Safety Limits for Aided Music Listening

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Learning Outcomes

After this course, participants will be able to:

- Describe the relationship between hearing loss and vulnerability to further noise-induced hearing loss
- Estimate the safety of specific gain settings based on hearing loss
- Describe the limitations of using computer models to predict outcomes

Introduction

http://www.aes.org/e-lib/browse.cfm?elib=19574

Audio Engineering Society

Conference Paper

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Computational Models to Predict Safety Limits for Aided Music Listening

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ABSTRACT
At equal sound exposure levels, listeners with a pre-existing hearing loss are less vulnerable to music-induced hearing damage than listeners with no hearing loss. But such listeners require and often prefer to listen to music with additional amplification. But how much gain and to what output levels (in dB) are safe is somewhat unknown at this time. In this study, we use computational models to predict hearing threshold shifts from amplified music exposure. We estimate safe output limits and corresponding free-field exposure limits for listening to music with hearing amplification by minimizing permanent and temporary threshold shifts.

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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 hearing aids), but…

How much amplification is too much?

(we want to avoid additional hearing loss)

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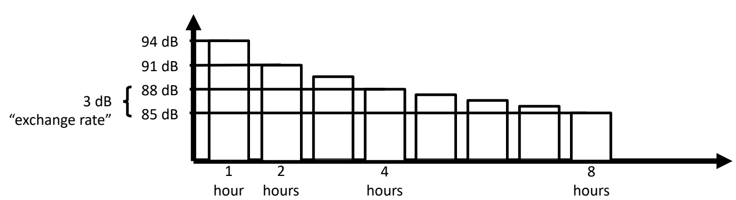
Consider an 85dB exposure limit

85 dBA (LEX,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

Macrae, John H. "Permanent threshold shift associated with overamplification by hearing aids." Journal of Speech, Language, and Hearing Research 34.2 (1991): 403-414.
Macrae, John H. "Prediction of asymptotic threshold shift caused by hearing aid use." Journal of Speech, Language, and Hearing Research 37.6 (1994): 1450-1458.

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 <u>less</u> temporary threshold shift than noise*
- A model of noise-induced hearing loss therefore provides a <u>*conservative*</u> estimate of music-induced hearing loss

* Lindgren F, Axelsson A. 1983. Temporary threshold shift after exposure to noise and music of equal energy. Ear Hear. 4:197–201.
* Strasser H, Irle H, Scholz R. 1999. Physiological cost of energy-equivalent exposures to white noise, industrial noise, heavy metal music, and classical music. Noise Control Eng. J. 47:187.
* Strasser H, Irle H, Legler R. 2003. Temporary hearing threshold shifts and restitution after energy-equivalent exposures to industrial noise and classical music. Noise Health 5:75– 84.

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

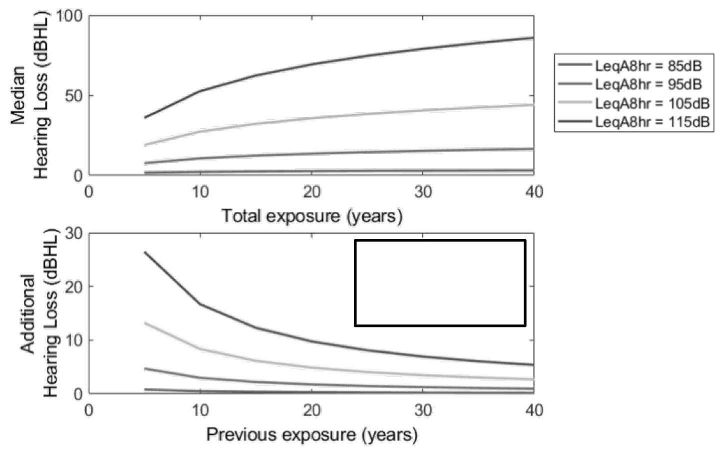
- based on additivity of noise exposures in a transformed domain (based on Stevens' power law, 1957)

ISO 1999: 2013. "Acoustics—Estimation of noise-induced hearing loss." (2013).
Humes, Larry E., and Walt Jesteadt. "Modeling the interactions between noise exposure and other variables." The Journal of the Acoustical Society of America 90.1 (1991): 182-188.
Stevens, Stanley S. "On the psychophysical law." Psychological review 64.3 (1957): 153.

Experiment 1 *(ISO 1999 Model)*
Hearing loss as a function of previous exposure

https://www.mathworks.com/matlabcentral/fileexchange/53565-iso-1999-2013

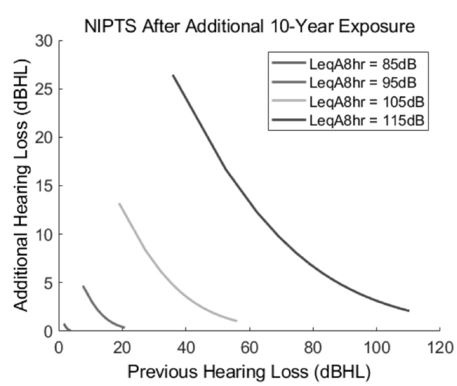
Hearing Loss Accumulates with Time



Reduced vulnerability to hearing loss

Plotting the same data on a different axis…

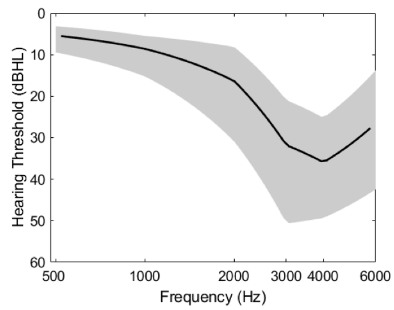
With a previous hearing loss, additional hearing loss is reduced



Consider an Example Hearing Loss

Model pre-existing thresholds as sound-induced hearing loss

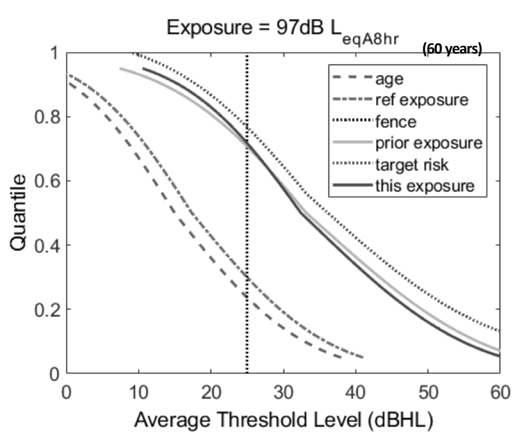
- 20 years exposure at 100dB L_{EqA8h} (median & 10-90th percentile shown here)



Exposure Limit Based on Excess Risk

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

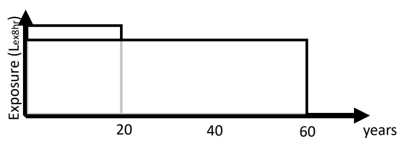
Initial 20 year exposure (100dB L_{EqA8h})
+ <u>Additional 40 year exposure</u>
Total 60-year exposure (97dB L_{EqA8h})



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.

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Experiment 2 *(power law model)*
Modeling specific hearing loss profiles

Humes, Larry E., and Walt Jesteadt. "Modeling the interactions between noise exposure and other variables." The Journal of the Acoustical Society of America 90.1 (1991): 182-188.

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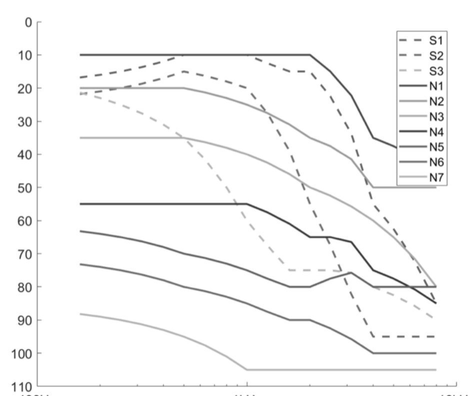
Let's try several audiograms

Based on
Bisgaard et al (2010)

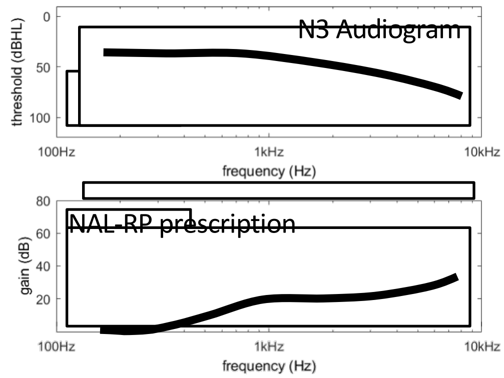
- 7 audiograms with flat and moderately sloping hearing loss
- 3 audiograms with steep hearing loss



Bisgaard, Nikolai, Marcel SMG Vlaming, and Martin Dahlquist. "Standard audiograms for the IEC 60118-15 measurement procedure." Trends in amplification 14.2 (2010): 113-120.

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)
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)
S1	91 dB(A)	81 dB(A)
S2	95 dB(A)	79 dB(A)
S3	105 dB(A)	74 dB(A)

continued

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

Safety limits here indicate ***difference*** from normal threshold (unaided) conditions

continued

Summary

continued

Conclusions

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)
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)
S1	91 dB(A)
S2	95 dB(A)
S3	105 dB(A)

8 hours LEQ

continued

Implications for Compression

Consider the long-term average

- exposure level & time
  and/or
- gain relative to normal exposure limits (re: representative input levels)

consider real-ear exposure

Gain	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

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S1	91 dB(A)
S2	95 dB(A)
S3	105 dB(A)

continued

Comparing the 2 models

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

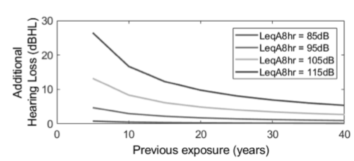
Experiment 1 – predicted exposure limit of 97 dB L_{EqA8h}
for the given hearing loss distribution

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



Ward WD. Adaptation and fatigue. In: Jerger J, editor. Modern developments in audiology. 2nd ed Academic Press; New York: 1973. pp. 301–344
Macrae, John H. "Permanent threshold shift associated with overamplification by hearing aids." Journal of Speech, Language, and Hearing Research 34.2 (1991): 403-414.
Macrae, John H. "Prediction of asymptotic threshold shift caused by hearing aid use." Journal of Speech, Language, and Hearing Research 37.6 (1994): 1450-1458.

Vulnerability: ~~conflicting~~ evidence

Seixas et al (2012):

"We also saw evidence that those with higher hearing thresholds at baseline suffered a larger noise-related decline..."

Individual differences?

Some people may be more vulnerable to sound-induced hearing loss than others. (Maison & Liberman, 2000; Konings et al, 2009)

If some are more vulnerable, we expect a correlation between those with early hearing loss and those with more NIPTS.

Seixas, Noah S., et al. "10-Year prospective study of noise exposure and hearing damage among construction workers." *Occup Environ Med* 69.9 (2012): 643-650.
Maison, Stephane F., and M. Charles Liberman. "Predicting vulnerability to acoustic injury with a noninvasive assay of olivocochlear reflex strength." *Journal of Neuroscience* 20.12 (2000): 4701-4707.
Konings, Annelies, Lut Van Laer, and Guy Van Camp. "Genetic studies on noise-induced hearing loss: a review." Ear and hearing 30.2 (2009): 151-159.

Limitations

Population

- These computer models are intended to predict risk of a population. The models cannot predict risk for an individual.

Excess Risk

- We matched the 8% excess risk of existing limits. Meaning that we allow additional hearing loss in 8% of the population.

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

One more note…

continued

How much gain is acceptable?

To avoid **temporary** threshold shifts

	Frequency (kHz)						
	.25	**.50**	**1**	**2**	**3**	**4**	**6**
N1	0	0	0	0	0	1	3
N2	0	0	0	0	0	1	1
N3	0	0	0	0	0	1	4
N4	0	0	0	0	0	1	2
N5	0	0	1	2	0	1	1
N6	0	0	0	0	0	1	1
N7	1	1	1	0	0	0	0
S1	0	0	0	0	0	1	7
S2	0	0	0	0	0	1	1
S3	0	0	0	0	0	1	2

Safety limits here indicate ***difference*** from normal threshold (unaided) conditions

continued

Q&A

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