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Aided Music Listening

Computational Models to Predict Safety Limits

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Motivation: safe music amplification

For music listeners with hearing loss…

We may want to let them “turn it up”
(e.g., with hearables, PSAPs, or hearing aids), but…

How much amplification is too much?

(we want to avoid additional hearing loss)

Consider an 85dB exposure limit

85 dBA ($L_{EX,8h}$) limits the risk of permanent hearing loss

(e.g., 85dB for 8 hours, 88dB for 4 hours, etc)

After 40 years of daily exposure to 85 dB, excess risk = 8%

But what about those with pre-existing hearing loss?

Background: safe amplification

Macrae (1991, 1994) measured hearing loss due to over-amplification

<60dB HL = generally safe with prescribed gains

60-100dB HL = some temporary hearing loss

>100dB HL = some permanent hearing loss caused by prescribed gain

This was based on sound field levels of 61dB(A)

- At higher levels, risk of over-amplification may be greater

Safe levels for amplified music

Goal: define safe exposure limits

Caveat:
Long-term average level does not predict music-induced hearing loss

- Music tends to result in less temporary threshold shift than noise*
- A model of noise-induced hearing loss therefore provides a *conservative* estimate of music-induced hearing loss

* Lindgren and Axelsson 1983; Strasser et al. 1999; Strasser et al. 2003

Hearing Loss Models

ISO 1999:2013

predicts population hearing thresholds as a combination of…

- hearing threshold levels due to age
- noise-induced permanent threshold shift

Modified Power Law (Humes & Jesteadt, 1991)

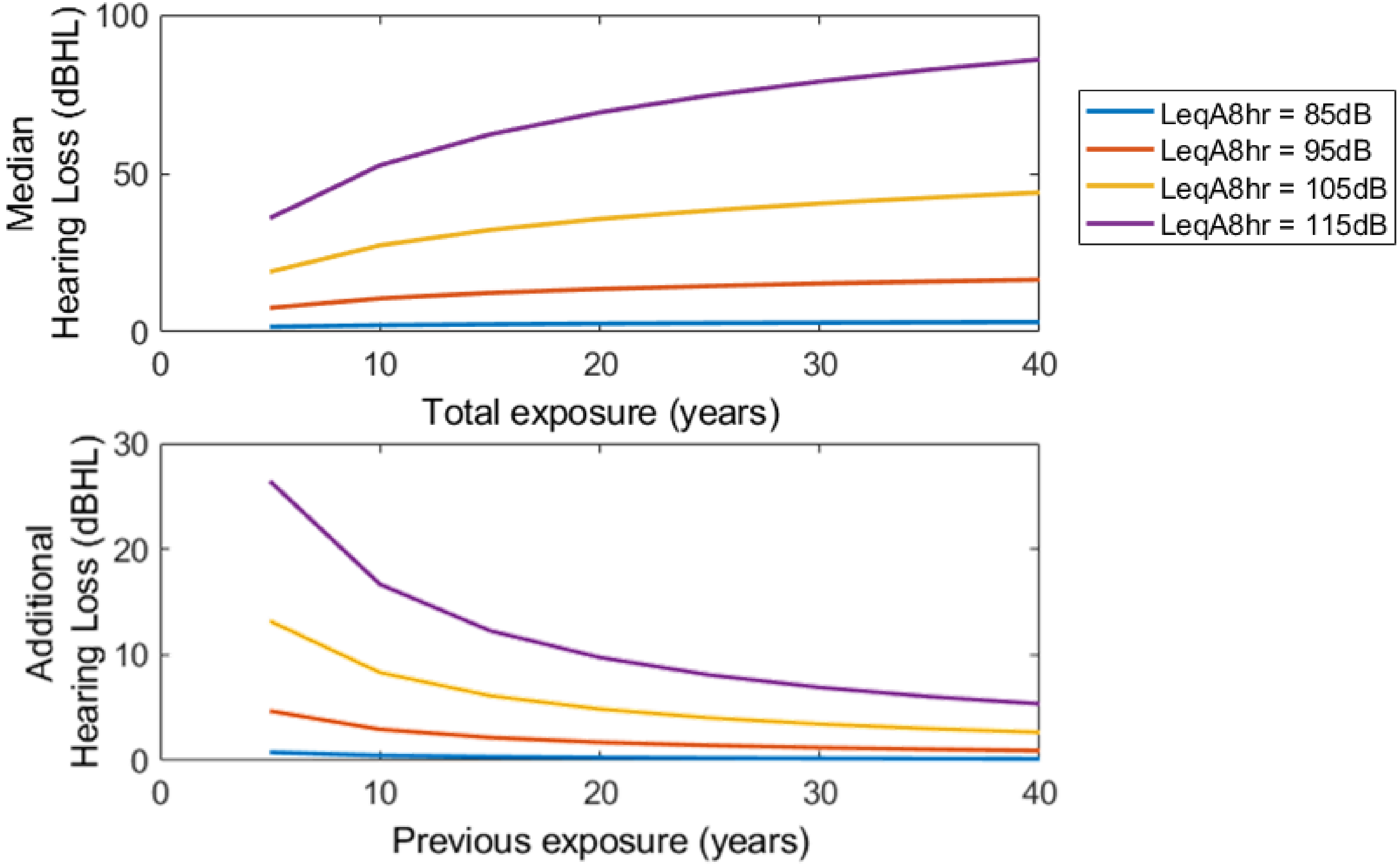
predicts temporary and permanent threshold shifts
for repeated exposures to steady state noise

- based on additivity of noise exposures in a transformed domain (based on Stevens’ power law, 1957)

Experiment 1: ISO 1999 Model

Hearing loss as a function of previous exposure

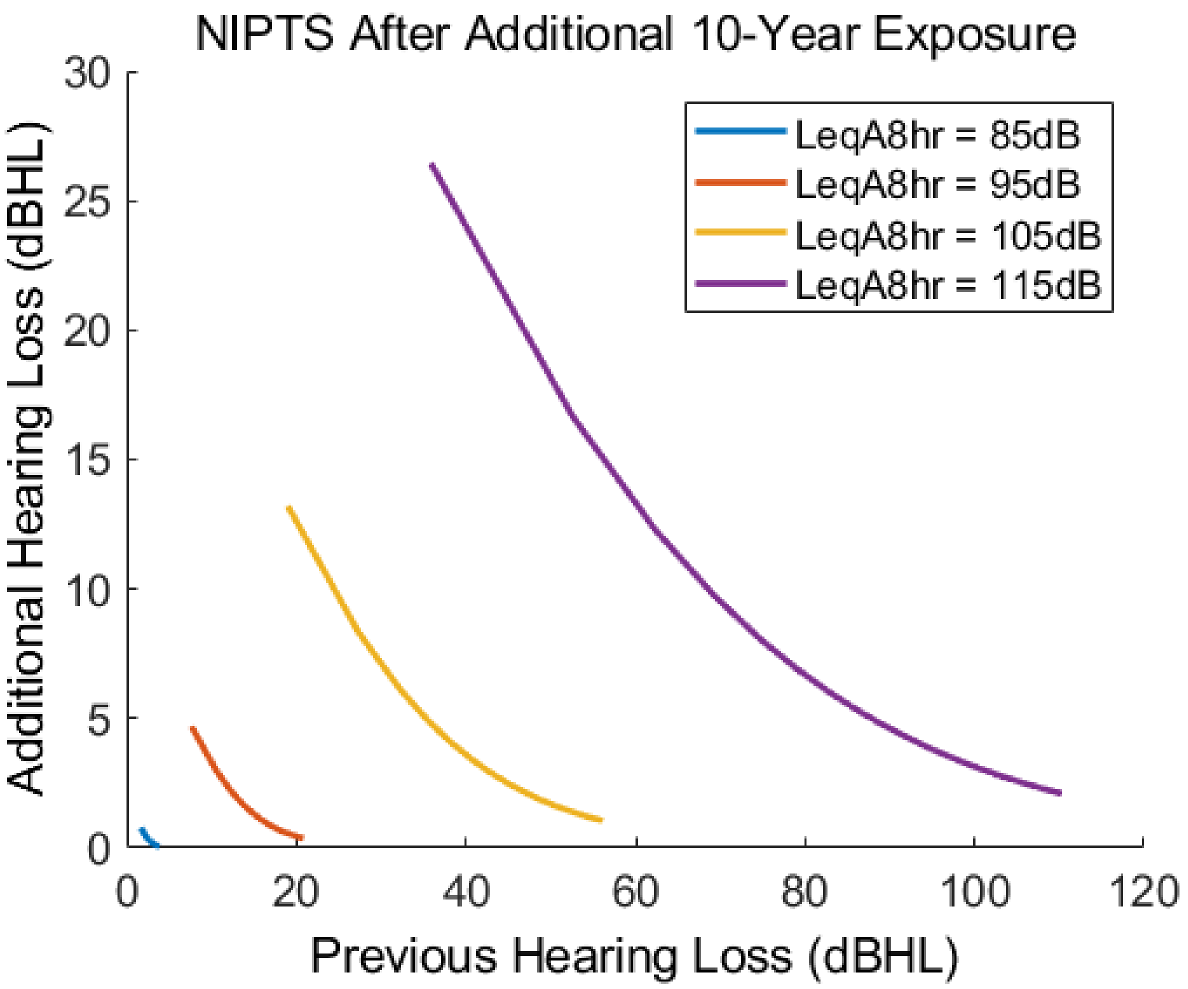
Hearing Loss Accumulates with Time



Reduced vulnerability to hearing loss

Plotting the same data on a different axis…

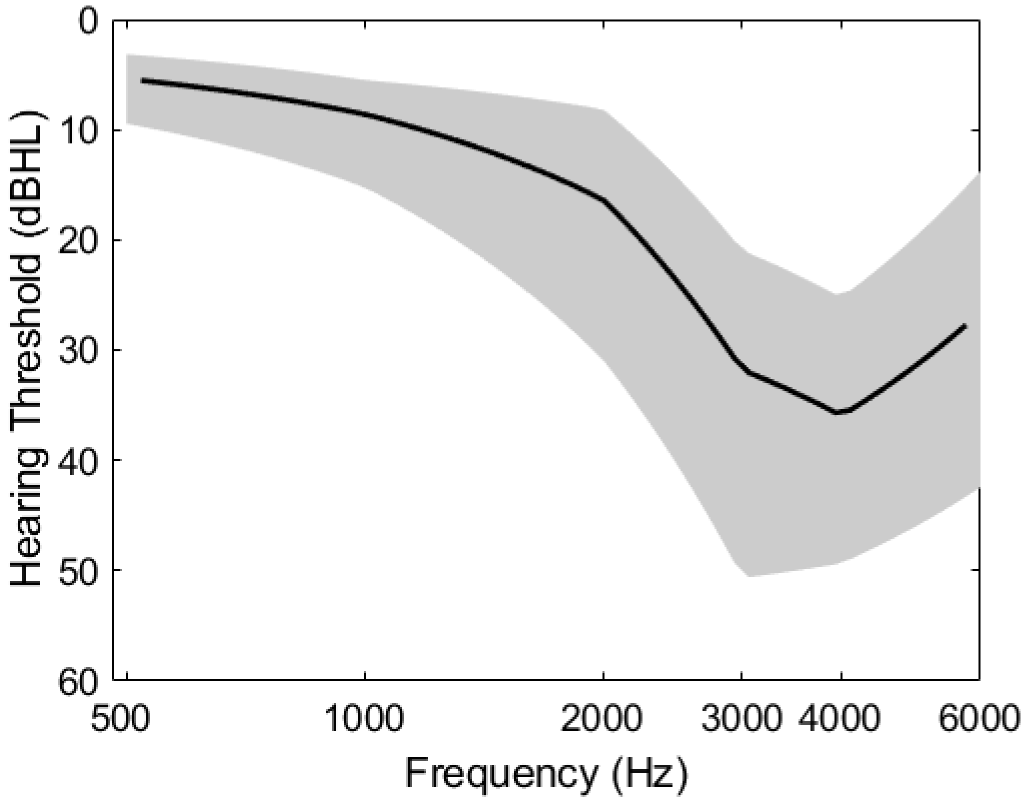
With a previous hearing loss, additional hearing loss is reduced



Consider an Example Hearing Loss

Model pre-existing thresholds as sound-induced hearing loss

- 20 years exposure at 100dB L_{EqA8h} (median & 10-90th percentile shown here)

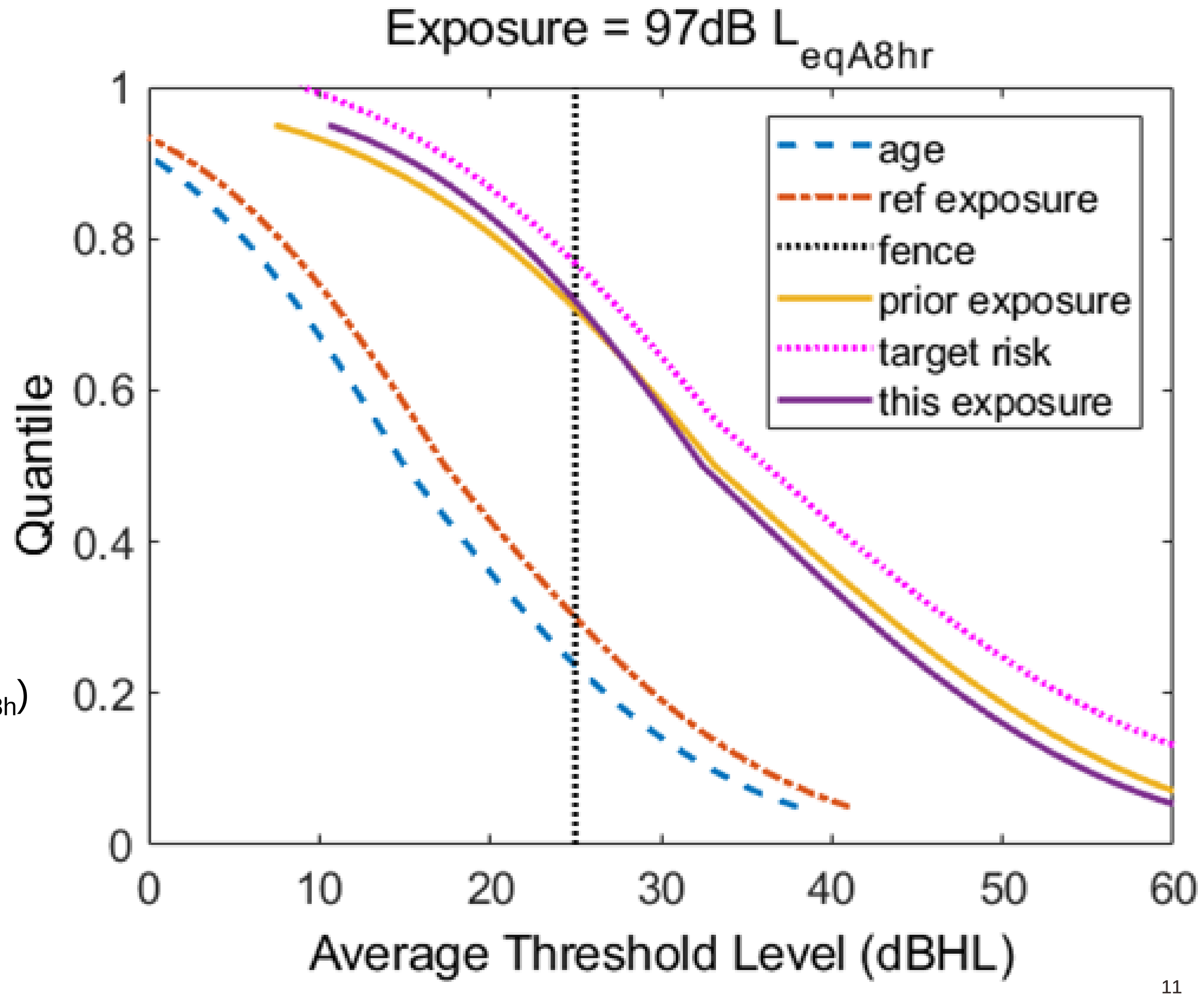


Exposure Limit Based on Excess Risk

Limit excess risk to match
reference exposure (85dB $L_{EX,8h}$)

Initial 20 year exposure (100dB L_{EqA8h})
+ Additional 40 year exposure

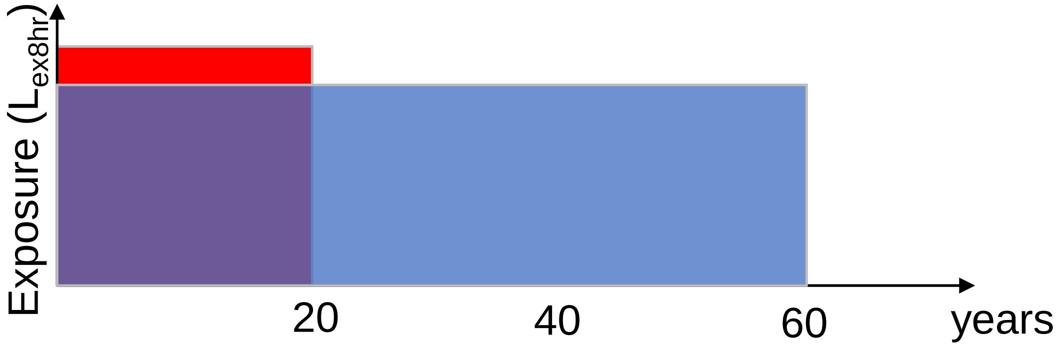
Total 60-year exposure (97dB L_{EqA8h})



Discussion of Experiment 1

For this particular example…
the exposure limit can be safely increased (from 85dB to 97dB)

This is a conservative estimate because…
it assumes the original hearing loss also occurred
due to a 97dB exposure rather than 100dB



Can We Model Specific Hearing Losses?

With the ISO 1999 model, it is ***not*** straight-forward to

1. Model a specific hearing loss
2. add amplification
3. change the exposure level

For that, we used the modified power law model in the second experiment.

Experiment 2: Modified Power Law Model

Specific hearing loss profiles

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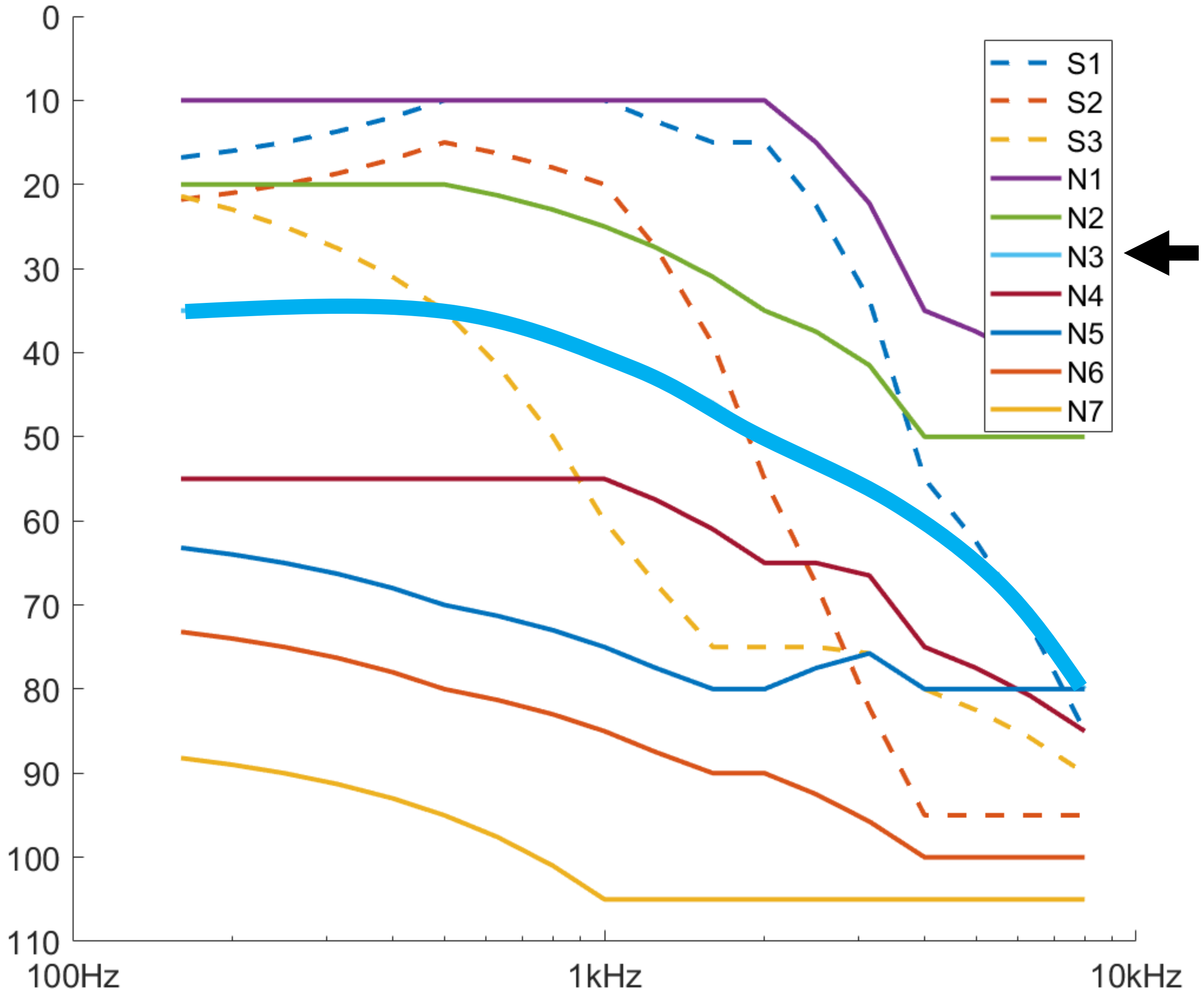
Let’s try several audiograms

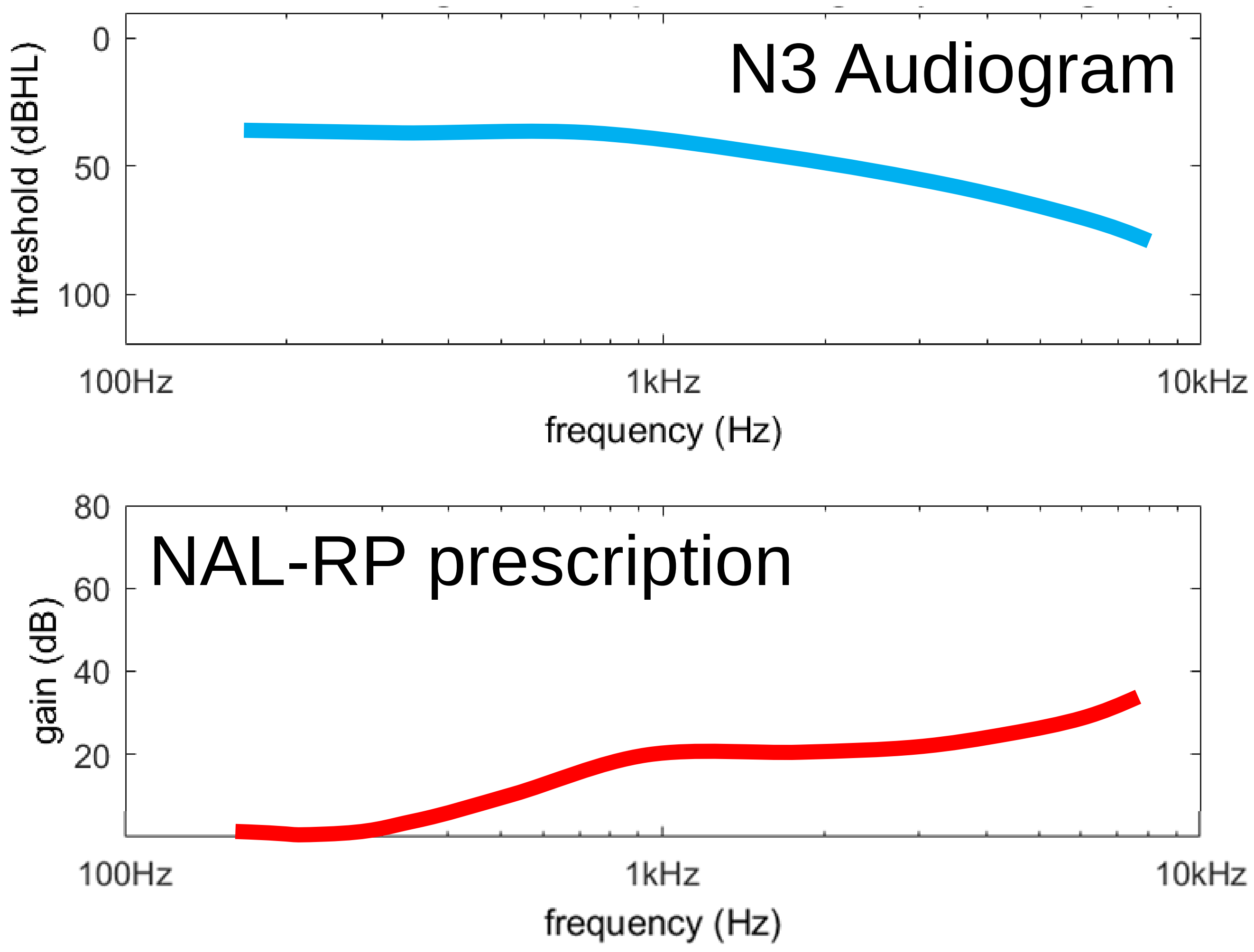
Based on Bisgaard et al (2010)

- 7 audiograms
  with flat and moderately sloping hearing loss
- 3 audiograms
  with steep hearing loss



Apply some amplification

- Use linear amplification as a simplification



Max Sound Field with Hearing Aids

- Limit additional hearing loss to < 1dB at 1,2,3,4kHz

Audiogram	Recommended exposure limit (unaided)	Recommended exposure limit (NAL-RP gain)
Normal	85 dB(A)	85 dB(A)
S1	91 dB(A)	81 dB(A)
S2	95 dB(A)	79 dB(A)
S3	105 dB(A)	74 dB(A)
N1	89 dB(A)	83 dB(A)
N2	94 dB(A)	79 dB(A)
N3	98 dB(A)	76 dB(A)
N4	101 dB(A)	74 dB(A)
N5	105 dB(A)	71 dB(A)
N6	113 dB(A)	73 dB(A)
N7	118 dB(A)	72 dB(A)

How much gain is acceptable?

To avoid
permanent threshold shifts

	Frequency (kHz)						
	.25	.50	1	2	3	4	6
N1	0	0	0	0	2	9	11
N2	0	0	7	8	9	11	11
N3	0	0	11	12	13	14	17
N4	0	7	14	15	16	18	19
N5	5	14	21	22	19	21	21
N6	10	17	25	25	27	29	28
N7	35	35	35	32	32	32	32
S1	0	0	0	0	6	13	19
S2	0	0	5	13	20	28	28
S3	0	2	16	19	19	20	23

Discussion

Summary

- For listeners with hearing loss, the models suggest…
  - Higher exposure limits for people with hearing loss
  - Care should be taken to avoid over-amplification

Audiogram	Recommended exposure limit (free field)
Normal	85 dB(A)
S1	91 dB(A)
S2	95 dB(A)
S3	105 dB(A)
N1	89 dB(A)
N2	94 dB(A)
N3	98 dB(A)
N4	101 dB(A)
N5	105 dB(A)
N6	113 dB(A)
N7	118 dB(A)

Comparing the 2 models

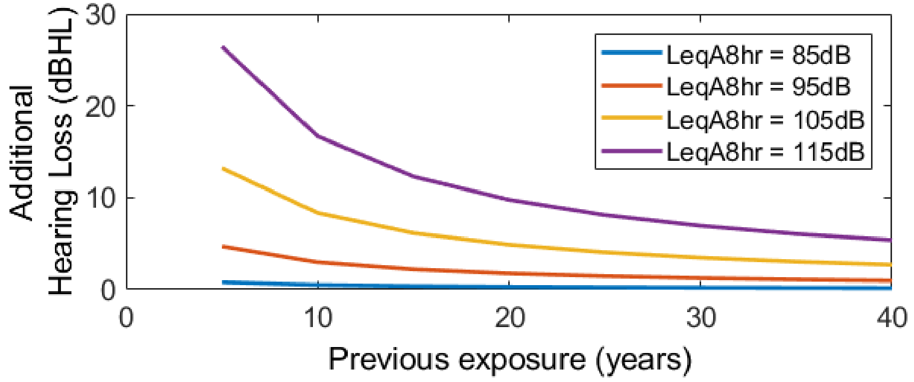
The two models are quite different,
but we found that they predict similar exposure limits.

- Experiment 1 – predicted exposure limit of 97 dB L_{EqA8h} for the given hearing loss distribution
- Experiment 2 – predicted exposure limit of 94(±3) dB(A) for the same median, 5th, and 95th percentile hearing losses

Vulnerability to further hearing loss

For people with pre-existing hearing loss…

- Ward (1973) and Macrae (1991, 1994) found *reduced* vulnerability
- Reduced vulnerability is also consistent with the ISO model of NIPTS as a function of years of exposure



- But… Seixas et al (2012) suggested *accelerated* threshold shifts

Vulnerability: conflicting evidence

Why did the Seixas data have the opposite trend?

It is difficult to tell given the available data

Individual differences?

some people may be more vulnerable to sound-induced hearing loss than others (Maison and Liberman, 2000).

Limitations & Future Work

- High frequency hearing loss
  - We only considered frequencies of 1-4kHz
  - Follow-up work may consider a wider spectrum

- Real-ear insertion gains often vary by >10dB
  - In cases where real-ear verification is not available, more conservative limits might be warranted