Susceptibility to Impulsive Noise: Evidence from early studies

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Exposure Limits

Exposure Limits

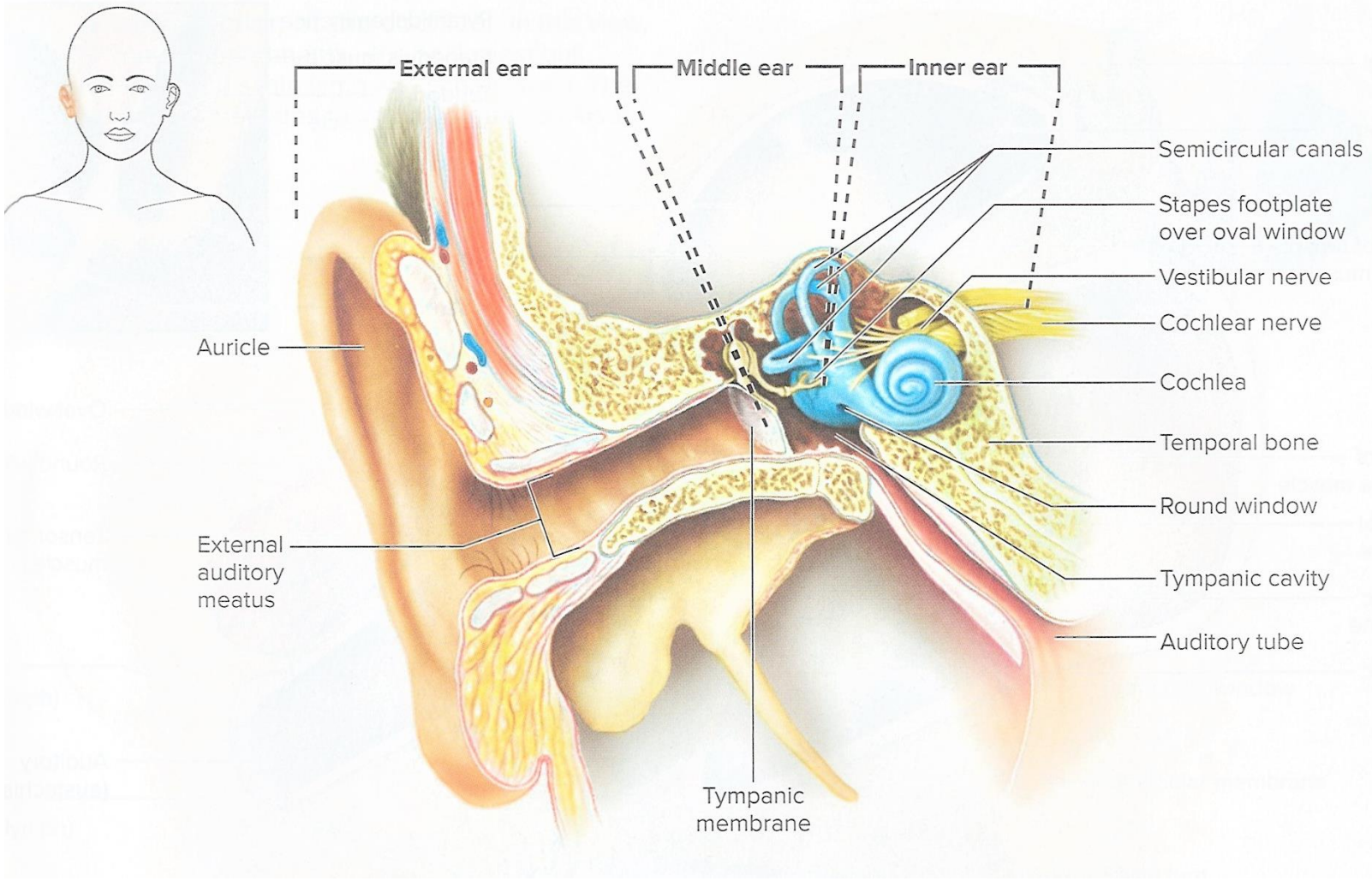
- How much is too much?
- Industry
  - Buy Quiet. How quiet?
  - Selection of exposure controls
  - Hearing Conservation Program enrollment
- Military
  - Risk management
  - Design requirements and medical standards
  - Resource planning
- Damage-risk Criteria (DRCs)

Important definitions

- Outcome of interest
  - TTS, eardrum rupture
  - PTS, tinnitus, synaptopathy
- Unacceptable harm
  - TTS (1, 2, 4 kHz mean) at 2 minutes greater than 25 dB
- Unacceptable risk
  - 25%, 10%, 5%, <1%
  - Safety margin

Susceptibility

- Individual Susceptibility:
  - Same exposure, but different outcome
- Many potential causes
  - External ear
  - Middle ear
  - Cochlear
  - Cellular/intracellular
  - Circulatory system
  - Peripheral-central interaction
  - Genetic drivers
    - Intracellular
    - Structural



Fox (2019)

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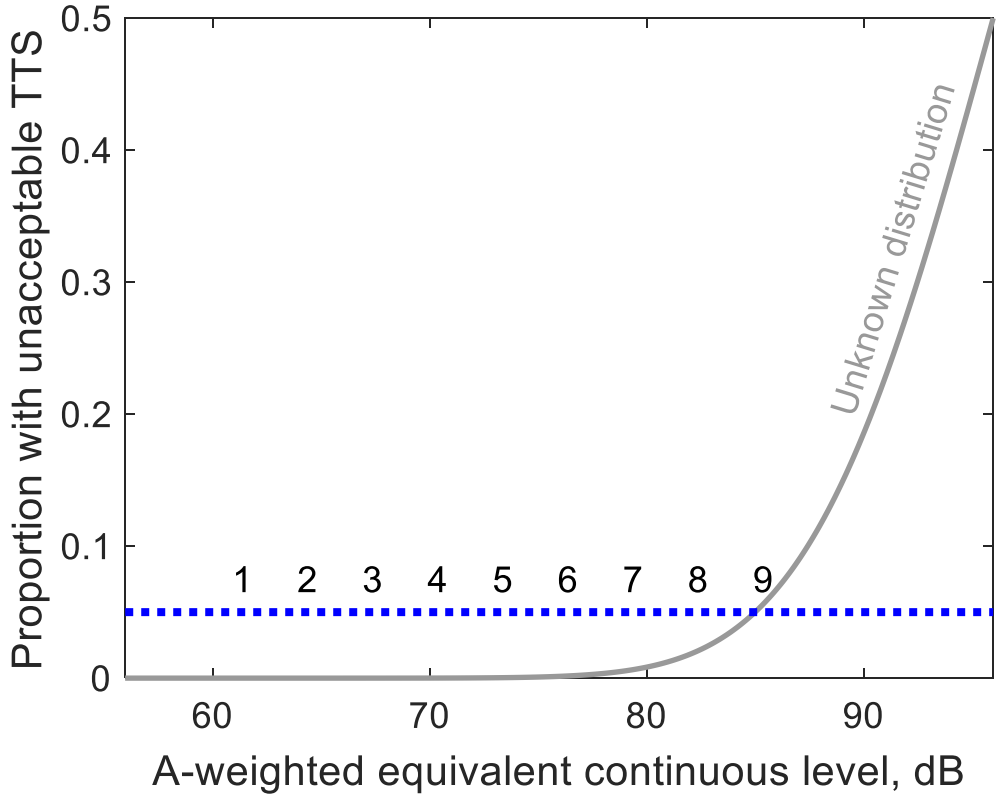
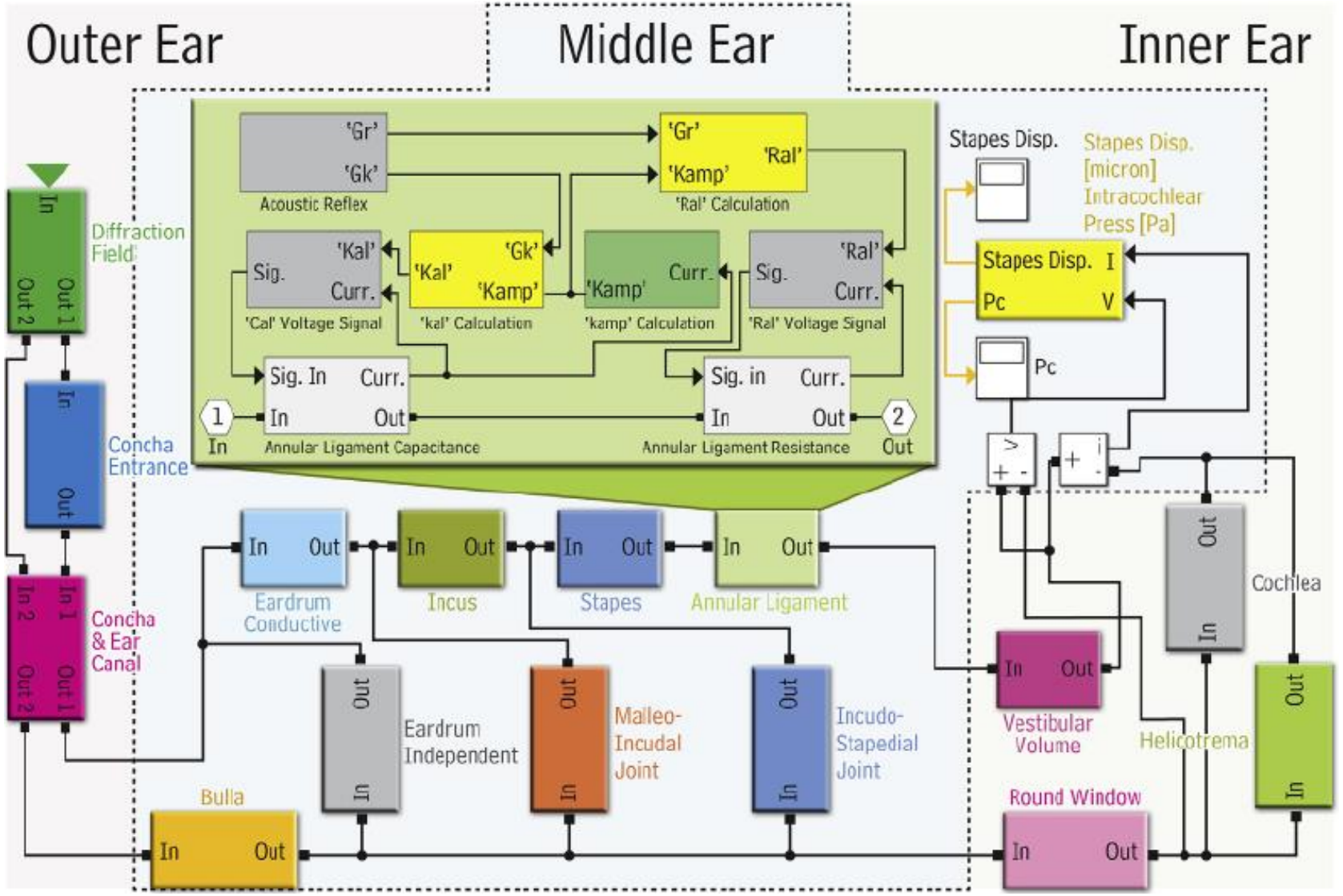
Empirical Limits

- Dose escalation
  - Start low, “walk up” to the limit
  - Primary method for pharmaceutical studies
- Advantages
  - Minimal prior information
- Disadvantages
  - Precise measurement required
  - Only know about the limit that was measured
    - No central tendency information



Model-Based Limits

- Divide the auditory system into components
- Get typical performance of components
- Predict mean response
- Account for more susceptible people
  - Normal distribution
  - 6 dB SD assumed, based on thresholds
- Input signal scaled up by 10 dB, for example
  - 150 dB → 160 dB



Price, 2007

Integrated Cochlear Energy (ICE), Zagadou, et al., 2016

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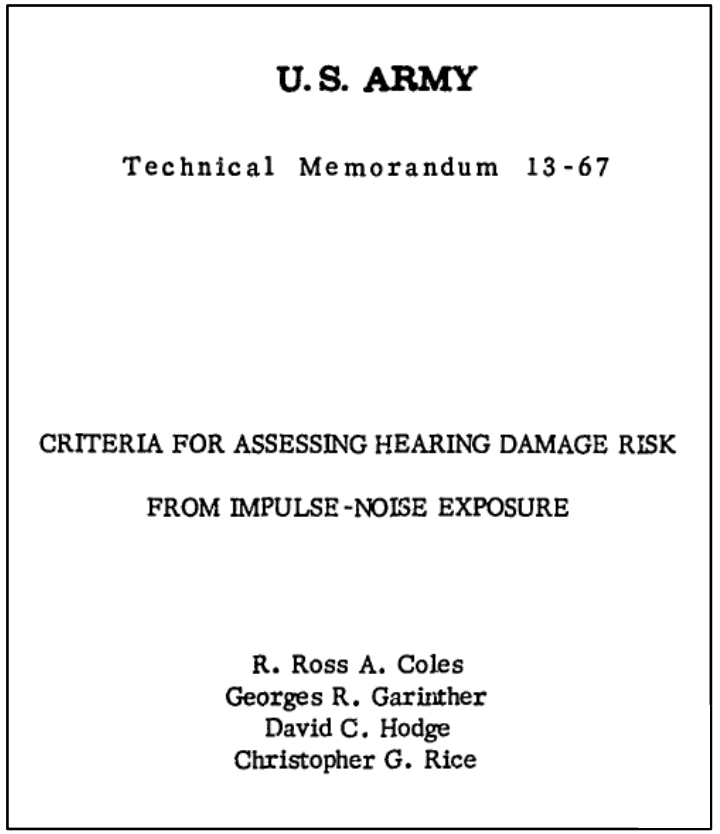
Research Question and Approach

Is there empirical support for assuming a 6 dB standard deviation?

- If the SD is greater than 6, the adjustment must be corrected.
- If the SD varies with frequency, the scaling process must be reconsidered.
  - Choose the frequency of greatest interest?
  - Account for susceptibility within the model instead of outside the head?

Approach

- Variability of TTS responses across human listeners exposed to the same impulses
- Studies used to develop the CHABA (1968) proposed standard and the prior military acquisition standard (MIL-STD-1474D)



U.S. ARMY

Technical Memorandum 13-67

CRITERIA FOR ASSESSING HEARING DAMAGE RISK

FROM IMPULSE-NOISE EXPOSURE

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Sample Data

TABLE 5A

TTS_2 Equalled or Exceeded in 50%, 25%, and 10% of Ears Exposed at Grazing Incidence to an M-14 Rifle

Exposure[a]			Test Frequency (Hz)														
			1000			2000			3000			4000			6000		
Peak Level (dB)	Number of Impulses	Ears	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%	50%	25%	10%
140	100	64	0	0	6	0	0	6	0	0	9	0	0	16	0	6	24
150	100	66	0	5	11	0	7	12	0	7	16	0	6	19	0	10	27
160	25	20	0	7	9	6	10	11	6	9	27	6	12	22	8	19	37
160	50	20	4	7	13	8	11	20	3	10	20	6	19	36	10	15	30
163	25	26	4	7	9	7	12	21	11	16	29	17	40	40	18	35	50
165	25	26	5	8	14	6	19	32	6	14	28	7	13	45	3	24	51
165	50	8	23	56	89	20	44	68	29	59	89	26	58	90	39	71	103

[a] B-duration, 4 msec

Relative to median

75th percentile: 5 dB

90th percentile: 20 dB

Coles et al., 1967, p. 32

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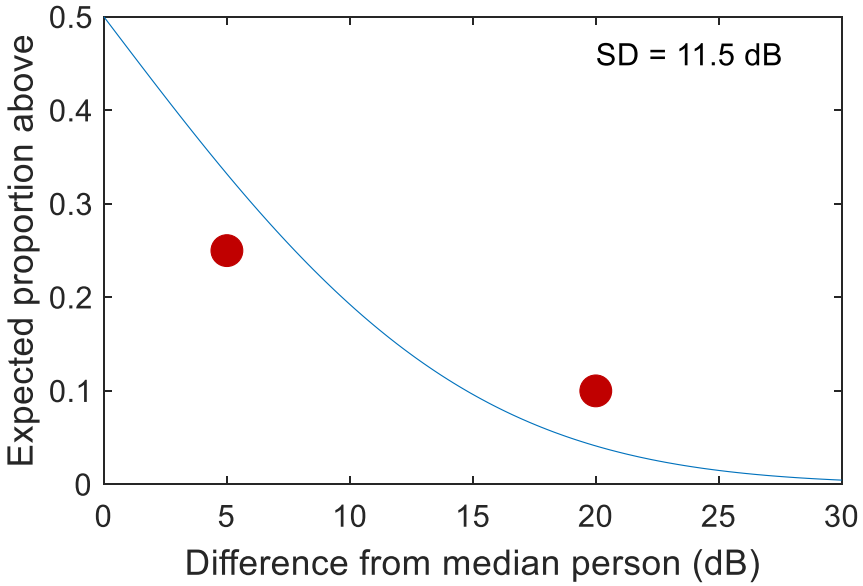
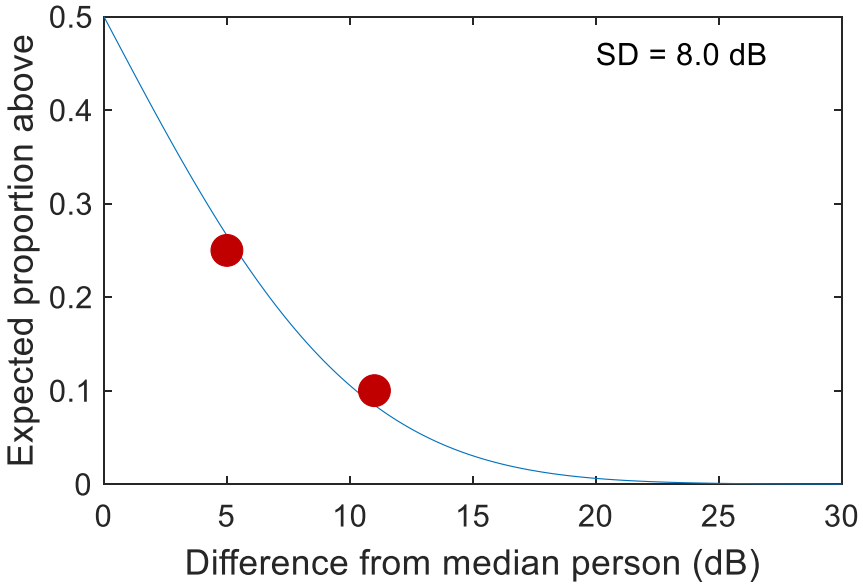
Data Sources and Procedure

- 96 data triplets
  - median, 75th, and 90th percentiles
- Estimate standard deviation
- Get medians and bootstrapped confidence intervals
  - 2^{16} resamples
- Small arms
- 140 to 165 dB SPL (N-weighted mean = 155 dB)
- 25 to 100 repetitions
- Combined numbers:

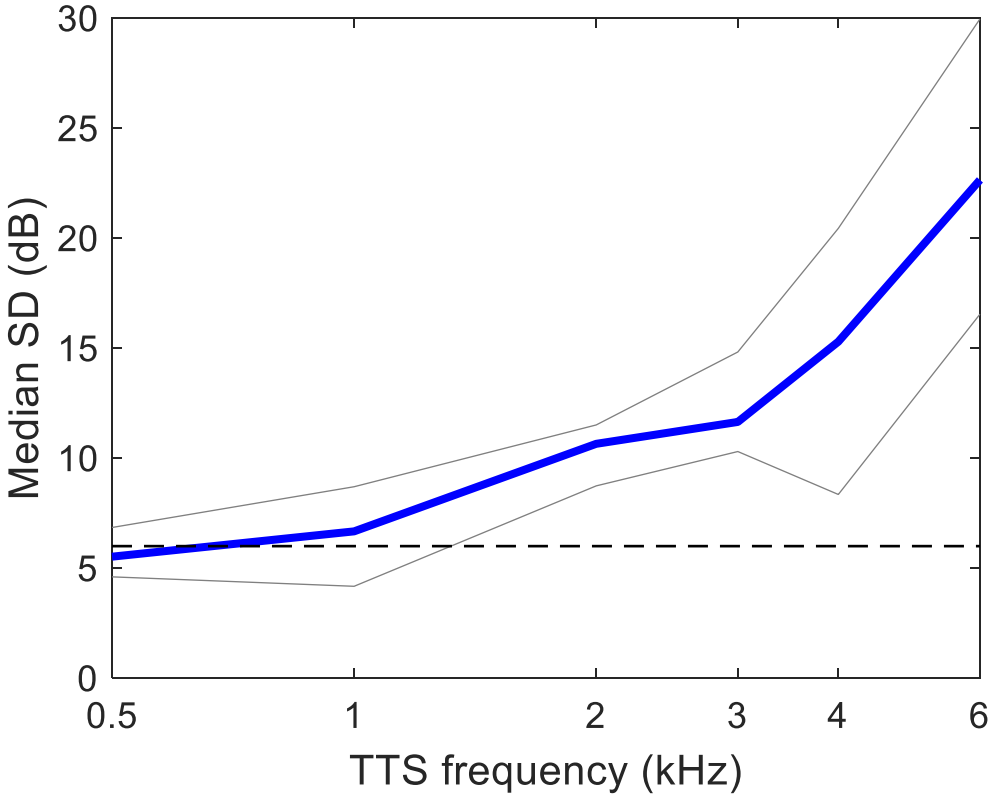
kHz	0.5	1	2	3	4	6
Ears	62	272	321	272	321	272
Studies	10	16	19	16	19	16





Results – Standard Deviations

- Susceptibility distributions increase with frequency.
- Assumption of 6 dB SD is incorrect above 1 kHz.
  - 6 dB at 0.5 kHz
  - 7 dB at 1 kHz
  - 11 dB at 2 kHz
  - 12 dB at 3 kHz
  - 15 dB at 4 kHz
  - 23 dB at 6 kHz
- Confidence intervals widen at 4 and 6 kHz

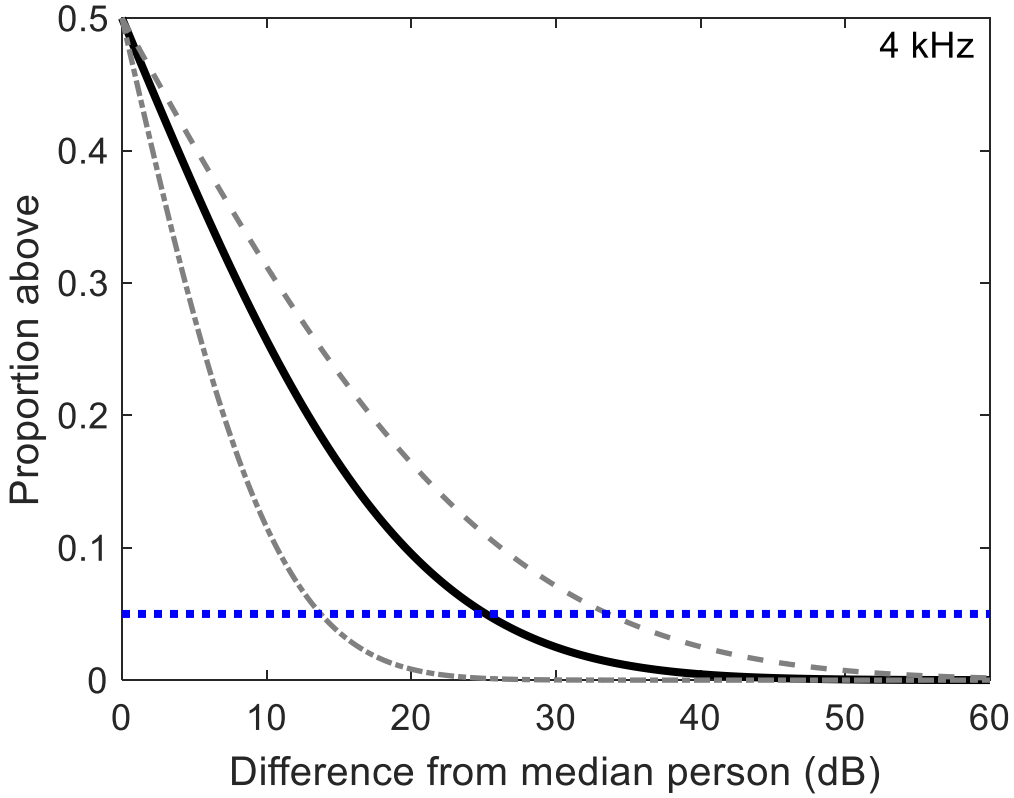


Results – Single Frequency

- Distributions were produced from medians and their confidence intervals.
- Estimates of 95th percentile (5 percent exceeded) span a wide range

<u>At 4 kHz:</u>

- Best estimate: 25 dB
- Range: 14 to 34 dB
- Following the Price conjecture, a signal with a 160 dB peak would need to be treated as if it had a peak between 174 and 194 dB SPL
  - Best estimate: 185 dB (above TM rupture risk)



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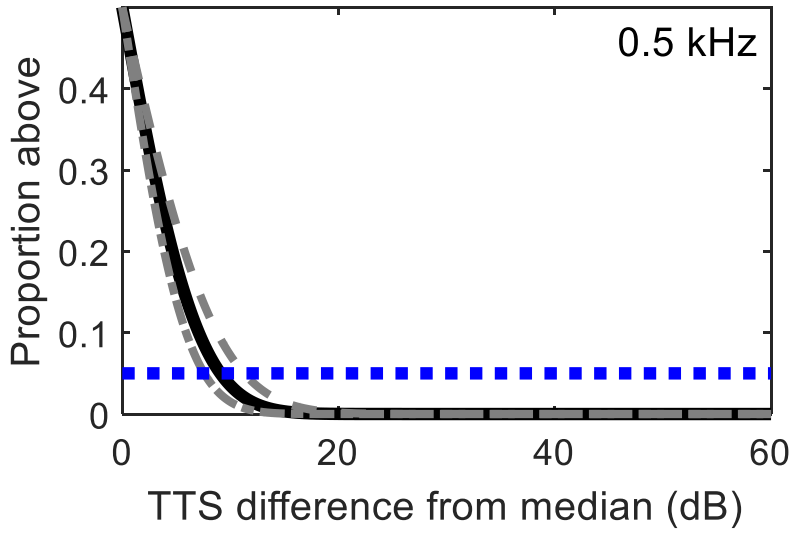
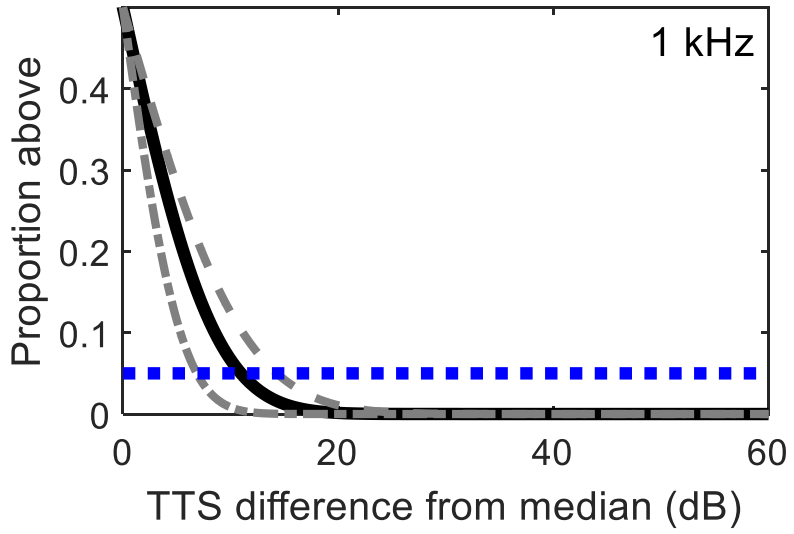
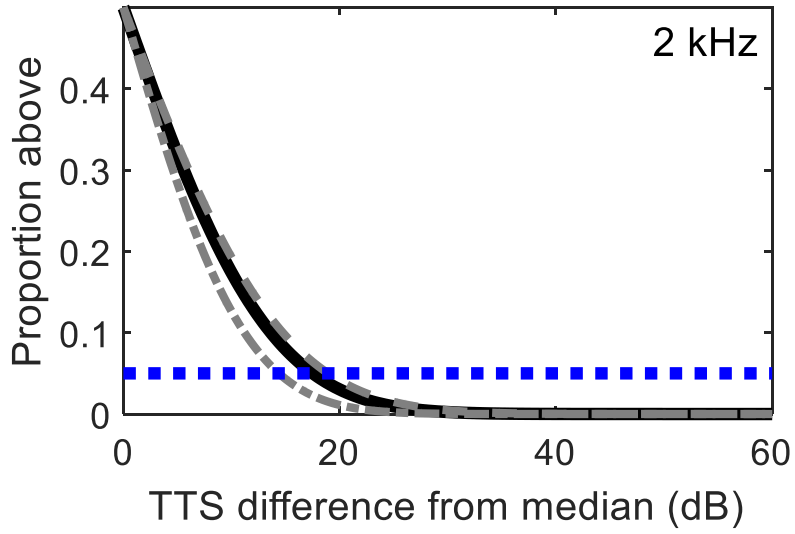
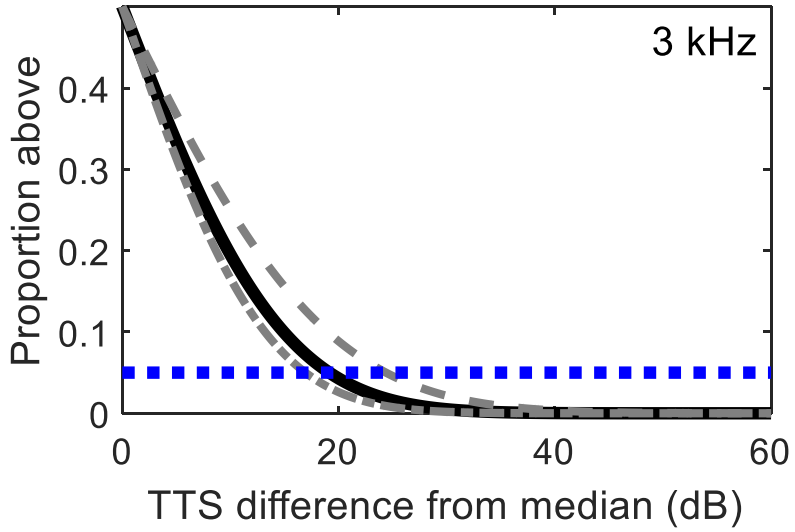
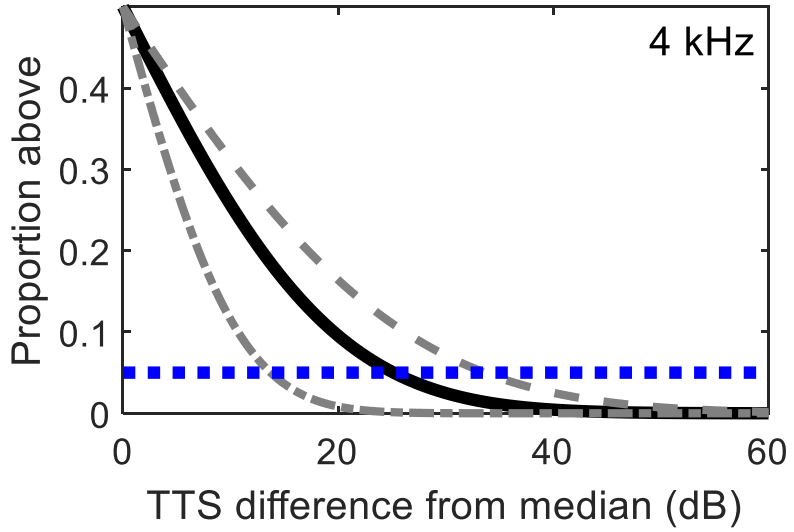
Results – Across Frequency

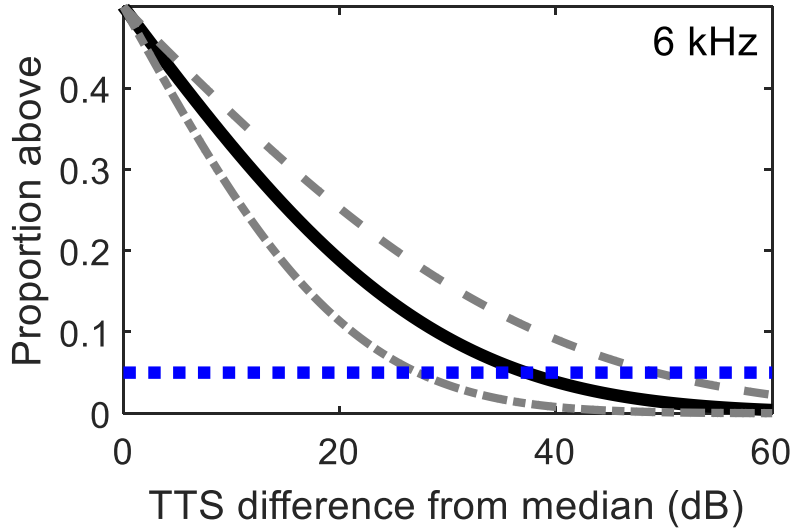












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Discussion and Conclusions

- Empirical DRCs estimate the tail directly, but not perfectly.
- Model-based DRCs start with central tendency and adjust for the most susceptible tail of the distribution.
- The SD in these adjustments will depend on the highest frequency of interest.
  - 6 dB (+10 dB adjustment) is reasonable if the frequency range does not extend beyond 1 kHz.
  - 15 dB (+25 dB adjustment) is needed to include 4 kHz.
  - 23 dB (+38 dB adjustment) is needed to include 6 kHz.
- The required adjustments might introduce logical problems.
  - TM rupture
  - Stapedial Annular Ligament
  - Excessively low damage threshold
    - 110 peak dB SPL → 150 dB peak dB SPL

Questions?

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