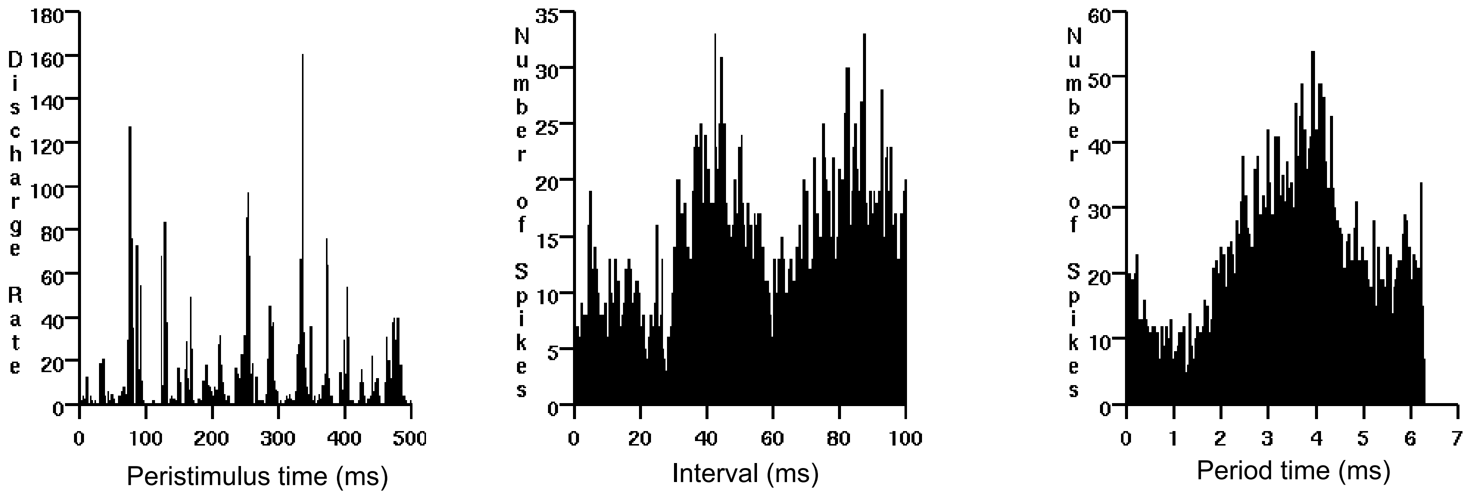
Stimulus-related temporal discharge patterns in IC (PTs to ~4 kHz, F0s to 1200 Hz)

Please see Langner and Schreiner, 1988.

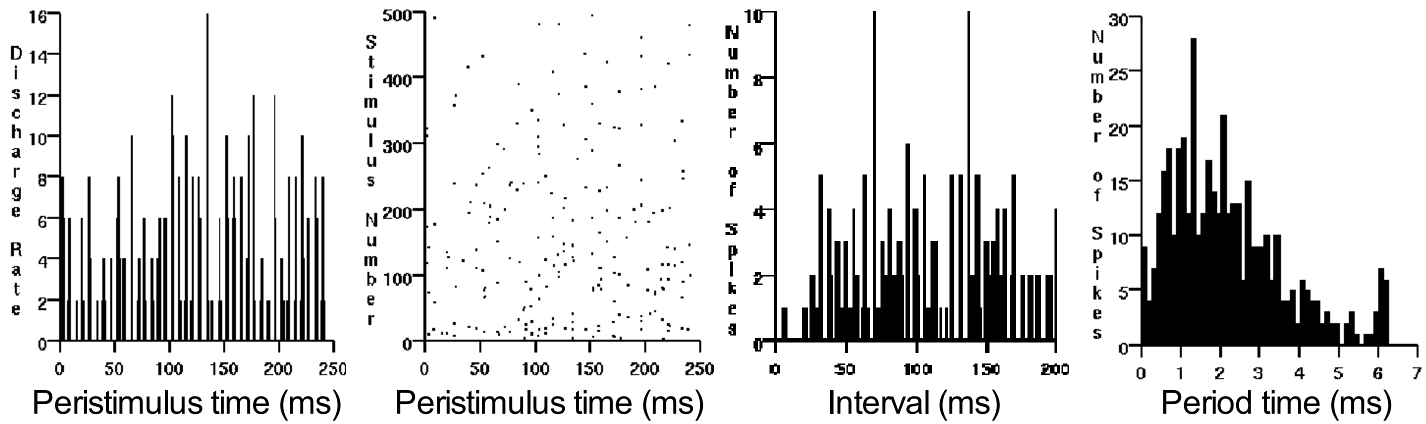
Coding of pitch in the inferior colliculus

AM broadband noise, Fm = 160 Hz, 1000 contralateral monotic presentations @ 80 dB SPL



PST histogram, all-order interval histogram, and period histogram (6.25 ms analysis period). Total number of spikes: 4421. Note the longer (~40 ms) preferred intervals for this unit and the pitch-related spacings (6.25 ms) between the individual interval peaks.

Click train, F0 = 160 Hz, 500 contralateral monotic presentations @ 80 dB SPL



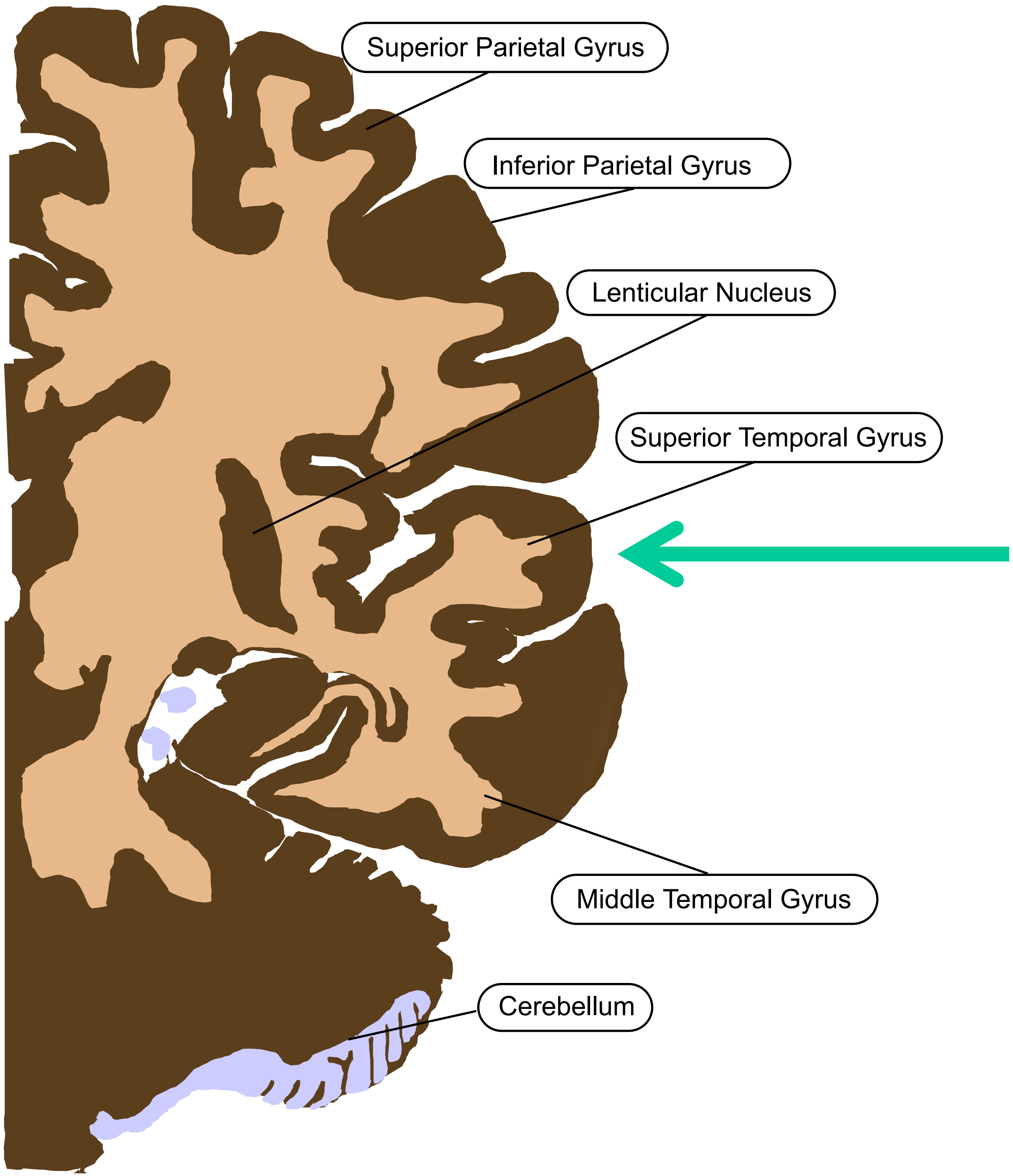
Total number of spikes: 418. Patterns of longer intervals are pitch-related.

Upper limits of temporal pattern information (rough estimate)

Cochlear hair cells: no limit, but weakening AC component
Auditory nerve: < 4-5 kHz abundant & highly significant;
 statistical significance depends on #spikes (> 5 kHz)
Cochlear nucleus: depending
Midbrain: 4-5 kHz in inputs (frequency-following response)
 Interval information: 1/F0 up to ~1200 Hz
Thalamus: 10% of units lock to 2-3 kHz with SI > 0.3
 (deRibaupierre, lightly anesthetized preps)
Primary cortex: 200 Hz averaged gross surface potentials
 (unanesthetized, 100 Hz anesthetized; Goldstein & Kiang, 1959);
 300 Hz averaged gross potentials (CSD, input layers, Steinschneider et al); anecdotal reports of locking to 1 kHz in single units, but these are very rare
Rule-of-thumb: anesthesia decreases fmax by factor of 2

Auditory thalamus: medial geniculate body

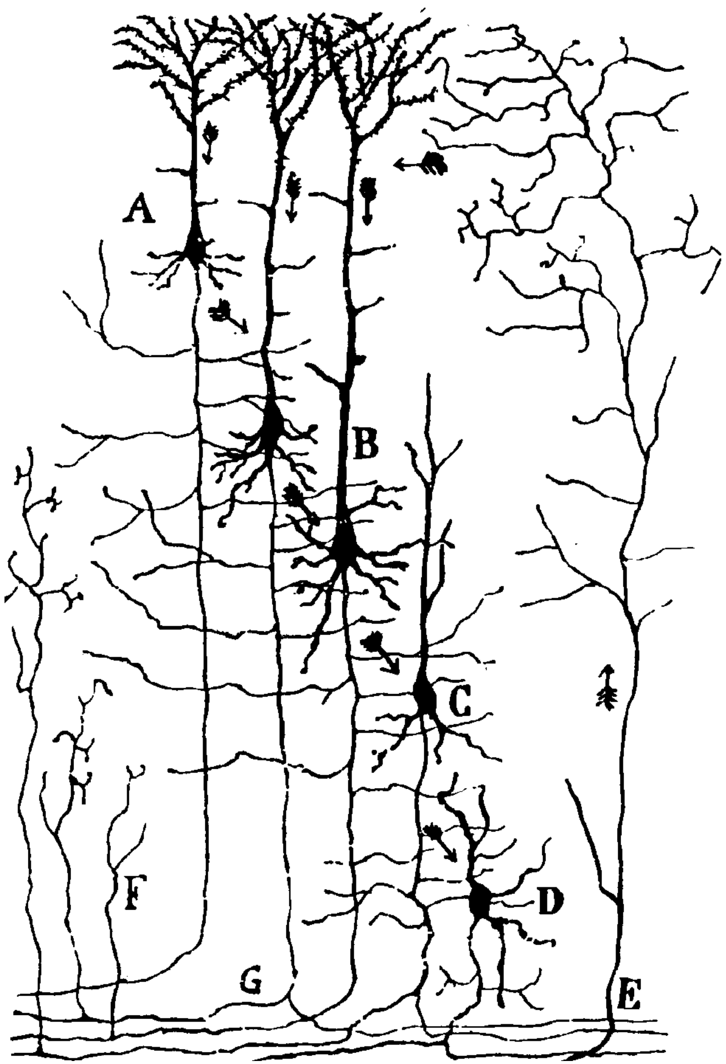
Please see Morest, D. K. The Neuronal Architecture of the Medial Geniculate Body of the Cat. *J. Anat*. 98 (Oct 1964): 611-30.

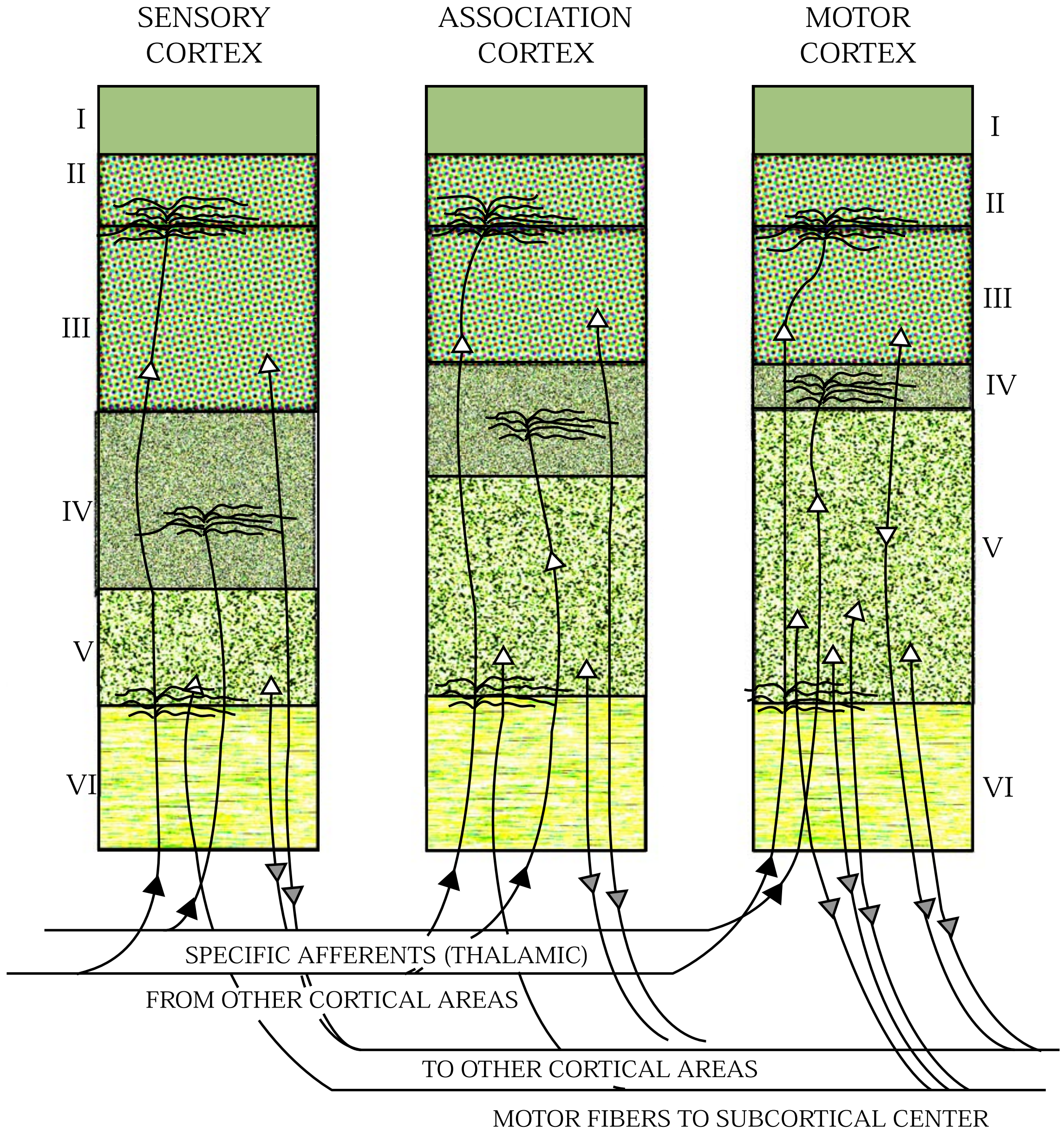


Gyri: hills
Sulci: valleys

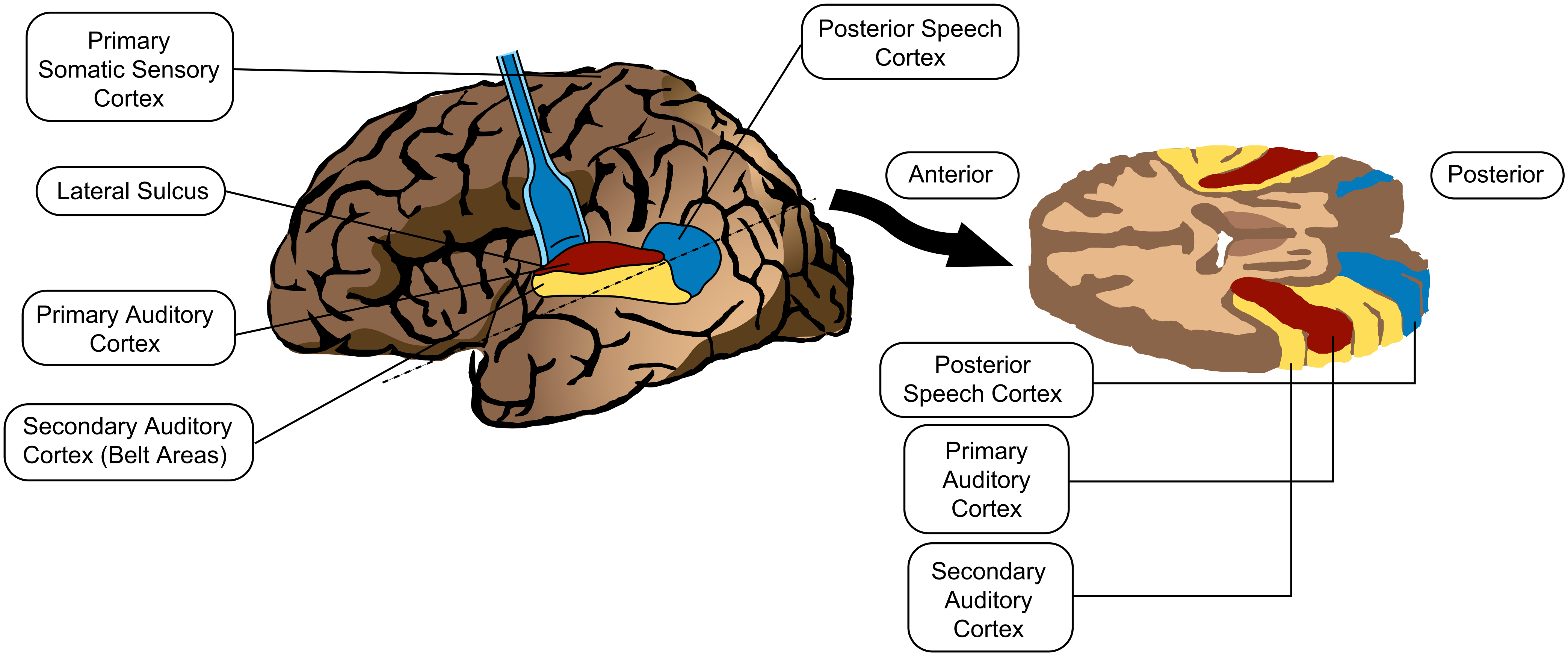
Auditory cortex is located in the Superior Temporal Gyrus (STG)

Laminated "cortical" structures





Primary and secondary auditory cortex

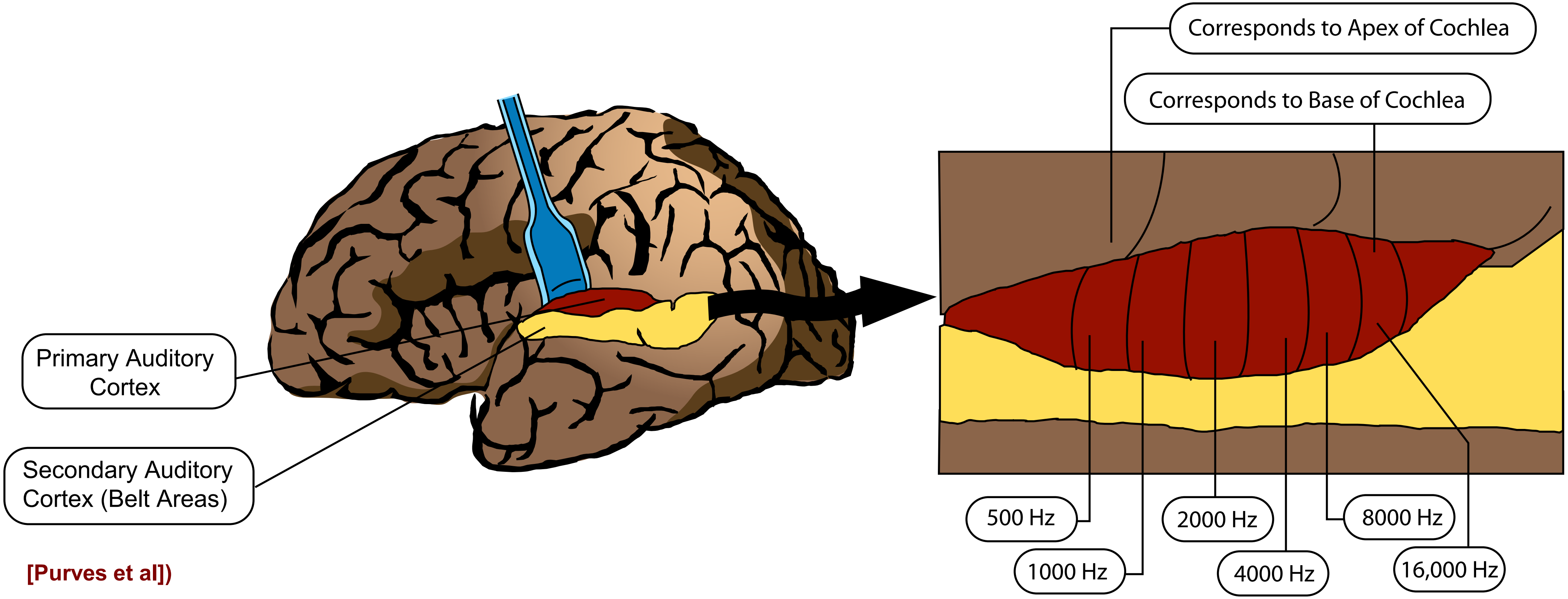


Cochleotopic organization of auditory cortex (cartoon)

Two concepts best kept separate in one's mind:

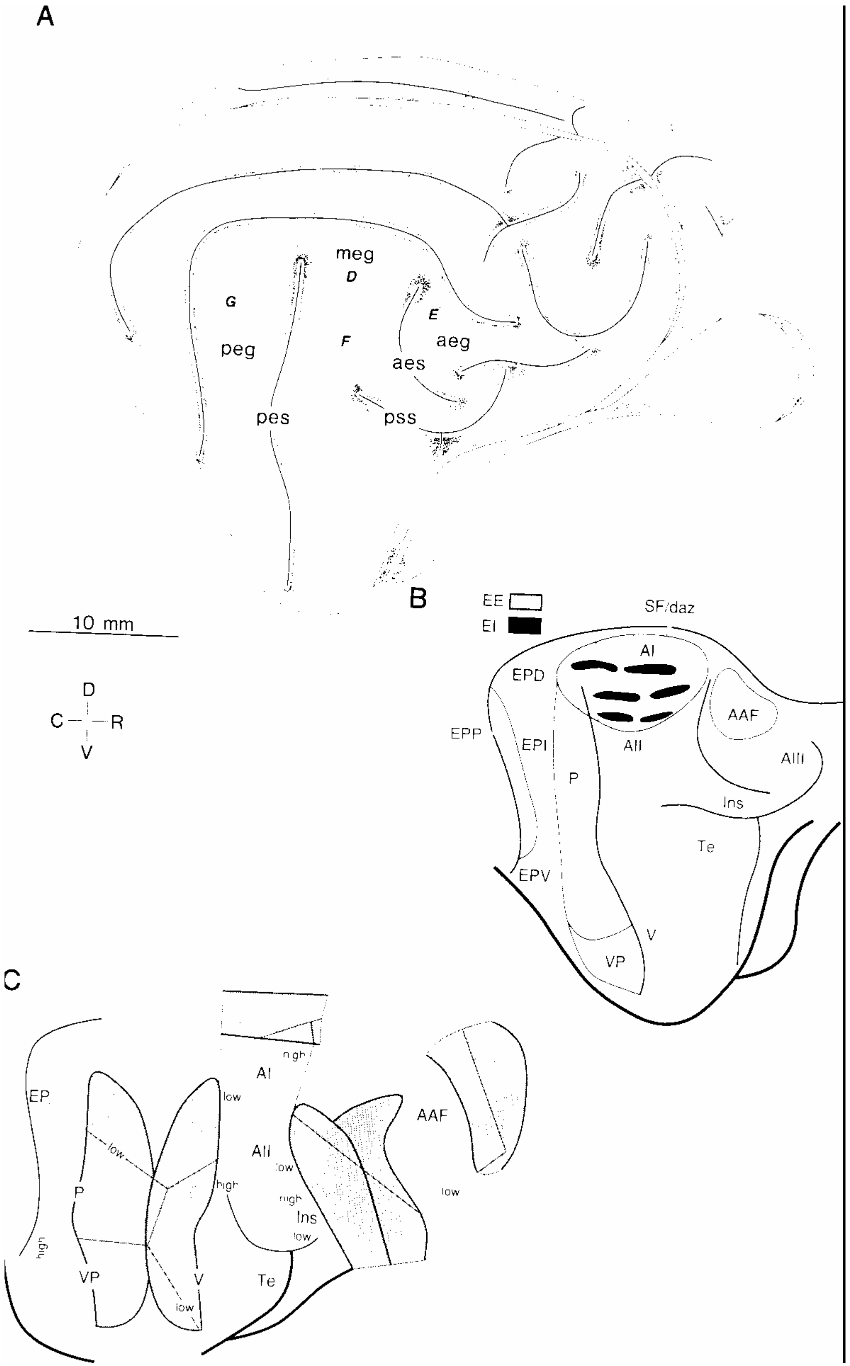
Cochleotopy as reflection of pathway mappings to sensory surface

Tonotopy as vehicle for neural representation of frequency per se



[Purves et al])

Auditory cortex: cat



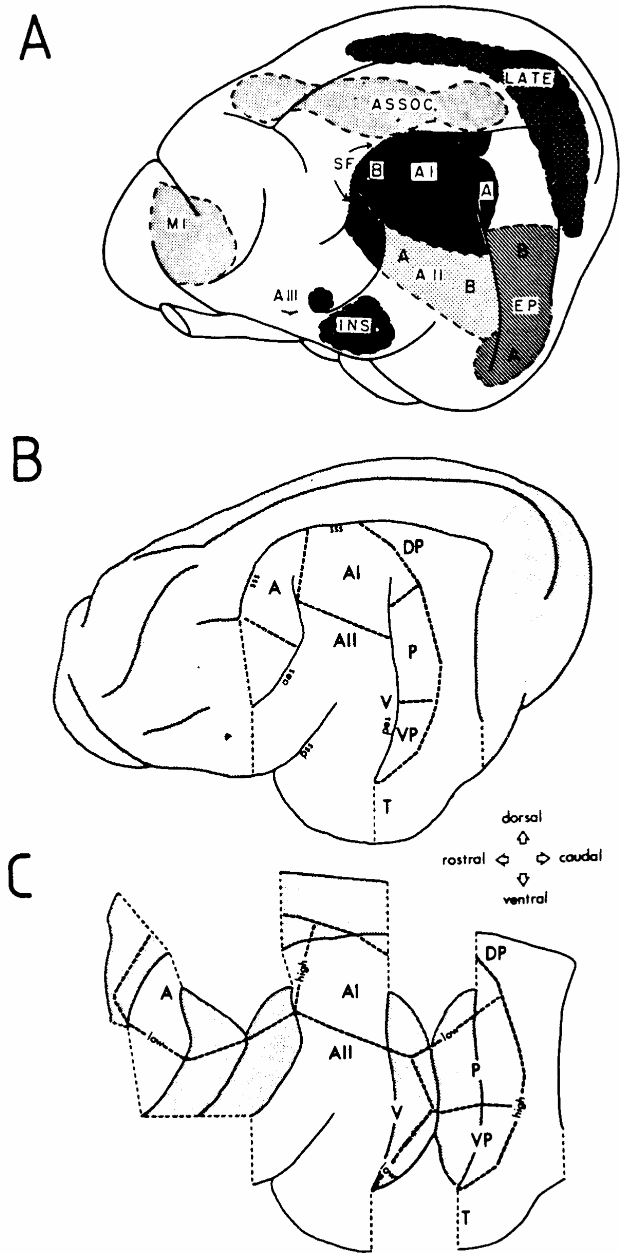


FIG. 23. Auditory cortical fields in cat. *A*: parcellation proposed by Woolsey (487) in 1960, showing cortical fields (AI, AII, EP, SF, INS, and AIII) described in text. In each field, orientation of cochlear representation is indicated by position of A (apex) and B (base). Auditory responses also recorded in association areas on suprasylvian and anterior lateral gyri (ASSOC.) and in pericruciate sensorimotor cortex (MI). Long-latency (LATE) responses are recorded in visual cortex. *B*, *C*: parcellation into four tonotopic (AI, A, P, and VP) and additional belt fields (AII, DP, V, and T) described by Reale and Imig (376). Because location of physiologically determined field boundaries in different animals varies with respect to sulci, positions shown are general approximations only. In *B*, field positions are shown relative to sulci on a lateral view of surface of left cerebral hemisphere; sss: suprasylvian sulcus; aes: anterior ectosylvian sulcus; pes: posterior ectosylvian sulcus; pss: pseudosylvian sulcus. In *C*, unfolded cortical surface forming gyral surfaces and sulcal banks in unshaded region in *B* is shown. Cortical surfaces forming sulcal banks are shaded, whereas those forming gyral surfaces are not. Tonotopic fields are delimited by heavy broken lines, and locations of highest and lowest best frequencies in these fields are indicated by *low* and *high*, respectively. [*A*: from Woolsey (487); *B*, *C*: from Imig and Reale (216).]

Auditory central pathways: ascending connections

Please see De Ribaupierre, F. “Acoustical information processing in the auditory thalamus and cerebral cortex.” In *The Central Auditory System*. Edited by G. Ehret and R. Romand. New York: Oxford University Press, 1997.

Please see Kaas, Jon H., Troy A. Hackett, and Mark Jude Tramo. "Auditory processing in primate cerebral cortex." *Current Opinion in Neurobiology* 9 (1999): 164-170.

Auditory central pathways: cortico-thalamic connections

Please see De Ribaupierre, F. "Acoustical information processing in the auditory thalamus and cerebral cortex." In *The Central Auditory System*. Edited by G. Ehret and R. Romand. New York: Oxford University Press, 1997.

Please see Kaas, Jon H., Troy A. Hackett, and Mark Jude Tramo. Auditory processing in primate cerebral cortex. *Current Opinion in Neurobiology* 9 (1999): 164-170.

Auditory cortex: responses to high frequency pure tones

Please see De Ribaupierre, F. “Acoustical information processing in the auditory thalamus and cerebral cortex.” In *The Central Auditory System*. Edited by G. Ehret and R. Romand. New York: Oxford University Press, 1997.

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Please see Kaas, Jon H., Troy A. Hackett, and Mark Jude Tramo. "Auditory processing in primate cerebral cortex." *Current Opinion in Neurobiology* 9 (1999): 164-170.

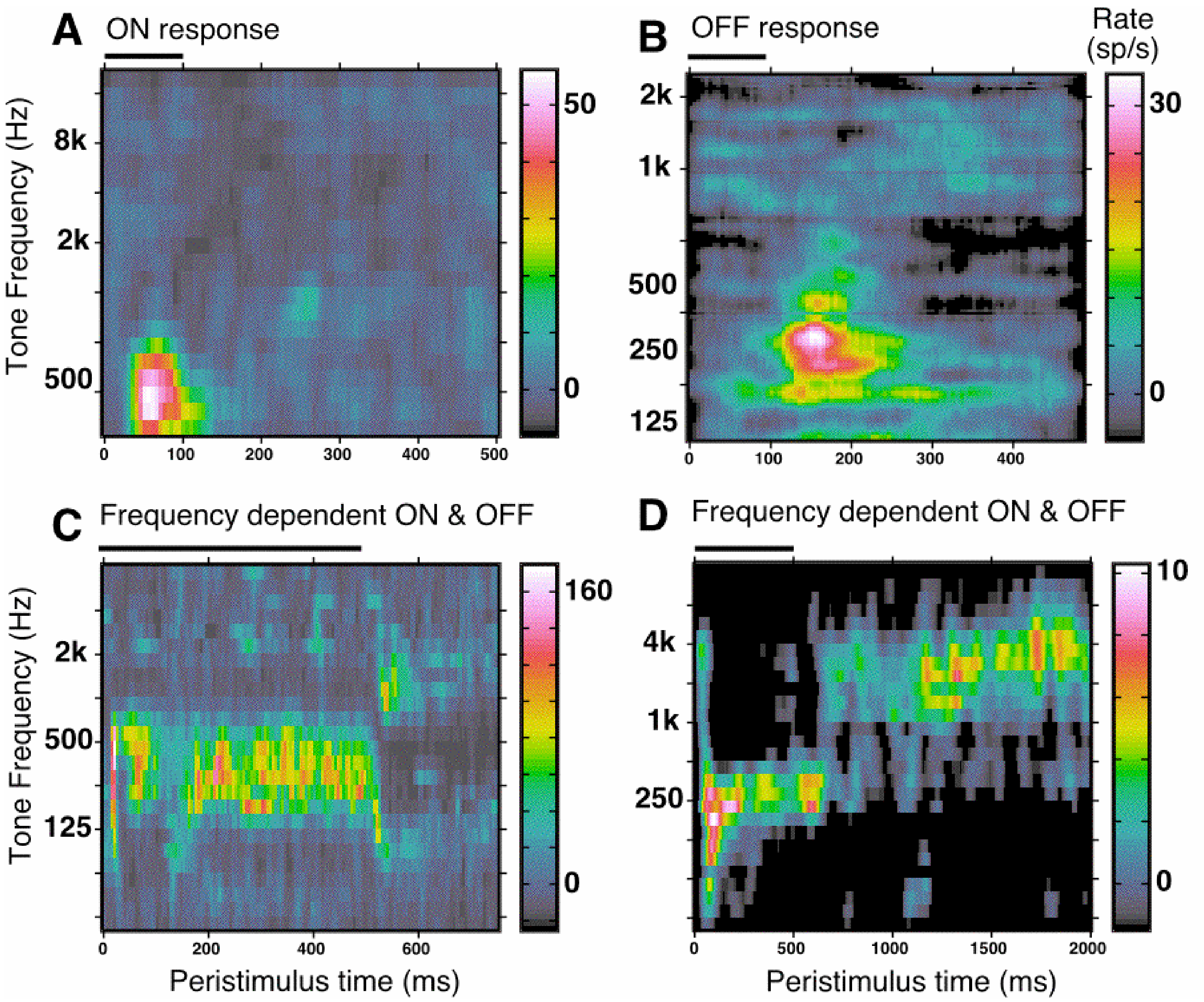
Auditory cortex: rate profiles for pure tones

Please see Philips, D. P., M. N. Semple, M. B. Calford, L. M. Kitzes. "Level- dependent Representation of Stimulus Frequency in cat Primary Auditory Cortex." Exp Brain Res. 102, no. 2 (1994): 210-26.

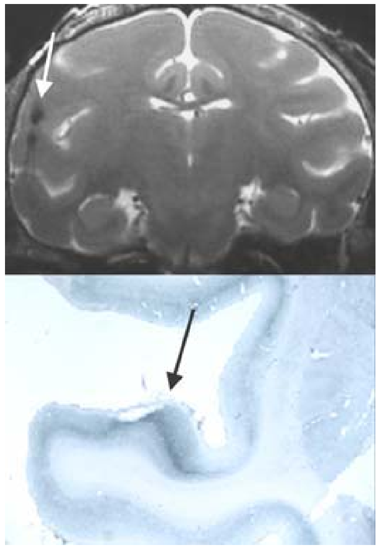
Pitch-related temporal patterns in field potentials in awake monkey cortex

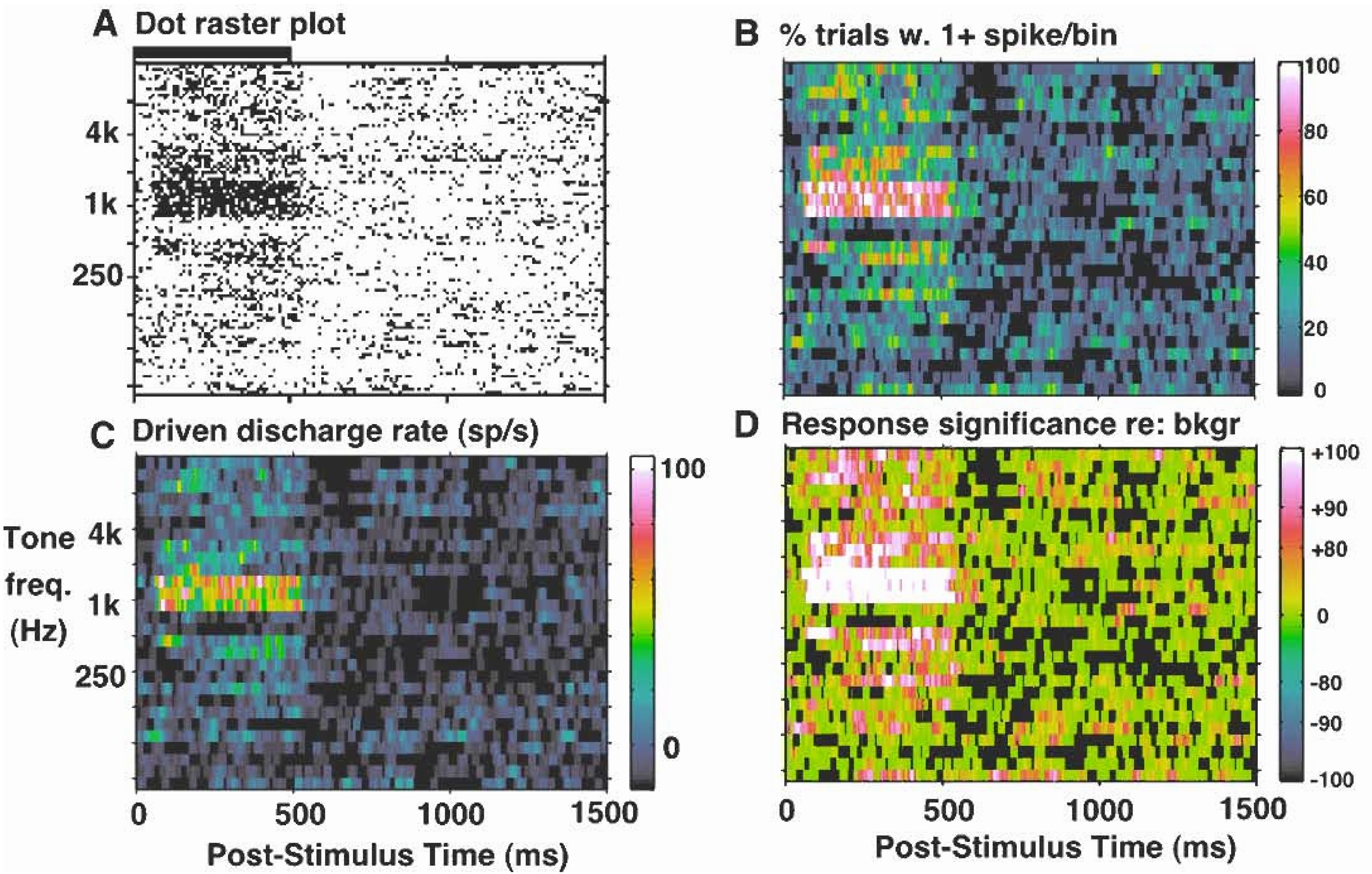
Please see Steinschneider, M., D. H. Reser, Y. I. Fishman, C. E. Schroeder, J. C. Arezzo. "Click Train Encoding in Primary Auditory cortex of the Awake monkey: evidence for two mechanisms subserving pitch Perception." *J. Acoust Soc Am*. 104, no. 5 (Nov, 1998): 2935-55.

Pure tone temporal response profiles in auditory cortex (A1)



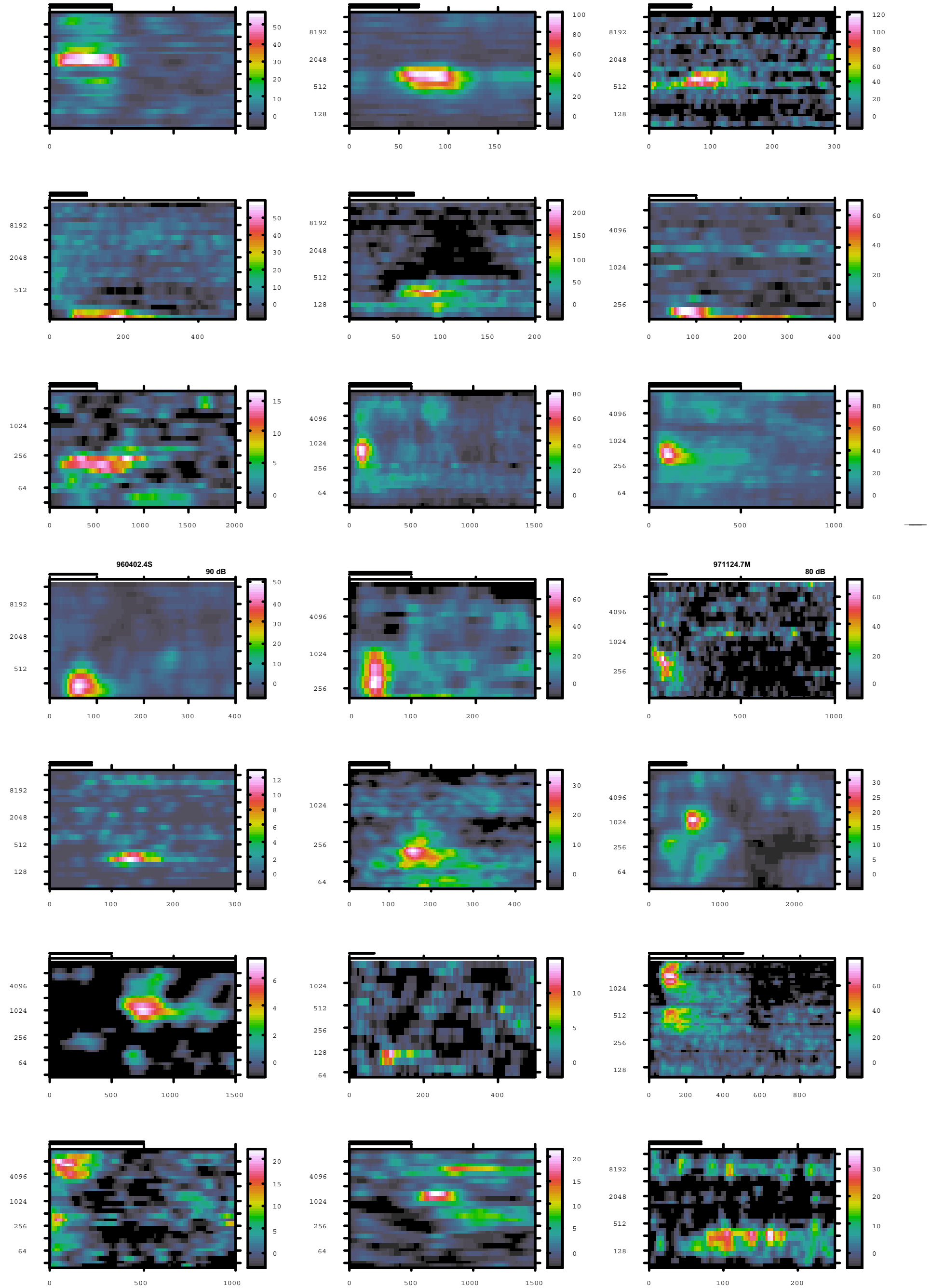
Tramo, Mark Jude. "Neural Representations of Acoustic Information in Relation to Voice Perception." Harvard University, PhD Thesis, 1999.





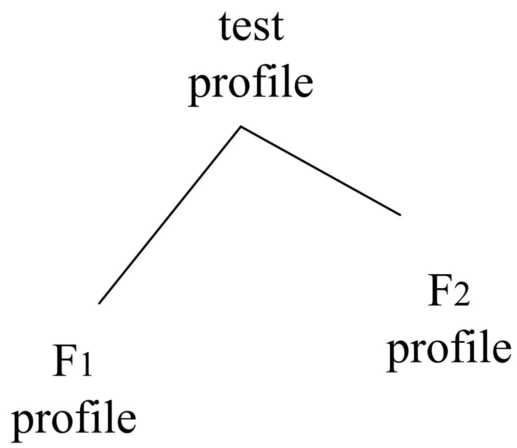
Tramo, Mark Jude. "Neural Representations of Acoustic Information in Relation to Voice Perception." Harvard University, PhD Thesis, 1999.

Temporal response profiles in auditory cortex

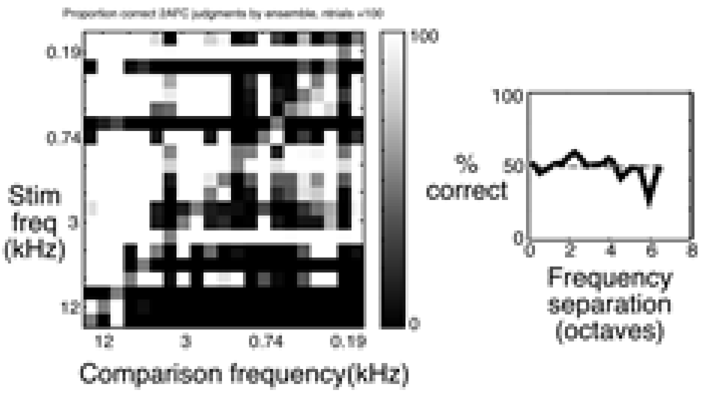


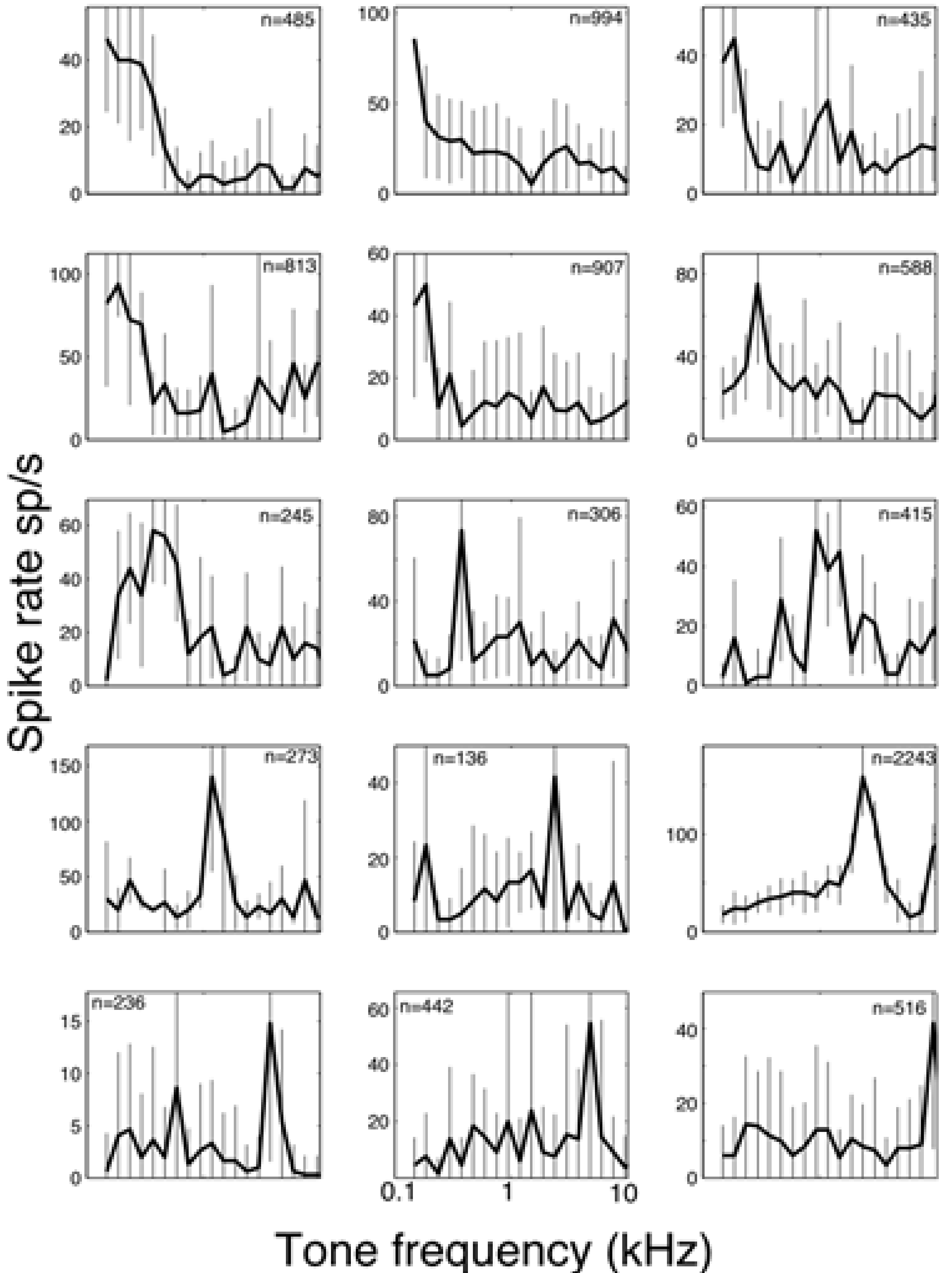
Tramo, Mark Jude. "Neural Representations of Acoustic Information in Relation to Voice Perception." Harvard University, PhD Thesis, 1999.

Rate-frequency profiles for 15 cortical ON units



Decision analysis





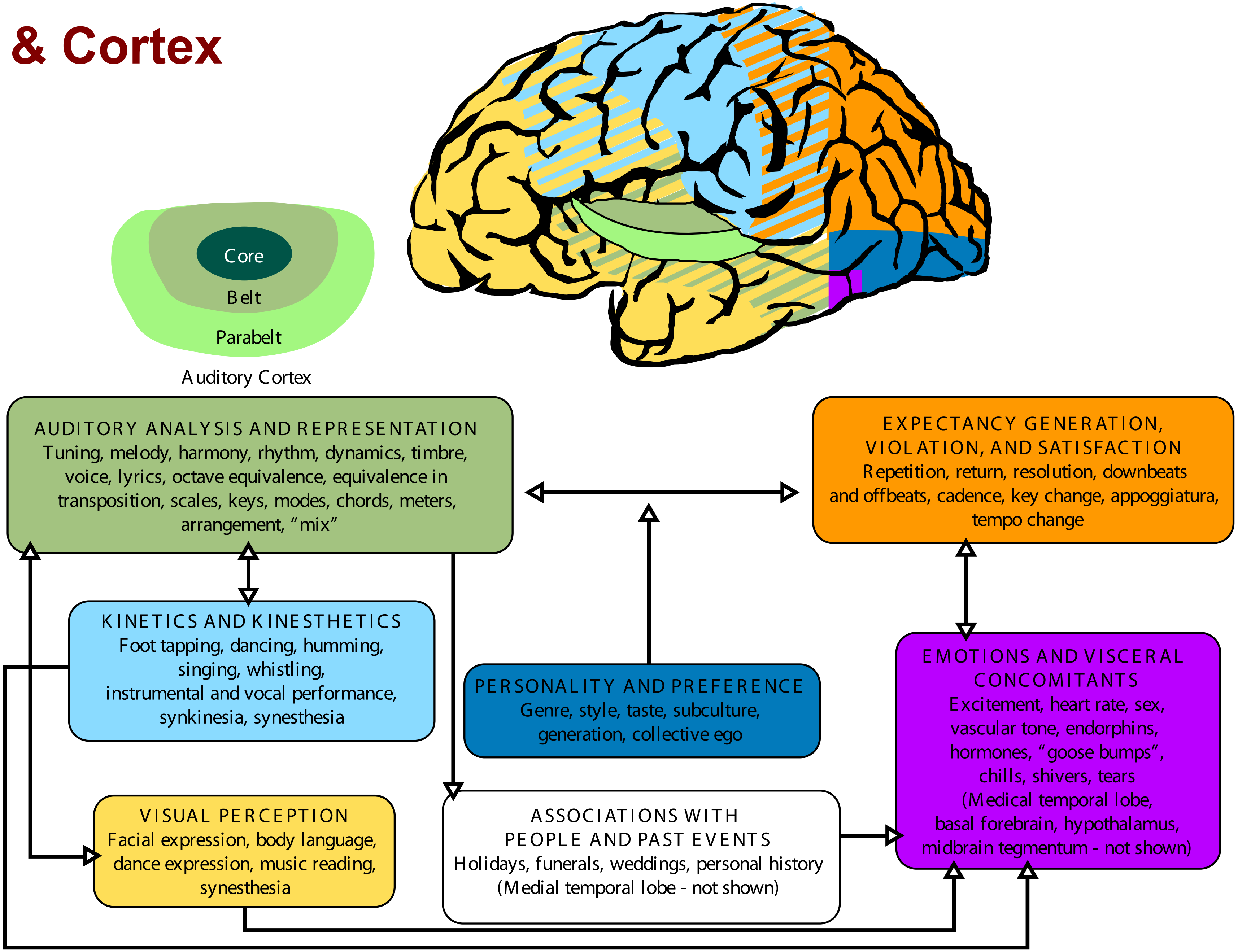
How do higher auditory stations represent and process sounds?

- What is the fate of neural timing information?

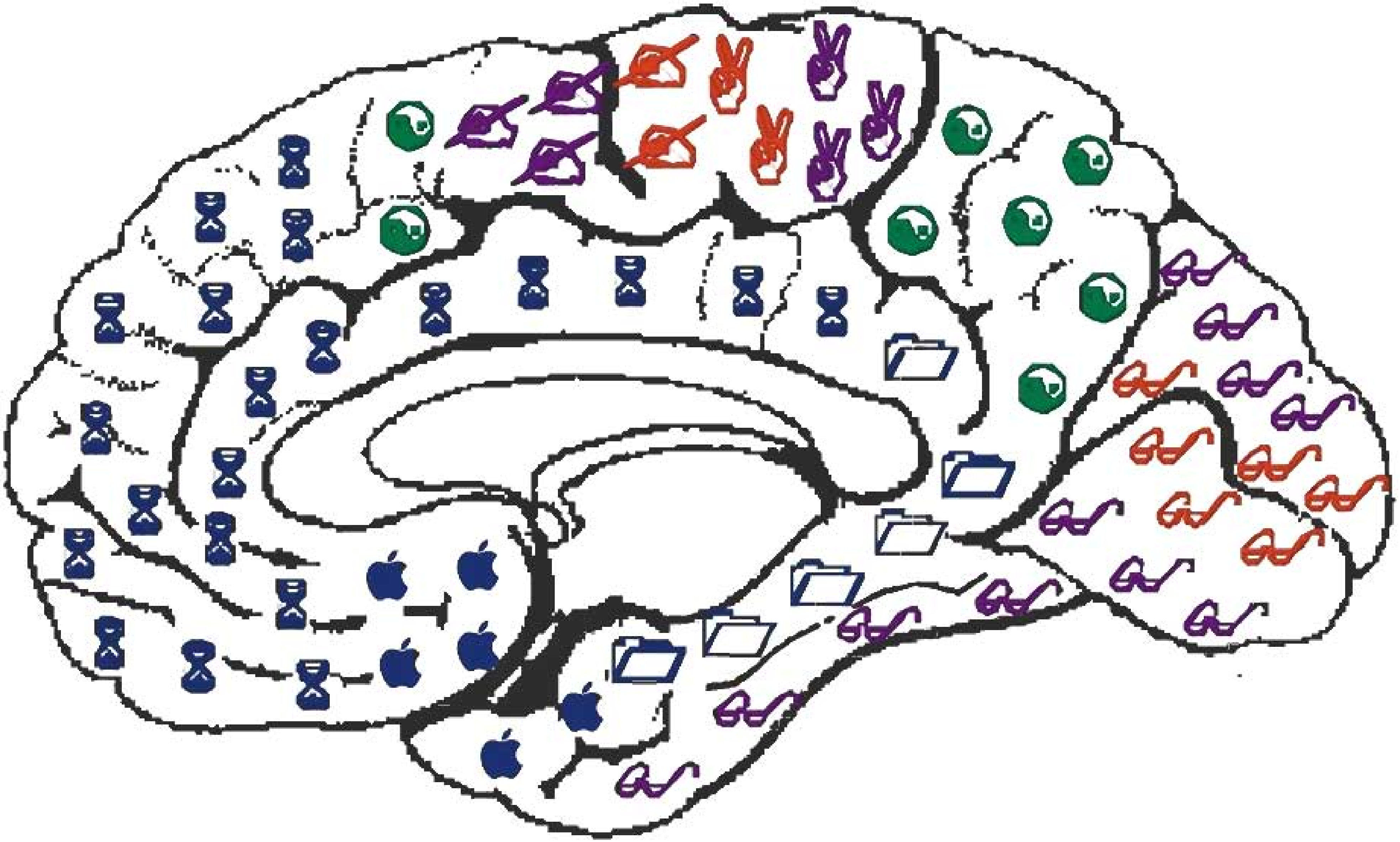
- How does the auditory CNS make use of it?
- Where do representations responsible for fine pitch distinctions reside?

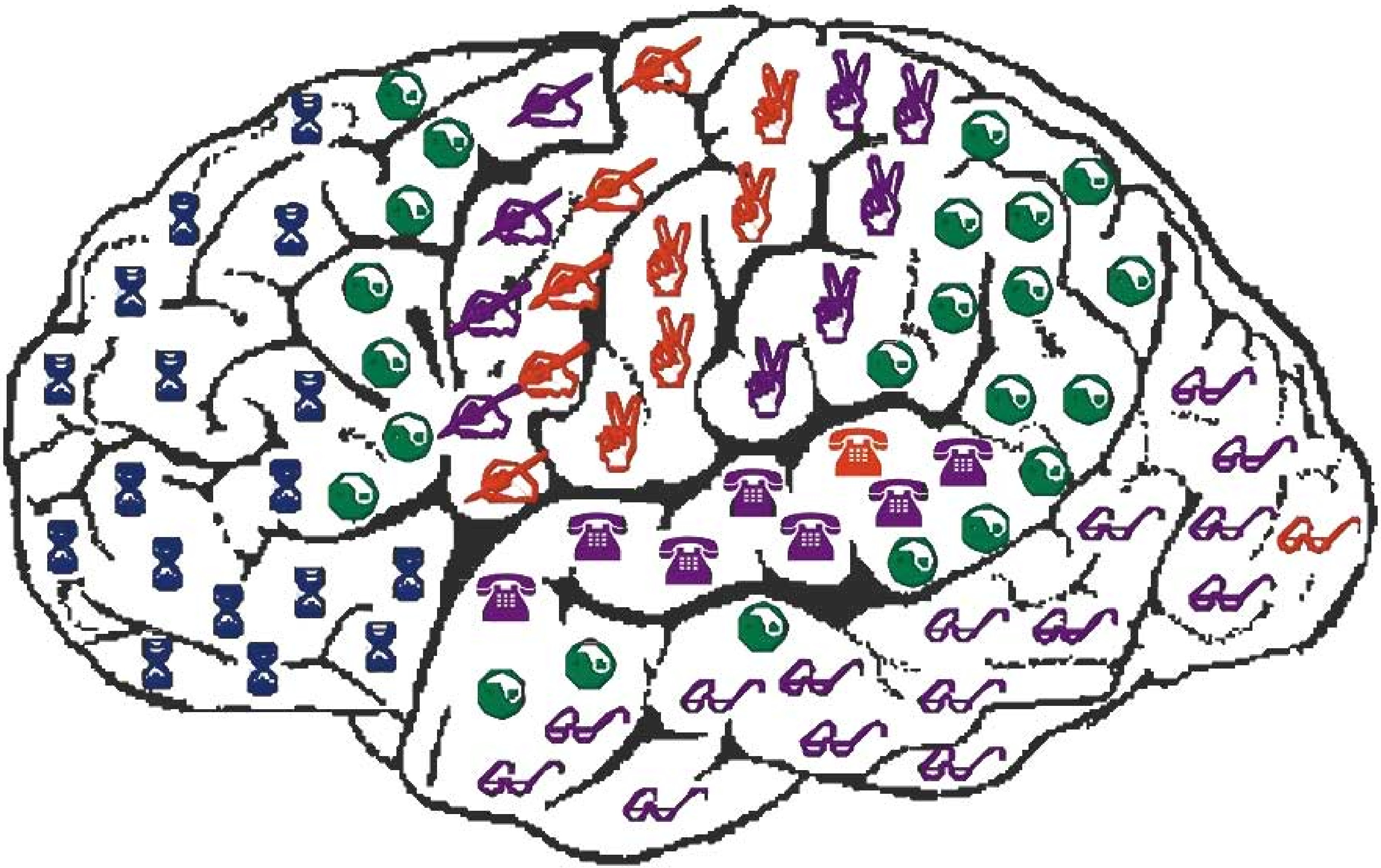
What are the central neural codes & computations?

Music & Cortex

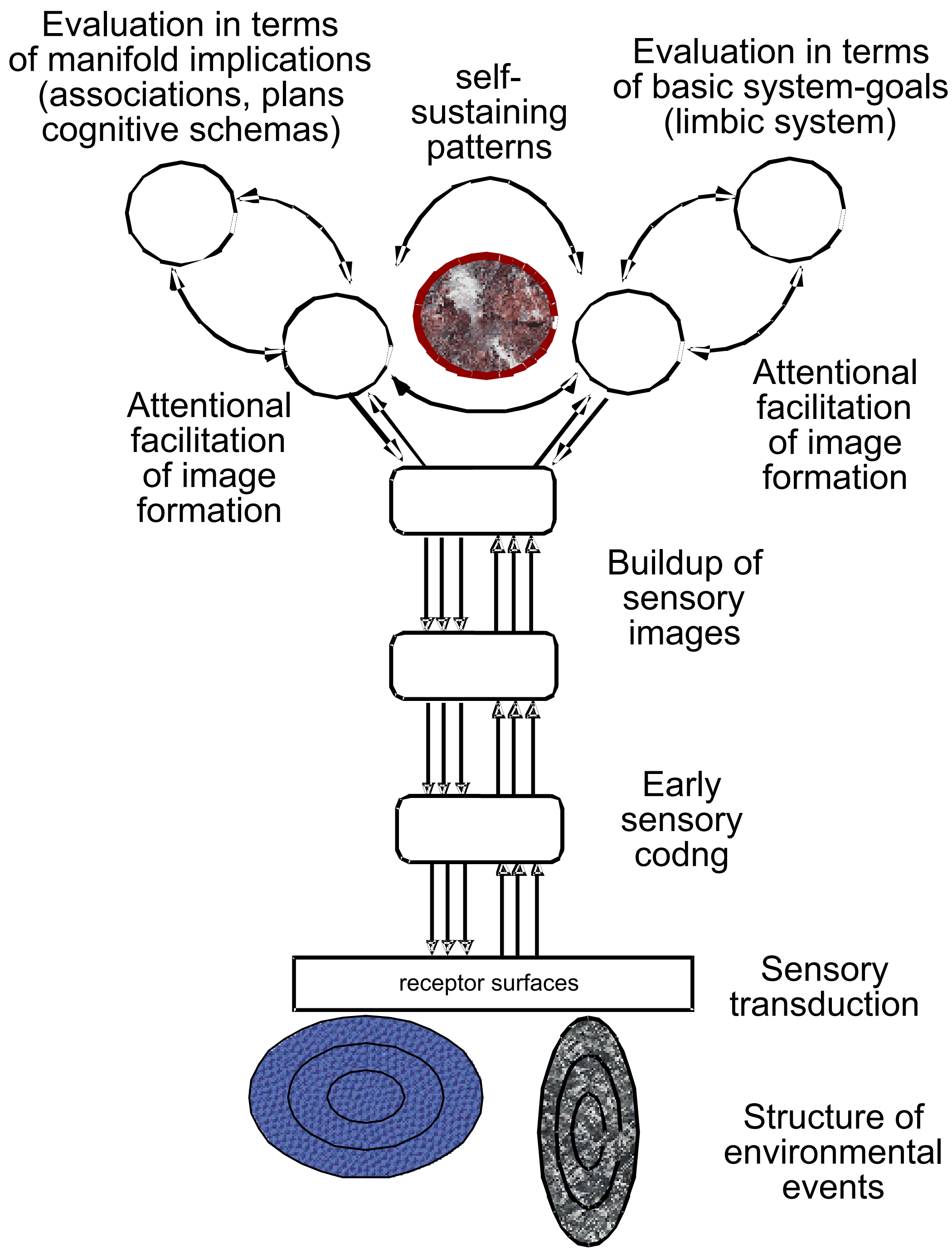


Adapted from figure 1 of Tramo, Mark Jude BIOLOGY AND MUSIC: Enhanced: Music of the Hemispheres Science 2001 291: 54-56.





Functional organization of the perceptual side



Some generalities about the auditory system

- **Rough cochleotopy is found at all levels, but not necessarily in all neural populations**
- **Highly ordered tonotopic maps exist only at low tone levels, near neural thresholds**
- **As one ascends the afferent pathway:**
- **Numbers of neurons at each level increases**
- **Fine timing information exists in great superabundance in lower stations, but becomes successively sparser**
- **Firing rates (spontaneous & driven) decline**
- **Inhibition increases; % nonmontonic rate-level fns incr.**
- **Diversity and complexity of response increases**
- **History-dependence and contextual effects increase**
- **Some modulation tuning that suc. declines in periodicity**

  Typical BMFs: AN: 200-300 Hz; IC: 50-100 Hz; Ctx (< 16 Hz)
- **No clear "pitch detectors"** (Schwarz & Tomlinson, 1991)
- **No narrow** **(BW < 0.3 octaves)** **"frequency channels" for BFs < 2 kHz**

Basic problems to be solved

• "Hyperacuity problem"

• Account for the precision of pitch discriminations given the relatively coarse tunings of auditory neurons (at all levels), especially lower-frequency ones (BFs < 2 kHz)

• "Dynamic range problem"

• Account for the ability of listeners to discriminate small fractional changes ($\Delta I/I$) in intensity over a large dynamic range, and especially at high SPLs, where the vast majority of firing rates are saturated.

• "Level-invariance problem"

• Account for the invariance (and precision) of auditory percepts over large dynamic ranges given the profound changes in neural response patterns that occur over those ranges (rate saturation, rate non-montonicities).

•Pitch equivalence

•Account for the ability to precisely match pitches of pure and complex tones (pitch equivalence, metamery) given differences in spectra and under conditions where stimulus intensities are roved 20 dB or more

•Relative nature of pitch & transpositional invariance

•Account for the ability to precisely match pitches an octave apart (and/or to recognize patterns of pitch sequences) in the absence of an ability to identify absolute frequencies/periodicities. Account for ability to recognize transposed melodies as similar.

Readings for next class
(Thurs Feb. 19th; no class on Tuesday)

- Moore, Chapter on Pitch
- de Cheveigne Chapter on Pitch models, to be posted on the course website
- Deutsch, Chapter by Rasch & Plomp

Sources

Please see Ehret, Gunter, and Raymond Romand, eds. *The Central Auditory System*. New York: Oxford University Press, 1997. ISBN: 0195096843.

AN rate profiles in response to high (8 kHz) & low (1 kHz) frequency pure tones

(from Aikin)

Please see Irvine, D. R. F. "The Auditory Brainstem." *Progress In Sensory Physiology 7*. Edited by D. Ottoson . Berlin: Springer-Verlag. 1986.

Please see Kim, Do. C. E. Molnar. "A Population Study of Cochlear Nerve Fibers: Comparison of Spatial Distribution of Average-rate and Phase-locking Measures of Responses to Single Tones." *J Neurophysiol*. 42 (1 Pt 1) (Jan, 1979):16-30.

AN rate profiles in response to multiformant vowels

Please see Irvine, D. R. F. The Auditory Brainstem. Edited by D. Ottoson , *Progress In Sensory Physiology* 7. Berlin: Springer-Verlag. 1986.

Please see Kim, Do. CE Molnar. A Population Study of Cochlear Nerve Fibers: Comparison of Spatial Distribution of Average-rate and Phase-locking Measures of Responses to Single Tones. *J Neurophysiol*. 42 (1 Pt 1) (Jan, 1979):16-30.