The application of auditory models to hearing aid research

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What are auditory models?

- For the purposes of this talk:
  - A mathematic description that can predict physiological and behavioral auditory function that results from acoustic stimulation
- Mechanistic models
  - simulations of physical systems
  - E.g., Meddis hair cell model, Carney auditory nerve model
- Phenomenological models
  - Models that explain data but are not based on physiological systems
    - Jeffress delay-line model of binaural localization
    - Plack forward masking model

Why care about auditory models?

- Audibility has been a focus for most of the hearing aid field's history
  - Need to understand suprathreshold behavior in complex environments
  - Need to understand effect of hearing aids on this suprathreshold behavior

Application of Auditory Models

- Models allow us to understand auditory function
  - o Understand needs of hearing aid wearers
  - o predict effect of hearing aid designs
    - Need to understand bionic auditory system
- Primary goal of auditory model application to hearing aids:
  - o Provide benefit to hearing aid users and practitioners who fit hearing aids

Uses of Auditory Models

- How have auditory models been applied to hearing aids to-date?

Uses of Auditory Models

- Signal Processing Design
  - Multiband compression
  - Others?

Uses of Auditory Models

- Signal Processing Design
- Fitting algorithms
  - Loudness models
  - Auditory nerve models, e.g. Bondy, 2004

Uses of Auditory Models

- Signal Processing Design
- Fitting algorithms
- Predicting sound quality
  - Noise reduction
  - Distortion
  - Feedback artifacts
  - Loudness

Uses of Auditory Models

- Signal Processing Design
- Fitting algorithms
- Predicting sound quality
- Explaining effect of hearing loss on auditory function
  - Changes to psychoacoustic measures
  - Failure of normal-hearing AI

Uses of Auditory Models

- Signal Processing Design
- Fitting algorithms
- Predicting sound quality
- Explaining effect of hearing loss on auditory function
- Front -end signal processing
  - Human auditory perception as an "optimal processor"
    - Computational auditory scene analysis
    - Automatic speech recognition

Uses of Auditory Models

- Signal Processing Design
- Fitting algorithms
- Predicting sound quality
- Explaining effect of hearing loss on auditory function
- Front -end signal processing

- What research challenges exist in the application of auditory models towards hearing aid benefit?

Challenge #1

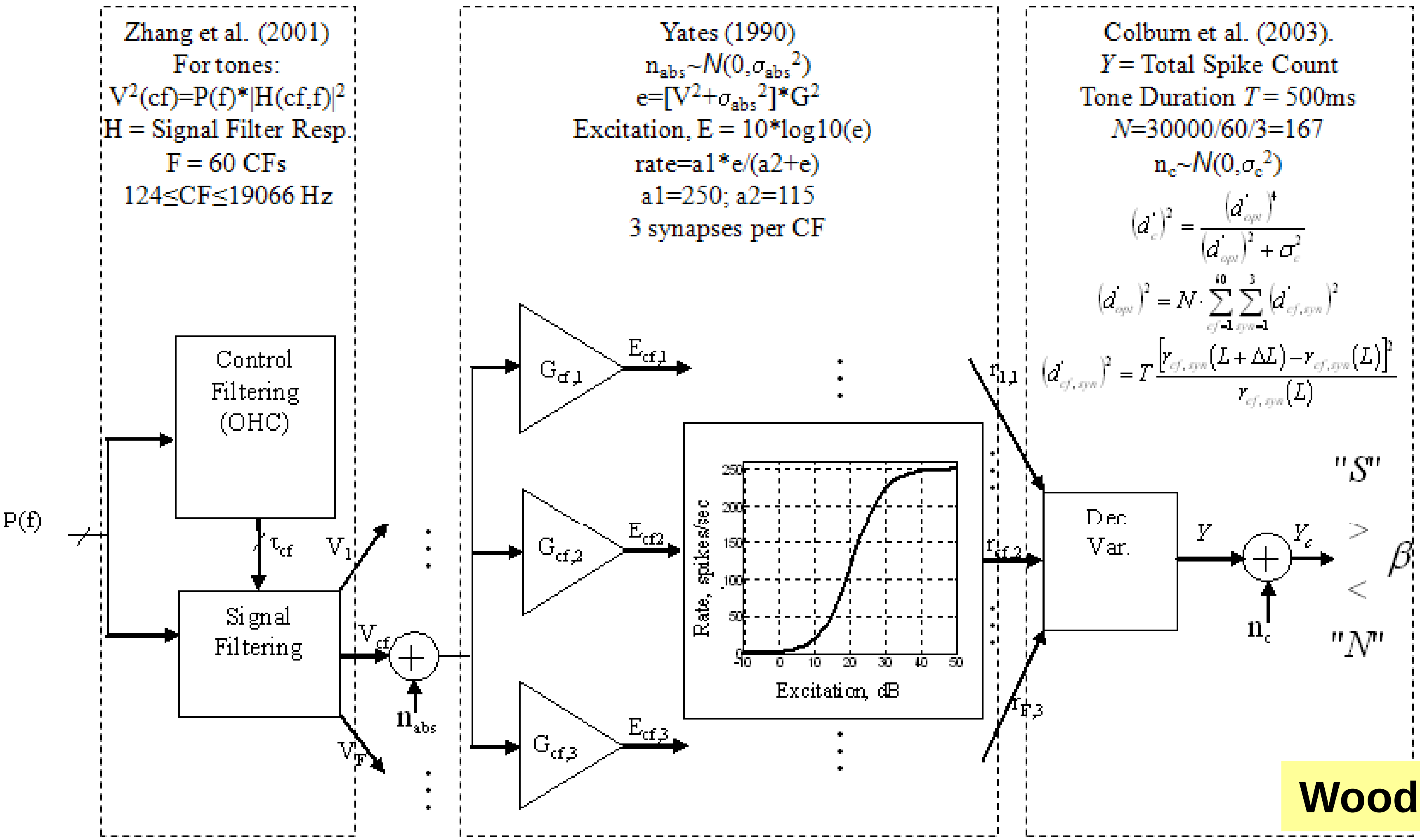
- Simulations to substitute for subject data
  - Optimize signal processing and fitting based on models rather than hours of listening and subjective assessment
    - Models of hearing impairment only as good as models of hearing loss

Challenge #2

- Need better models of the effect of hearing loss on auditory function
  - Account for variability seen in a wide variety of performance measures
  - Differentiate effects of damage to inner hair cells, outer hair cells, and stria vascularis
    - Add hoc rules currently in use (e.g. 80% outer, 20% inner)
  - Treat the mechanism, not the symptom

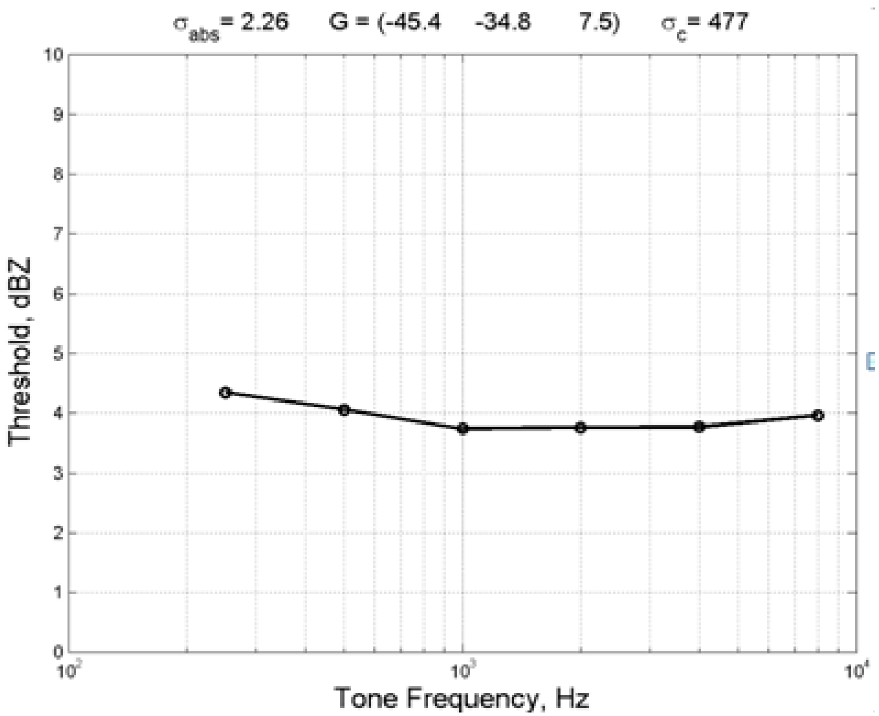
- *Simulate effect of reduced endocochlear potential*

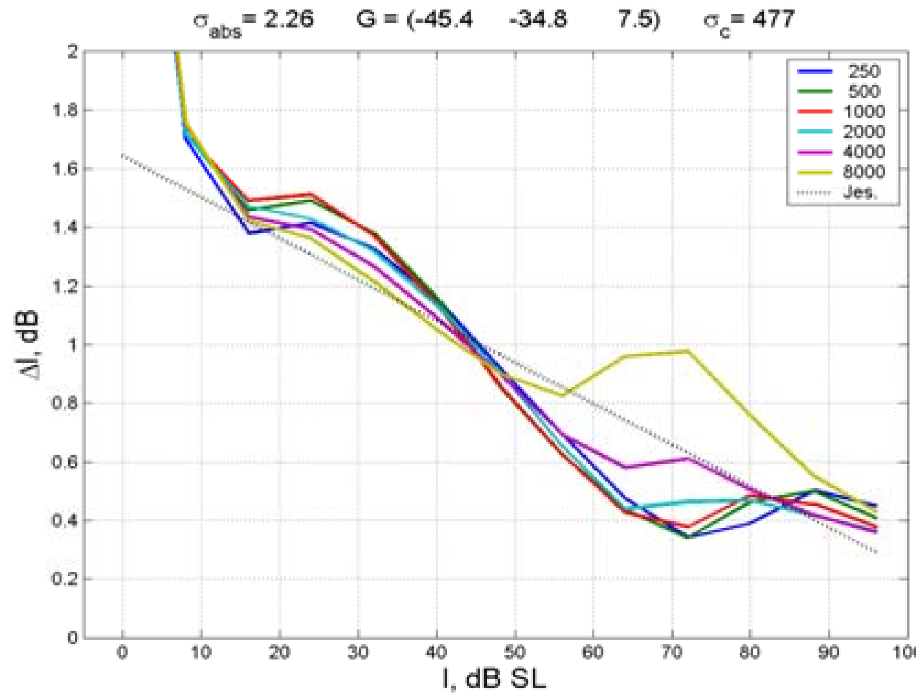
Modeling Strial Loss



Woods, 2004

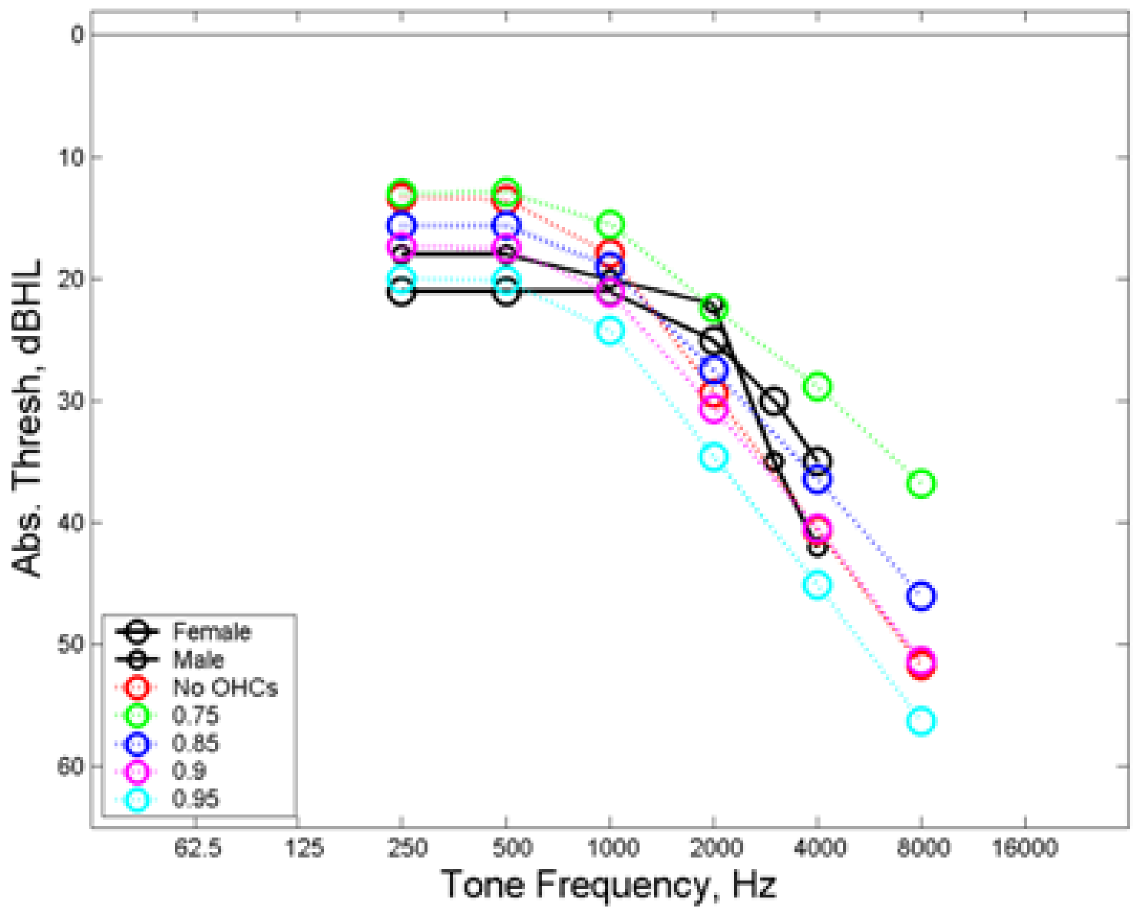
Modeling Strial Loss





Woods, 2004

Modeling Strial Loss



Woods, 2004

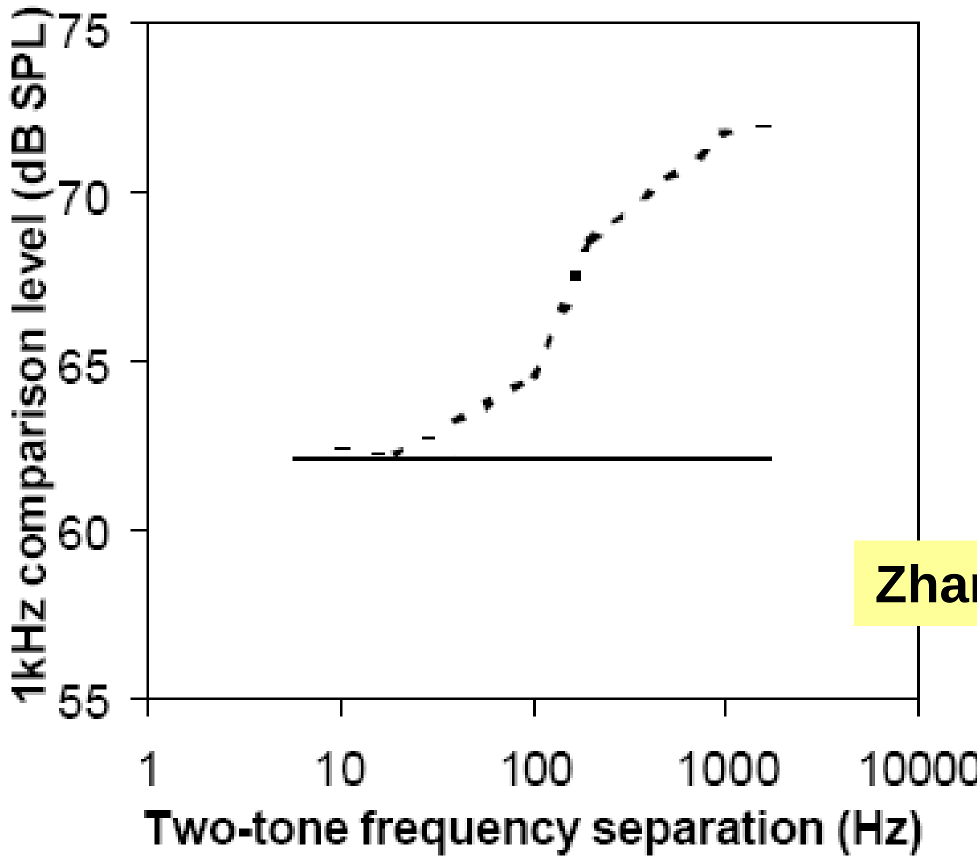
- Develop diagnostics to better define the mechanism of an individual's hearing loss
- Better characterization of mechanism of loss is not enough
  - o Differential diagnostics must drive different treatments
    - Feature applications, fitting algorithms
  - o Must demonstrate better hearing aid wearer performance using this more sophisticated approach

Challenge #3

- Aided Psychoacoustics
  - Differences in psychoacoustic measures explain functional differences between normal and impaired hearing
    - E.g., broader auditory filters, greater forward masking
  - Need for investigation of psychoacoustic measures when aided
    - Use to optimize hearing aid processing
    - Validate with real-world outcome measures
    - More critical with more complex aid processing
      - E.g. wireless ear-to-ear and binaural function

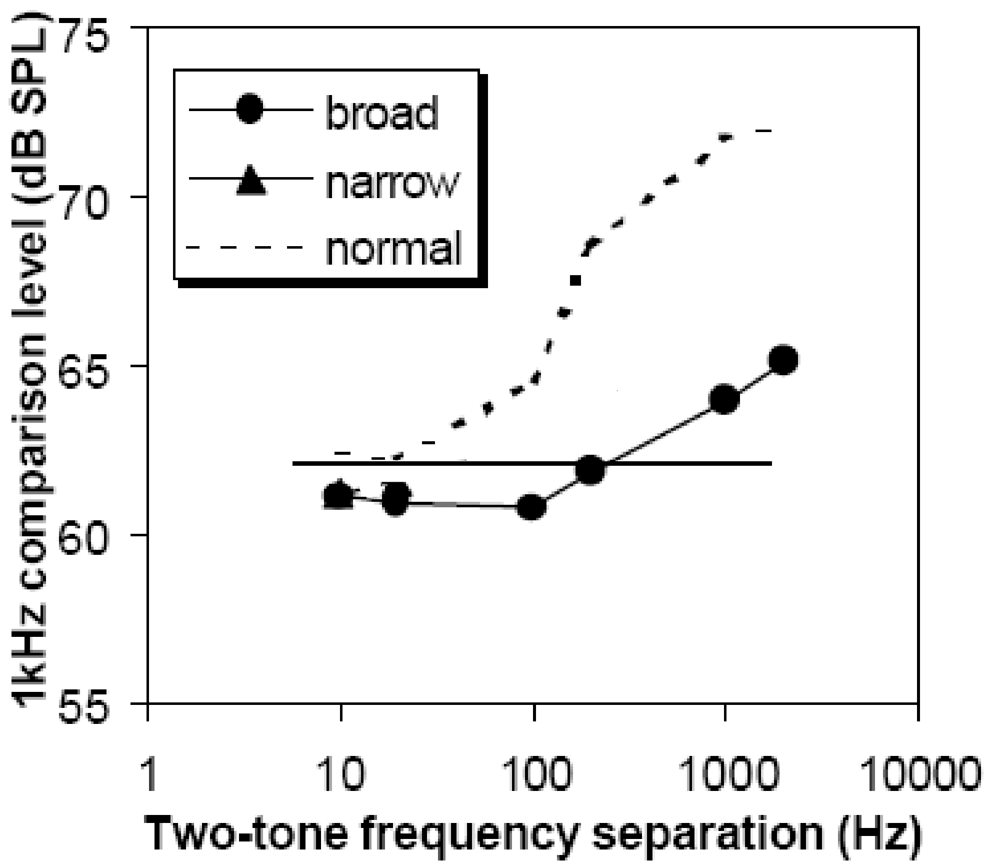
- *Loudness Summation and Forward Masking*

Loudness Summation



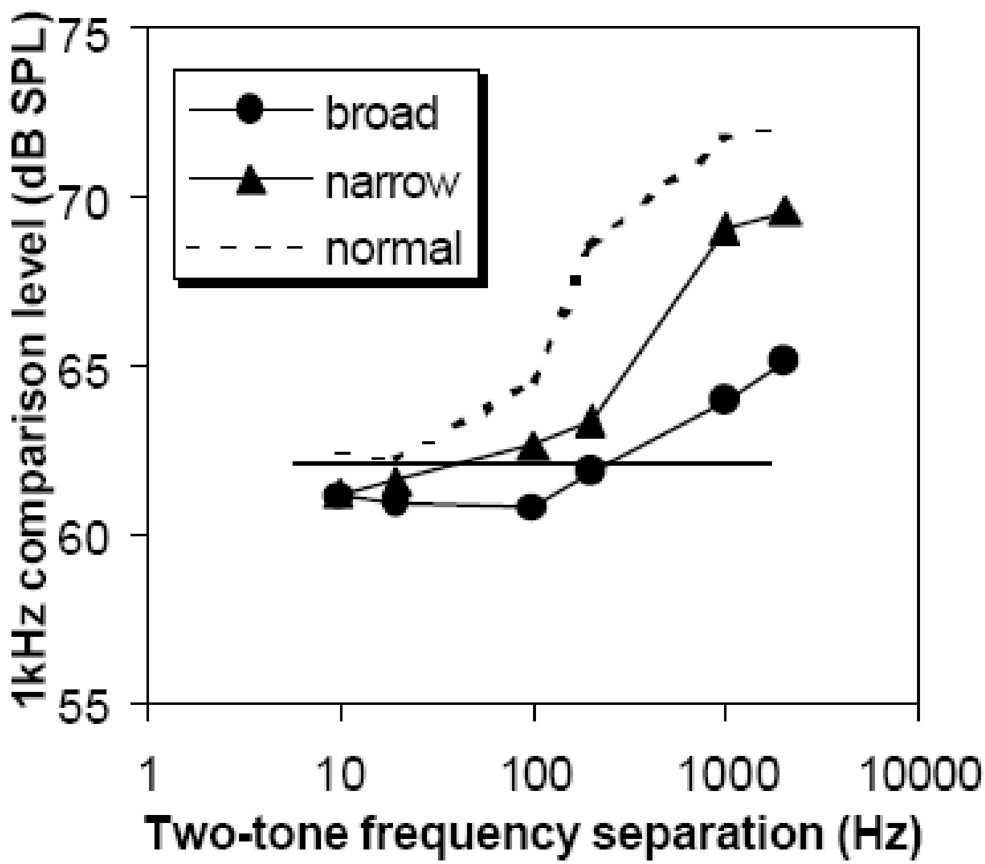
Zhang and Zeng, 1987

Loudness Summation



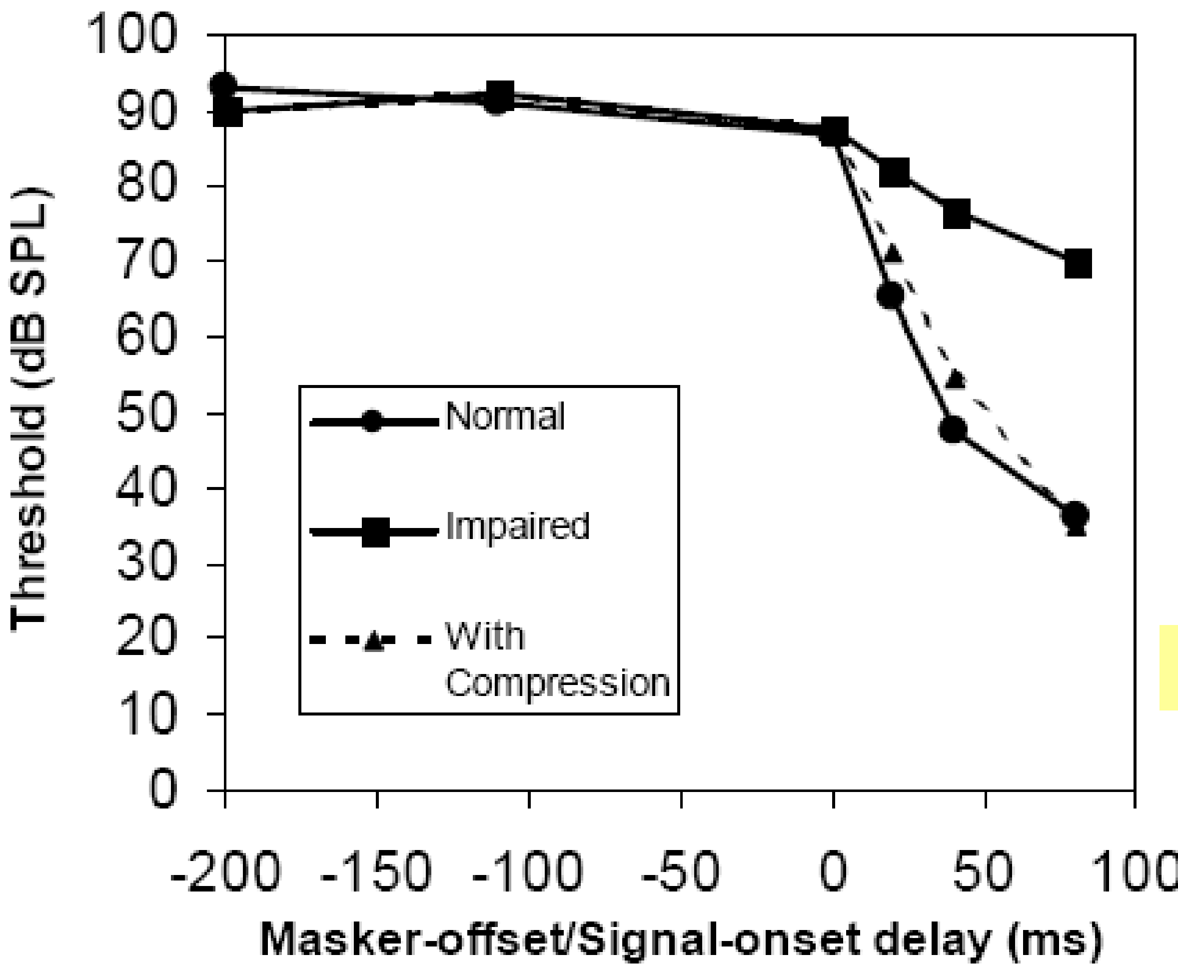
Edwards, 2002

Loudness Summation



Edwards, 2002

Forward Masking



Glasberg et al., 1987

Edwards, 2001

- Understanding aided psychoacoustics is to understand bionic auditory function
  - Need to demonstrate that designs based on “normalizing” aided psychoacoustics results in improved patient benefit

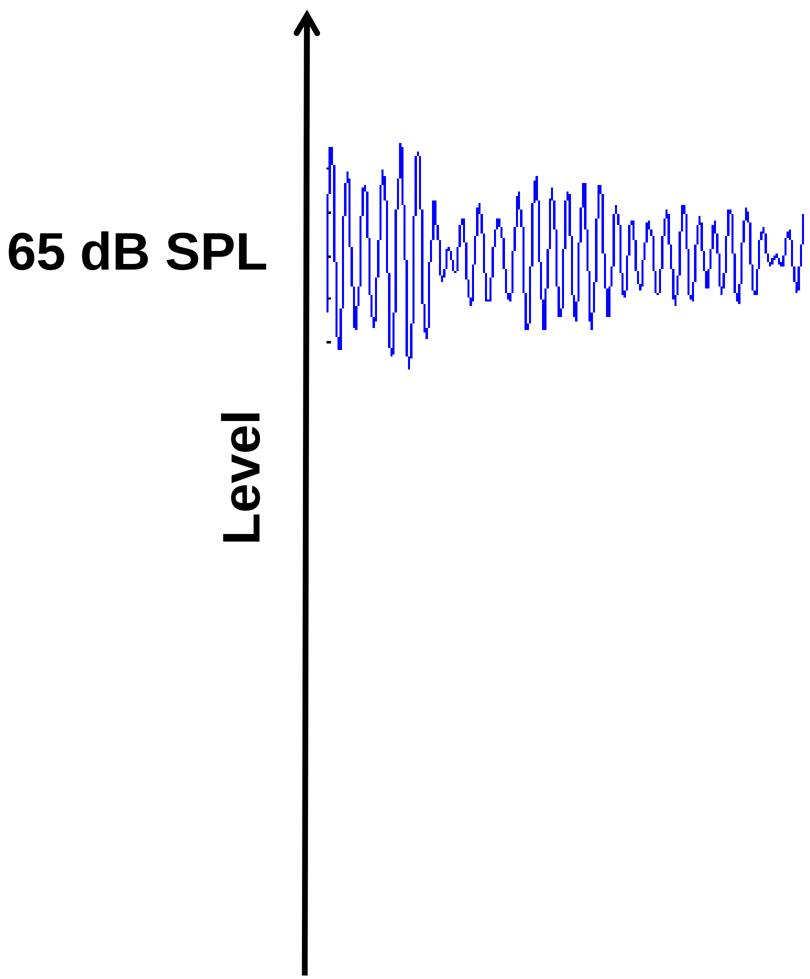
Challenge #4

- Explain hearing aid benefit
  - Audibility has driven much of our understanding of hearing aid benefit to date
    - Need more sophisticated understanding of suprathreshold performance
      - Drive new hearing aid designs
  - Understand individual differences
    - Drive individual treatments

- *Acceptable Noise Levels*

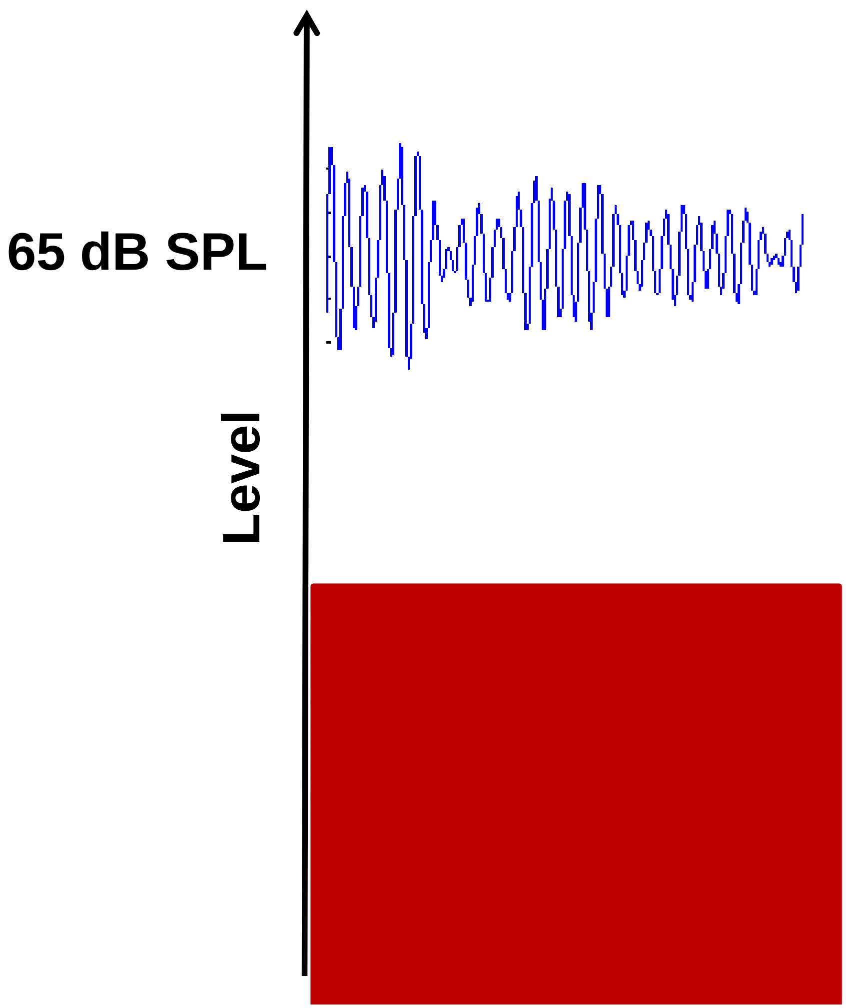
Measuring ANL

- Fix the level of speech



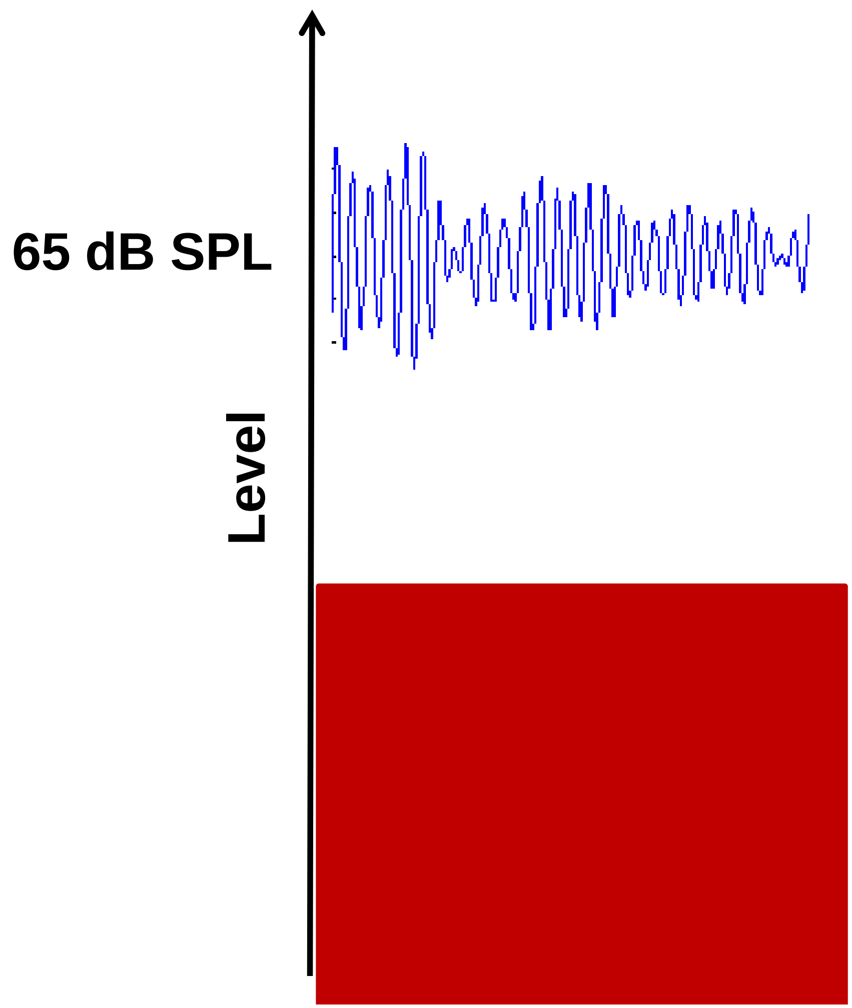
Measuring ANL

- Add low level noise



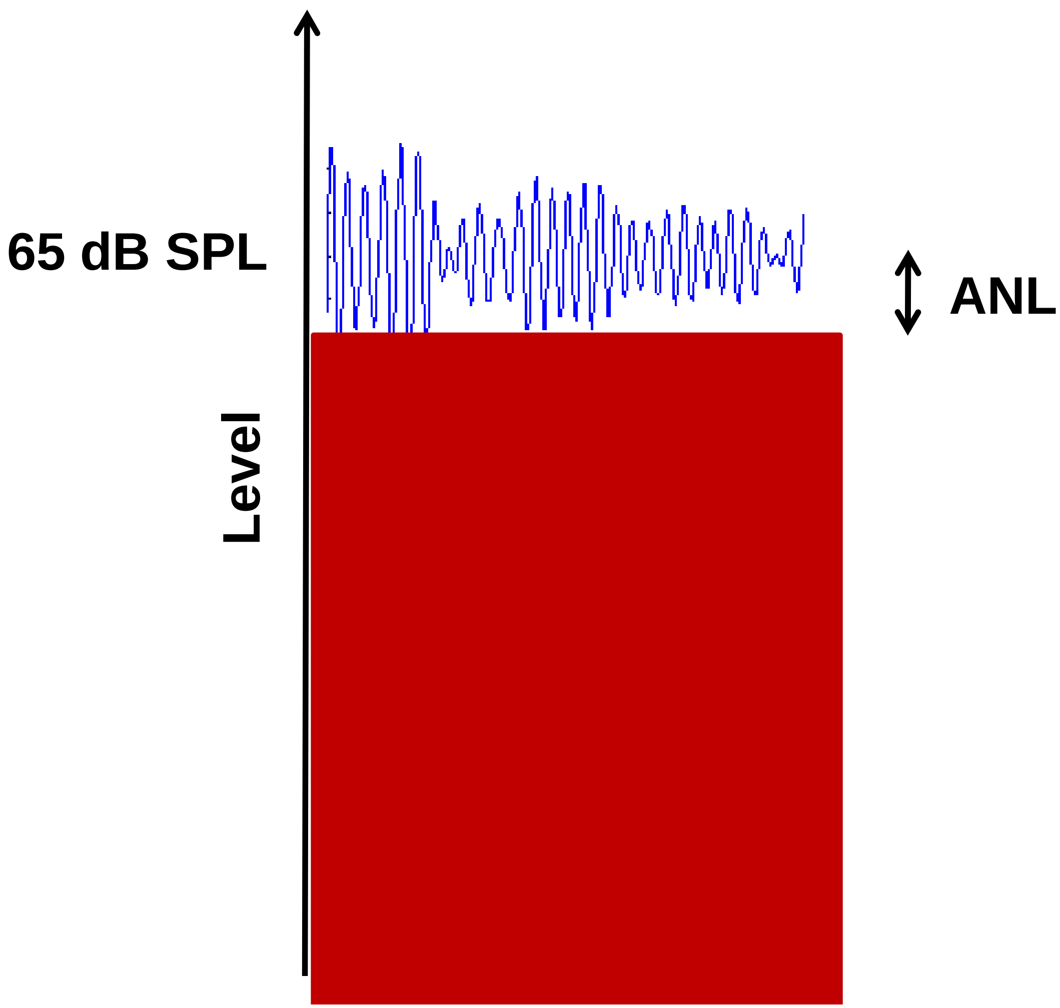
Measuring ANL

- Listener adjusts noise to maximum tolerable level for prolonged listening



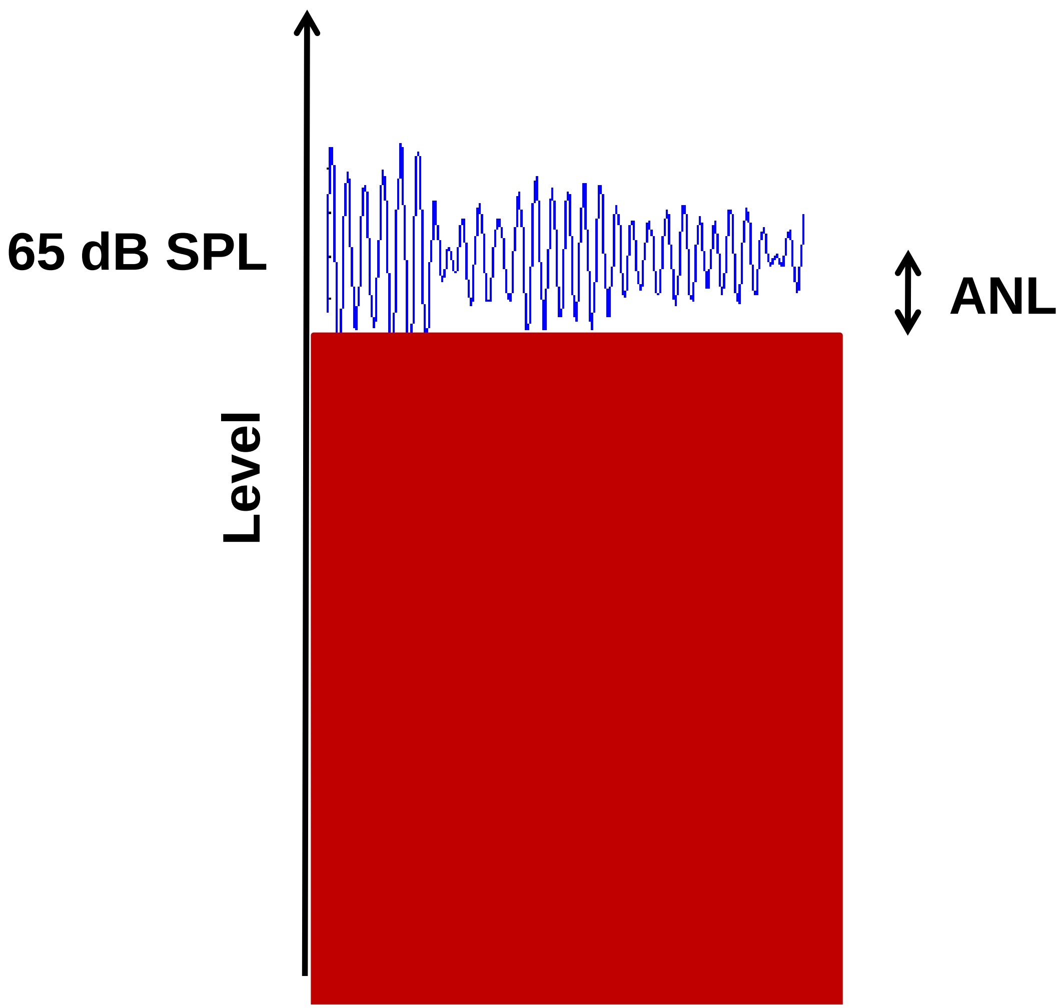
Measuring ANL

- $\text{ANL} = \text{Level}_{\text{speech}} - \text{Level}_{\text{noise}}$



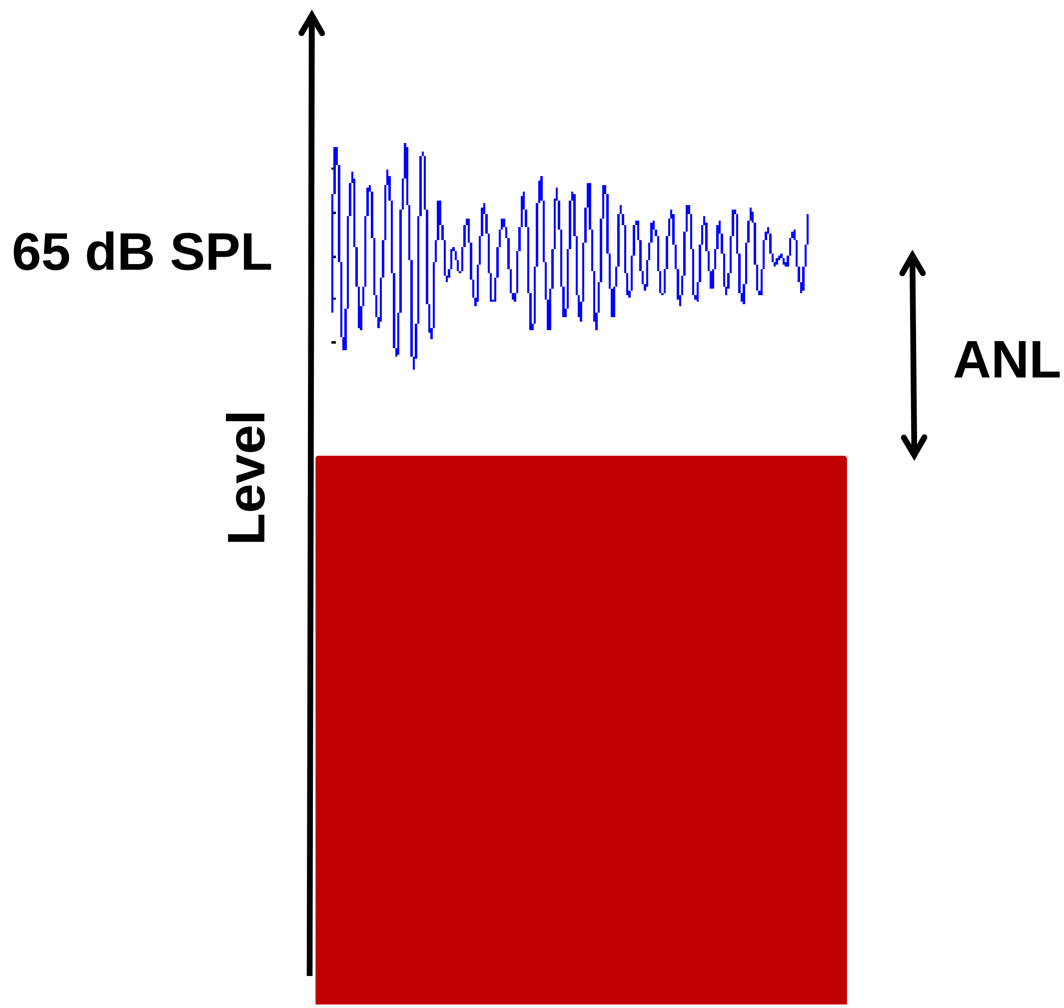
Measuring ANL

- Small ANL = High tolerance for noise
  = Successful HA user

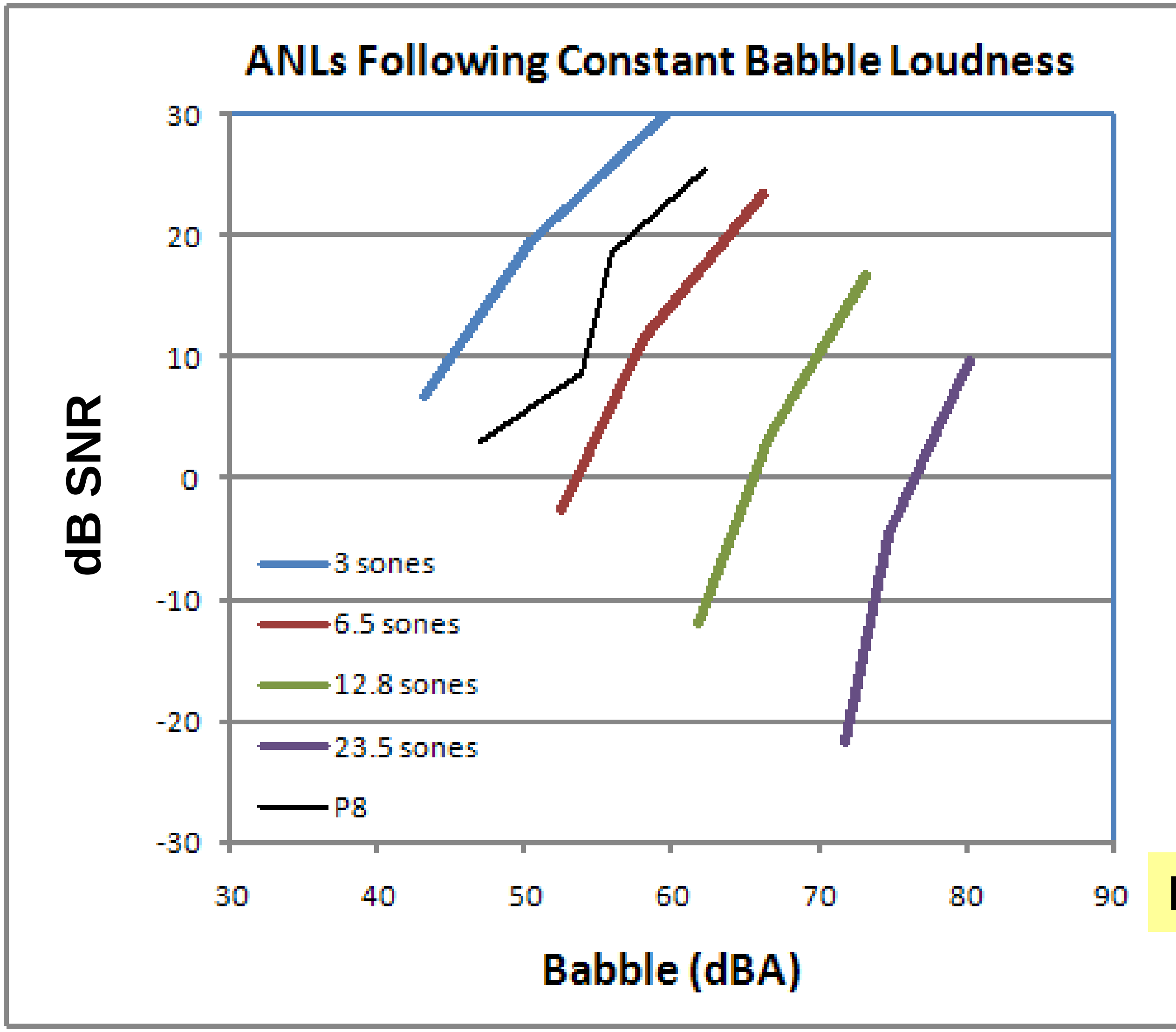


Measuring ANL

- Large ANL = Low tolerance for noise
  = Unsuccessful HA user

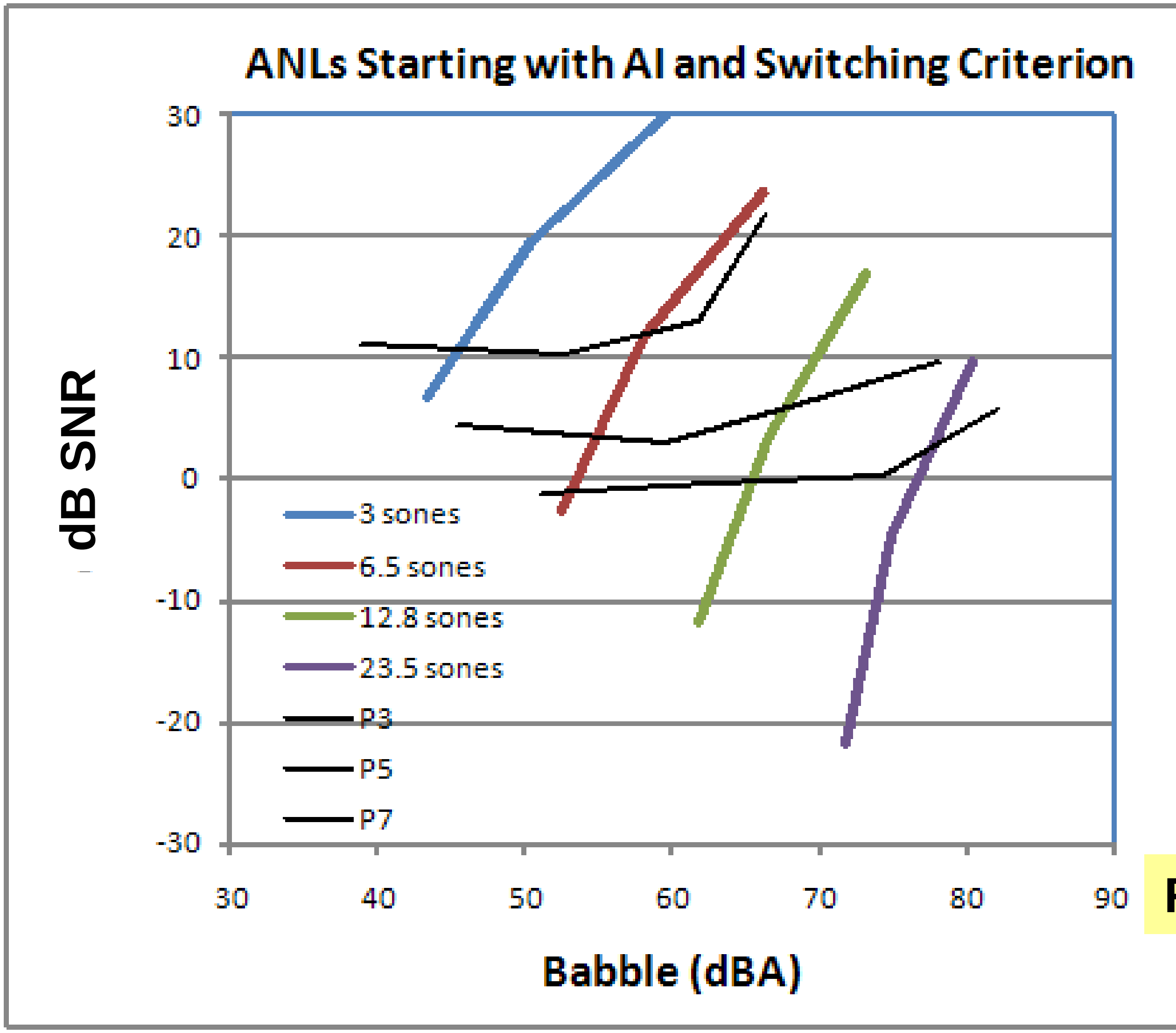


Loudness Model and ANL



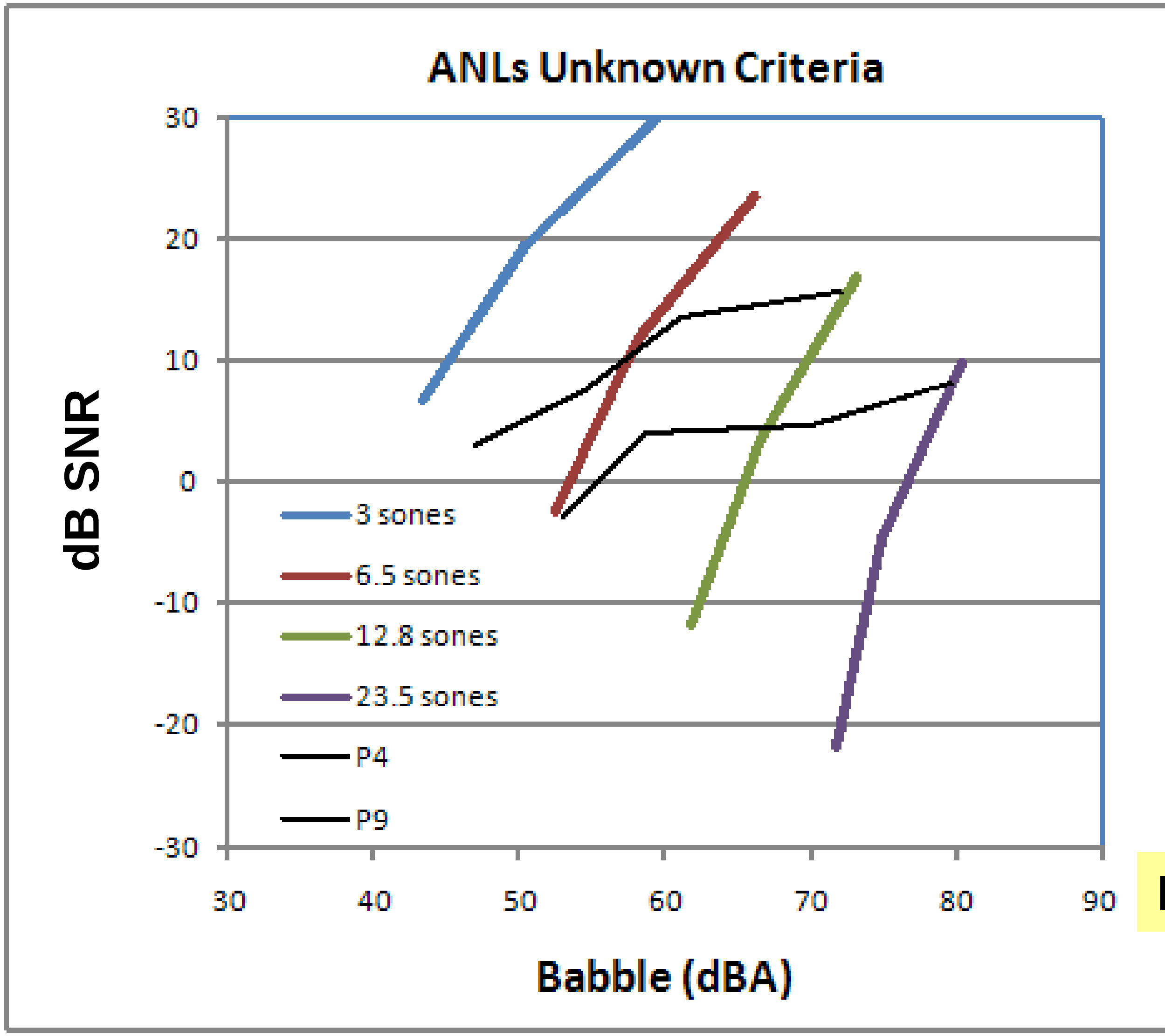
Recker et al., 2009

Loudness Model and ANL



Recker et al., 2009

Loudness Model and ANL



Recker et al., 2009

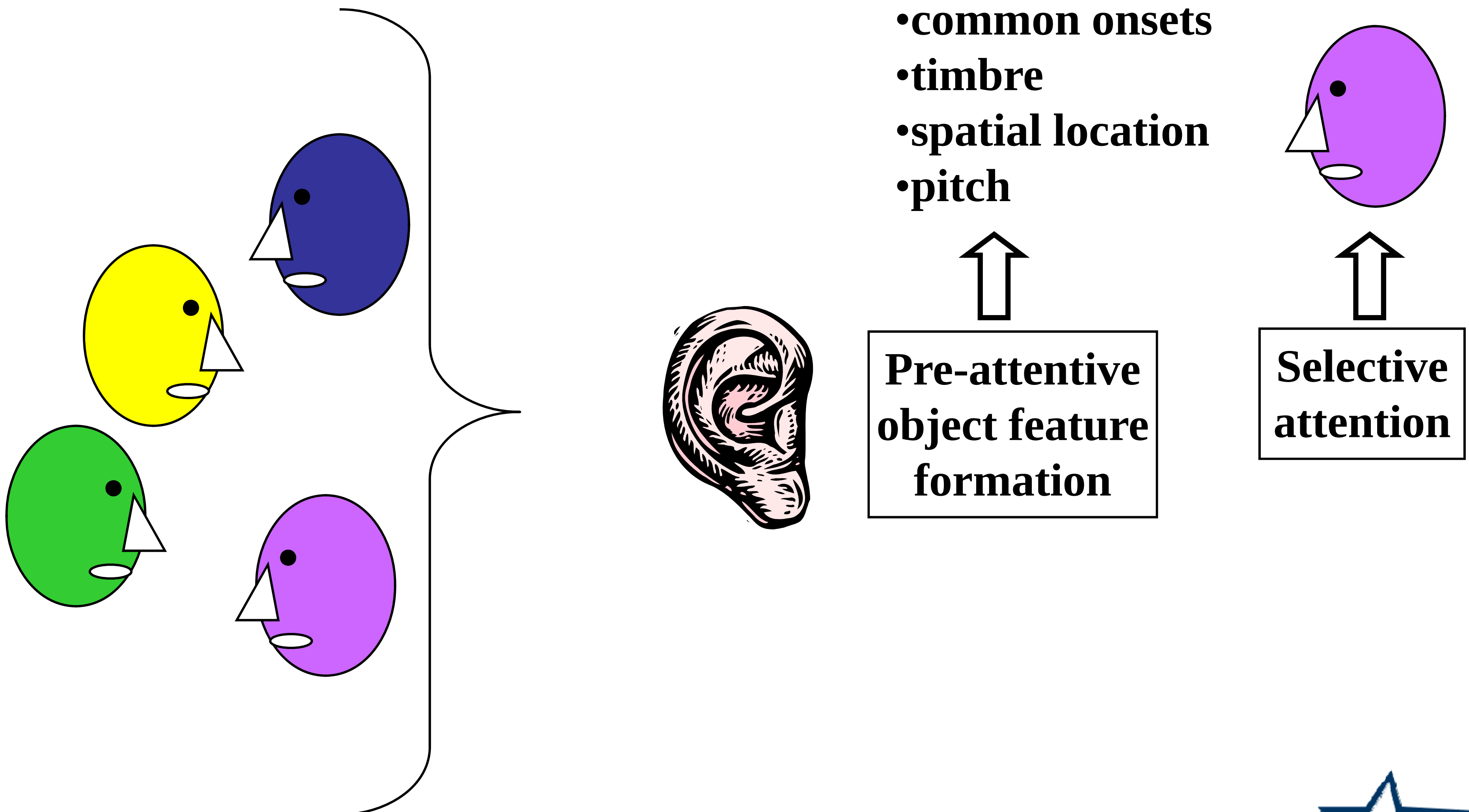
Challenge #5

- Outcome measures are becoming more realistic
  - Real talkers as interferers
  - Spatial configurations
  - Switching attention

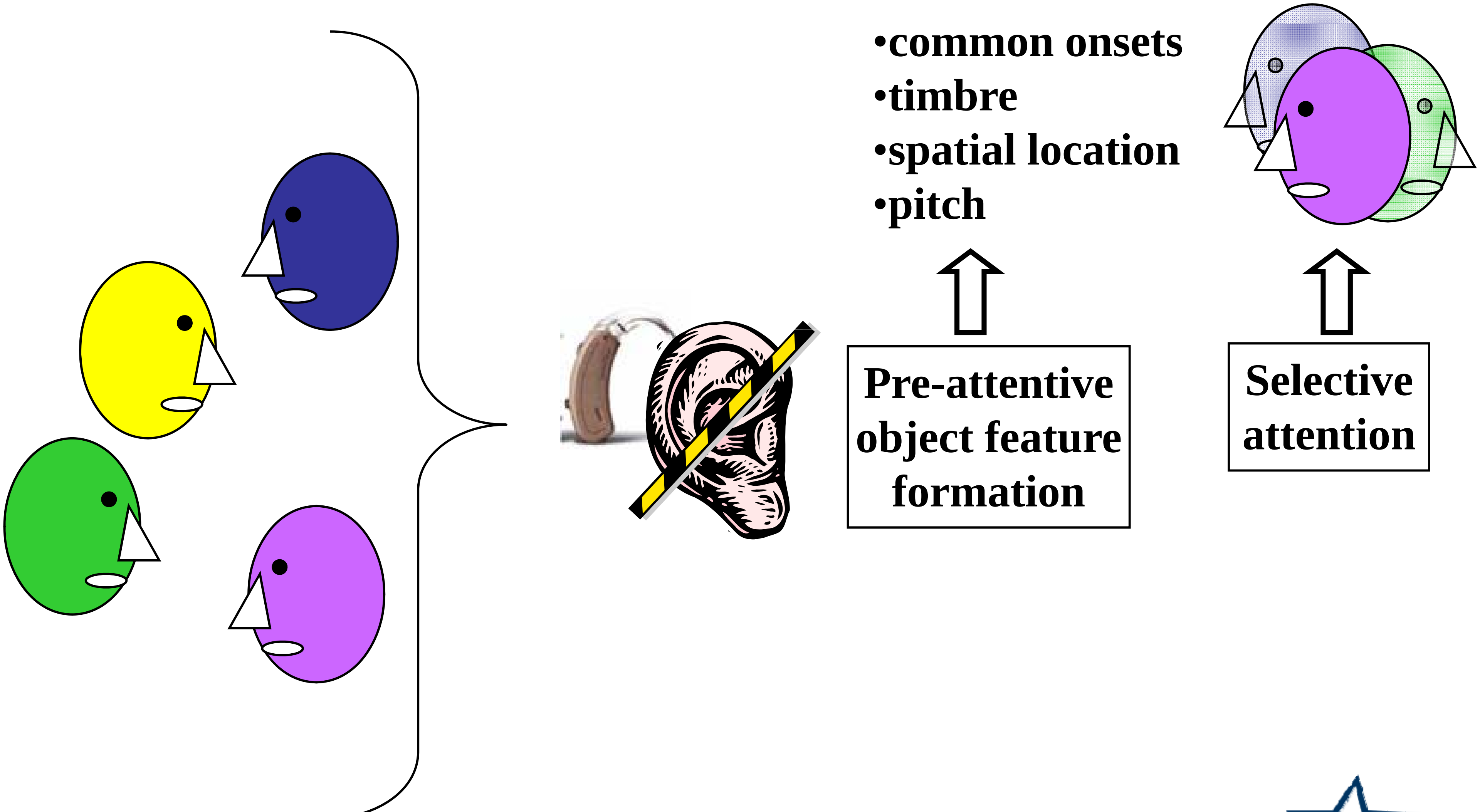
Challenge #5

- Model higher-level auditory function
  - Auditory scene analysis is becoming a critical factor in understanding unaided and aided auditory perception
  - Need to develop models that account for source segregation and other higher-level functions

Cocktail Party



Cocktail Party



- If models can predict explain deficits—e.g. poorer informational masking—then technology can be better developed and fit

Auditory Model Challenges

- Substitute for subject data
- Need better models of effect of hearing loss on auditory function
- Aided Psychoacoustics
- Explain hearing aid benefit
- Model higher-level auditory function

Thank You

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