An annoyance model for urban air mobility vehicle noise in the presence of a masker

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Outline

- Background: Urban Air Mobility
- Masking Discount Hypothesis
- Proposed Model
- Psychoacoustic Test
- Analysis
- Results
- Conclusions

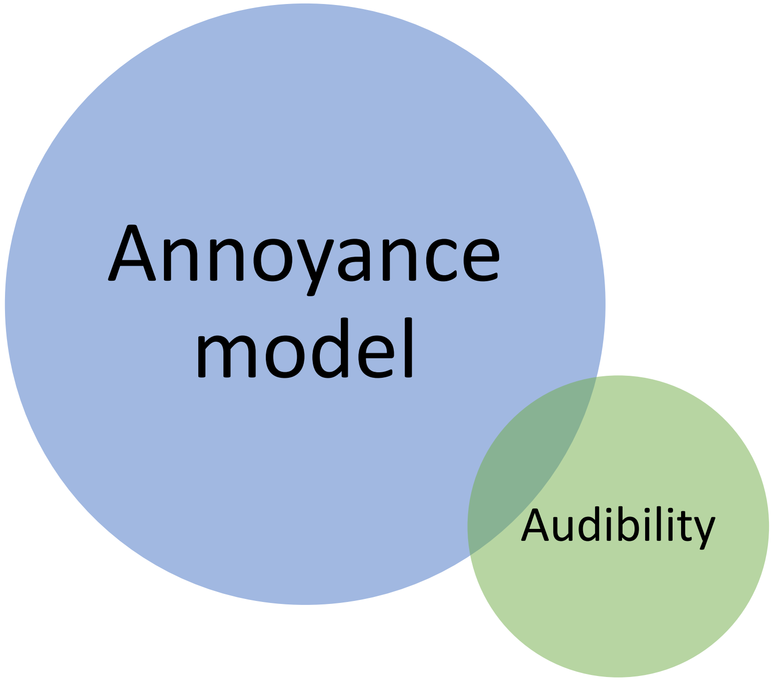
Background: Urban Air Mobility (UAM) and Noise

- Safe, efficient and accessible transportation for passengers and cargo [1]
- Noise impact must be mitigated in communities where UAM operations take place [2]
- Models of annoyance to UAM noise are needed [3]

[1] Thipphavong et al., "Urban Air Mobility Integration Concepts and Considerations," 2018 Aviation Tech., Int., and Operations Conf., (2018)
[2] Hill et al., "UAM Vision Concept of Operations (ConOps) UAM Maturity Level (UML) 4'', NASA (2020)
[3] Rizzi et al., "Urban Air Mobility Noise: Current Practice, Gaps, and Recommendations," NASA/TP-2020-5007433 (2020).

Background: Focus of today's talk

- How does audibility affect annoyance?
- Masking a UAM-like sound with background noise
- How can we model the reduction (i.e., discount) on annoyance?

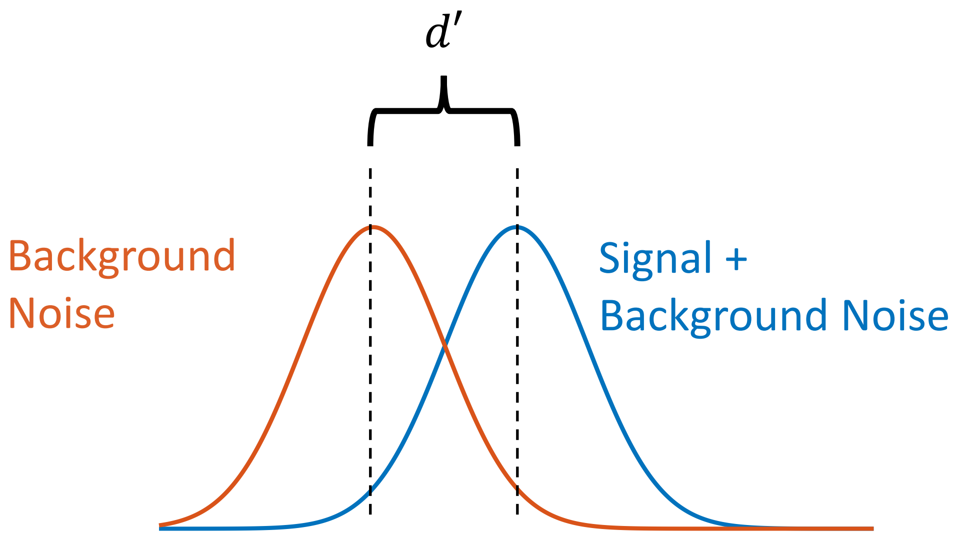


Masking Discount Hypothesis

- How does audibility (or masking) affect annoyance?
- Hypothesis:

  If a signal is partially masked → Annoyance is reduced (discounted)

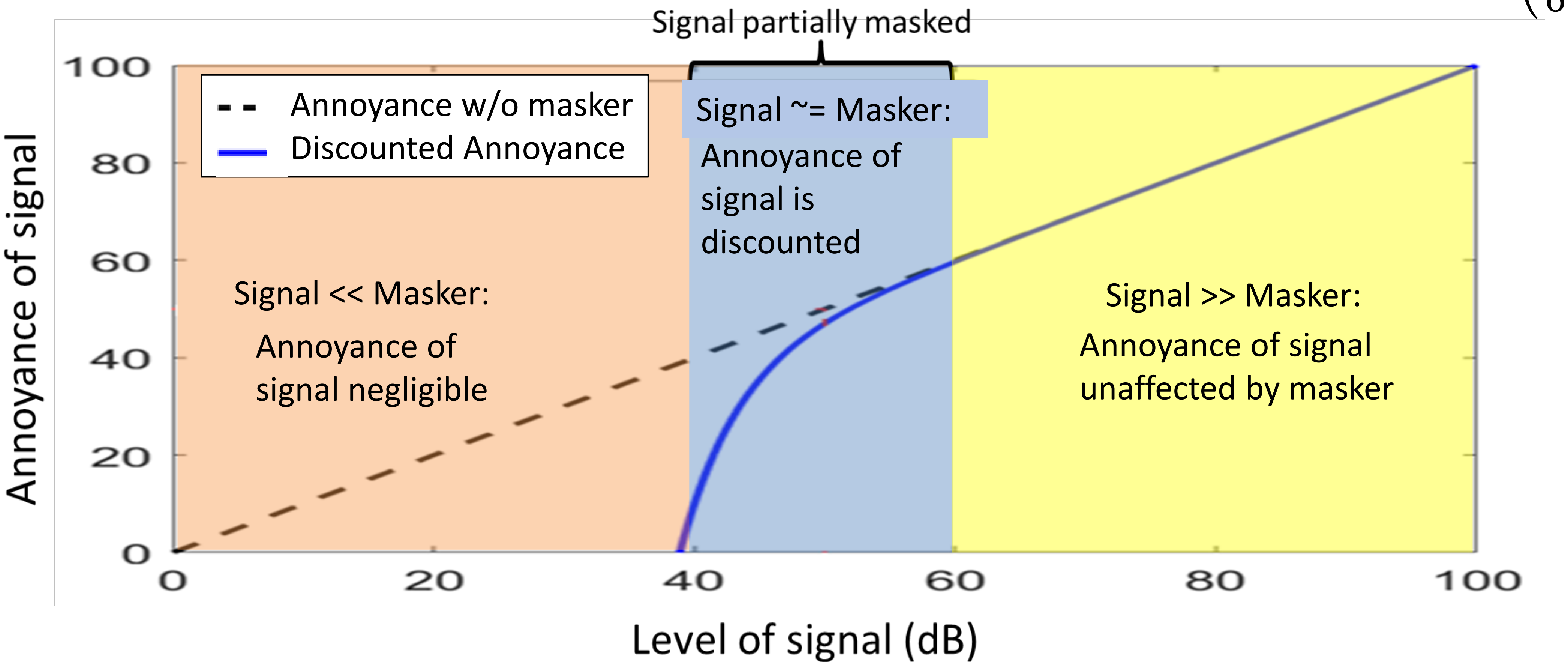
- Quantify detectability index (*d'*) like a perceptual signal-to-noise ratio [4]
  - Audibility Threshold when *d'* = 1,
    - Signal audible about 50% of the time
    - Doubling d' corresponds to a 3 dB gain in signal level



[4] Green, "Auditory detection of a noise signal," J Acoust Soc Am 32, 121 (1960)

Proposed Model

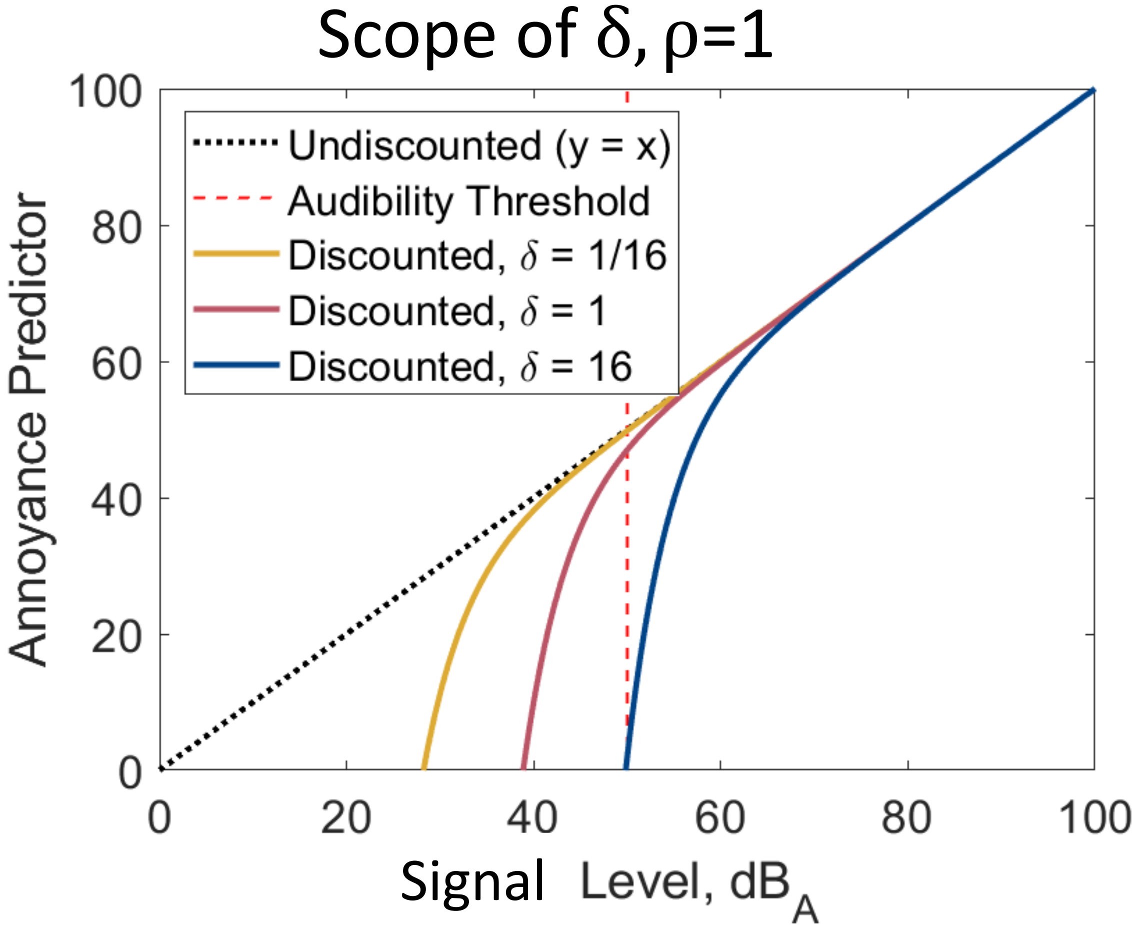
$$\begin{matrix}Discounted\\Annoyance\end{matrix} = \begin{matrix}Annoyance\\w/o\ masker\end{matrix} + w_D(d') \quad \Rightarrow \quad \begin{matrix}Discounted\\Annoyance\end{matrix} = \begin{matrix}Annoyance\\w/o\ masker\end{matrix} - \frac{\alpha}{\left(\frac{d'}{\delta}\right)^{\rho}}$$ [5]

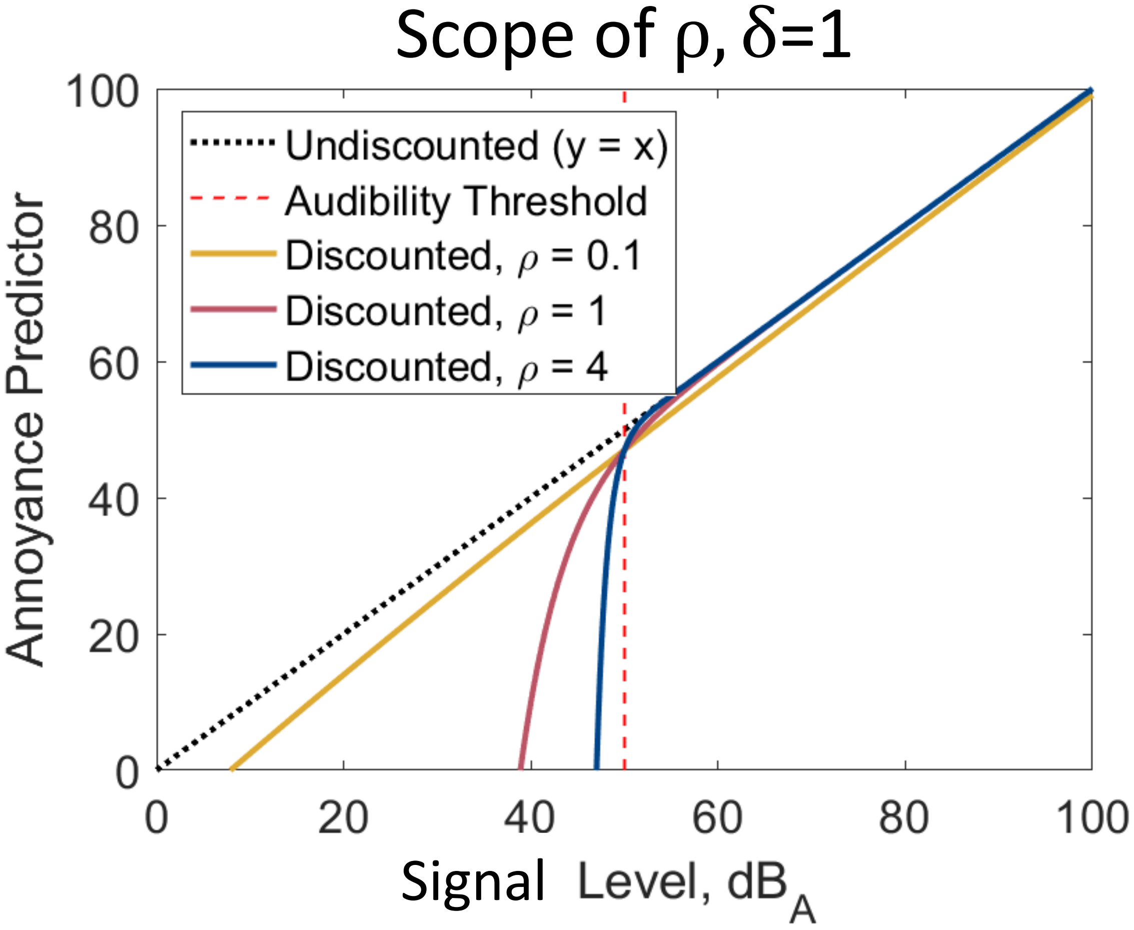


[5] Christian, "The effect of background noise on human response," NATO/STO-TR-AVT-314.

Discount Form

$$Discount: w_D = -\frac{3}{\left(\frac{d'}{\delta}\right)^{\rho}}$$





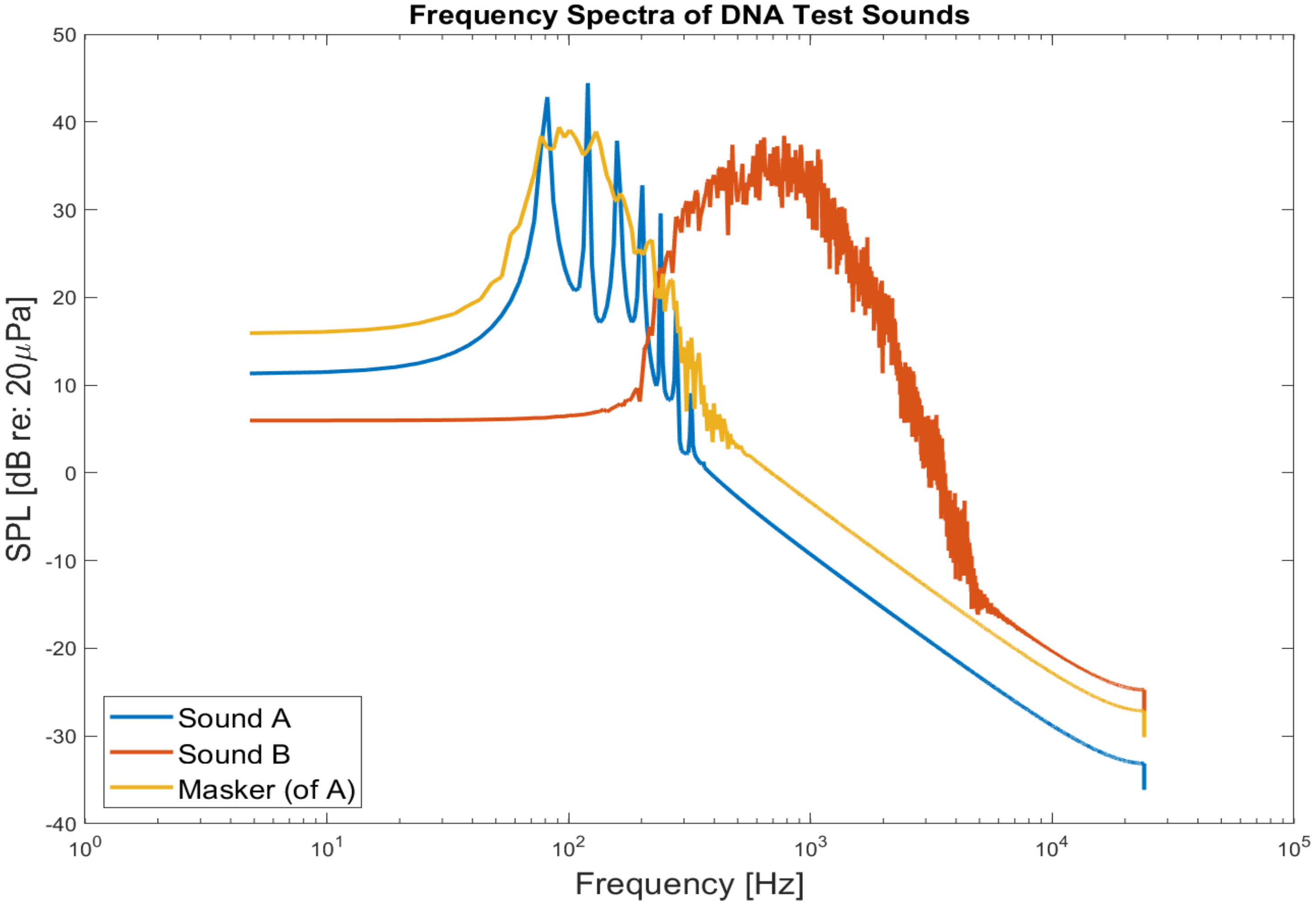
Psychoacoustic Test Goals

1. Measure *d'*,
2. Measure Equal Annoyance Points (EAPs),
3. Predict EAPs using measured *d'*,
4. Compare EAP predictions with measurements to determine values of discount parameters δ and ρ

$$Discount\colon w_D = -\frac{\alpha}{\left(\frac{d'}{\delta}\right)^{\rho}}$$

Psychoacoustic Test Content

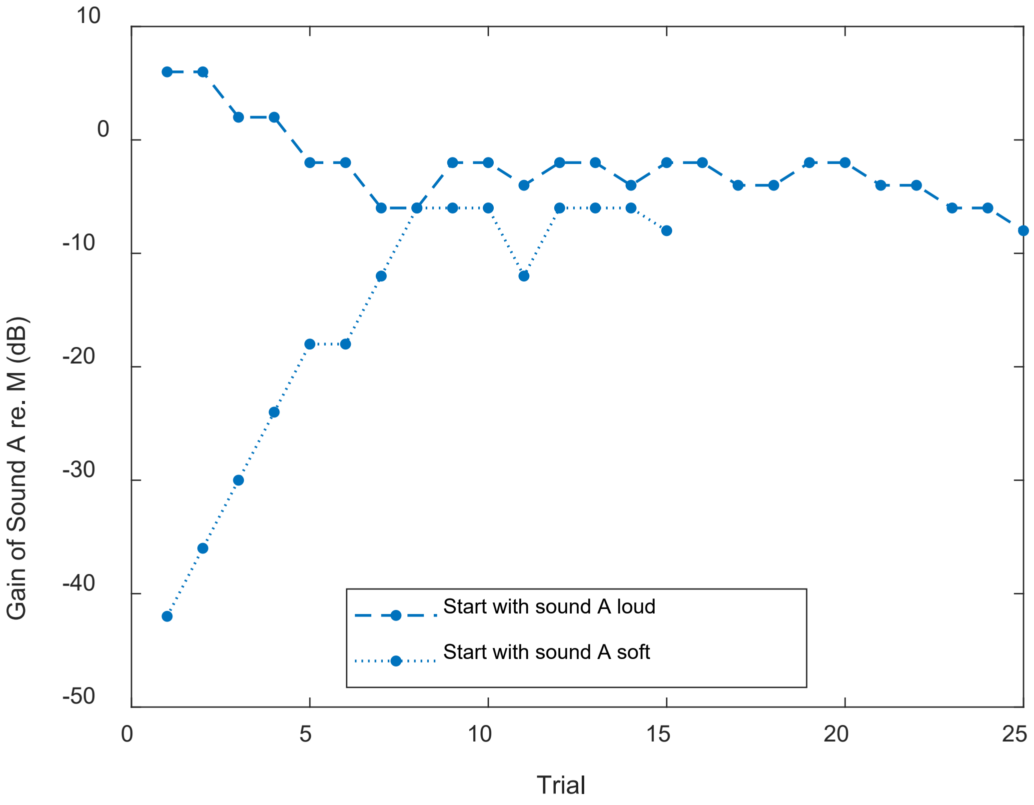
- 5 Subjects
- Sound A: Harmonic tone complex (80-320 Hz)
  - Similar to rotorcraft loading and thickness noise
- Sound B: Shaped broadband noise (300-2000 Hz)
  - Similar to rotorcraft self noise
- Masker: Designed to mask Sound A
  - Equal amount of masking in 1/3 octave bands [6]



[6] Sneddon et al., "Laboratory study of the noticeability and annoyance of low signal-to-noise ratios sounds" NCEJ, 51 (5), 2003.

1. Measuring *d’*

- Three Alternative Forced Choice (3AFC) adaptive staircase method to determine d’ [7]
  - All three intervals contain masker, only one interval has a target sound
  - **“Which interval had the extra sound?”**
  - Find subject's Detection Threshold *d’*
  - Extrapolate *d'* at other relative gains

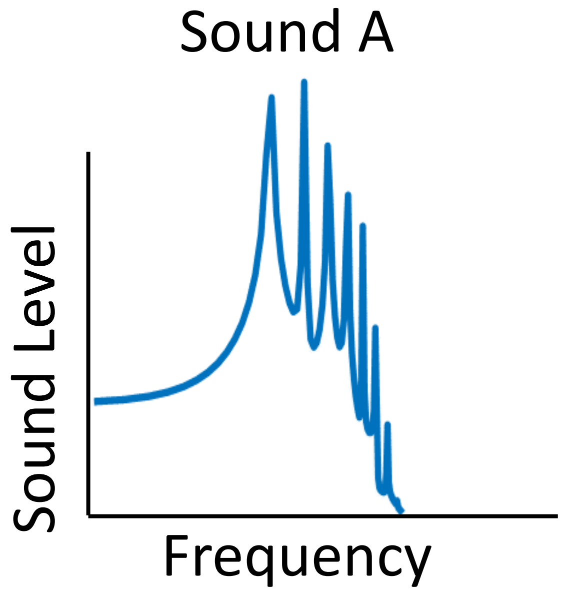


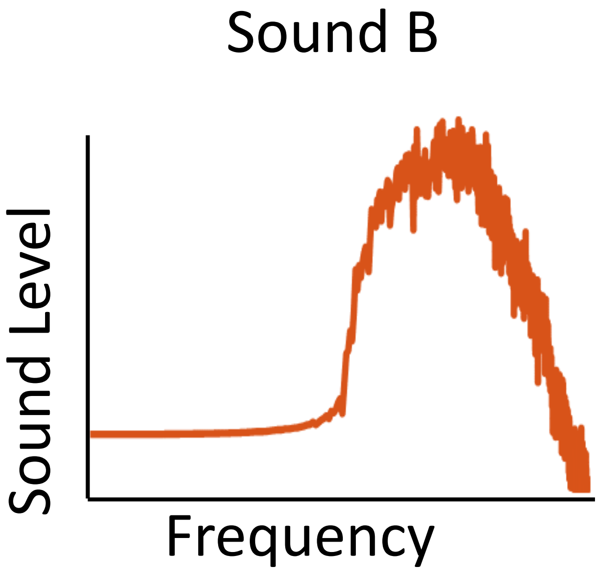
[7] Boucher and Christian, ICHIN III TM , 2024.

2. Measuring
Equal Annoyance Points (EAPs)

- Paired Comparisons to determine how masking changes EAPs
  - **At what relative level is Sound A equally annoying to Sound B?**

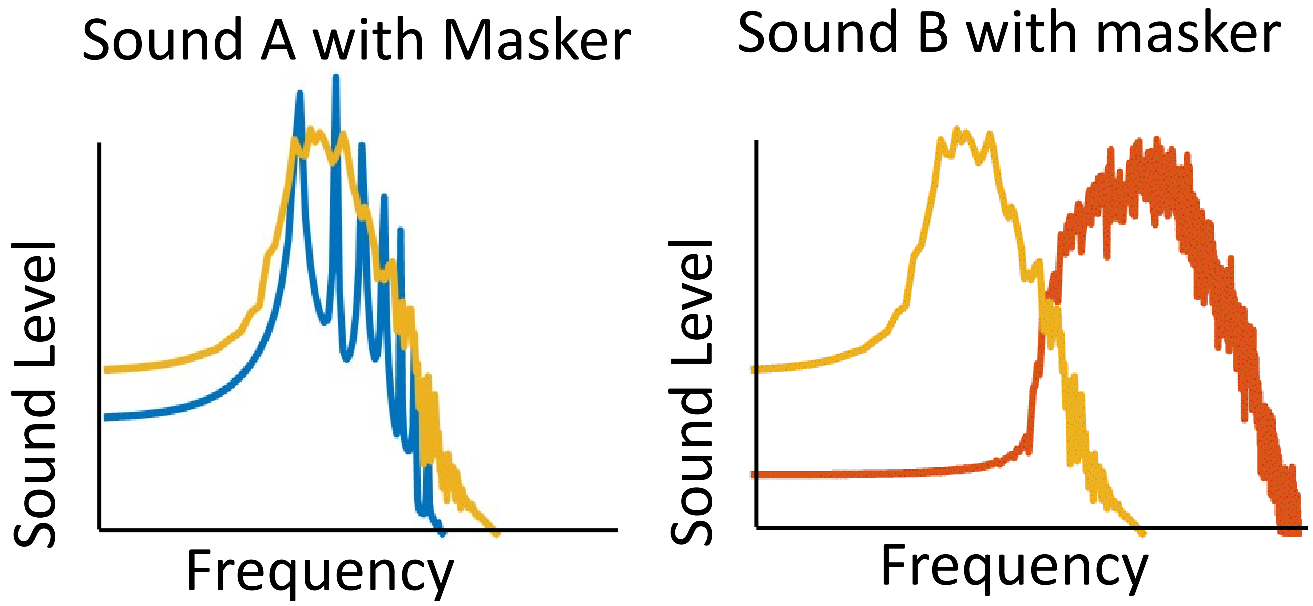
  - No masker → Unmasked EAP





2. Measuring
Equal Annoyance Points (EAPs)

- Paired Comparisons to determine how masking changes EAPs
  - **At what relative level is Sound A equally annoying to Sound B?**
  - With masker → Masked EAP



- Vary signal levels and masker levels
  - 6 total EAPs measured

3. Predicting Equal Annoyance Points (EAPs)

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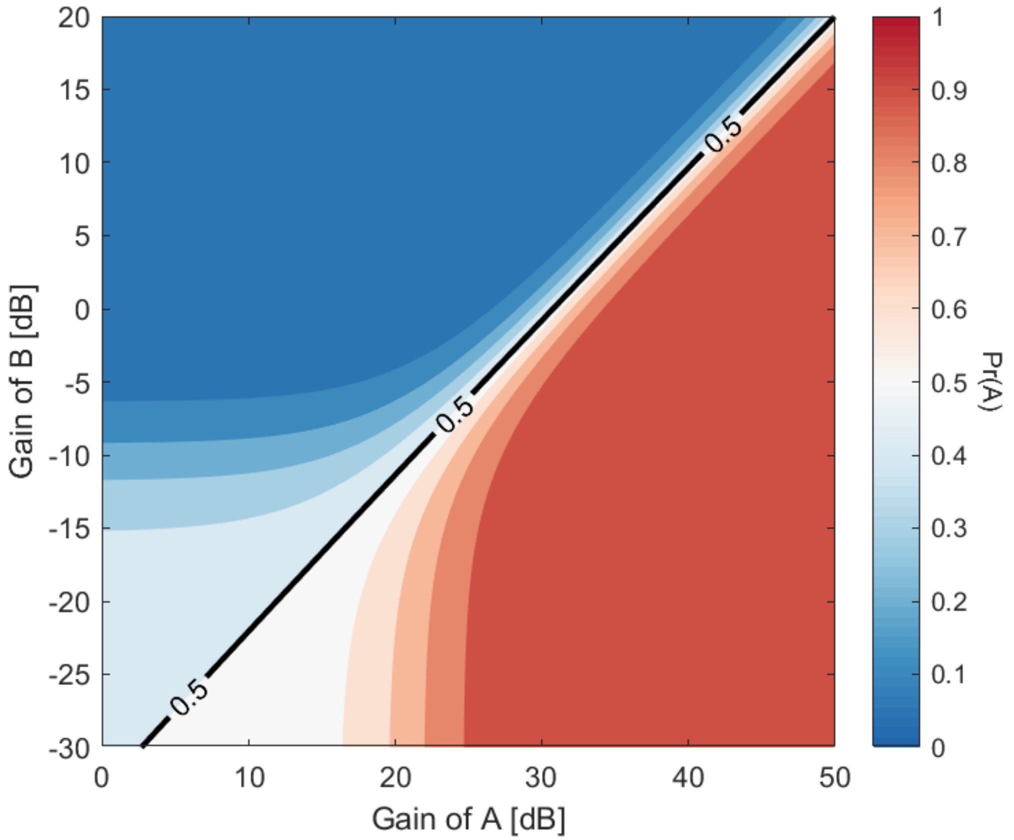
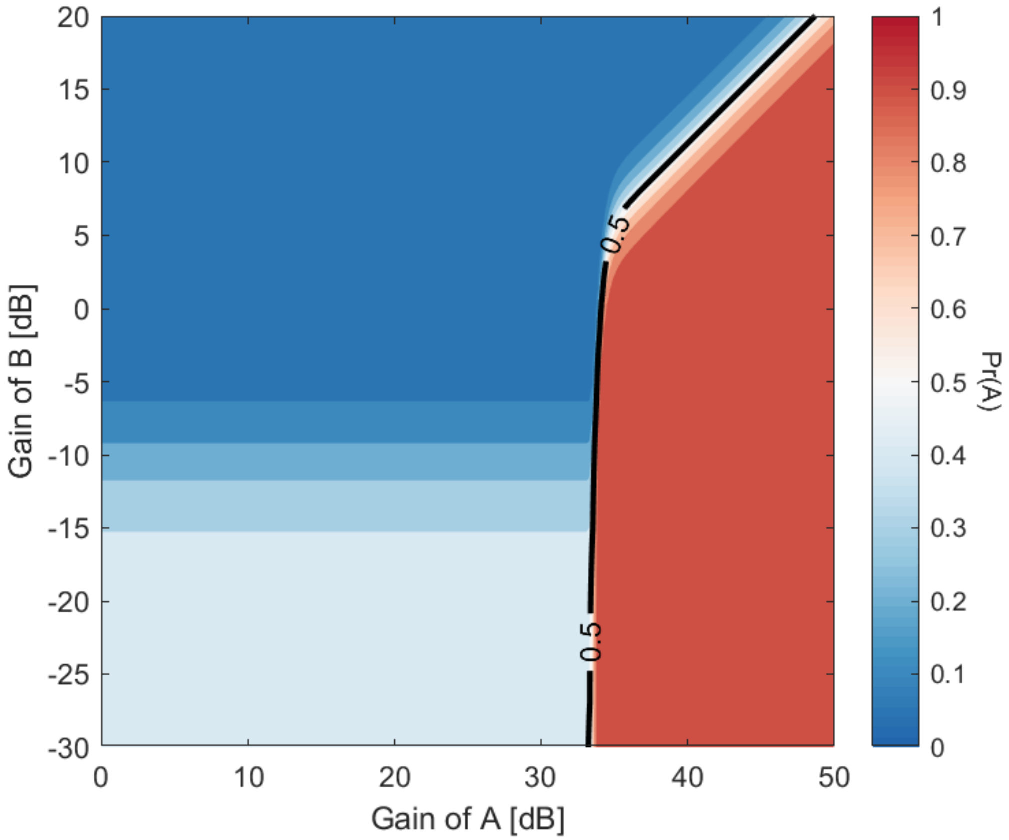
- $\Pr(A)$ is the probability of perceiving interval A as more annoying. It is based on:
  - The gain of sounds A, B, and the masker,
  - The subject's unmasked Equal Annoyance Point, and
  - The subject's masked discount term (with trial parameter values)
- Can plot $\Pr(A)$ surface with 3 axes: Gain A and Gain B in x and y and $\Pr(A)$ in z

3. Predicting Equal Annoyance Points (EAPs)

- Plot $\mathrm{Pr}(A)$ using trial values for δ and ρ.
  - Predicted EAPs shown as $\mathrm{Pr}(A)$ = 0.5 black line



δ = 0.2 and ρ = 0.1 at a masker gain of 25 dB

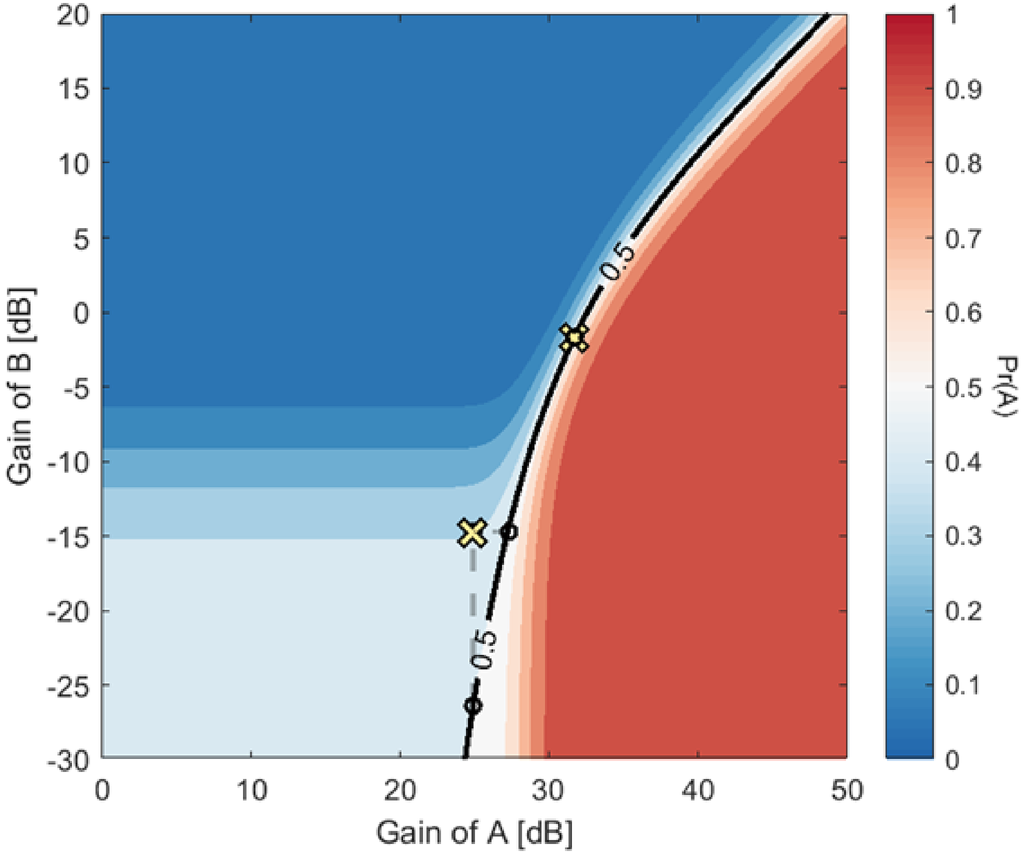


δ = 20 and ρ = 10 at a masker gain of 25 dB

4. Compare: Parameter Optimization

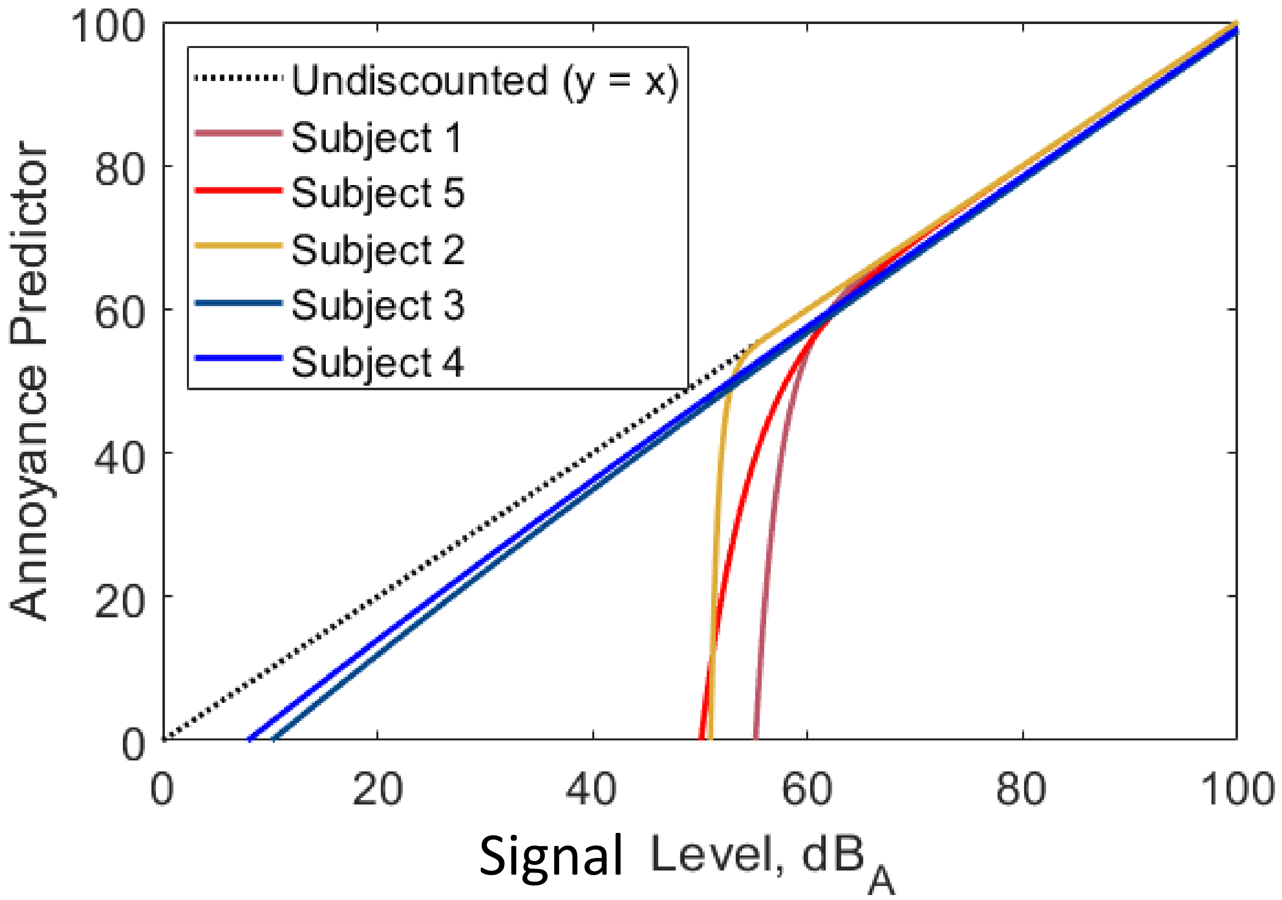
- Compare measured EAPs to predicted EAPs via cost function
- Vary predicted EAPs' values of δ and ρ to minimize the composite error ε
  - Two measured EAPs shown as yellow X's for "Loud" and "Soft" signal levels at a masker gain of 25 dB
  - Predicted EAPs shown as black line $\mathrm{Pr}(A)$ = 0.5
  - Measured vs Predicted differences shown as dashed lines

$$\varepsilon = \sum_{n=1}^{6} |\Delta \mathrm{Pr}(A)_n| \cdot \sqrt{\frac{1}{\frac{1}{(\Delta G_{An})^2} + \frac{1}{(\Delta G_{Bn})^2}}}$$



Results

- Subjects fell into 3 categories:
  - Strong Discount (masking discounts annoyance), Weak Discount (masking only discounts annoyance near detection threshold), and No Discount



	Subject	δ	ρ
Strong Discount	1	14	2
	5	17	1
Weak Discount	2	2	6
"No" Discount	3	20	0.1
	4	1	0.1

Conclusions

- Hypothesis:

  If a signal is partially masked → Annoyance is reduced (discounted)

- Experiment and analysis revealed three distinct types of subjects
  - Hypothesis is true in subjects with Strong and Weak Discounts
  - Annoyance reduction is much smaller in subjects with “No” Discount
- Future work:
  - More subjects, refine methods
  - Population level evaluation

Thank You

Questions?

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Extra: Pr(*A*) Calculation

$$C_A = L_A + Q_A - 3\left(\frac{d'(\Delta G_{AM})}{\delta}\right)^{-\rho}$$

$$\mathrm{AP}(A) = 10 \cdot \log\left[10^{(C_A/10)} + 10^{(C_M/10)}\right]$$

$$\Pr(A) \propto \frac{1}{2} \cdot \mathrm{erf}\left(\frac{\Delta\mathrm{AP}}{2 \cdot \sqrt{2}}\right)$$