Phase ~~and Feedback~~ in the Nonlinear Brain

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Auditory processing pre-COSYNE workshop

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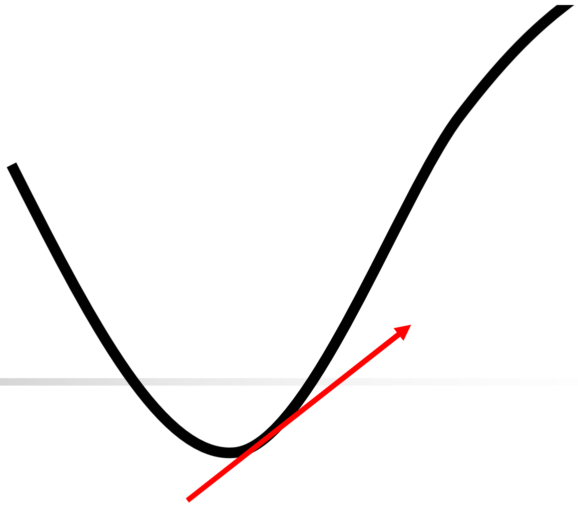
Simplistic Models

- “Dehydrated cats and the application of Fourier analysis to hearing problems become more and more a handicap for research in hearing.”—von Bekesy

- Overly simplistic models are bad
  - Wrong path
  - For example, critical band filters
    - Pitch and phase

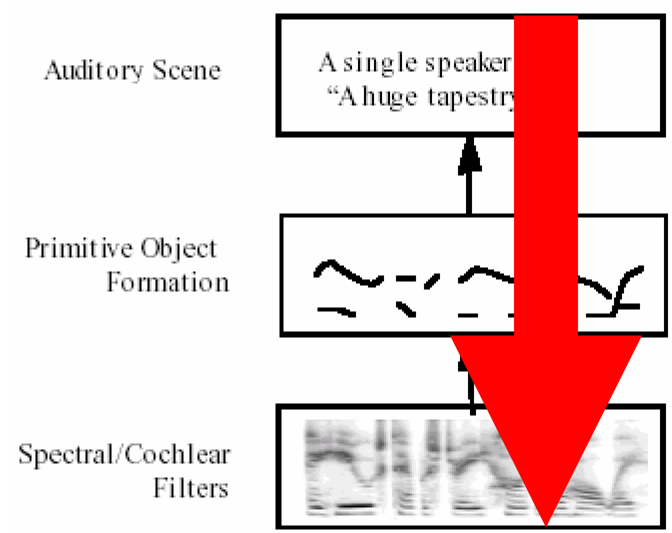
Tony's Goals



- Linearity
  - Taylor says everything is linear
    - To a point
  - Temporal codes
    - I don't know the answer….
  - Attentional effects
    - Big problem.. Not today
  - Phase perception

A Critique of Pure Audition

- Marr
  - Pure vision
- Churchland
  - A critique of pure vision
- Slaney
  - A critique of pure audition
  - Where are efferents?



Motivation

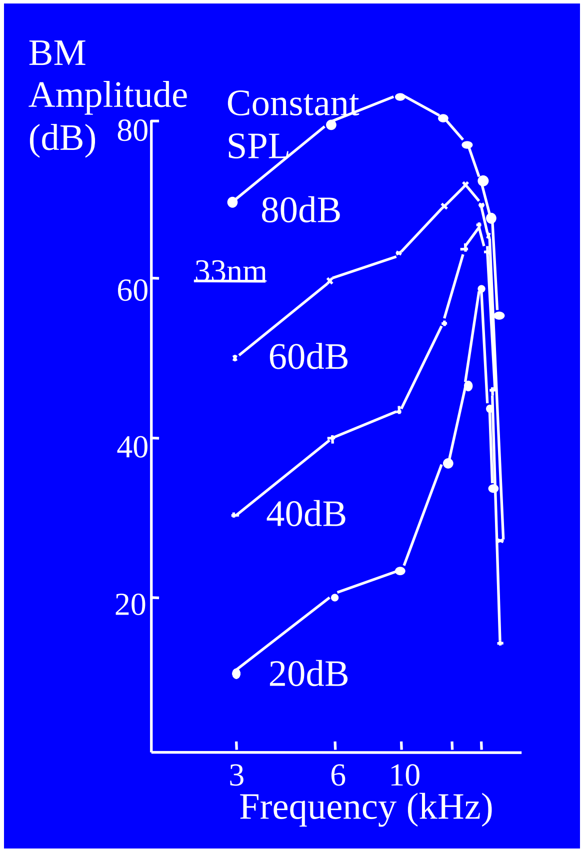
S. Shamma. “Speech processing in the auditory system.” 1985.

R. Carlyon, S. Shamma. “An account of monaural phase perception.” 2003.

Good Shihab

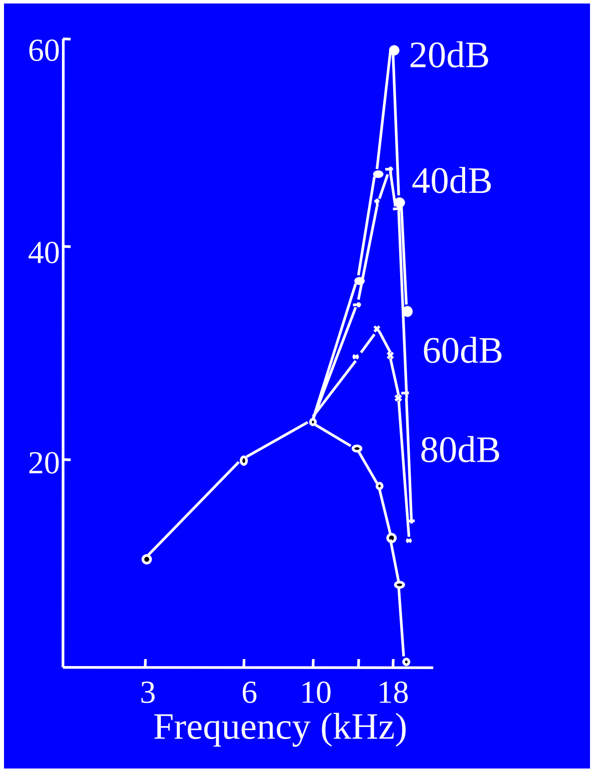
Bad Shihab

Nonlinear Cochlear Mechanics



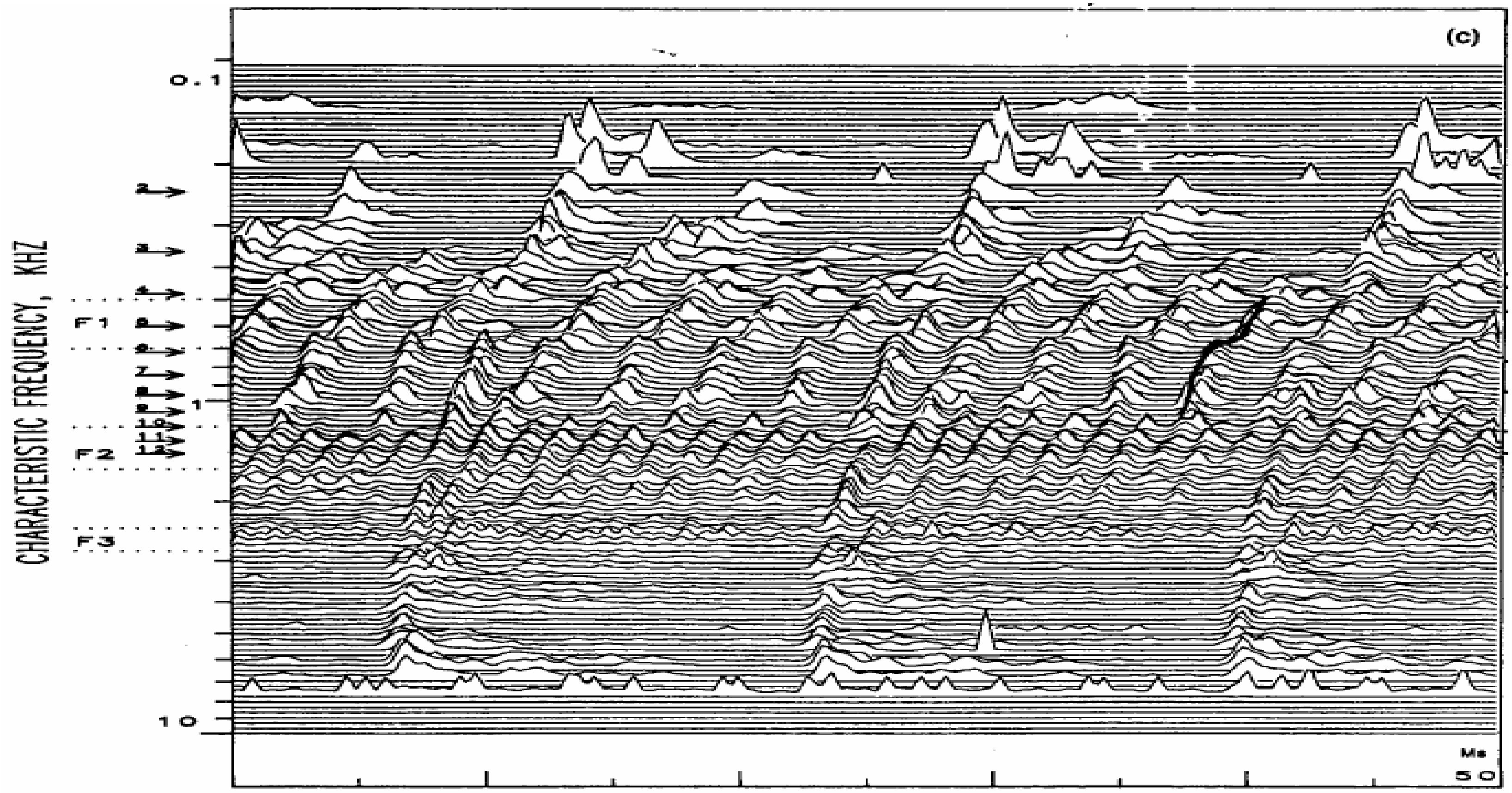
Mössbauer Data

SPL	Q_3	CF
80dB	1	10k
60dB	2.7	16k
40dB	4.8	17k
20dB	8.3	17k



From "Basilar membrane measurements and the travelling wave," by B.M. Johnstone, R. Patuzzi, and G. K. Yates, *Hearing Research*, 22 (1986) 147-153.

Cat Vowels (/da/)



Goal

- Test phase perception models with more sophisticated cochlear models

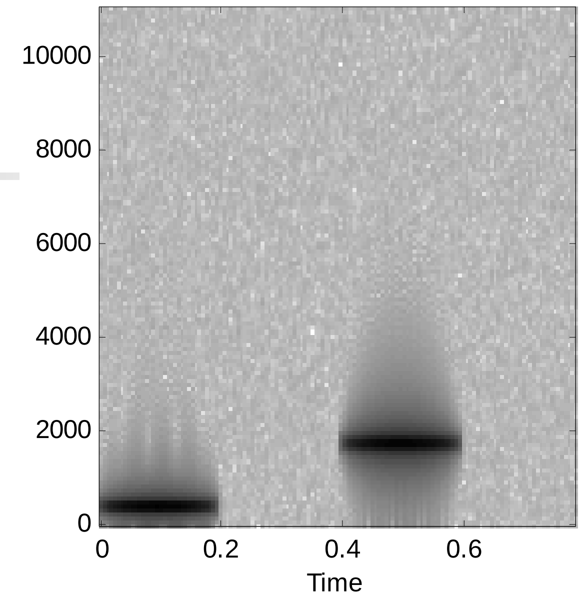
- Auditory models
  - Gammatone
  - Gammatone with hair cell model
  - Lyon’s passive Ear
  - STRF

Nonlinearities

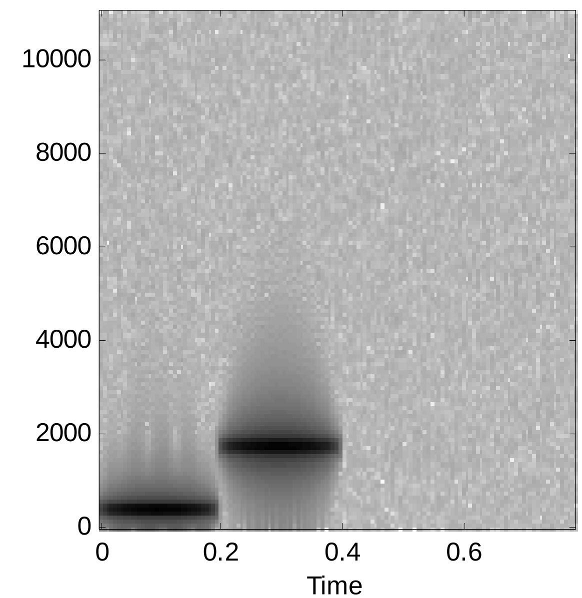
- Capture effect
  - Dominant frequency is represented
  - A few dB matter
- Stochastic resonance
  - Sub-threshold signals entrain firings
- Temporal coding
  - Non-linear mapping

Phase Models

- Within “channel”
  - Auditory nerve channel
  - Phase matters



- Between channels
  - Phase does matter!
  - Single sinusoids
    - 2 octave separation



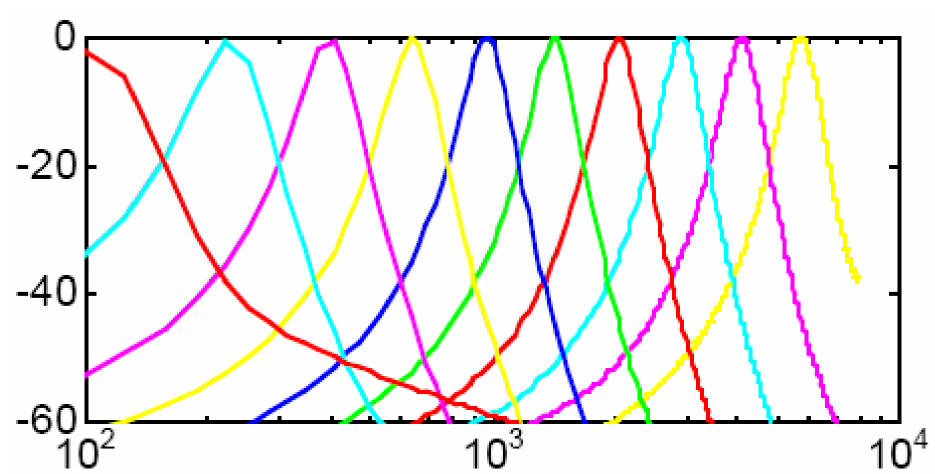
Phase Perception Model

- Short-term ← Today
  - Within channel
  - Sensitive to small phase change
  - STRF fails

- Long term
  - Speech-rate perception
  - Large phase changes (relative to CF)
  - STRF works great

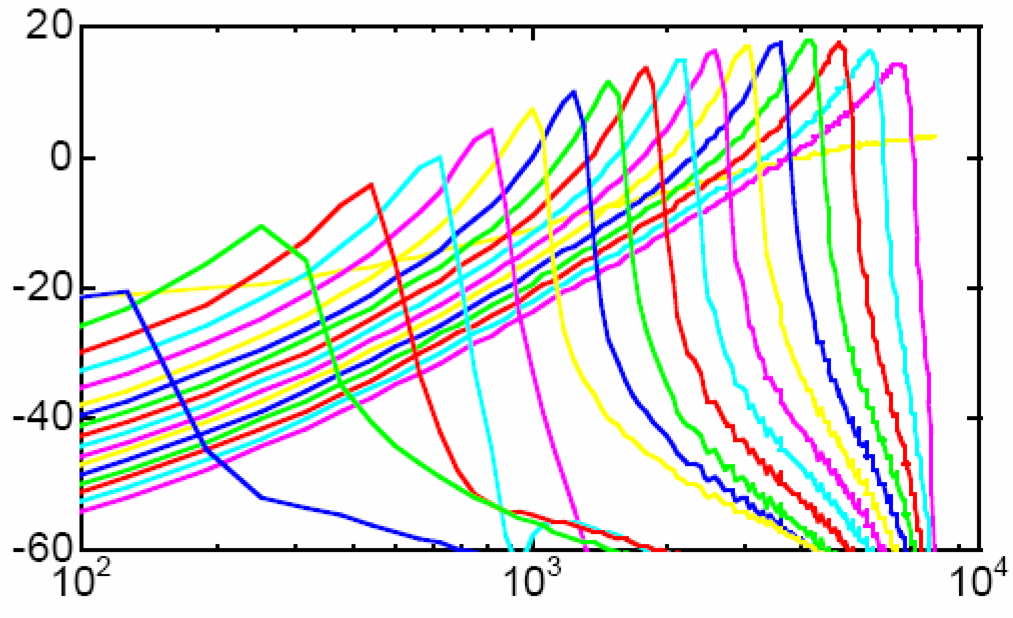
Models – Gammatone

- Critical band filters
  - Psychoacoustic data
  - Linear bandpass filters
- Meddis Hair Cell
  - Nonlinear reservoir model



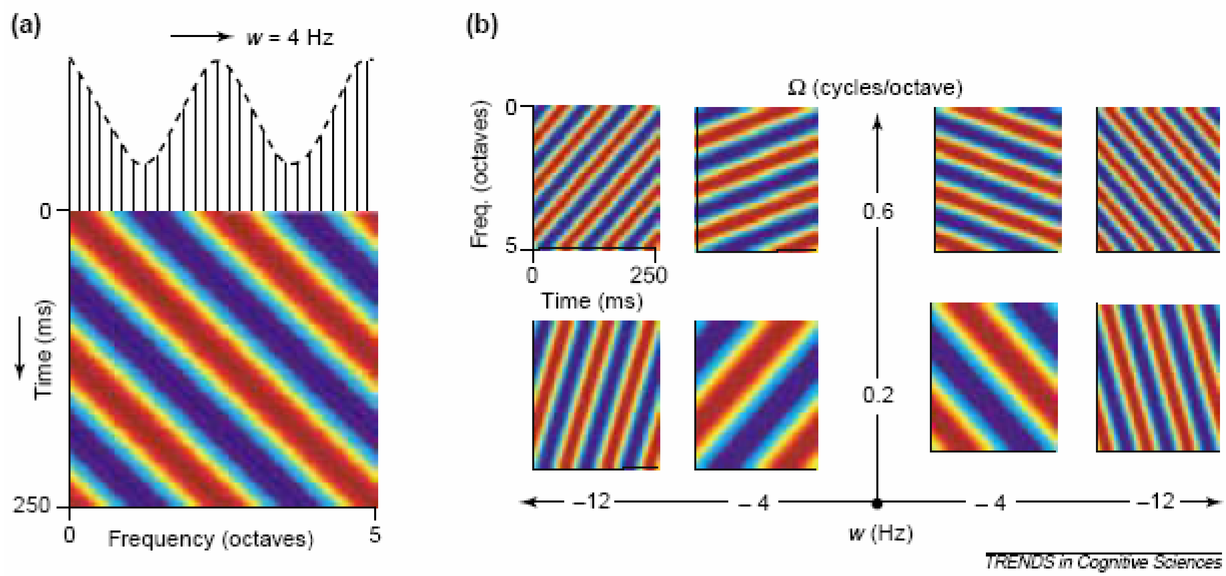
Models – Lyon’s Passive Ear

- Lowpass filters
  - Transmission line
  - Cascade
- Nonlinear automatic gain control (AGC)
  - Passive



Models – STRF

- Spatial temporal response function
  - Based on Shamma's cortical data
- Fit spectrogram data
  - Two-dimensional sinusoids
  - Image domain



Patterson Phase Results

- Stimulus
  - Constant phase shift per critical band
  - Shifted phase gradually
    - Small local changes
    - Large global change
- Result
  - Couldn't prove channel effect!

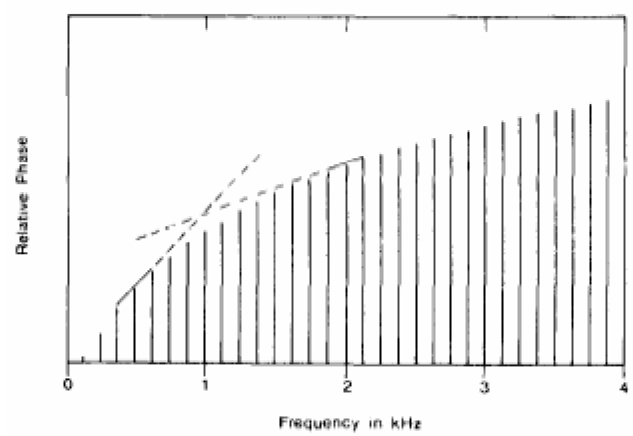
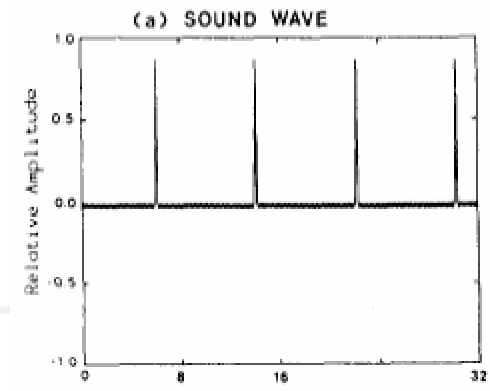
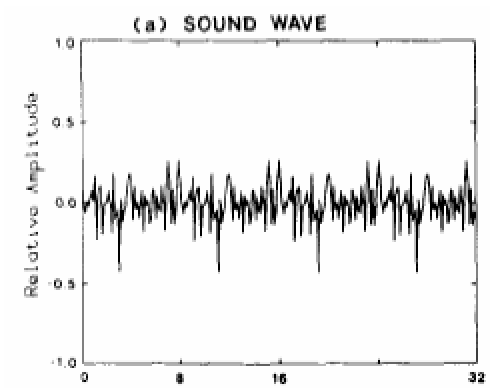


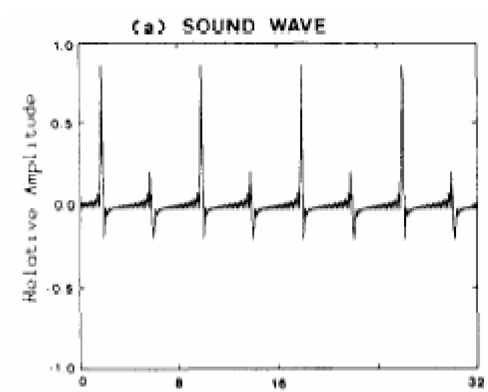
FIG. 11. The general form of the phase spectrum for the MPH waves. Since the function is approximately linear in any local region, it minimizes WC phase changes. At the same time, the effect of the deceleration cumulates across larger frequency regions to produce significant BC phase shifts.

Patterson Stimuli

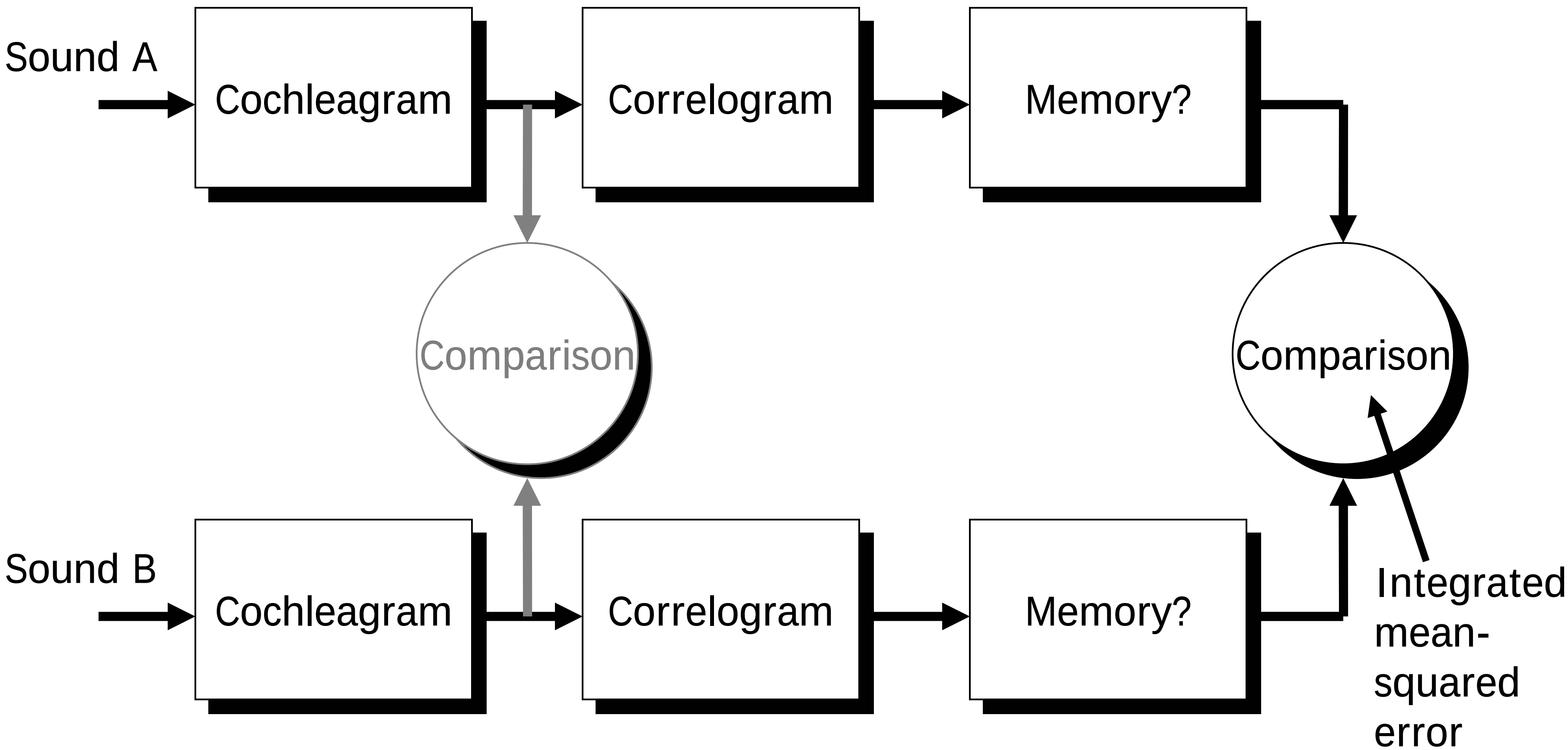
- Harmonic signal
  - 31 harmonics
- Phase Alignment
  - Cosine phase
  - Random phase
  - Alternating phase (APH)







Our Model

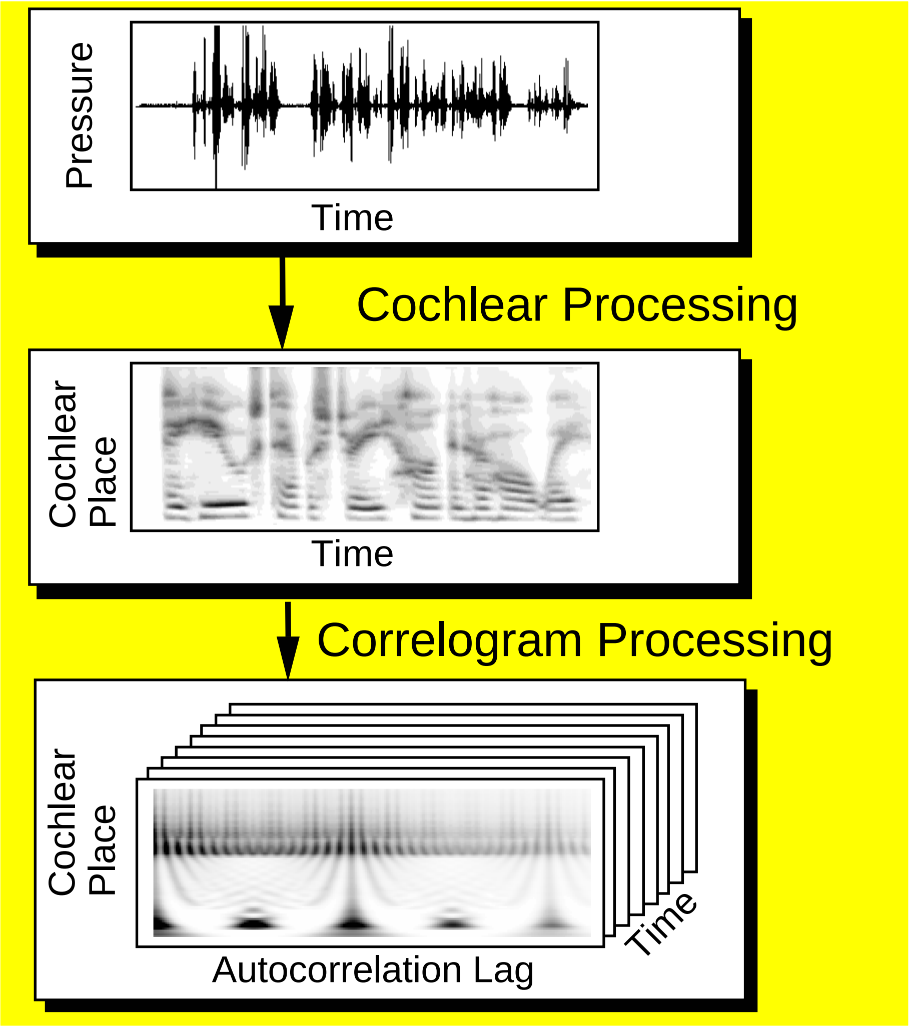

Sound A
Cochleagram
Correlogram
Memory?
Comparison
Comparison
Sound B
Cochleagram
Correlogram
Memory?
Integrated mean-squared error

Auditory Dimensions

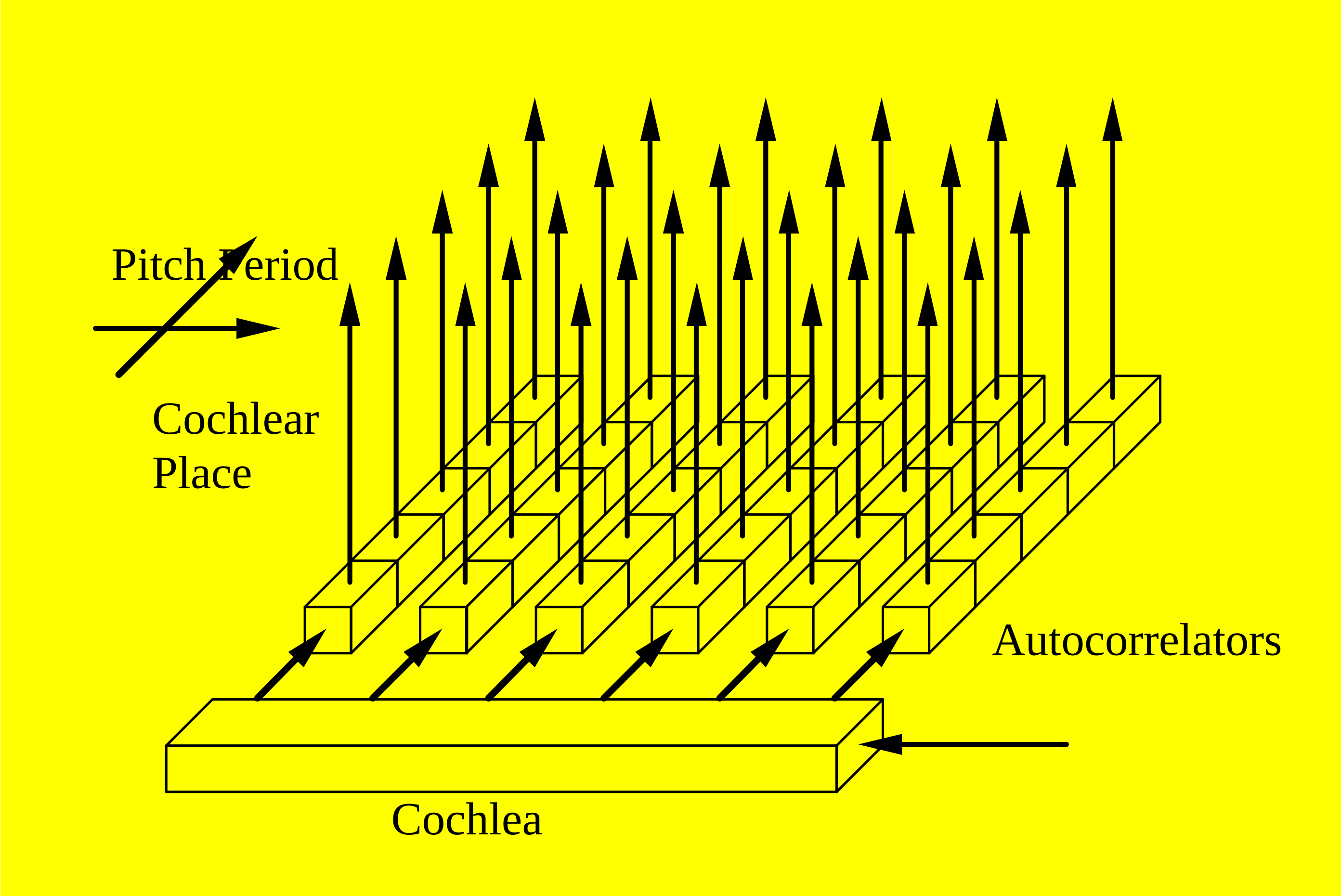
One Dimensional

Two Dimensional

Three Dimensional

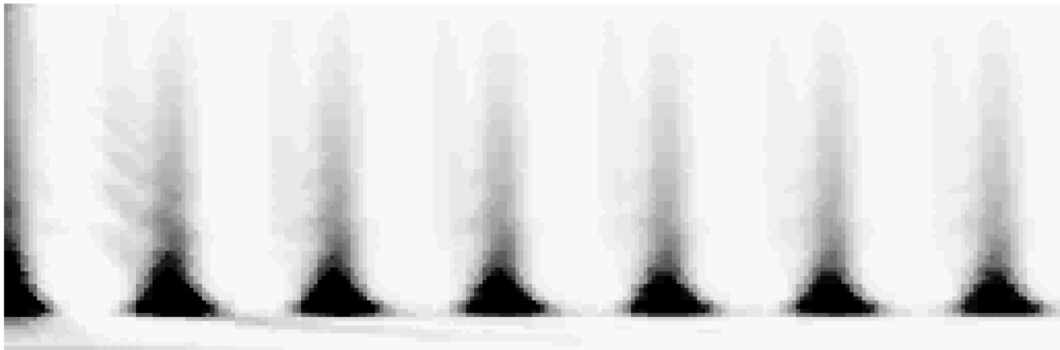


Correlogram Structure



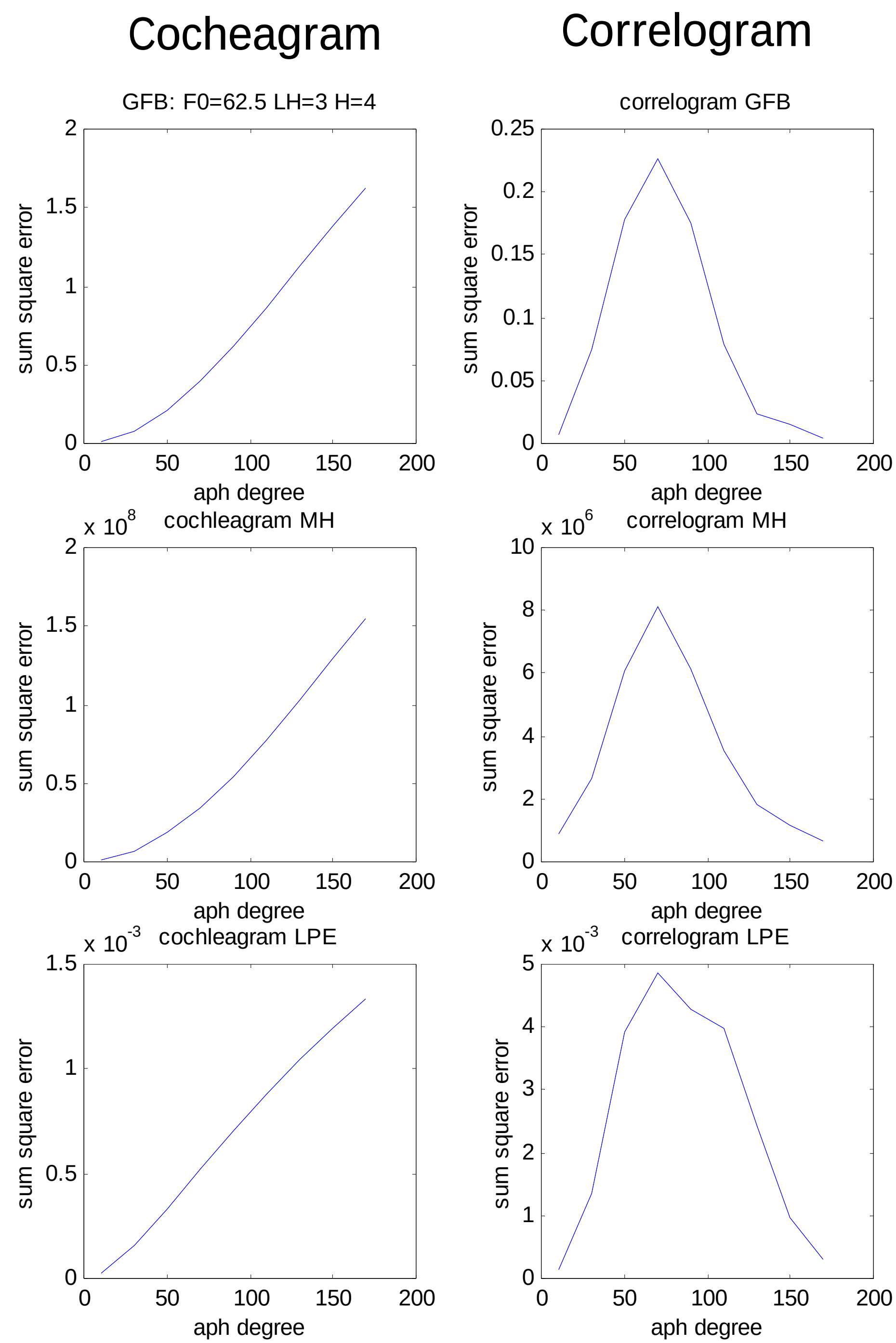
Duda Tones

- Simple tone
- Harmonic complex
- Tone build up (slow and fast)
- Tone removal (from top and bottom)
- Wiggle



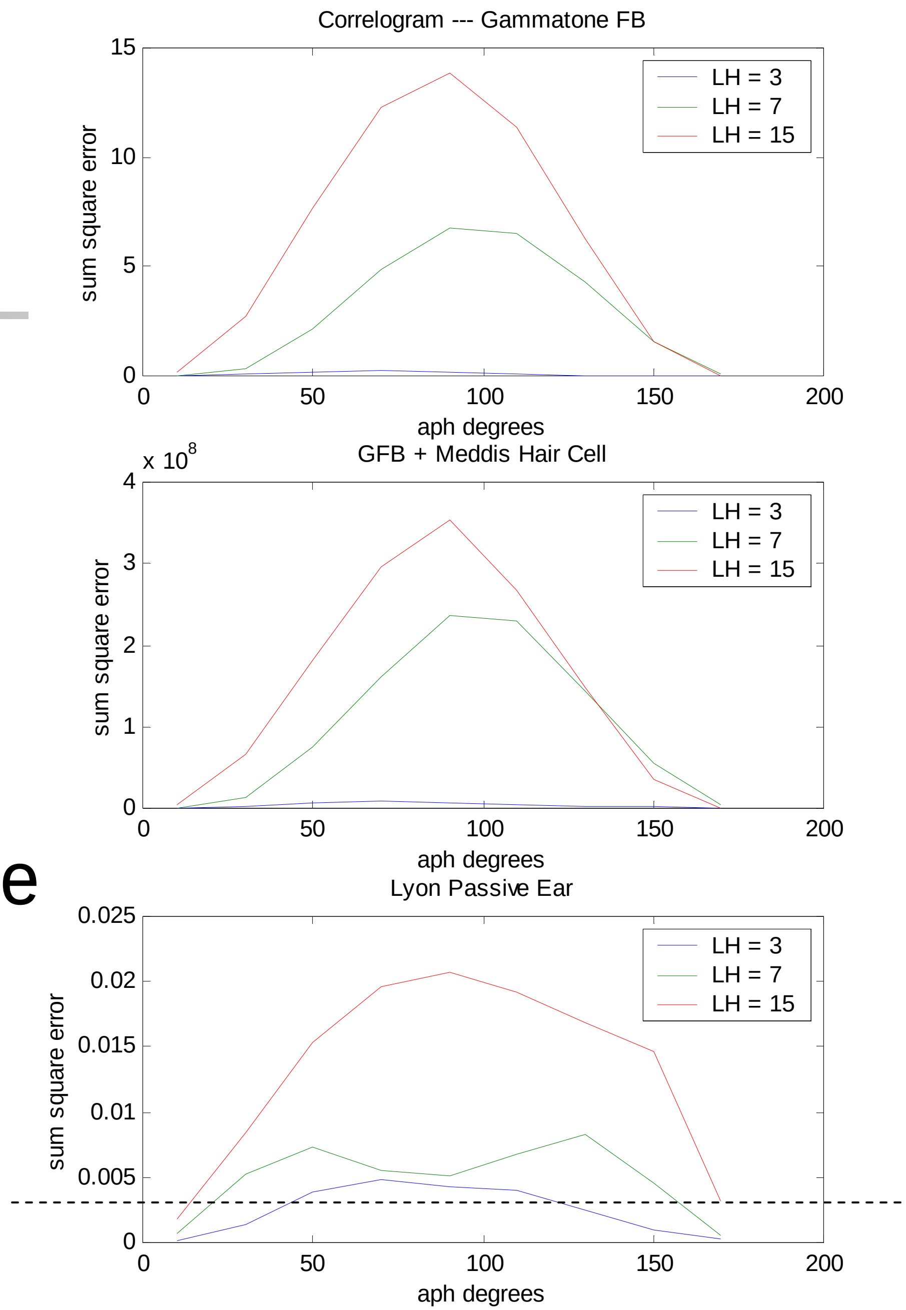
Results

- APH
  - Alternating phases are shifted
- Cochleagram
  - Auditory nerve
  - Error grows
- Temporal pattern
  - Error falls



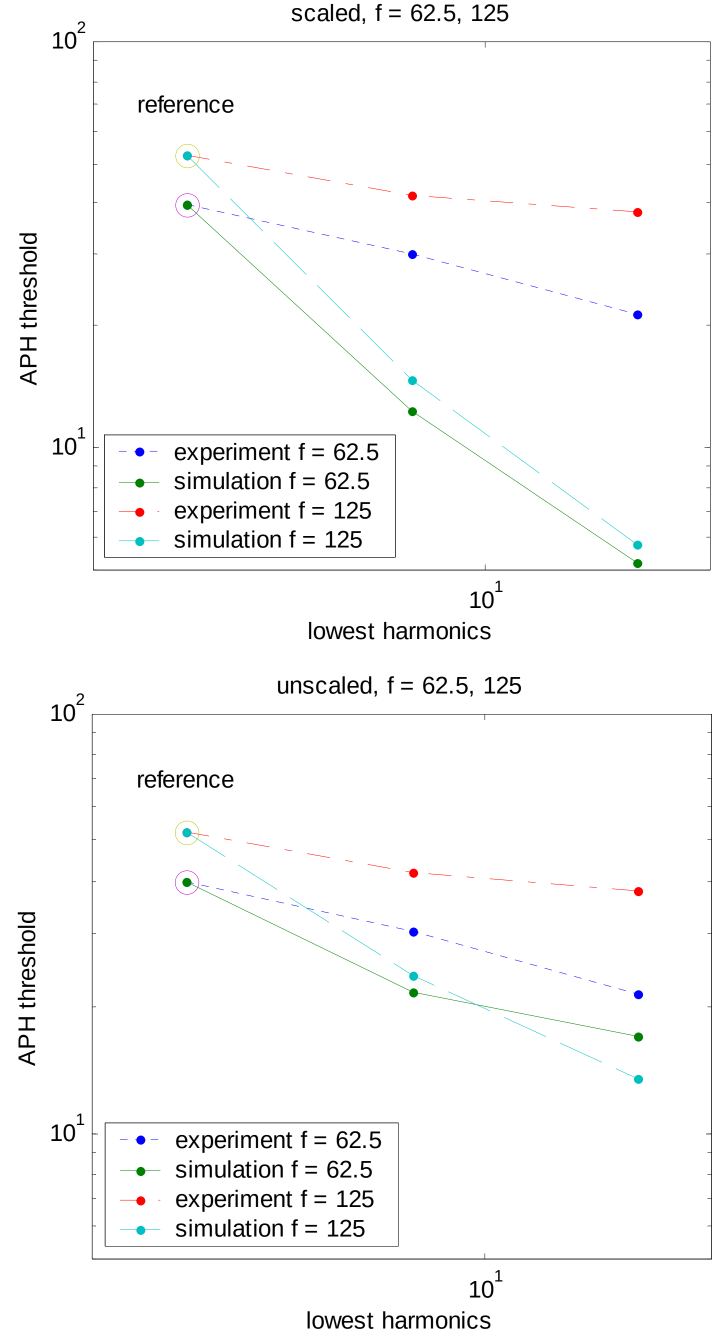
APH Results

- Test
  - Error wrt phase
  - Lowest harmonic
- Gammatone
  - Too much variance
  - No one threshold
- Lyon’s Ear



Threshold

- Gammatone
  - No one threshold
- Lyon’s Passive Ear
  - Consistent results
  - Depends on loudness (scaling)



Craig and Jeffress

- Two components
- Reverse polarity
- Task
  - Detect difference
  - Identify phase

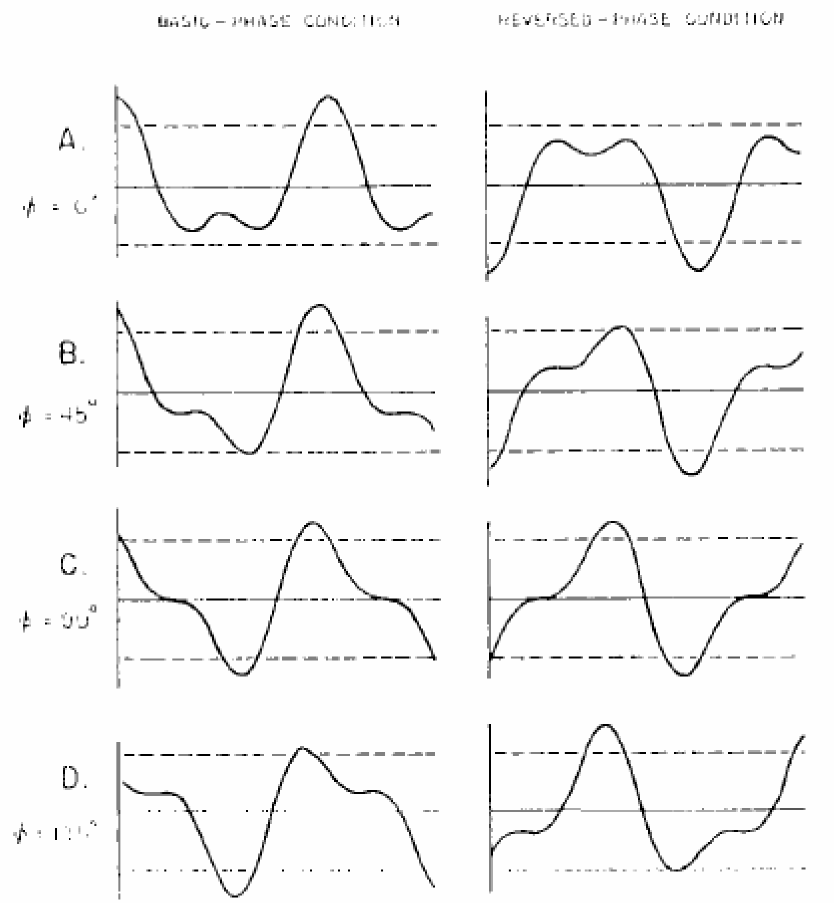
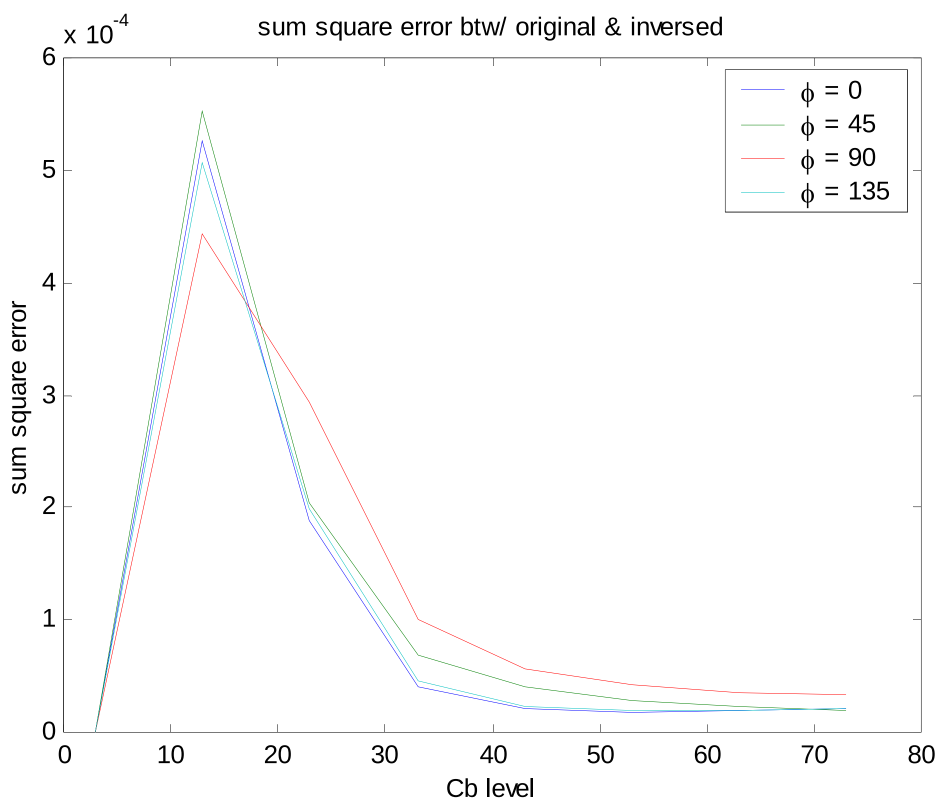
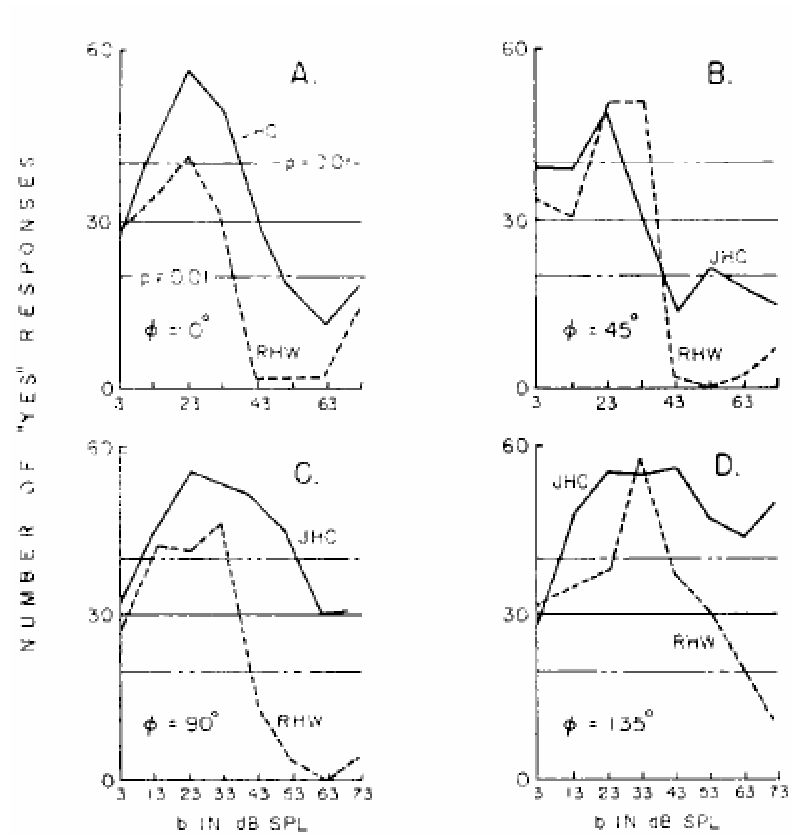


Fig. 3. The two-component stimulus, $Y = A \cos \omega t + B \cos (2\omega t + \varphi)$, for the four phase conditions used in this study (drawn with an arbitrarily selected component-amplitude ratio, $A = 2B$). Positive values indicate inward displacements of the eardrum.

Craig & Jeffress Results





To Do

- Improve results
  - Tune model bandwidths
  - Better cochlear/hair cell integration
- Verify two distinct regimes
  - Break in performance
  - Not

Conclusions

- Phase perception model
  - Two different models
    - Short-term within channel
    - Long-term STRF?
- Better auditory model
  - Less about critical bands