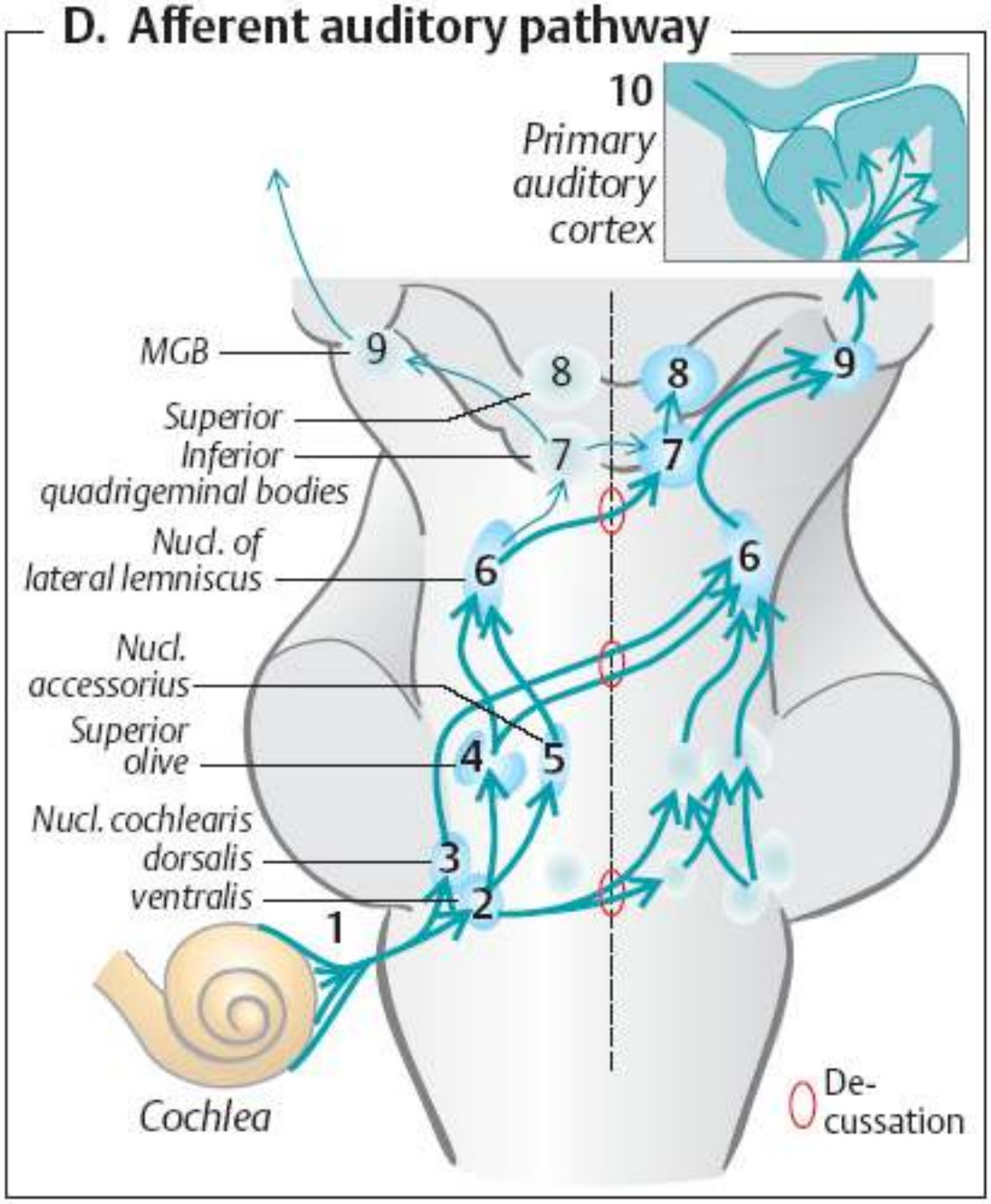
Auditory pathway



How the brain works.

Auditory pathway Mono-aural overview





Auditory pathway Binaural part

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

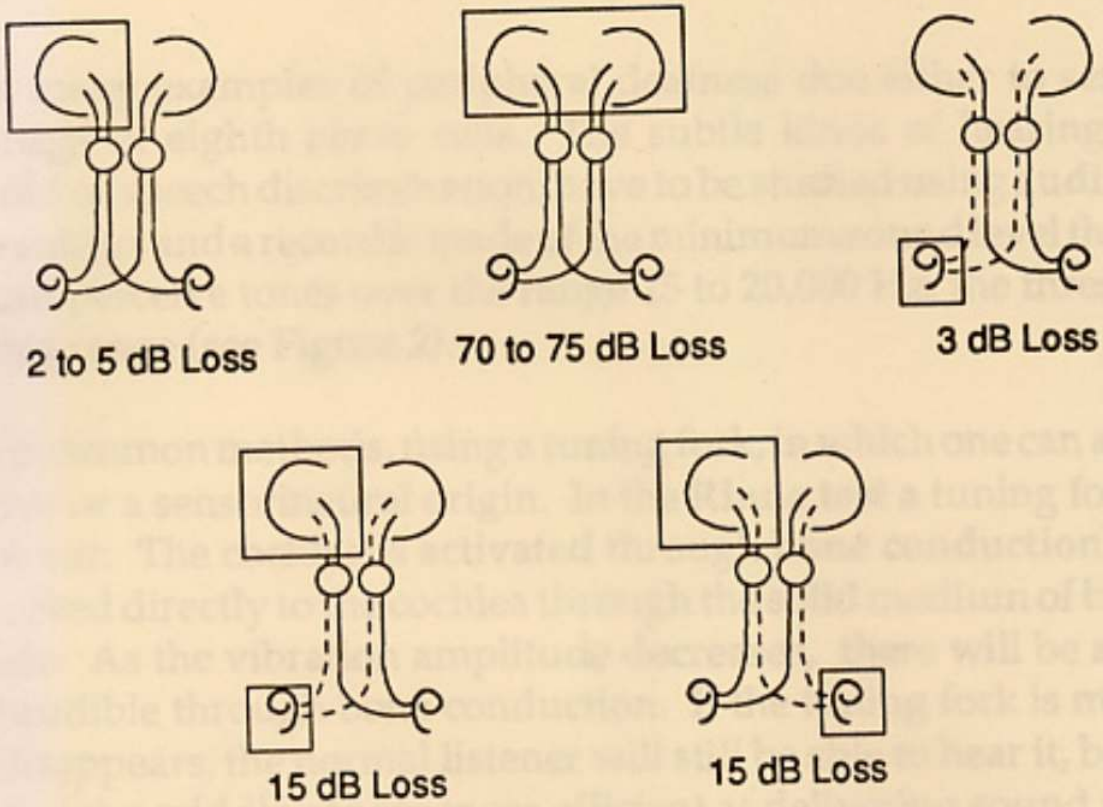
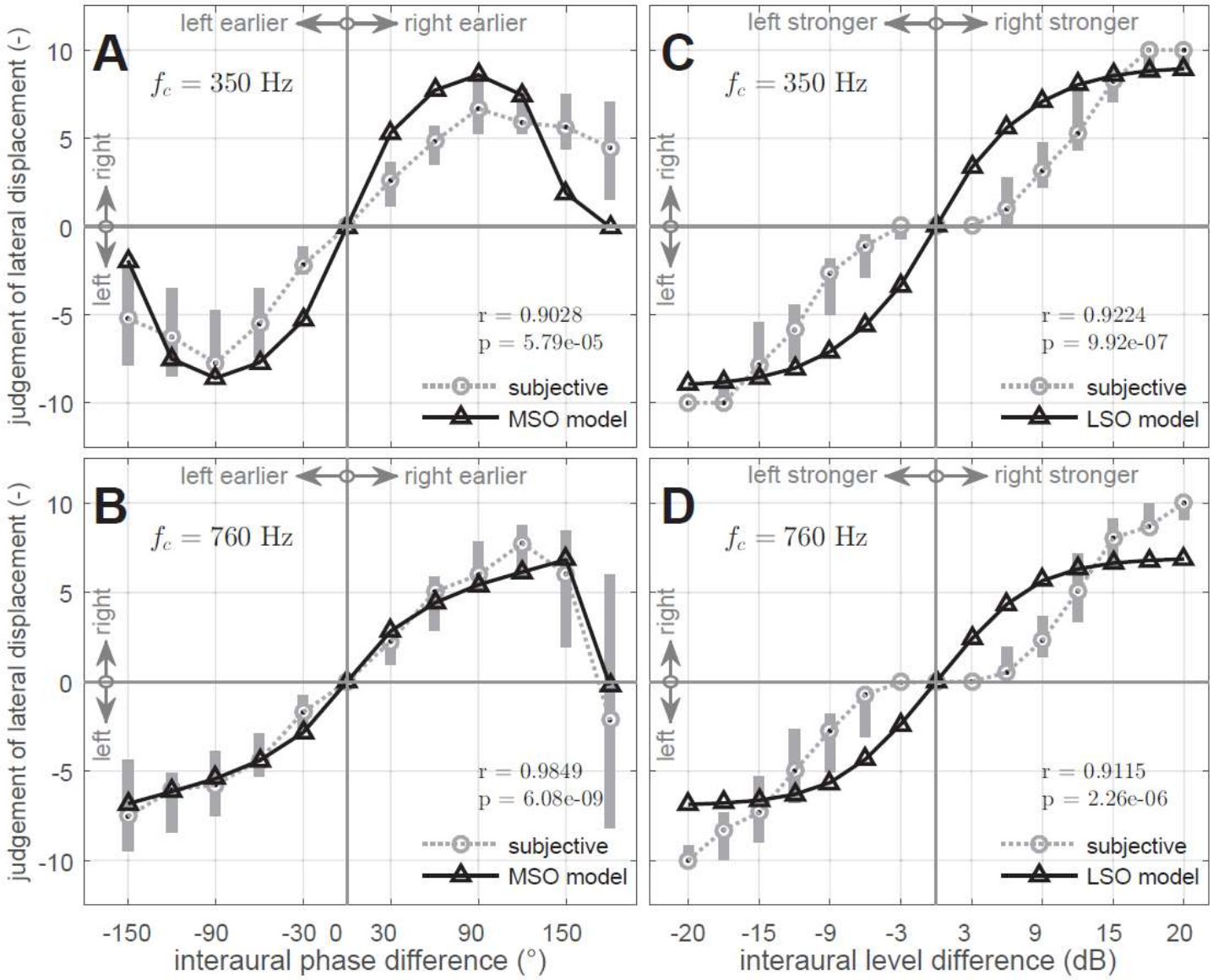


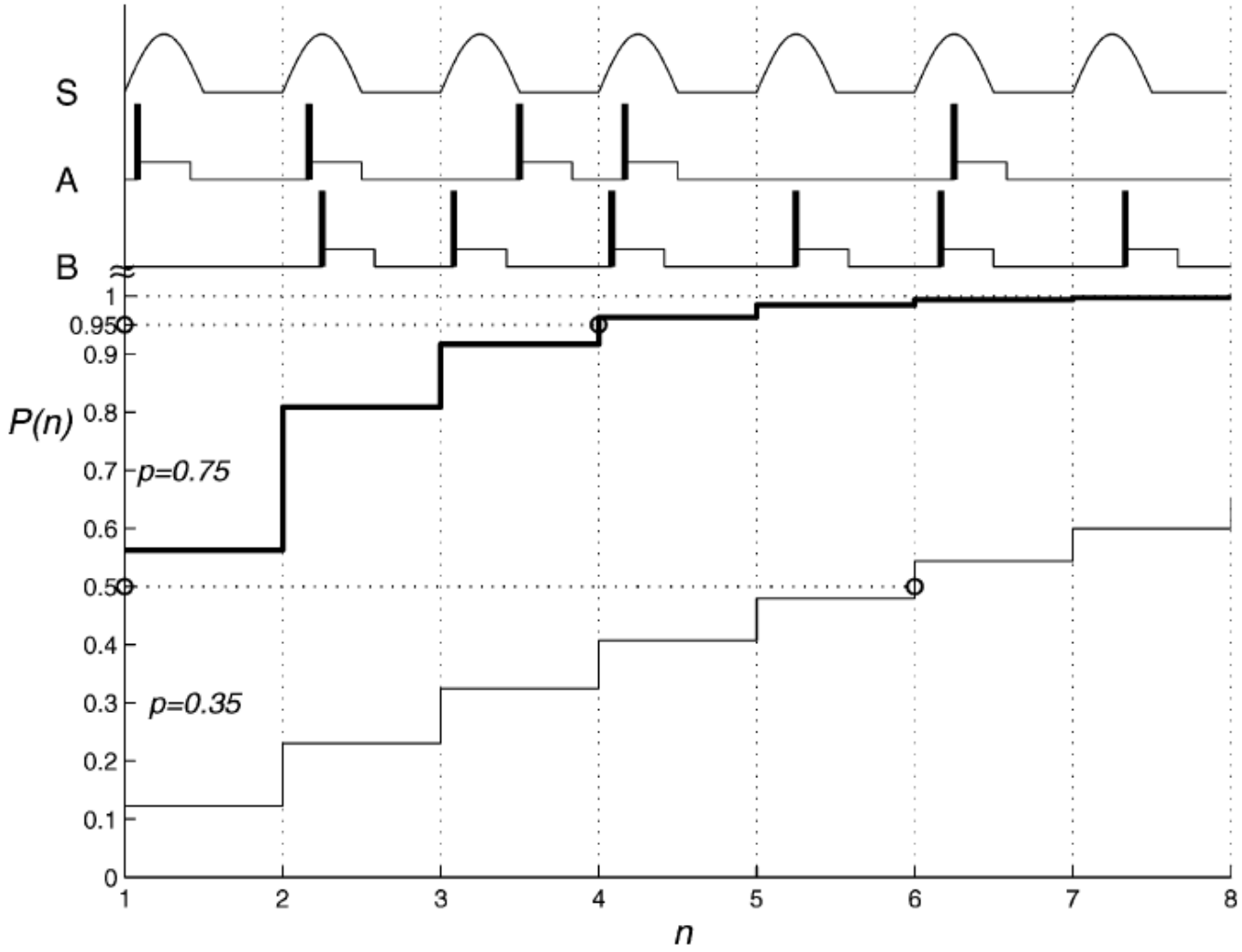
Figure 18. Summary of experiments demonstrating bilaterality of auditory pathways in dog. Number below each diagram is hearing loss in decibels; box around symbol for cerebral cortex or cochlea indicates destruction of it. In D, hearing depends on uncrossed fibers of left lateral lemniscus, whereas in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

sound azimuth, model and subjective response



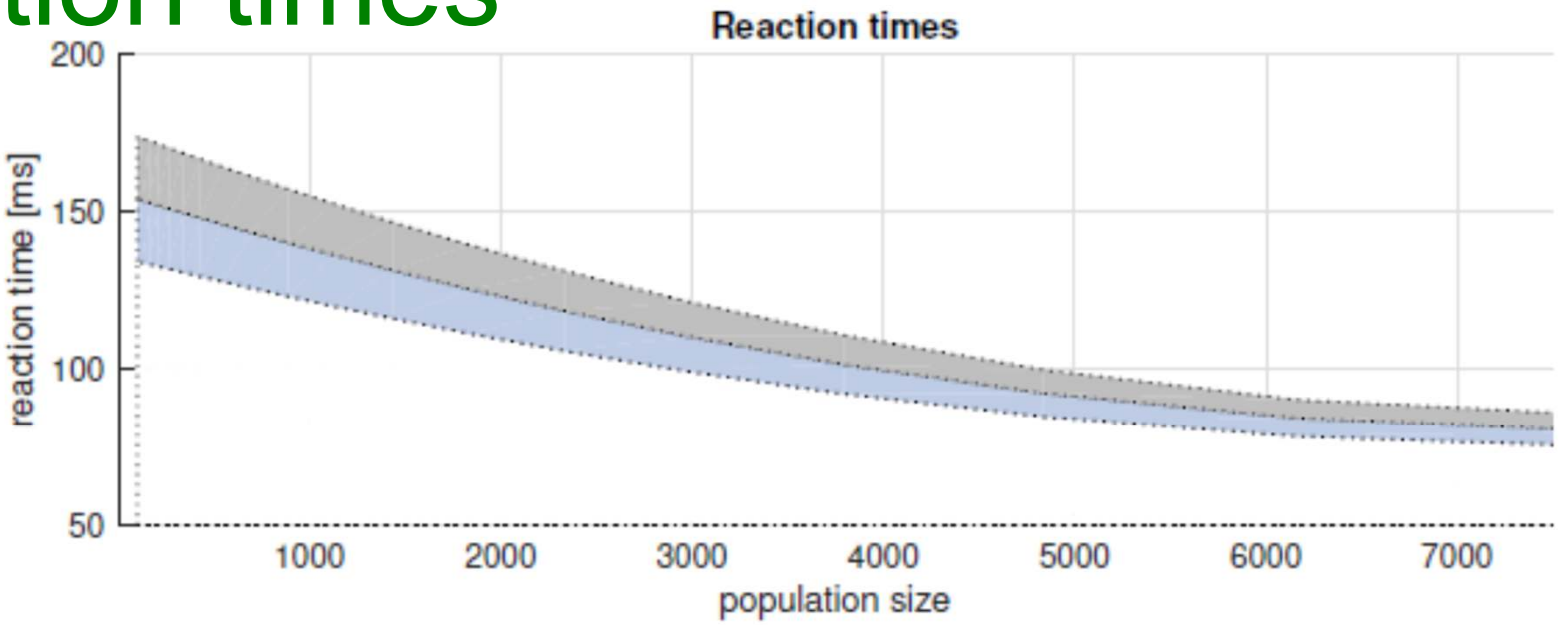
[Bouse, Vencovsky, Rund, Marsalek, JASA, 2019]

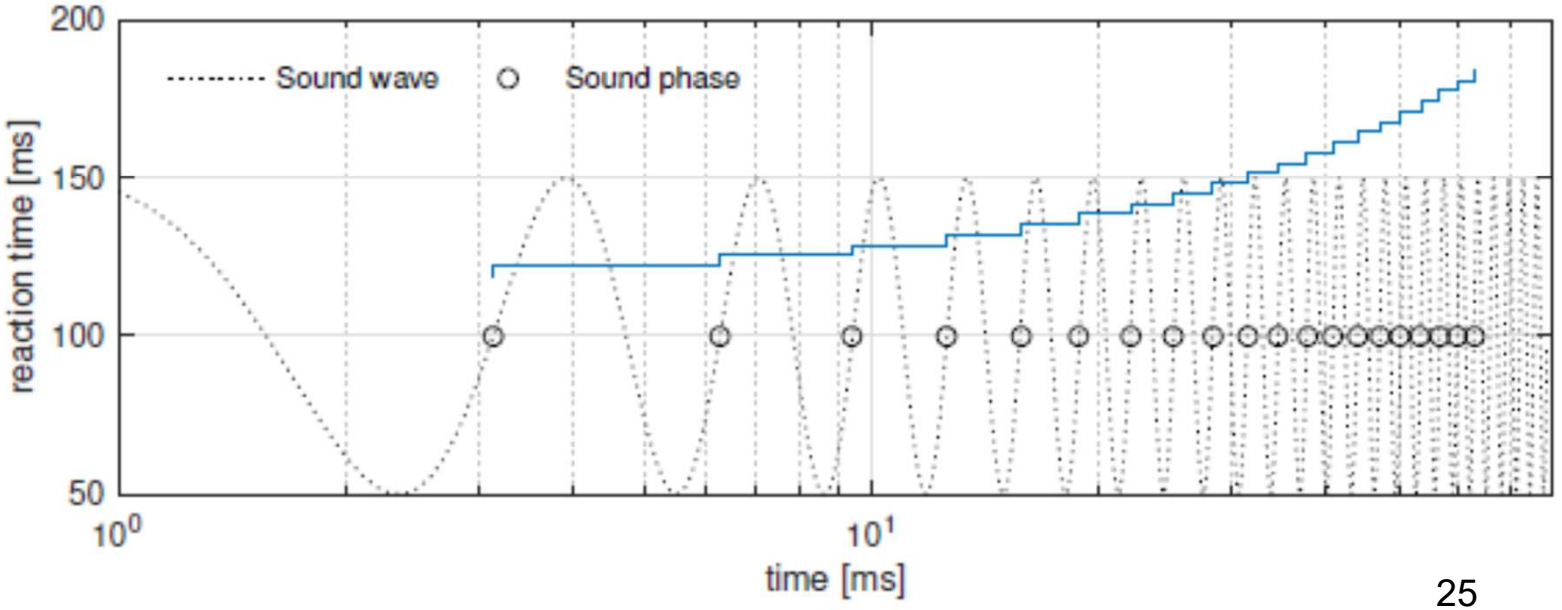
(Coincidence) detection probability of two spikes converging on MSO neuron



[Marsalek, Lansky, Biol Cybern, 2005]

Reaction times

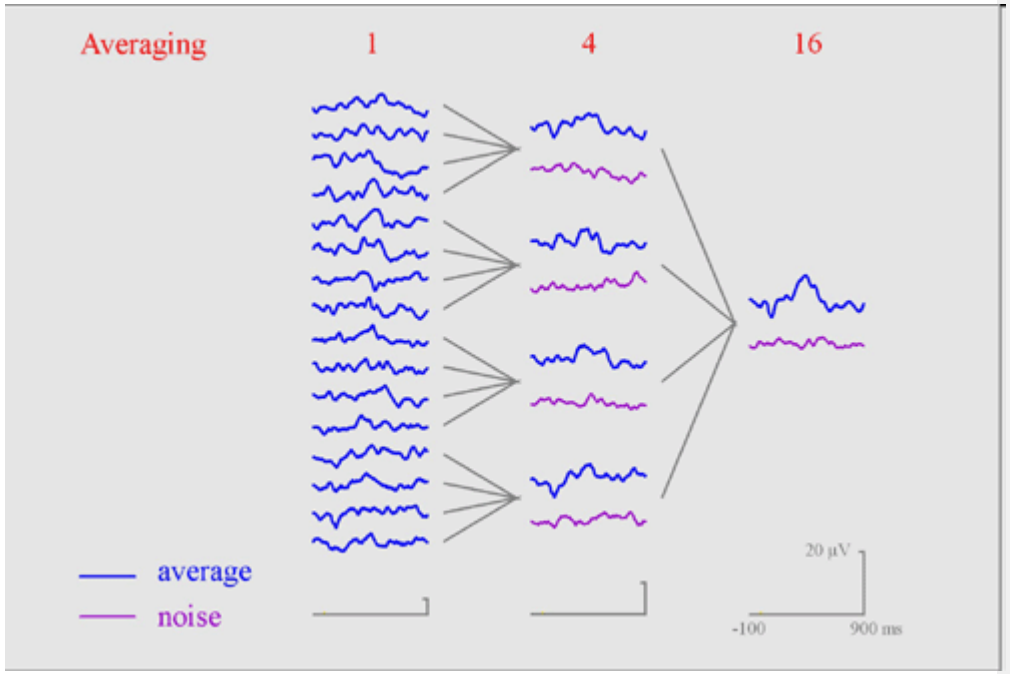


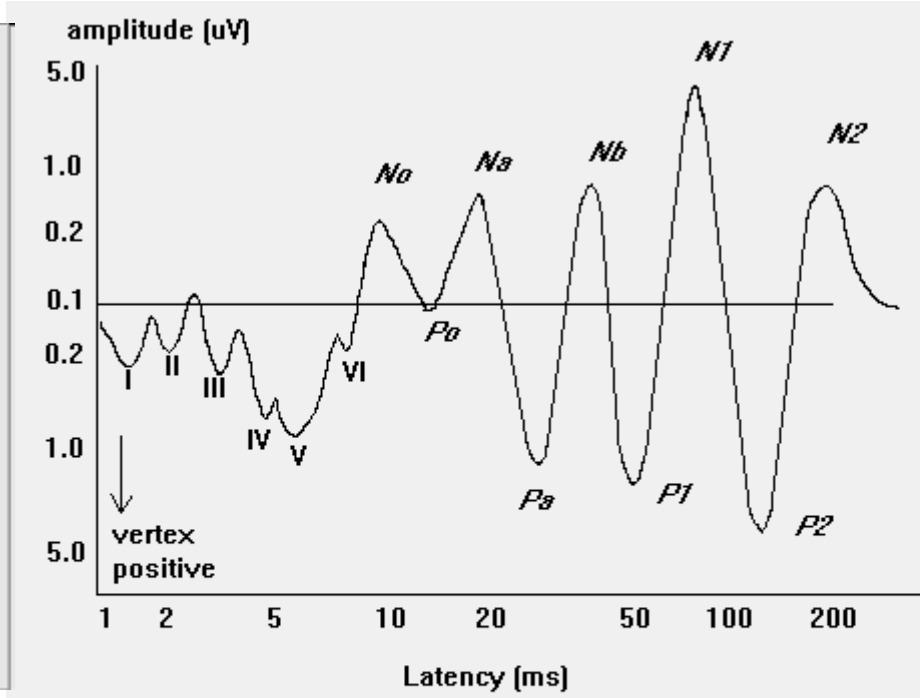


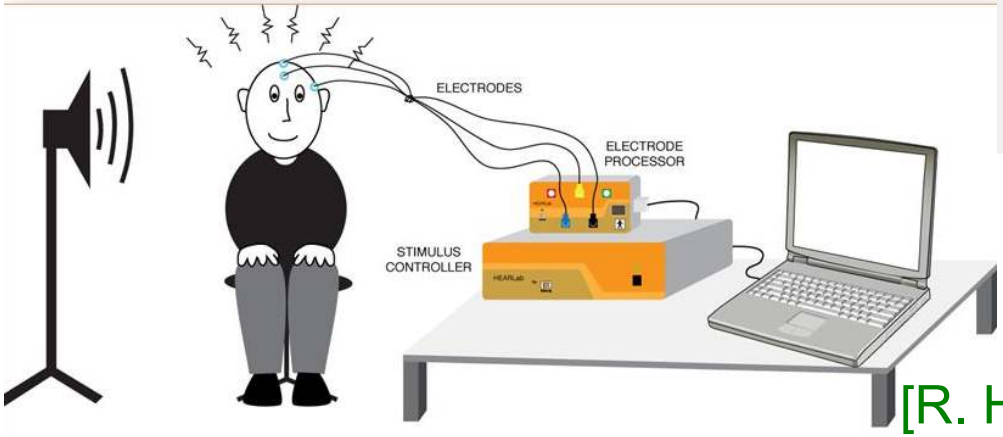
[Toth, Marsalek, Pokora, Biol Cybern, 2017]

Where is ergodicity used: Evoked (Response) 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]
(V. Strength in barn owl)
etc

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

Summary

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- 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.

Conclusions

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

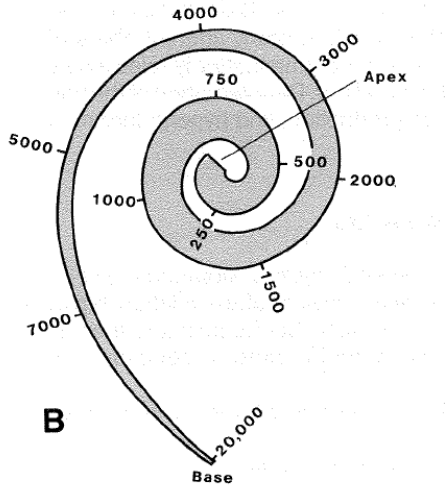
2 Neurons encode signals by trains of action potentials, spike trains.

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.

END
OF THE LECTURE



Thanks for your attention

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Contacts: Petr.Marsalek@FEL.CVUT.CZ
Petr.Marsalek@LF1.CUNI.CZ