Auditory perception class: critical bands

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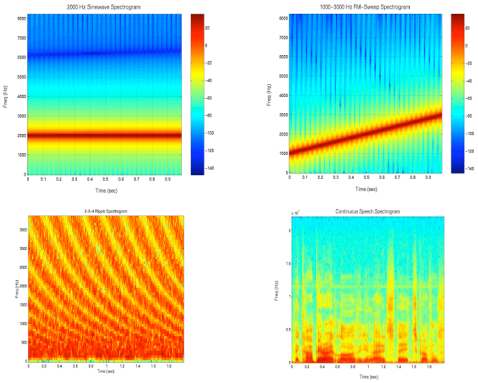
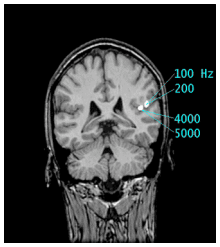
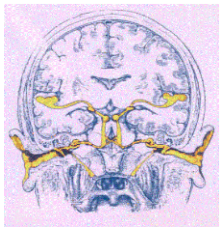
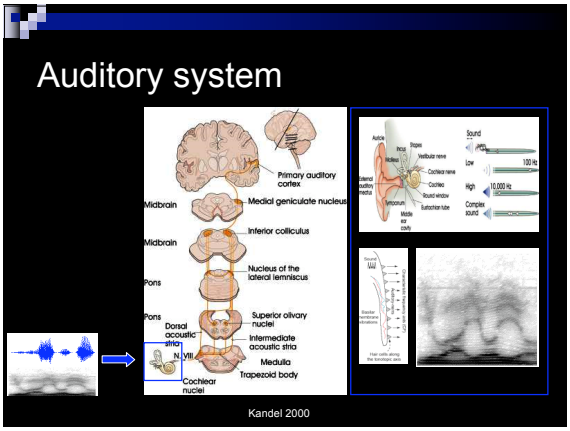


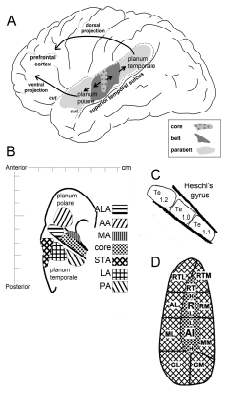


Coronal slice (structural MRI) illustrating localized activation in superior auditory cortex (upper bank of superior temporal gyrus) to sinusoidal tones of different frequencies.

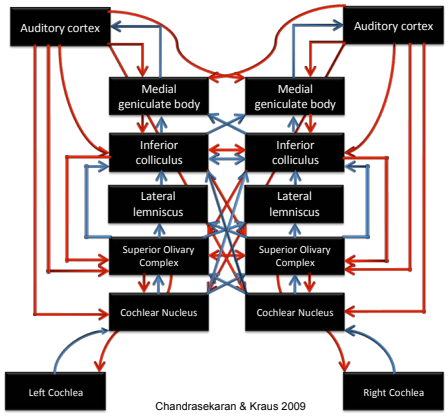


Coronal slice illustrating auditory pathway from ear to auditory cortex



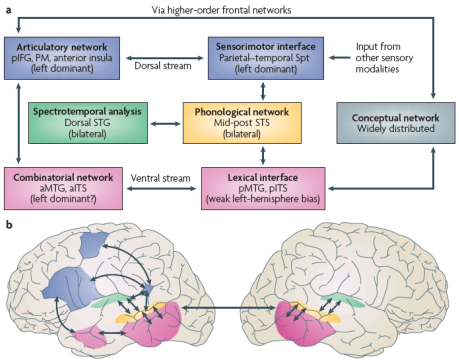


Hall & Garcia, in press



Chandrasekaran & Kraus 2009

Functional anatomy of speech sound processing



Hickok & Poeppel, 2007, Nat Rev Neurosci

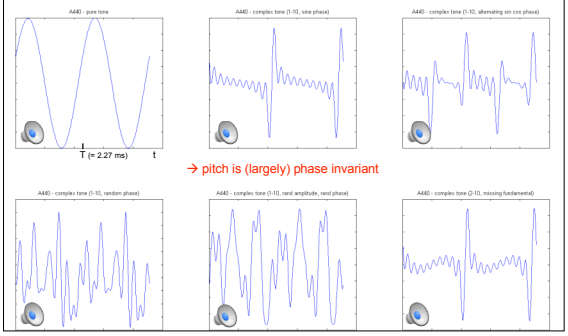
A few reminders about the characteristics

- Frequency range of human auditory system
  - 20 Hz to 20,000 Hz (textbook); 80 Hz to < 10,000 Hz (really); most psychophysics is done between 200 - 5,000 Hz (because that is the range in which one obtains *interpretable* data)
- Intensity range
  - Extends over many orders of magnitude (depending on frequency); at the 'sweet spot' (~1000-3000 Hz) about a 120 dB dynamic range
- Sensitivity
  - JNDs for frequency: ~0.2% (e.g., at 1000 Hz base frequency, listeners can distinguish 1000 Hz from 1002 Hz -- impressive!)
  - JNDs for loudness discrimination: ~1 dB
  - Sensitivity to timing differences: a few microseconds in spatial hearing

Perceptual attributes of sounds

- Pitch
  - sound frequency, fundamental frequency of complex periodic signals, or inter-harmonic spacing
- Loudness
  - Signal amplitude (ASA Demo)
- Timbre
  - Distribution of energy across frequency, shape of the spectrum
- Spatial location
  - Binaural hearing (inter-aural time and intensity differences), head-related transfer function.

Pure vs. complex tones (all A440) - pitch, timbre phase

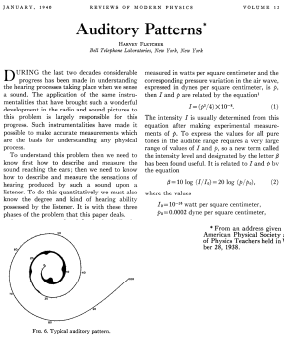


→ pitch is (largely) phase invariant

Masking

- The interference one sound causes in the reception of another sound
  - Peripheral component/cause: overlapping excitation pattern
  - Central component/cause: uncertainty - "informational masking"
- Masking experiments have been used extensively to investigate spectral and temporal aspects of hearing
  - Masking to study frequency selectivity: the critical band
  - Forward and backward masking (temporal and spectral constraints)
  - Comodulation masking release ('unmasking' of sub-threshold signal by comodulated signal in different regime)

Classic experiment: Fletcher 1940



JANUARY, 1940 REVIEWS OF MODERN PHYSICS VOLUME 12

Auditory Patterns*

HARVEY FLETCHER
Bell Telephone Laboratories, New York, New York

DURING the last two decades considerable progress has been made in understanding the hearing processes taking place when we sense a sound. The application of the same instrumentalities that have brought such a wonderful development in the radio and sound pictures to this problem is largely responsible for this progress. Such instrumentalities have made it possible to make accurate measurements which are the basis for understanding any physical process.

To understand this problem then we need to know first how to describe and measure the sound reaching the ears; then we need to know how to describe and measure the sensations of hearing produced by such a sound upon a listener. To do this quantitatively we must also know the degree and kind of hearing ability possessed by the listener. It is with these three phases of the problem that this paper deals.

measured in watts per square centimeter and the corresponding pressure variation in the air wave, expressed in dynes per square centimeter, is p, then I and p are related by the equation[1]

$$I = (p^2/4) \times 10^{-4}. \quad (1)$$

The intensity I is usually determined from this equation after making experimental measurements of p. To express the values for all pure tones in the audible range requires a very large range of values of I and p, so a new term called the intensity level and designated by the letter β has been found useful. It is related to I and p by the equation

$$\beta = 10 \log (I/I_0) = 20 \log (p/p_0), \quad (2)$$

where the values

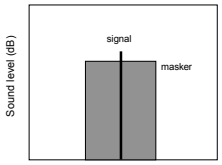
$I_0 = 10^{-16}$ watt per square centimeter,
$p_0 = 0.0002$ dyne per square centimeter,

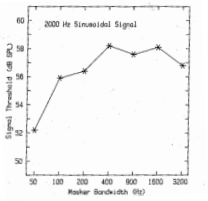
* From an address given before the joint dinner of the American Physical Society and the American Association of Physics Teachers held in Washington, D. C., on December 28, 1938.

FIG. 6. Typical auditory pattern.

Classic experiment: Fletcher 1940

Determine threshold of sinusoidal signal in noise.
Noise always centered at signal frequency.

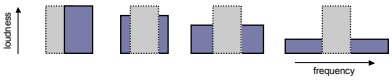




Schooneveldt & Moore 1989

- ASA Demo – count tones in noise, as function of bandwidth.
- Increases in noise bandwidth result in more noise passing through a given filter, yielding more masking. However, when the noise bandwidth exceeds the filter bandwidth, there is no more threshold change. The point at which further increases yield no further threshold in creases: *critical band*.
- Starting with Fletcher, masking studies have been used to evaluate frequency selectivity of auditory system.
- Interpretation of masking data: auditory periphery can be described as a set of contiguous, overlapping bandpass filters, with overlapping passbands. These "auditory filters" comprise the first stage in the spectro-temporal analysis of all sounds.

Critical bands by loudness comparison



Zwicker & Feldtkeller 1967; Scharf 1970; Rossing 1982

Reference noise band compared to test noise band with increasing bandwidth (constant power). When the bandwidth of the test noise exceeds the critical bandwidth, the loudness begins to increase. (ASA Demo)

Model of masking: Power spectrum model

1. The (peripheral) auditory system contains an array of linear overlapping bandpass filters.
2. When detecting signal in noise, listener makes use of just one filter, centered close to the signal frequency. This filter will pass the signal but remove a great deal of the noise.
3. Only the noise components passing through the filter will mask the signal.
4. The threshold is determined by the amount of noise passing through the filter. The threshold corresponds to some signal-to-noise ratio K at the output of the filter.

- Simplifying assumption made by Fletcher: rectangular filters, 'flat top', width of the filter is CB.
- Estimate value of CB indirectly by measuring power of sinusoidal signal P_s required for detection in broadband white noise of power density N_0.

Noise falling within CB is $N_0 \times CB$. Following 4 above, $P_s/(N_0 \times CB) = K$

$$CB = P_s/(N_0 \times K)$$

By measuring P_s and N_0 and estimating K, the value of the critical band can be determined. (Fletcher estimated K=1; Scharf, 1970, revised that to about 0.4) (P_s/N_0 called '*critical ratio*')

Estimating the Shape of the auditory filter based on power-spectrum model:

$$P_s = K \int_0^\infty N(f)\, W(f)\, df$$

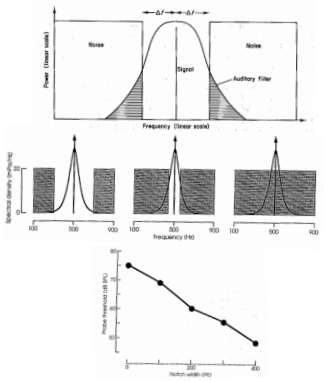
- Masker is represented by its long-term power spectrum N(f)
- Weighting function, or auditory filter is W(f)
- P_s is power of the signal at threshold

Method a bit indirect filtershape presumably not rectangular, therefore …

New approaches

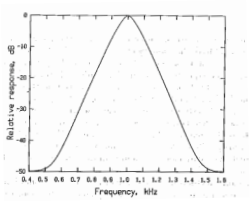
1. Notched noise (Patterson)
2. Determining filtershape (psychophysics, neurophysiology)

Notched noise method

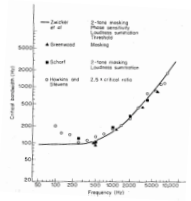


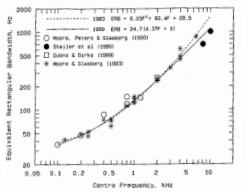
Patterson, R.D. (1974). Auditory filter shape. J. Acoust. Soc. Am., 55, 802-809.

Shape of auditory filter from notched noise

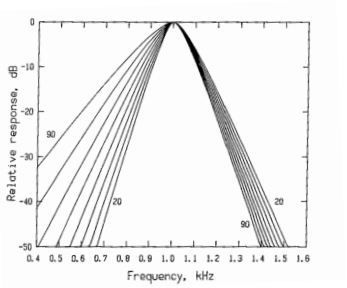


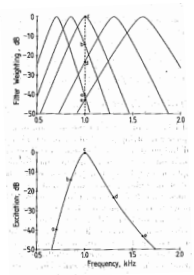
The width of the critical band (auditory filter) changes with center frequency





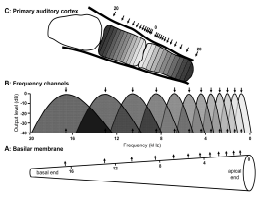
The shape of the critical band (auditory filter) changes with signal amplitude





Summary: critical bands

1. Human auditory perceptual analysis is quantized into < 30 “critical bands”
2. of perceptually near-identical frequency analysis classes
3. corresponding to approximately equal length bands of cochlear tissue (receptor surface)



Hall & Garcia, in press