Prevention of Music-Induced Hearing Loss
Part I: Theory

Brian Fligor, ScD
Director of Diagnostic Audiology
Children's Hospital Boston
Instructor in Otology and Laryngology
Harvard Medical School

Special Thank You To …

- Co-investigator
  - Terri Ives, ScD, AuD
  - Sandra Levey, PhD
- Mentored Graduate Student Researchers
  - Cory Portnuff, AuD, PhD-candidate University of Colorado, Boulder
  - Jamie Weiner, AuD, Towson University
- Research Sponsors
  - Etymotic Research, Inc., Elk Grove Village, IL
  - Department of Otolaryngology and Communication Enhancement, Children's Hospital Boston

Topics to Discuss

Primarily:

- ✓ The science of NIHL
- ✓ Briefly: regulations for minimizing NIHL
- ✓ PLD earphones *potential* output
- ✓ PLD earphones and user *behavior*
- ✓ Musician exposure, audience exposure
- ✓ Implications for MIHL and its prevention

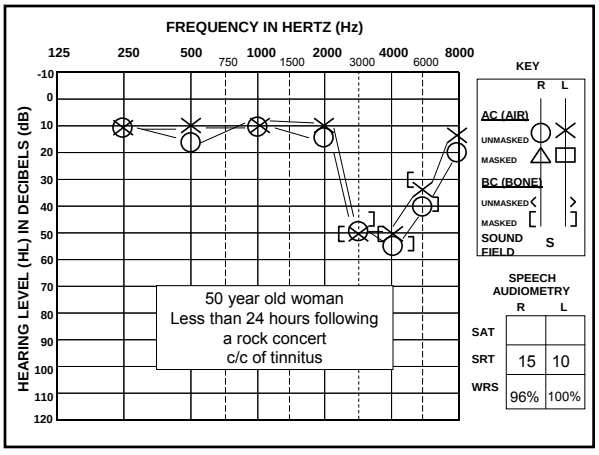
A Case Study: 50 year-old woman

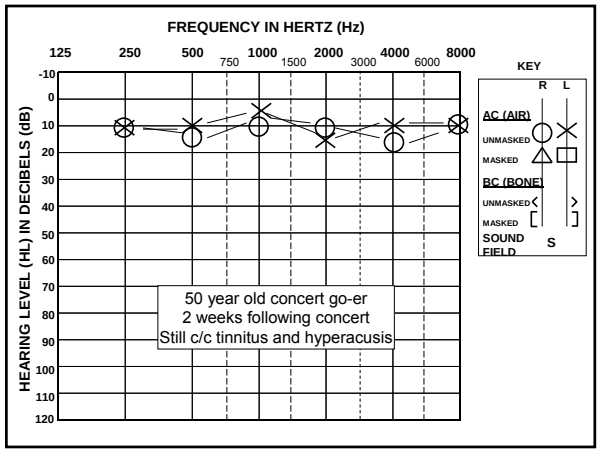
• A 50-year-old woman attended a rock concert 4 years ago at a <1000 seat venue, left after ~1.5 hours as levels were "way too high."

• Experienced ringing in her ears on the drive home, still very pronounced ringing the next day so saw an ENT.

• Noise exposure history was otherwise negative, and otologic history was non-contributory to complaint of tinnitus.

• Lawsuit against the band and concert venue, citing unremitting tinnitus and hyperacusis, settled out of court.





Preliminary opinion

• TTS of 35-50 dB, with unresolved tinnitus and hyperacusis is consistent with acoustic trauma

• Previous recordings made by me at similar venues on 2 different occasions of a different band indicated levels of 100-105 dB(A) and 107-110 dB(A); Avg level at outside venues = 103.4 dB(A) (Clark, 1992)

• Models of TTS growth indicated for fractile 0.5, the 35-50 dB TTS would result from 98.6-107.4 dBA

• 85 dB(A), trade 3 DRC:

1-2 hrs, 98.6 dB(A) = 289% - 579% Noise dose

1-2 hrs, 107.4 dB(A) = 2211% - 4422% Noise dose

Levels on Stage: 500 capacity club

Type II SLM, stage right	All Levels dBA FFE				
Warm up Act	L dB(A)	C (min)		time to 100% Dose	T (min)
8:15	108	5		8:15	2.4
8:30	108	5		8:30	2.4
8:35	110	5		8:35	1.5
8:45	108	5		8:45	2.4
set Length	30 minutes				
Estimated Dose	**1394%**				
Main Act	L dB(A)	C (min)		time to 100% Dose	T (min)
8:55	108	5		8:55	2.4
9:00	109	5		9:00	1.9
9:05	107	5		9:05	3.0
9:10	108	5		9:10	2.4
9:15	107	5		9:15	3.0
9:20	109	5		9:20	1.9
9:25	110	5		9:25	1.5
9:30	108	5		9:30	2.4
9:35	109	5		9:35	1.9
set Length	40 minutes				
Estimated Dose	**2107%**				
Total for the night	**3501%**				

Noise-Induced Hearing Loss

Gradually Developing Noise-Induced Permanent Threshold Shift (NIPTS)

- 78 dBA – 130 something (?) dBA
- Outer hair cells
- Metabolic overload after duration of exposure
- Gradual loss in sensory hearing
- NITTS: recovery after a rest period

Acoustic Trauma (AT)

- 140 dB Peak SPL (132 dB SPL - Price, 1981)
- Usually from impulse: brief, fast rise time
- Can result from marked "overdose"
- Mechanical Damage after single exposure
- Immediate loss of sensory hearing

Injury from Chronic Noise Exposure:

- *F*(time & intensity)
- *F*(frequency) – A-weighting "network"

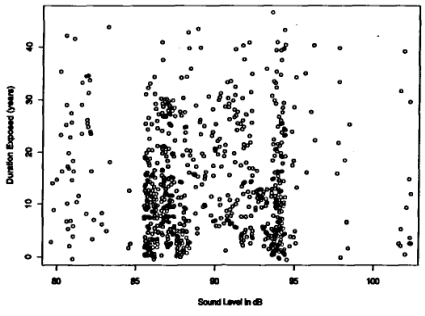
NIPTS (also NITTS):

− Hearing threshold decrease poorest in the 3000 – 6000 Hz range (4000 Hz Notch)

Other injuries:

- tinnitus
- abnormal pitch perception
- loudness tolerance problems

ONHS 1968-1972, NIOSH



Scatter Plot of Noise Exposure (level and years) of 792 workers

Noise (& Music)-Induced Hearing Loss

Exposure:

- Function of time of exposure and the level (dBA) of the exposure ("Noise Dose" or "TWA")
- "Acceptable" risk is a judgment call

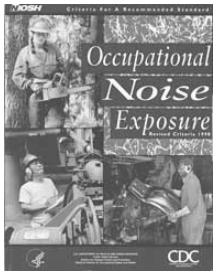
Population Fractiles of susceptibility:

0.1	→	0.5	→	0.9
Fragile		Avg		Tough
(10% most)				(10% least)

Noise Dose, based on 85dBA trade 3 (conservative) or 90dBA trade 5 (liberal)?

OSHA (1981): **Minimum Standard for Safety**

Organization	TWA Noise Exposure	Estimated % at Risk
ISO	*90 dBA*	*21%*
	85 dBA	*10%*
	80 dBA	*0%*
EPA	*90 dBA*	*22%*
	85 dBA	*12%*
	80 dBA	*5%*
NIOSH	*90 dBA*	*29%*
	85 dBA	*15%*
	80 dBA	*3%*
Prince, et al 1997	85 dBA	8%



1998: Best Practices

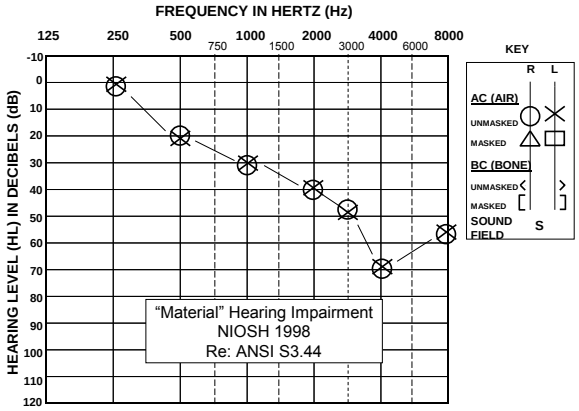
NIOSH revised the REL: 85 decibels, A-weighted, as an 8-hr time-weighted average (85 dBA as an 8-hr TWA) with a 3 dB exchange rate.

http://www.cdc.gov/niosh/topics/noise/

Material Hearing Impairment?

NIOSH 1998 Definition:

> 25 dB HL Avg. 1k, 2k, 3k, and 4kHz
(What's that like?)



Relevant Literature in MIHL Risk

Hearing Loss in Musicians:
Prevention and Management
March 2009, Plural Publishing
Ed. Marshall Chasin, Au.D.

- Musicians are at risk for occupational NIHL (MIHL)
- All musicians are at risk, rockers and classical ensembles
- Unlike other occupationally-exposed populations, musicians use their hearing for professional success
- Essentially unregulated by OSHA

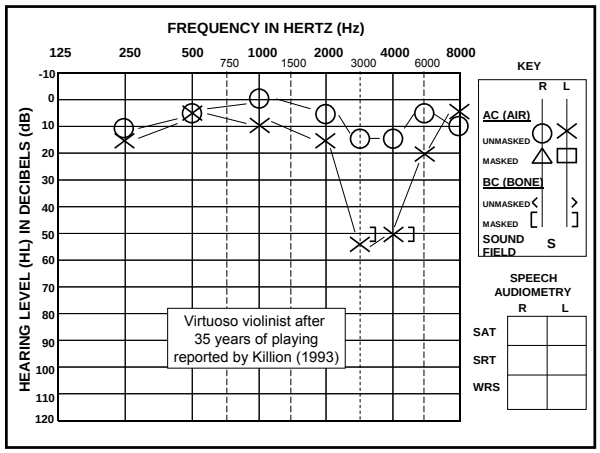
Music-Induced Hearing Loss

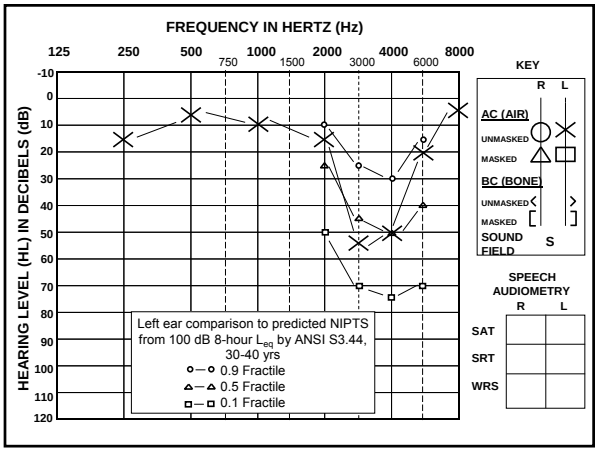
- Degree of Music-induced hearing loss is a function of time and intensity
  - Axelsson and Lindgren (1981)
  - Kahari, Zachau, Eklof, Sansjo, & Moller (2003)
  - Royster, Royster, & Killion (1991)

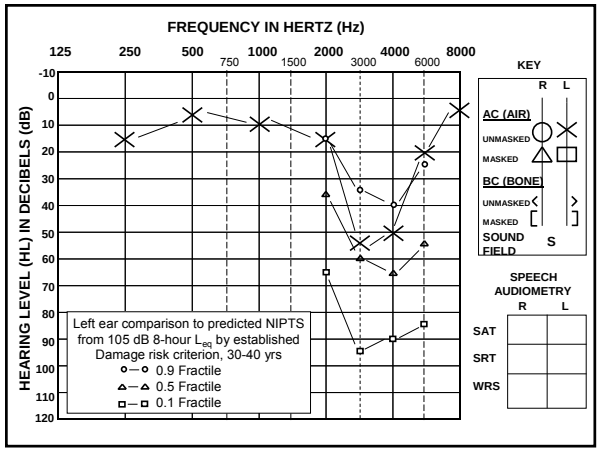
Music-Induced Hearing Loss

Royster, Royster, & Killion (1991)

Violinists – asymmetric SNHL, with greater degree of HL on left side. Measured 6-8 dB higher level at left side of head than right side of head, due to head-shadow effect.







Music-Induced Hearing Loss

- Early results of longitudinal study of non-occupational NIHL in teenagers in Argentina (Biassoni, et al., 2005):
  - 14 - 17 yo, male and female
  - All non-occupational noise exposed, measured by dosimetry (discos most significant exposure, D = 1600%)
  - Of 132 who had normal HTL at 14 yrs, 35% of boys and 24% of girls had statistically significant shifts above 3kHz at age 17 yrs

Chung et al (2005)

Survey posted on MTV.com, attitudes toward health issues facing teens and young adults, including hearing loss and loud music exposure

- 9,458 respondents (mean age 19.2yrs)
- Hearing loss is a “very big problem” = 8%*
- Use hearing protection at concerts = 14%
- After listening to amplified music, experienced:
  - Tinnitus = 61%
  - TTS = 43%

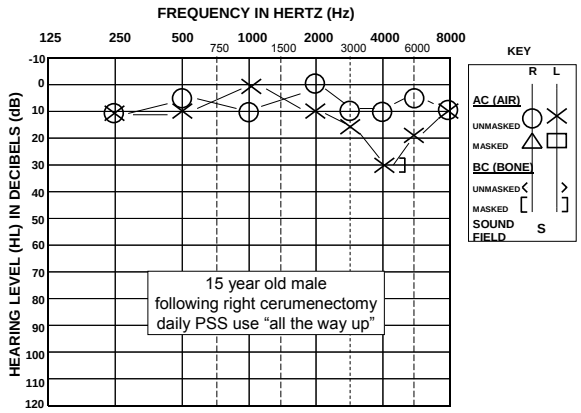
* Those 8% HL is “very big problem” more likely to have some education on NIHL

Suspicion of NIHL in Children

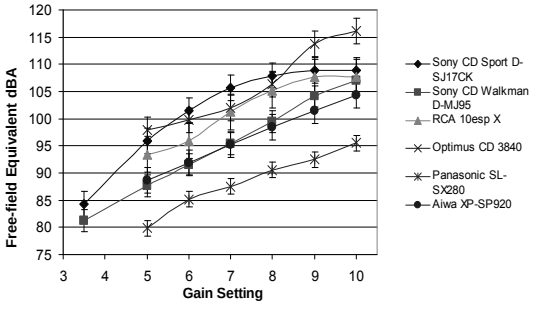
NHANES III, Niskar et al., 2001

Roughly 12.5% of children and teenagers age 6-19 years have early signs of Noise-induced hearing loss

- Noise is 2nd most common cause of hearing loss in adults, and the NHANES III numbers suggest it is most common cause in young people



Ear and Hearing Paper, 2004



Fligor & Cox (2004)

Risk for Music Induced Hearing Loss

Recommendations from Fligor & Cox (2004)

- Limit listening level to 60% of max
- Limit listening time to 1 hour
- Because in-ear earphones were 7-9 dB higher than over-the-ear at the same gain setting, shorter time or lower level is necessary

Fligor & Cox (2004)

David Letterman: Truth or Fiction?

http://www.eartunes.com/uploads/if/if102_letterman_ipod_bleed_ear.mov

ASHA Survey and Zogby Poll

ASHA (2006 survey)

- All MP3 players: 108-125 dBA; iPod 120-125 dBA
- 2cc coupler measurement
- Cannot be compared to damage-risk criteria (need free-field to coupler difference)

Zogby (2006 Poll)

- 43% of adults used PMP 1-4 hrs/day
- 9% of adults used PMP > 4 hrs/day

PLD Headphone Options

Stock (iPod)

Isolator ER-6

Earbud Shure E4C

Supra-Aural

Portnuff CDF and Fligor BJ (2006, NIHL in Children Conference) "Sound Output Levels of the iPod and Other MP3 Players: Is There Potential Risk to Hearing?"

Portnuff & Fligor, In preparation

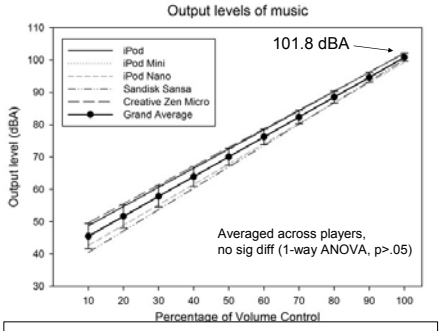


Figure 1. Free-field equivalent output levels of 5 mp3 players, using stock earphones, as a function of volume control settings. Error bars represent 1 standard deviation around the grand average.

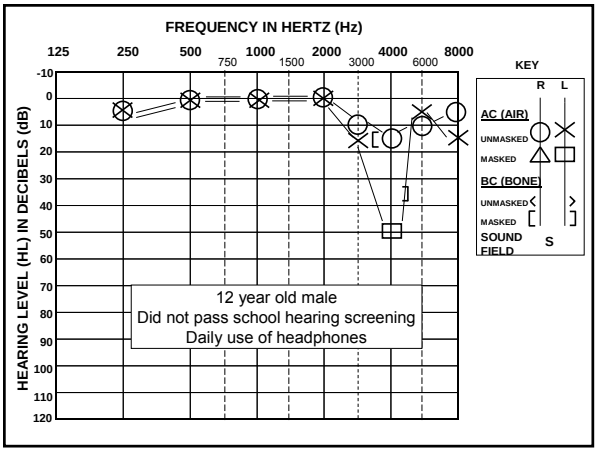
Listening Time Guidelines

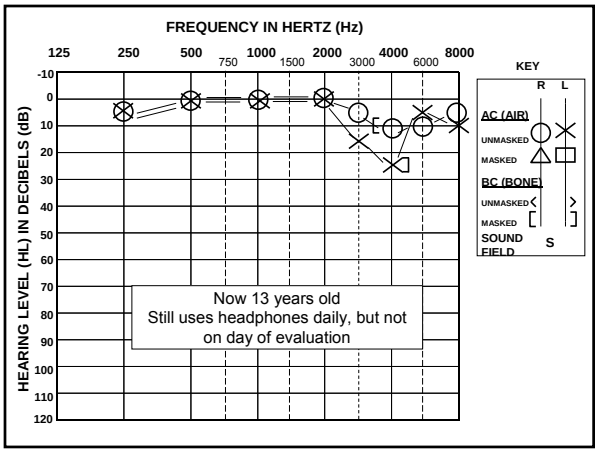
- As people are exposed to more than just their MP3 player… time to 50% noise dose

% of Volume Control	Maximum listening time per day			
	Earbud	Isolator	Supra-Aural	iPod, stock earphones
10-50%	No limit	No limit	No limit	No limit
60%	No limit	14 hours	No limit	18 hours
70%	6 hours	3.4 hours	20 hours	4.6 hours
80%	1.5 hours	50 minutes	4.9 hours	1.2 hours
90%	22 minutes	12 minutes	1.2 hours	18 minutes
100%	5 minutes	3 minutes	18 minutes	5 minutes

Table 2. Average time to 50% noise dose (8-hour TWA) using NIOSH damage-risk criteria. "Earbud" includes stock earphones and iPod In-ear earphones. "Isolator" includes Etymotic ER6i earphones and Shure E4c earphones. "Supra-Aural" includes Koss headphones that rest on top of the ear.

NOTE: Do **NOT** over-interpret this table to suggest "isolator" headphones are more dangerous! We'll see what in a minute…





Music-Induced Hearing Loss and Headphone Users

- Previous studies indicate between 5-10% of PSS users are at risk for music-induced hearing loss.
  - Rice, Breslin & Roper (1987) & Rice, Rossi & Olina (1987)
  - Clark (1992)
- Chosen listening levels of PSS users in "noisy" environment (Williams, 2005)
  - Mean 79 dB TWA
  - 24% > 85 dB TWA
  - 3% > 100 dB TWA

MIHL and Headphone Users

Chosen listening levels in "noisy" environments:

- Airo, Pekkarinen, & Olkinuora (1996)
  - Mean CLL in quiet = 69 dBA
  - 15% > 85 dBA TWA in quiet
  - Mean CLL > 85 dBA when ambient sound levels ≥ 72 dBA

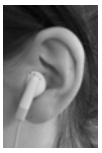
Fligor and Ives, In review

100 Subjects, 4 earphones, 4 listening environments

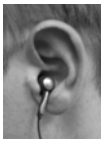
PCO School of Audiology

Koss
KSC11

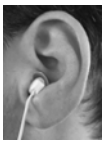
Apple iPod
Stock



Sony
MDR-EX51LP



Etymotic Research
ER6i



Descriptive Statistics

Average Environmental Sound Isolation:

Koss KSC11	Apple iPod earbud
1 dB	1 dB
Sony in-ear	ER6i in-ear
9 dB	25 dB

All 4 earphones

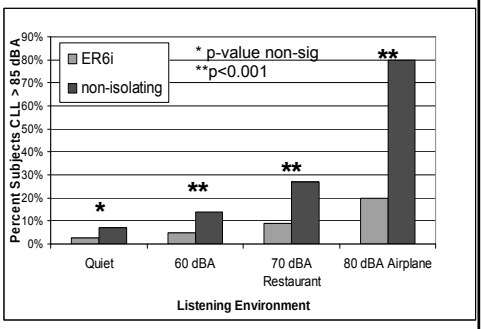
CLL in quiet: 6% ≥ 85 dBA [3.6-8.3%]

No significant difference in CLL between earphones

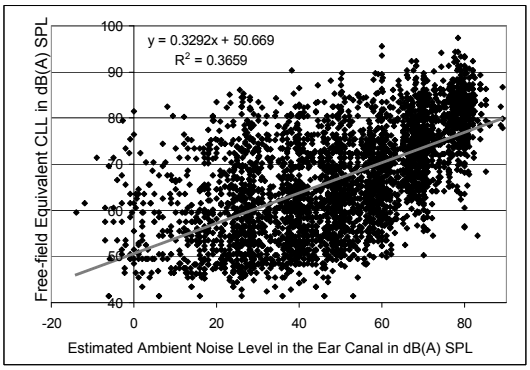
Male vs. female: Avg CLL in quiet no difference

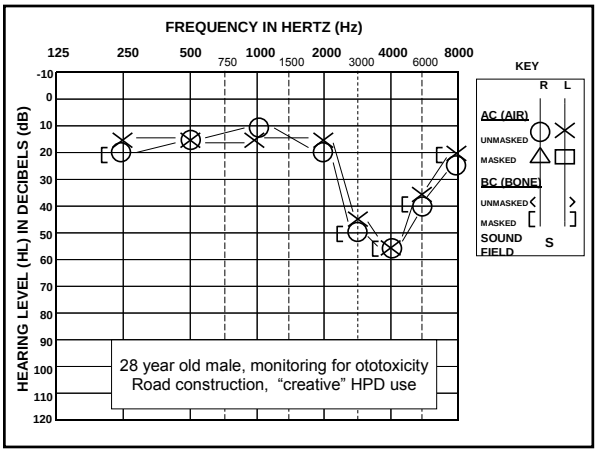
male = 12%, female = 3% ≥ 85 dBA ($p < 0.01$)

Descriptive Statistics



Individual Chosen Listening Level



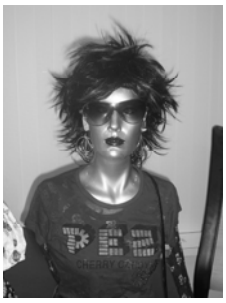


Levey, Levey & Fligor, In review
Listening Levels in NYC

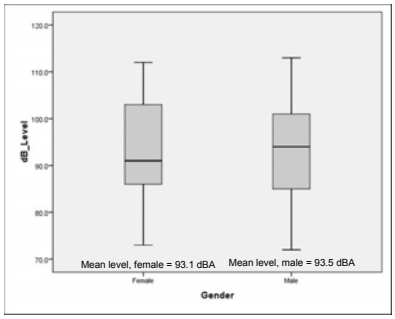
Ambient, sidewalk = 60.5 dBA

Gershon, et al 2006: subway = 83-106 dBA

"Roxie"
(from the *Jolene Cookbook*)



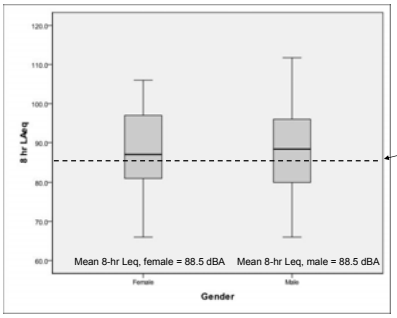
Listening Level, dBA



No significant difference for gender (p>0.05)

Box-and-whisker plot showing listening level median, interquartile range, and maximum and minimum

Daily sound exposure (8-hr LAeq)

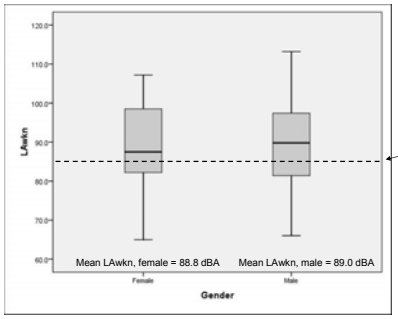


"Risk"

No significant difference for gender (p>0.05)

Box-and-whisker plot showing 8-hr Leq median, interquartile range, and maximum and minimum

Estimated weekly sound exposure (LAwkn)



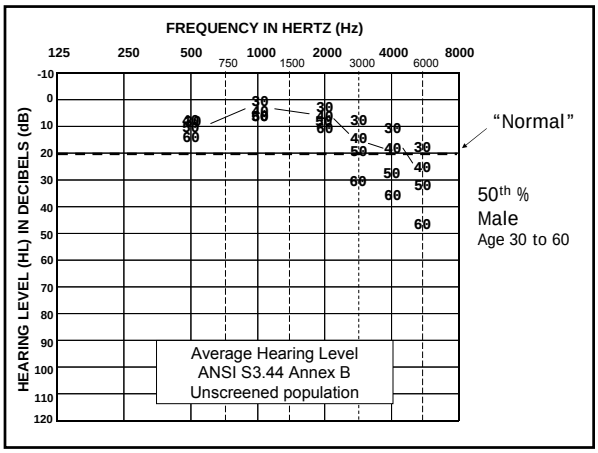
"Risk"

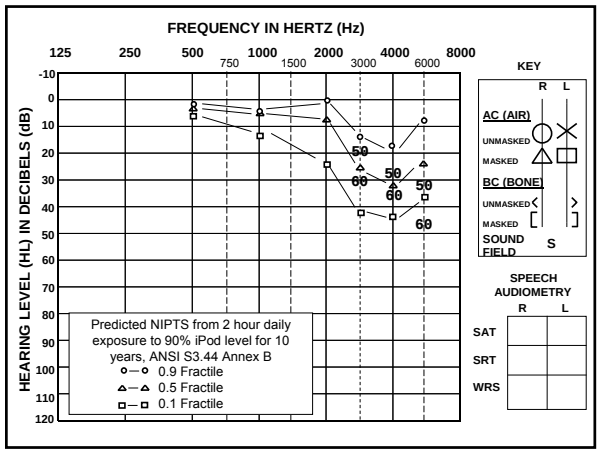
No significant difference for gender (p>0.05)

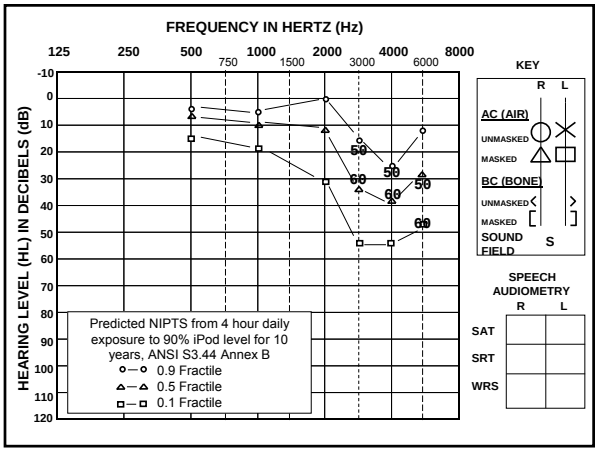
Box-and-whisker plot showing weekly average exposure median, interquartile range, and maximum and minimum

Why We Should Care

- 5 - 25% of PLD users listen 85 - 100 dB(A) TWA
- >100 million .mp3 players sold since hit market 2001 (~70% of market share Apple iPod)
- Most conservative estimate, extrapolate
  - only 5% exceed 85 dB(A)
  - 10-15% listen 4 hrs/day (Zogby, 2006)
  - Consider the 0.1 Fractile
    - 0.05% of 100 million: **50,000** could be expected to sustain "significant" hearing loss if they listen for long enough time (e.g., years)







Prevention of Music-Induced Hearing Loss
Part II: Prevention in Practice

Brian Fligor, ScD
Director of Diagnostic Audiology
Children's Hospital Boston
Instructor in Otology and Laryngology
Harvard Medical School

MIHL prevention in practice

- Live music consumers
- Live music producers/performers

Elements of a Hearing Loss Prevention Program (HLPP)

Application to music exposure

- Noise Survey (assessment)
- Engineering Controls
- Audiometric Monitoring
- Education and Motivation
- Hearing Protection Devices

Why not have level warning indicator?

Vastly different earphone sensitivity!

Etymotic Research, Inc.

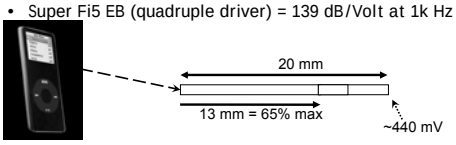
- ER 4 = 108 dB/Volt at 1k Hz
- ER 4P = 120 dB/Volt at 1k Hz

Shure, Inc.

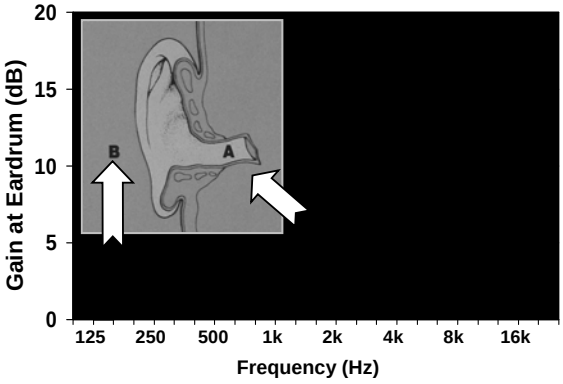
- SCL3 = 129 dB/Volt at 1k Hz
- SE530 (triple driver) = 133 dB/Volt at 1k Hz

Ultimate Ears

- Super Fi3 (single driver) = 134 dB/Volt at 1k Hz
- Super Fi5 EB (quadruple driver) = 139 dB/Volt at 1k Hz



Transfer Function of the Open Ear



A "Diagnostic Test" for headphones

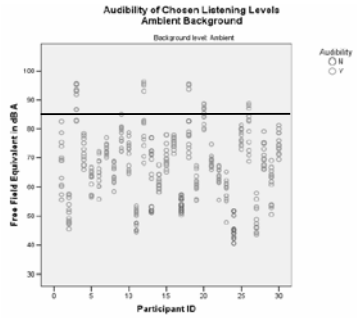
"If I can hear it, that means it's too loud!"

- So, if you can't hear it, that means it's ok?
- Environment and earphone type dependent

…Jamie Weiner's AuD project

Quiet Background, 34 dB(A)

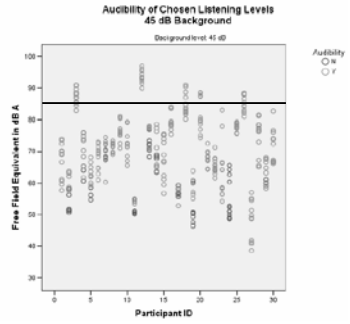
30 subjects, 3 songs each, 4 "looks" each song



Jamie Weiner, AuD Thesis

45 dB(A) pink noise ambient

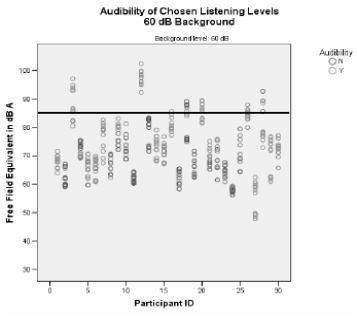
30 subjects, 3 songs each, 4 "looks" each song



Jamie Weiner, AuD Thesis

60 dB(A) pink noise ambient

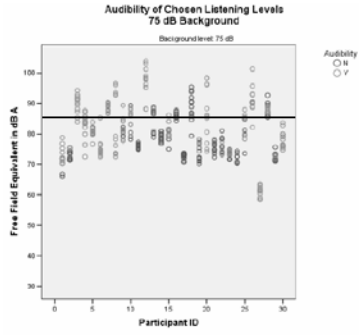
30 subjects, 3 songs each, 4 "looks" each song



Jamie Weiner, AuD Thesis

75 dB(A) pink noise ambient

30 subjects, 3 songs each, 4 "looks" each song



Jamie Weiner, AuD Thesis

Accuracy of our "Diagnostic Test"

Positive Predictive Value (PPV)
Probability that the disease is present when the test is positive
= True Positive/(True Positive + False Positive)

Sound booth, Quiet, 34 dB(A)
PPV = 0.09 (sensitivity = 1.00; specificity = 0.09)

45 dB(A) pink noise
PPV = 0.12 (sensitivity = 1.00; specificity = 0.21)

60 dB(A) pink noise
PPV = 0.16 (sensitivity = .84; specificity = 0.38)

75 dB(A) pink noise
PPV = 0.42 (sensitivity = 0.67; specificity = 0.55)

Risk: Not Level – Level Over Time!

Type II SLM, stage right	All Levels dBA FFE		
Warm up Act	L dB(A)	C (min)	T (min)
8:15	108	5	2.4
8:30	108	5	2.4
8:35	110	5	1.5
8:45	108	5	2.4
set Length	30 minutes		
Estimated Dose	**1394%**		
Main Act	L dB(A)	C (min)	T (min)
8:55	108	5	2.4
9:00	109	5	1.9
9:05	107	5	3.0
9:10	108	5	2.4
9:15	107	5	3.0
9:20	109	5	1.9
9:25	110	5	1.5
9:30	108	5	2.4
9:35	109	5	1.9
set Length	40 minutes		
Estimated Dose	**2107%**		
Total for the night	**3501%**		

Exposure Calculation

$$T = \frac{8 \text{ hours}}{2^{(L-Lmax)/ER}}$$

L = Exposure Level dBA
T = Time to 100% Noise Dose
Lmax = Maximum allowed dBA in 8 hrs
ER = Exchange Rate (e.g., 3 or 5)

Noise Dose = C / T

C = Exposure Time

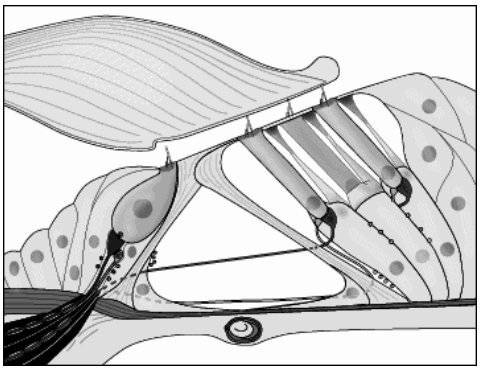
Exchange Rate: 3 dB or 5 dB?

85 dBA TWA, 3-dB trade

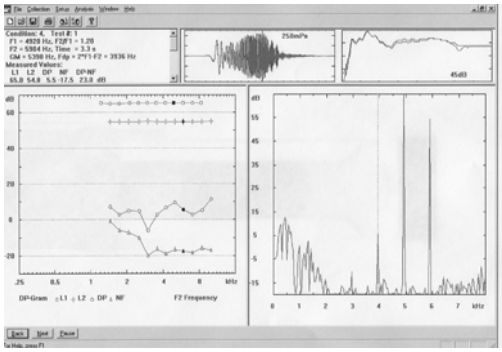
L dBA	*T* min 100%
85	480
86	381
87	302
88	240
89	190
90	151
91	120
92	95
93	76
94	60
95	48
96	38
97	30
98	24
99	19
100	15

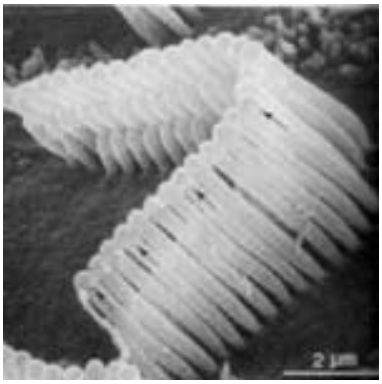
90 dBA TWA, 5-dB trade

L dBA	*T* min 100%
85	960
90	480
95	240
96	209
97	182
98	158
99	138
100	120
101	104
102	91
103	79
104	69
105	60
106	52
107	45
110	30

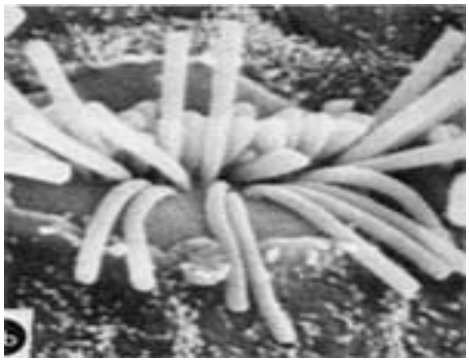


http://www.iurc.montp.inserm.fr/cric/audition/english/corti/cofunct/cofunct.htm

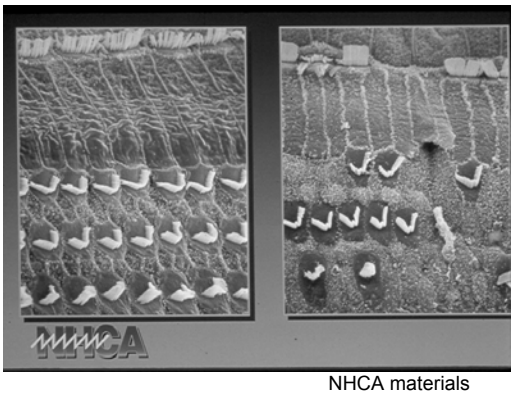




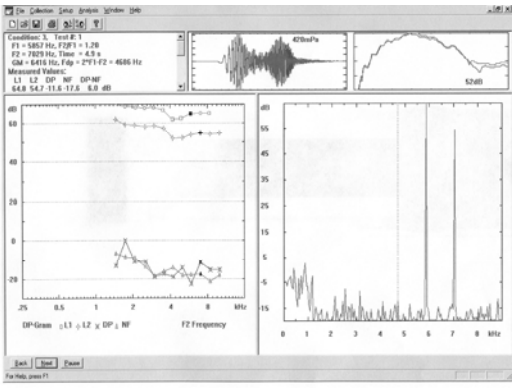
NHCA materials

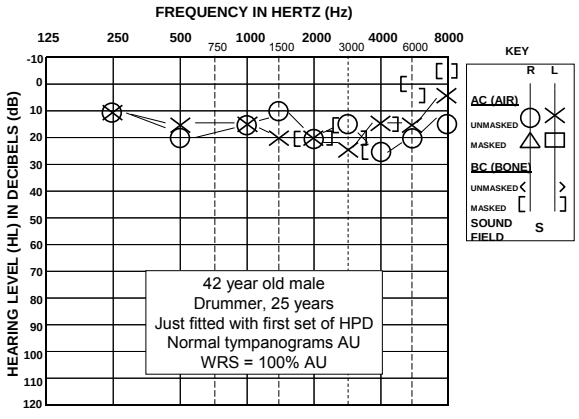


NHCA materials

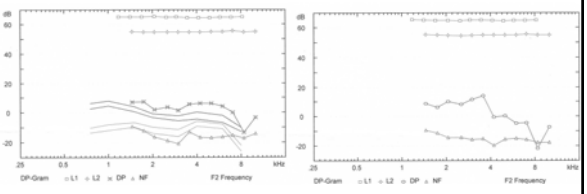


NHCA materials

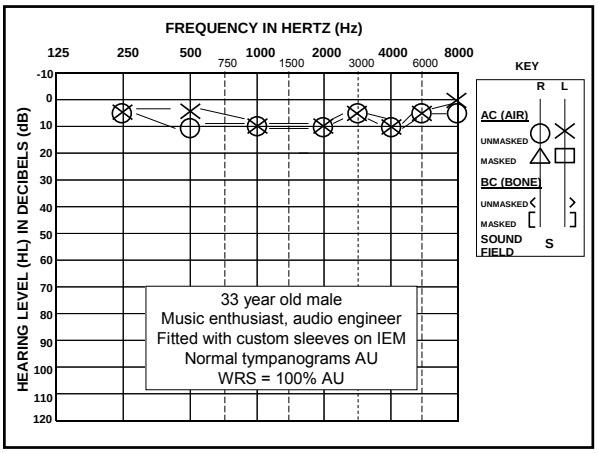




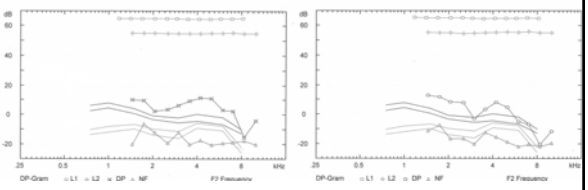
DPOAEs, 42 year old drummer (25 years experience), borderline normal audiogram



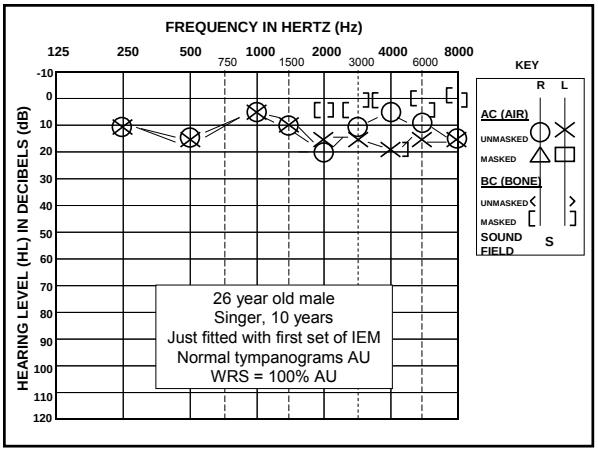
Reduced/Absent DPOAE at F2 = 8391 Hz Bilaterally



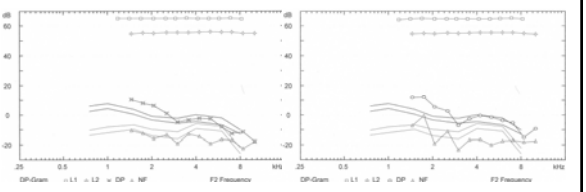
DPOAEs, 33 year old music enthusiast/audio engineer, normal audiogram



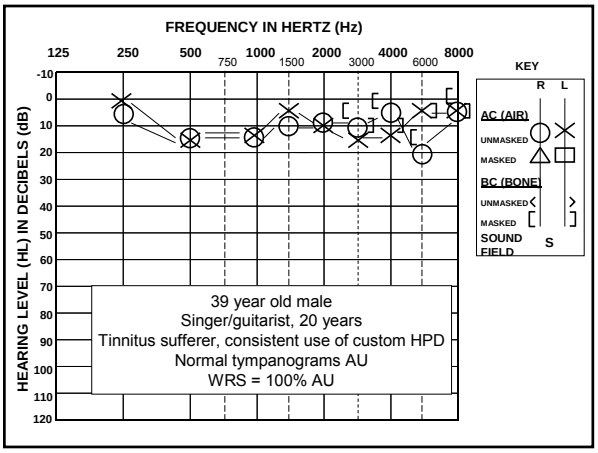
- Reduced/Absent DPOAE at F2 = 8391 Hz Bilaterally
- Right ear has some dips below 95% of normals re: Gorga et al. (1997)



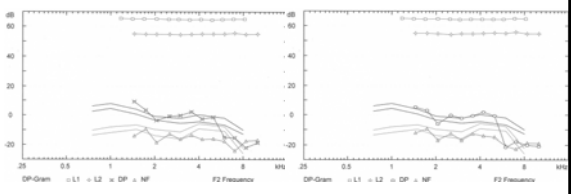
DPOAEs, 26 year old singer (10 years experience), essentially normal audiogram



Reduced DPOAE at F2 = 3000 – 10,0031 Hz Bilaterally re: 95% normals (Gorga, et al., 1997)



DPOAEs, 39 year old singer/guitarist (20 years experience), essentially normal audiogram Tinnitus sufferer



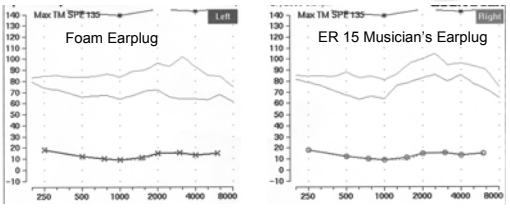
- Absent DPOAEs at F2 = 6000 – 10,031 Hz Bilaterally
- Reduced DPOAEs at other discrete frequencies re: 95% normals (Gorga, et al., 1997)

Flat Frequency Attenuators

Complaint against foam plug:

"Muffling"/ "Distortion" - what is this?

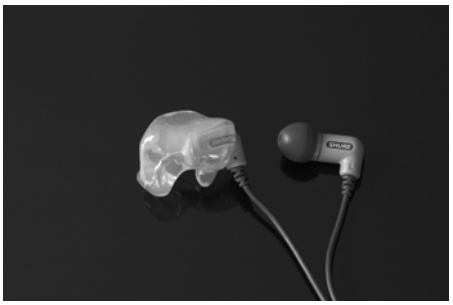
- Change of timbre of music (change of harmonics relative to the fundamental frequency)
- Loss of natural ear canal resonance



Levels on Stage: hypothetical if used ER 15

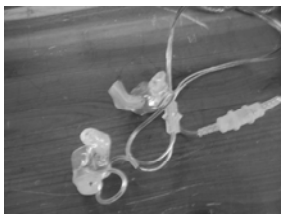
hypothetical	L dB(A) - ER 15		time to 100% Dose	T (min)
8:15	93		8:15	75.6
8:30	93		8:30	75.6
8:35	95		8:35	47.6
8:45	93		8:45	75.6
Set Length	30 minutes			
Estimated Dose	**43.6%**			
hypothetical	L dB(A) - ER 15		time to 100% Dose	T (min)
8:55	93		8:55	75.6
9:00	94		9:00	60.0
9:05	92		9:05	95.2
9:10	93		9:10	75.6
9:15	92		9:15	95.2
9:20	94		9:20	60.0
9:25	95		9:25	47.6
9:30	93		9:30	75.6
9:35	94		9:35	60.0
Set Length	40 minutes			
Estimated Dose	**65.8%**			
Total for the night	**109.4%**			

Reducing Levels on Stage: In Ear Monitors

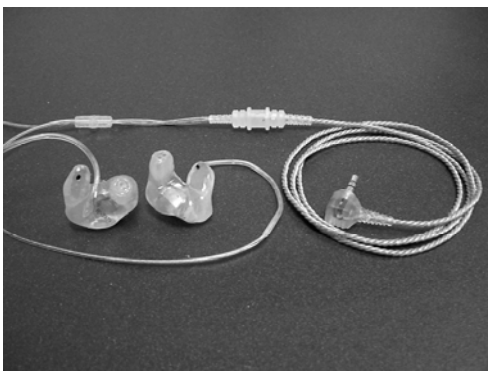


Universal fit and custom sleeve

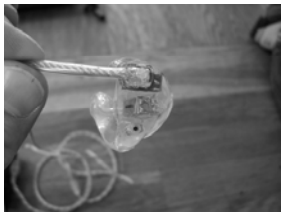
Reducing Levels on Stage: Custom



Dual Driver In-ear Monitor



Modifying input from mix and ambient



Dual Driver In-ear Monitor
With Ambient Microphones

Elements of a Hearing Loss Prevention Program (HLPP)

Application to music exposure

- Noise Survey (assessment)
- Engineering Controls
- Audiometric Monitoring
- Education and Motivation
- Hearing Protection Devices

- The finances:
  You are more obviously "selling" a service
  - CPT Code: 92596 "Ear Protector Evaluaton"

Possibly the most appreciative consumers of our service…

Professional Musicians