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Noise Exposures in America

Rick Neitzel, PhD, CIH, FAIHA

Professor, Univ. of Michigan School of Public Health

Rick Neitzel, PhD

Rick Neitzel, PhD, CIH, FAIHA is a Professor of Environmental Health Sciences and Global Public Health at the University of Michigan School of Public Health. He has published more than 140 peer-reviewed manuscripts focused on exposures to, and impacts of, noise and other occupational and environmental hazards. He is particularly interested in incorporating new methodologies and exposure sensing technologies into research and has a strong interest in translating his research findings into occupational and public health practice. He is the principal investigator of the ongoing nationwide Apple Hearing Study. He has created a job-exposure matrix for occupational noise exposures in the U.S. and Canada. Dr. Neitzel is Chair of the ACGIH® Threshold Limit Values for Physical Agents (TLV®-PA) Committee. He is also a Fellow of the American Industrial Hygiene Association and has been a Certified Industrial Hygienist since 2003.

Disclosures

- **Presenter Disclosure**: Financial: Rick Neitzel is employed by the University of Michigan and Apple Inc. to support his work on the Apple Hearing Study, which he is leading through his position at the University of Michigan. He received an honorarium for presenting this course. Non-financial: Rick Neitzel has no relevant non-financial relationships to disclose.
- **Content Disclosure**: This learning event does not focus exclusively on any specific product or service.
- **Sponsor Disclosure**: There is no external sponsor for this course.

Learning Outcomes

After this course, participants will be able to:

- Identify trends in noise exposures and associated health impacts in America.
- Identify major sources of noise exposure in America.
- Discuss how to utilize resources intended to promote understanding of noise exposures in America.

What we'll discuss today

- Noise
- Health effects
- Exposure
  - Assessment
  - Limits
  - Estimates
- Noise reduction options

https://www.osha.gov/noise/exposure-controls

https://sph-umich.shinyapps.io/ahs-inad-2023/

Images © Rick Neitzel

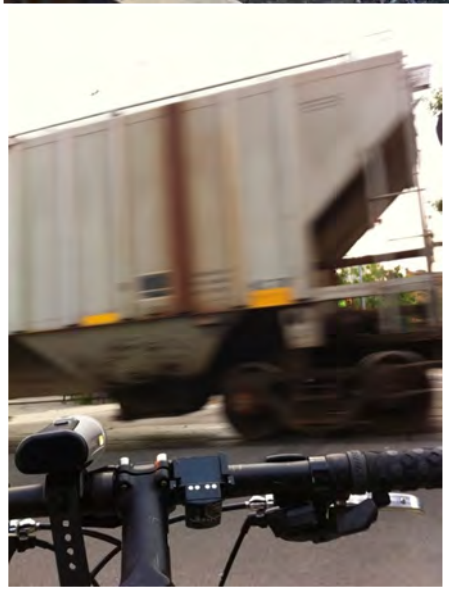
Noise

- Ubiquitous
  - Communities and workplaces
  - Low-, middle-, and high-income nations

- Unlike other environmental hazards, in US…
  - Occupational noise not heavily enforced
  - Community noise relegated to (and largely ignored by) local governments since 1980s

https://www.noisyplanet.nidcd.nih.gov/have-you-heard/mapping-the-sounds-of-new-york-city

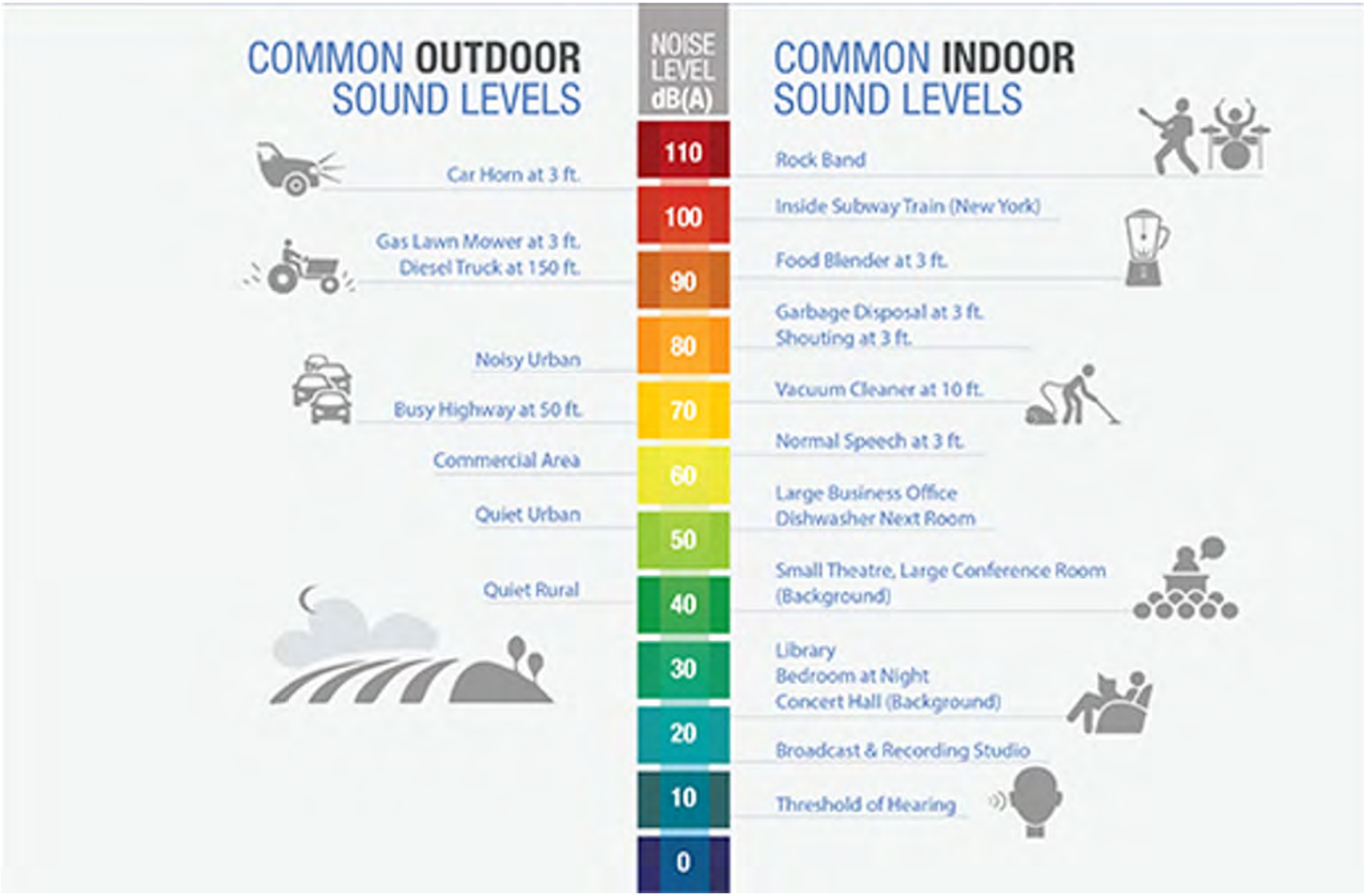
Common noise complaints



What's this?

Images © Rick Neitzel

A quick calibration



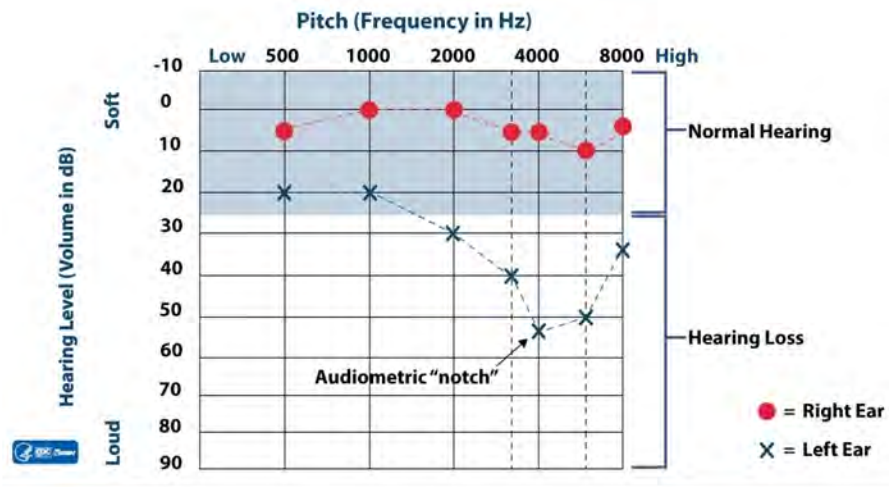
https://www.faa.gov/regulations_policies/policy_guidance/noise/basics

Select health effects of noise

- Noise-induced hearing loss (NIHL) (duh)
- Non-auditory impacts of noise
  - Cardiovascular disease (CVD)
  - Increased risk of occupational injury
- And other impacts we won't talk about
  - Mental health issues? Endocrine disruption? Adverse birth outcomes? Stress? Cognitive decline?

Noise-induced hearing loss

- Chronic exposures cause metabolic changes in cochlear hair cells, eventual cell death, NIHL
- Mechanical damage (acoustic trauma) from extreme exposure
- Tinnitus and hyperacusis



https://www.cdc.gov/niosh/topics/noise/preventoccunoise/images/understand3.png?_=31238

Image © Rick Neitzel

Economic impacts of NIHL

- HL in estimated 13.4% of working population
- Impacts on those with HL
  - Reduced wages (25% less than normal hearing)
  - 2.5X as likely to be unemployed
- If the 20% of HL from noise were prevented
  - Annual economic benefit $58-152B ($123B core estimate)
- Conservative; does not consider additional costs
  - Health care and special education

Neitzel et al, *JSLHR*, 2017

Non-auditory impacts of noise

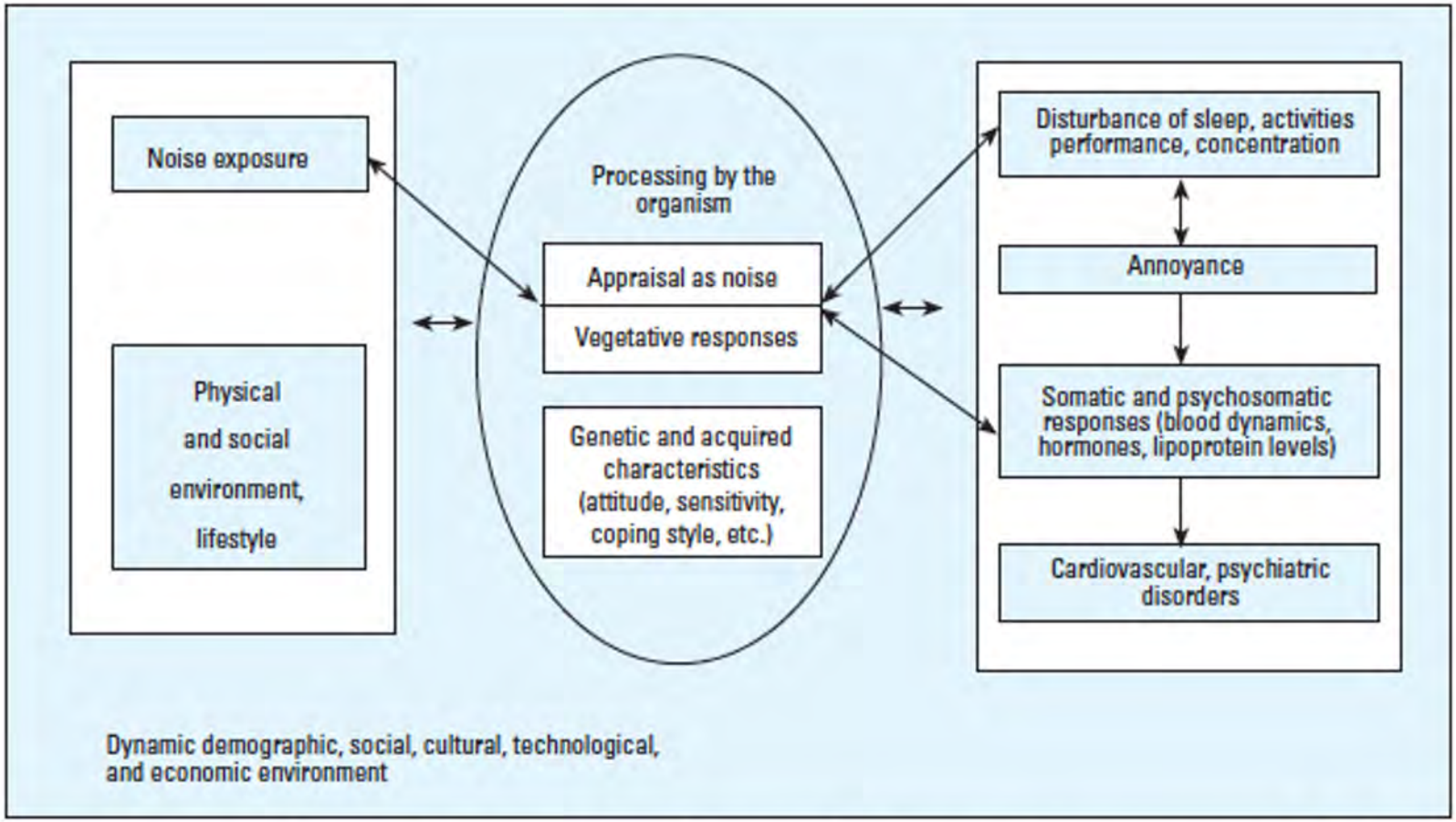


Figure 1. Conceptual model of the interaction of noise with humans and the occurrence of effects on health and quality of life (*2*).

Van Kempen et al, *Environ Health Persp*, 2002

Environmental noise and CVD

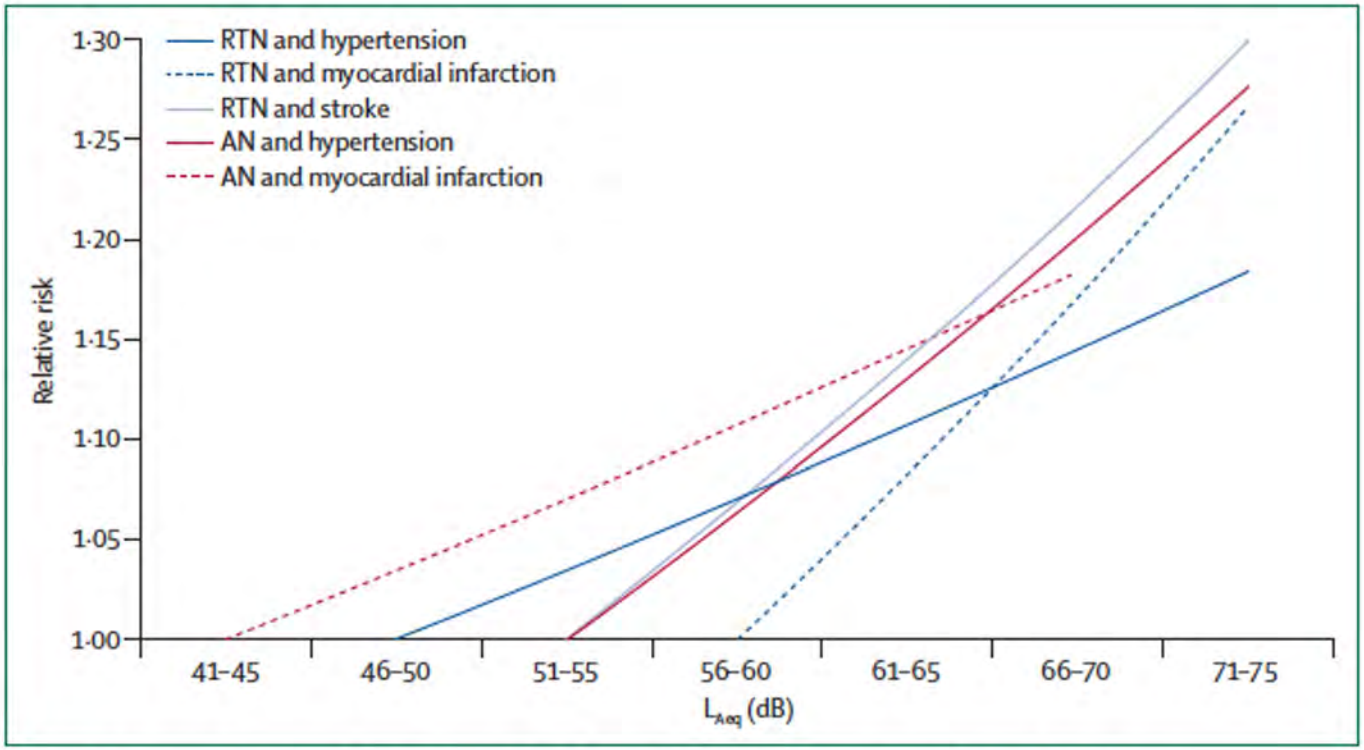


***Figure* 3: Exposure–response curves of road and aircraft noise and cardiovascular endpoints**
RTN and hypertension (24 studies, noise indicator L_{Aeq16h}); RTN and myocardial infarction (five studies, noise indicator L_{Aeq16h}); RTN and stroke (one study, noise indicator L_{DEN}); AN and hypertension (five studies, noise indicator L_{DN}); and AN and MI (one study, noise indicator L_{DN}). RTN=road traffic noise. AN=aircraft noise.

Meta-analysis showed 7-17% increase in CVD risk per 10 dB increase

Basner et al, *Lancet,* 2014

Environmental noise and CVD

- World Health Organization: >1 million healthy life years (i.e., Disability-Adjusted Life Years, DALYs) lost annually due to environmental noise

- Note: does not consider occupational noise

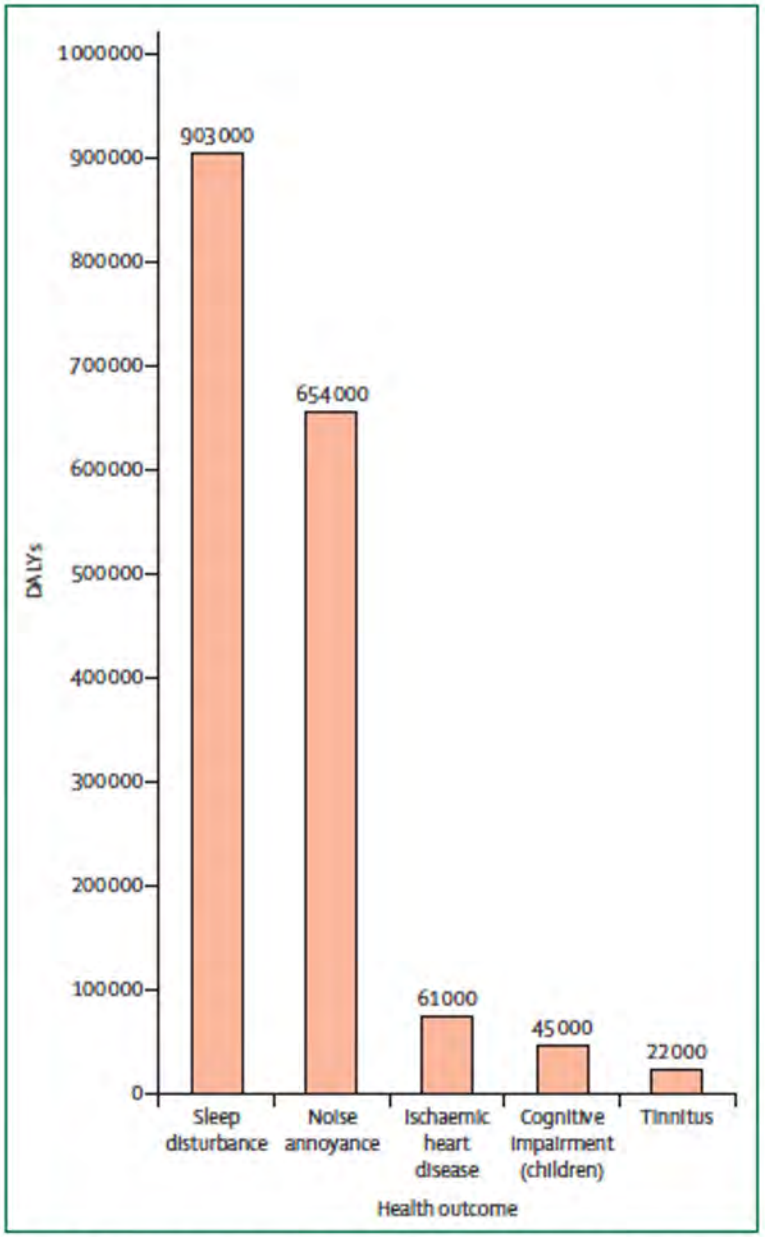


Figure 2: **DALYs attributed to environmental noise exposure in Europe.**

Basner et al, *Lancet,* 2014

Environmental noise and CVD

- Estimated US CVD savings from 5 dB reduction in population noise in 2014: $3.9 billion

Table 3. Model Results

Model	Current situation	5-dB reduction scenario estimate	Difference (current – reduction scenario)
Model 1: coronary heart disease			
Number of people exposed ≥55 dBA L_{DN}	145.5 million	0	−145.5 million
Number of affected individuals	15.4 million	15.1 million	−279,000
Population risk (%)	4.89	4.80	−0.09
Annual cost, direct ($)	96 billion	94.3 billion	−1.7 billion
Annual cost, indirect ($)	81.1 billion	79.6 billion	−1.5 billion
Model 2: hypertension			
Number of people exposed ≥ 55 dBA L_{DN}	145.5 million	0	−145.5 million
Number of affected individuals	77.9 million	76.7 million	−1.2 million
Population risk (%)	24.7	24.3	−0.4
Annual cost, direct ($)	47.5 billion	46.8 billion	−684 million
Annual cost, indirect ($)	3.5 billion	3.4 billion	−50 million

Swinburn et al, *Am J Prev Med*, 2015

Occupational noise and CVD

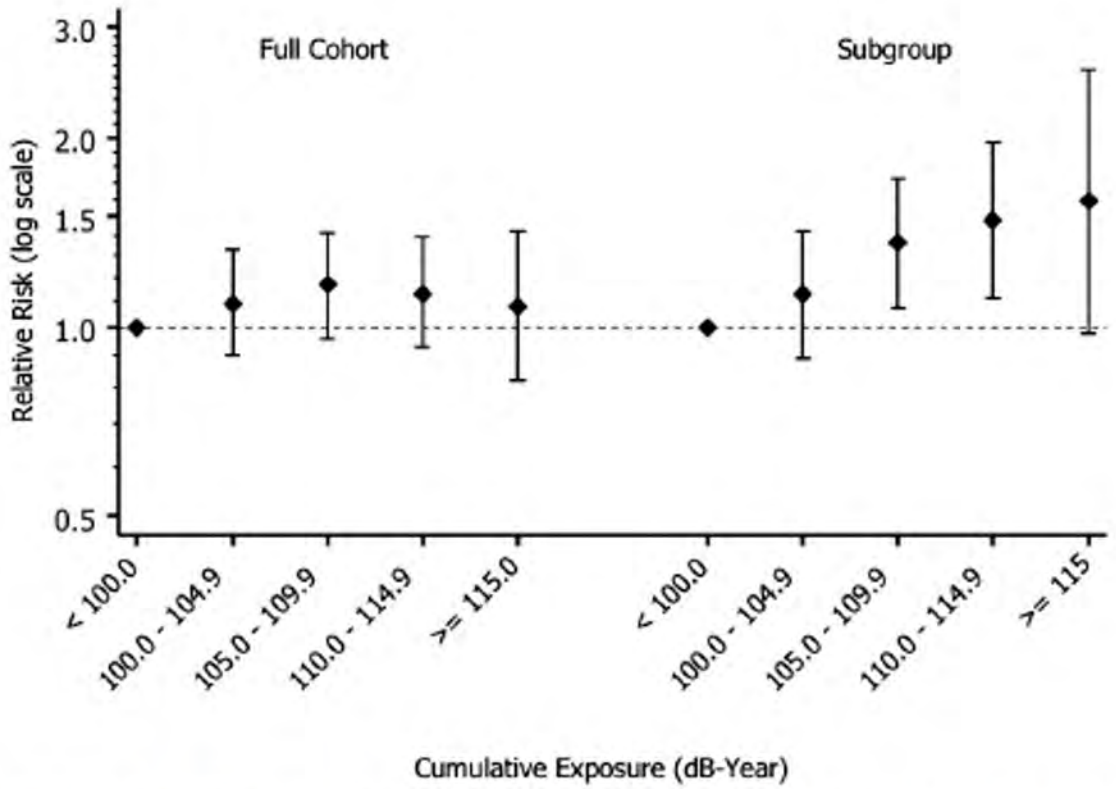


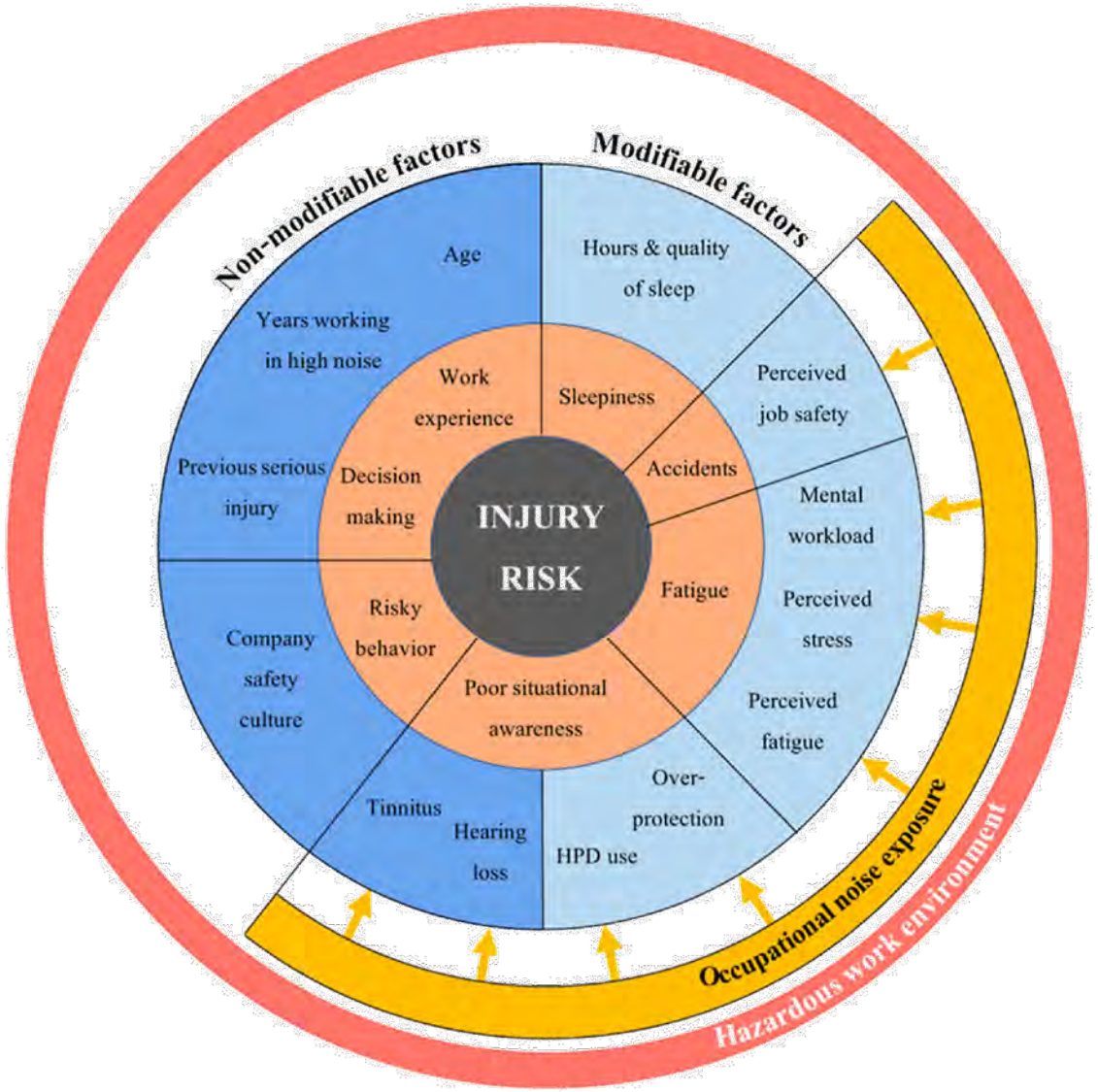
FIGURE 2. Relative risk estimates and 95% confidence intervals for acute myocardial infarction mortality by cumulative exposure (dB(A)-year). Full cohort (n = 27,464) and subgroup without hearing protection (n = 8668). Reference group, those exposed for less than 100 dB(A)-year at threshold level. Adjusted for age, calendar year, and South Asian ethnicity.

Retrospective cohort, 27,464 workers, mean 92 dBA, 24 years avg f/u

Davies et al, *Epidemiol*, 2005

Noise and injuries

- Conceptual model of noise exposure, hearing loss (HL) and communication difficulty, and injury



Shkembi et al, *Ann Work Expos Health*, 2022

Occupational noise, hearing loss, & injuries

Table 5. Fully adjusted multivariate mixed model results with random intercepts for plant, job and person within plant-job. [RR=relative risk; 95% CI=95% confidence interval; Pr>F=significance test for fixed effects; HTL=hearing threshold level; dBA=A-weighted decibels; dB=decibel]

	Acute injury (including minor injuries)			Serious [a] acute injury		
	RR [b]	95% CI	Pr>F	RR [b]	95% CI	Pr>F
Noise and HTL modeled as categorical variables						
Noise (mean dBA)		Reference	0.0135		Reference	0.0005
<82	1.00			1.00		
82–84.99	1.15	0.94–1.41		1.26	0.96–1.64	
85–87.99	1.34	1.07–1.70		1.39	1.05–1.85	
≥88	1.61	1.13–2.30		2.29	1.52–3.47	
HTL (average 0.5,1, 2, 3 kHz) (dB)		Reference	0.0008		Reference	0.2751
<10	1.00			1.00		
10–24.99	1.06	1.00–1.13		1.07	0.94–1.20	
≥25	1.21	1.09–1.33		1.17	0.96–1.42	
Age (each 1 year increase)	0.99	0.98–0.99	<0.0001	0.99	0.98, 1.00	0.0038
Female	1.63	1.51–1.77	<0.0001	1.46	1.24–1.72	<0.0001
Heavy/very heavy physical demands	1.16	0.90–1.50	0.2427	1.40	1.04–1.89	0.0274
Tenure < 1 year	1.29	1.15–1.44	<0.0001	1.07	0.84–1.36	0.5796
White	0.88	0.81–0.96	0.0026	0.96	0.82–1.13	0.6486

Retrospective cohort, 9,220 workers, 6 years

Cantley et al, *Scand J Work Environ Health*, 2015

Hearing loss, tinnitus, & injuries

Table 4. Fully adjusted multivariate mixed model results* with random intercepts for plant, job, and person within plant-job. Tinnitus and PTA_{46} (binaural average at 4, 6 kHz) combined into a categorical variable with four levels.

	All injury			*Serious injury*		
Outcome	*Relative risk*	*95% CI*	*Pr > F*	*Relative risk*	*95% CI*	*Pr > F*
Mean noise exposure			0.0144			0.0091
<82 dBA	1.00	Reference		1.00	Reference	
82 to <85 dBA	1.17	0.95, 1.44		1.31	0.99, 1.73	
85 to <88 dBA	1.37	1.08, 1.74		1.34	0.98, 1.82	
≥88 dBA	1.57	1.09, 2.25		1.99	1.28, 3.10	
$PTA_{.5123}$ (binaural average at .5,1,2,3 kHz)			0.0553			0.4750
<25 dBHL	1.00	Reference		1.00	Reference	
≥25 dBHL	1.11	1.00, 1.23		1.08	0.87, 1.33	
Asymmetrical hearing loss	0.97	0.85, 1.11	0.6393	1.09	0.84, 1.42	0.4991
HPD use reported	0.87	0.78, 0.97	0.0140	1.16	0.92, 1.45	0.2127
Combined Tinnitus and PTA_{46} variable			<.0001			0.0259
No tinnitus & PTA_{46} (binaural average at 4, 6 kHz) <25 dBHL	1.00	Reference		1.00	Reference	
No tinnitus & PTA_{46} (binaural average at 4, 6 kHz) ≥25 dBHL	0.99	0.91, 1.07		0.97	0.83, 1.14	
Tinnitus & PTA_{46} (binaural average at 4, 6 kHz) <25 dBHL	1.03	0.89. 1.20		0.79	0.55, 1.14	
Tinnitus & PTA_{46} (binaural average at 4, 6 kHz) ≥25 dBHL	1.25	1.13, 1.38		1.25	1.02, 1.54	

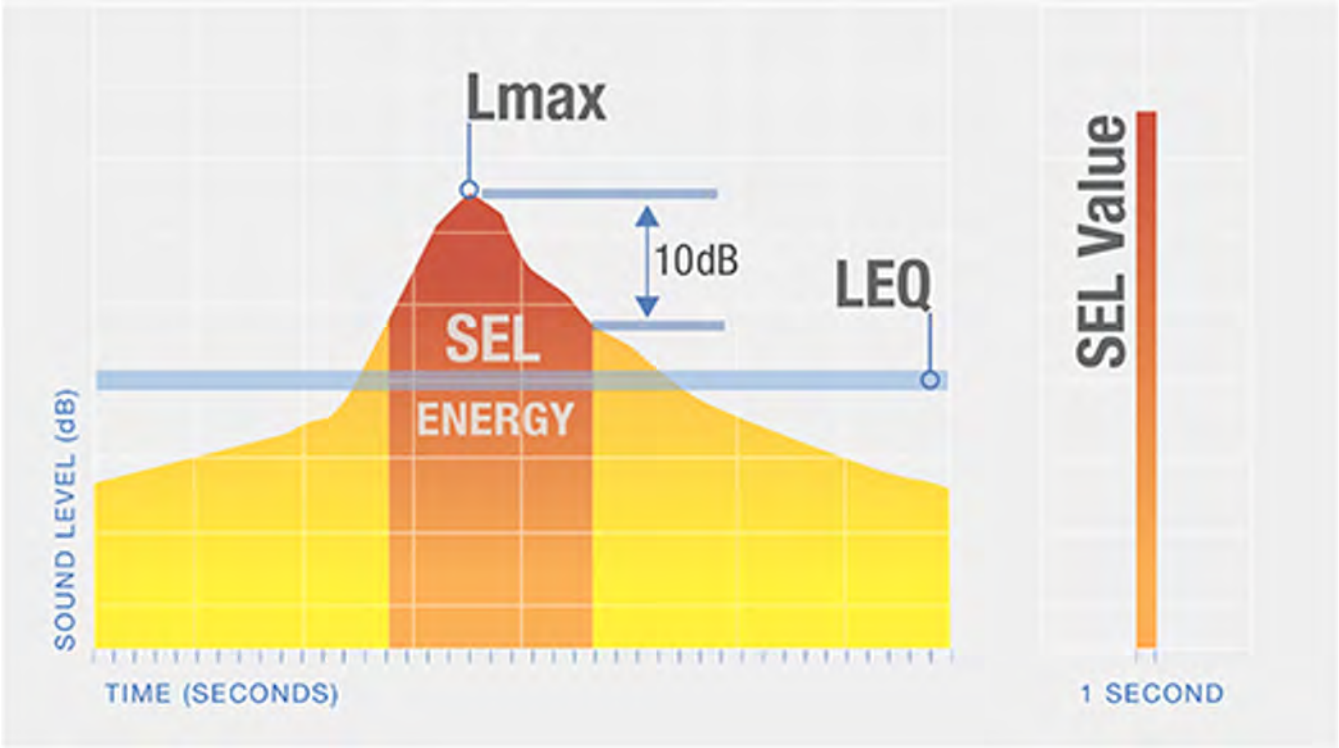
*Simultaneously adjusted for noise, $PTA_{.5123}$ (0.5, 1, 2, 3 kHz), tinnitus (Y/N); and PTA_{46} at 4, 6 kHz (<25 dB, ≥25dB) category, age, sex, race/ethnicity, high physical demand, tenure < 1 year, asymmetrical hearing loss, reported HPD use, and calendar year.

Retrospective cohort study, 8,818 workers, 6 years

Cantley et al, *Int J Audiol*, 2014

Noise measurement

- Equivalent continuous noise level (L_{EQ}) is foundation of noise exposure assessment



https://www.faa.gov/regulations_policies/policy_guidance/noise/basics

Commonly used noise metrics

- L_{EQ}
  - Assumes all periods contribute equally to risk
- L_{DN} (Day-Night Level)
  - LEQ with 10 dB penalty artificially added for nighttime noise (10 PM to 7 AM)
  - Accounts for increased sensitivity during night time

https://www.faa.gov/regulations_policies/policy_guidance/noise/basics

If you remember nothing else from today…

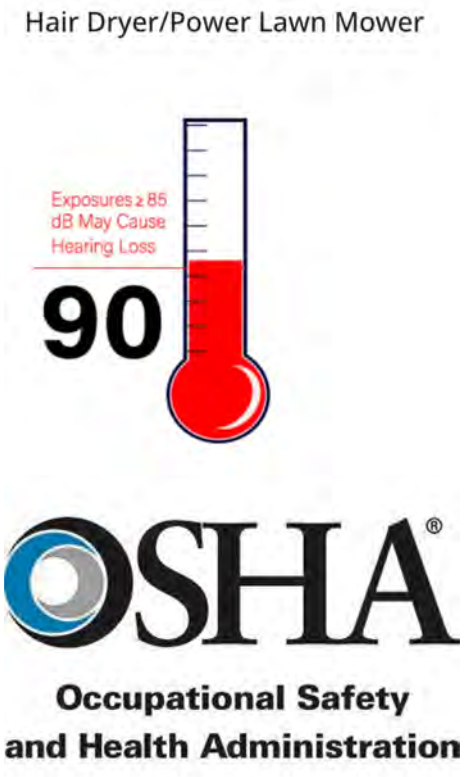
- Three equally important components for any environmental exposure
  - Exposure frequency (how often)
  - Exposure duration (how long)
  - Exposure intensity/level (how much)

- Without information about all of these components, cannot make accurate inferences about risk

https://blogs.cdc.gov/wp-content/uploads/sites/22/2017/01/SLM-e1483981246591.jpg

Regulation of occupational noise

- Permissible Exposure Limit in US (Occupational Safety and Health Administration, OSHA)
  - 90 A-weighted decibels (dBA) average in 8-hour shift
  - 1 in 4 workers will have substantial hearing loss after 40 years exposure at this level

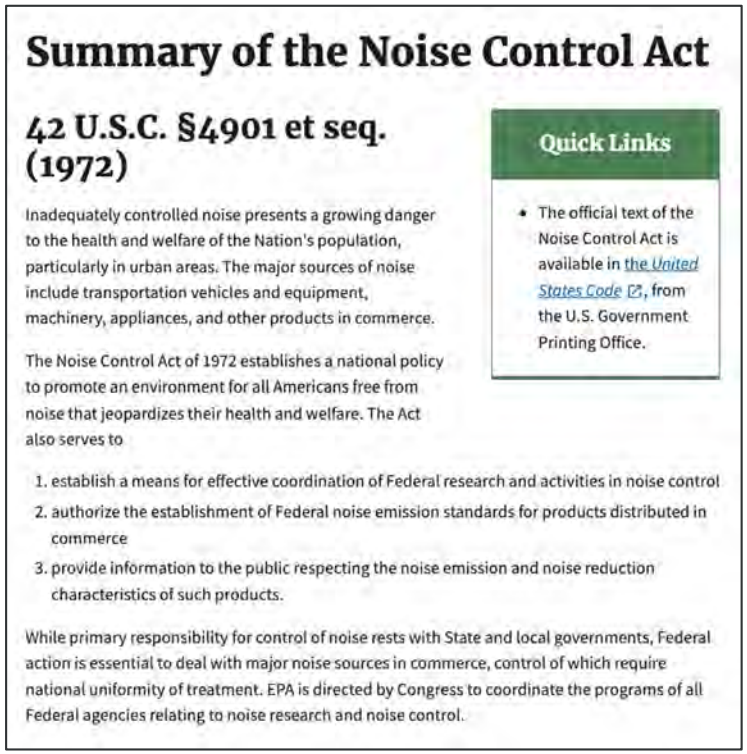


- US regulations lag rest of world

https://www.cdc.gov/niosh/topics/noise/noisemeter_html/old/hp90.html
https://www.osha.gov/quicktakes/05272020

Regulation of environmental noise

- Through Noise Control Act (NCA) of 1972, US Congress gave EPA power to regulate noise
  - Construction equipment
  - Transportation equipment
  - Any motor or engine
  - Electrical or electronic equipment



Summary of the Noise Control Act

42 U.S.C. §4901 et seq. (1972)

Inadequately controlled noise presents a growing danger to the health and welfare of the Nation's population, particularly in urban areas. The major sources of noise include transportation vehicles and equipment, machinery, appliances, and other products in commerce.

The Noise Control Act of 1972 establishes a national policy to promote an environment for all Americans free from noise that jeopardizes their health and welfare. The Act also serves to

1. establish a means for effective coordination of Federal research and activities in noise control
2. authorize the establishment of Federal noise emission standards for products distributed in commerce
3. provide information to the public respecting the noise emission and noise reduction characteristics of such products.

While primary responsibility for control of noise rests with State and local governments, Federal action is essential to deal with major noise sources in commerce, control of which require national uniformity of treatment. EPA is directed by Congress to coordinate the programs of all Federal agencies relating to noise research and noise control.

Quick Links

- The official text of the Noise Control Act is available in the United States Code, from the U.S. Government Printing Office.

https://www.epa.gov/laws-regulations/summary-noise-control-act

EPA Office of Noise Abatement and Control (ONAC)

- 1972-1981 ONAC created emission limits on:
  - Truck-mounted waste compactors
  - Medium and heavy trucks
  - Air compressors
  - Motorcycles
- ONAC defunded in 1981

EPA History: Noise and the Noise Control Act

NOTE: **In the 1970s, EPA coordinated all federal noise control activities through its Office of Noise Abatement and Control. EPA phased out the office's funding in 1982 as part of a shift in federal noise control policy to transfer the primary responsibility of regulating noise to state and local governments. However, the Noise Control Act of 1972 and the Quiet Communities Act of 1978 were never rescinded by Congress and remain in effect today, although they are essentially unfunded.**

https://www.epa.gov/history/epa-history-noise-and-noise-control-act

Community noise limit recommendations

- To protect against NIHL
  - 24-hr average L_{EQ} ≤70 dBA
  - Protects everyone against any hearing loss

- To protect against annoyance, sleep disturbance, other effects
  - Day or night-time exposures 30-55 dBA (depends on effect and environment)

https://www.epa.gov/aboutepa

https://www.who.int/

Noise exposure estimates

- Occupational estimates woefully out of date
  - Last national-scale estimates by EPA and NIOSH in early-1980s
- Community estimates also woefully out of date
  - Last national-scale estimates by EPA in early 1980s
  - US population approximately 200 million

https://commons.wikimedia.org/wiki/File:1980s_fashion_with_acid-washed_jeans.jpeg

Occupational noise exposures

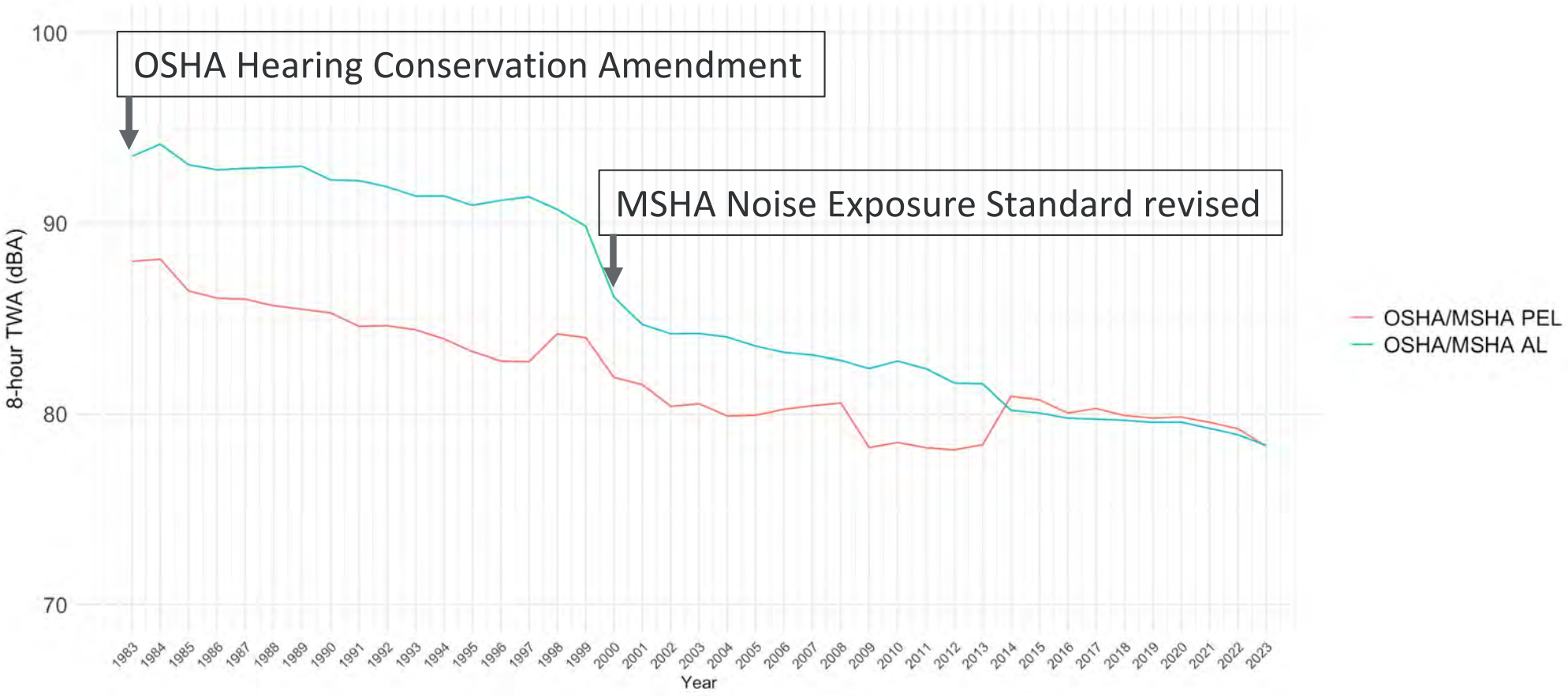
- Current estimate 20-25M US workers with 8-hour L_{EQ} of 85 dBA or more (e.g., “hazardous” noise)
- High noise occupations/industries include
  - Military, transportation, manufacturing, construction, mining, agriculture, and (in some cases) service
- Much larger uncertainty in community level estimates

Tool for occupational noise exposure estimation

- Job Exposure Matrix for Noise in US and Canada

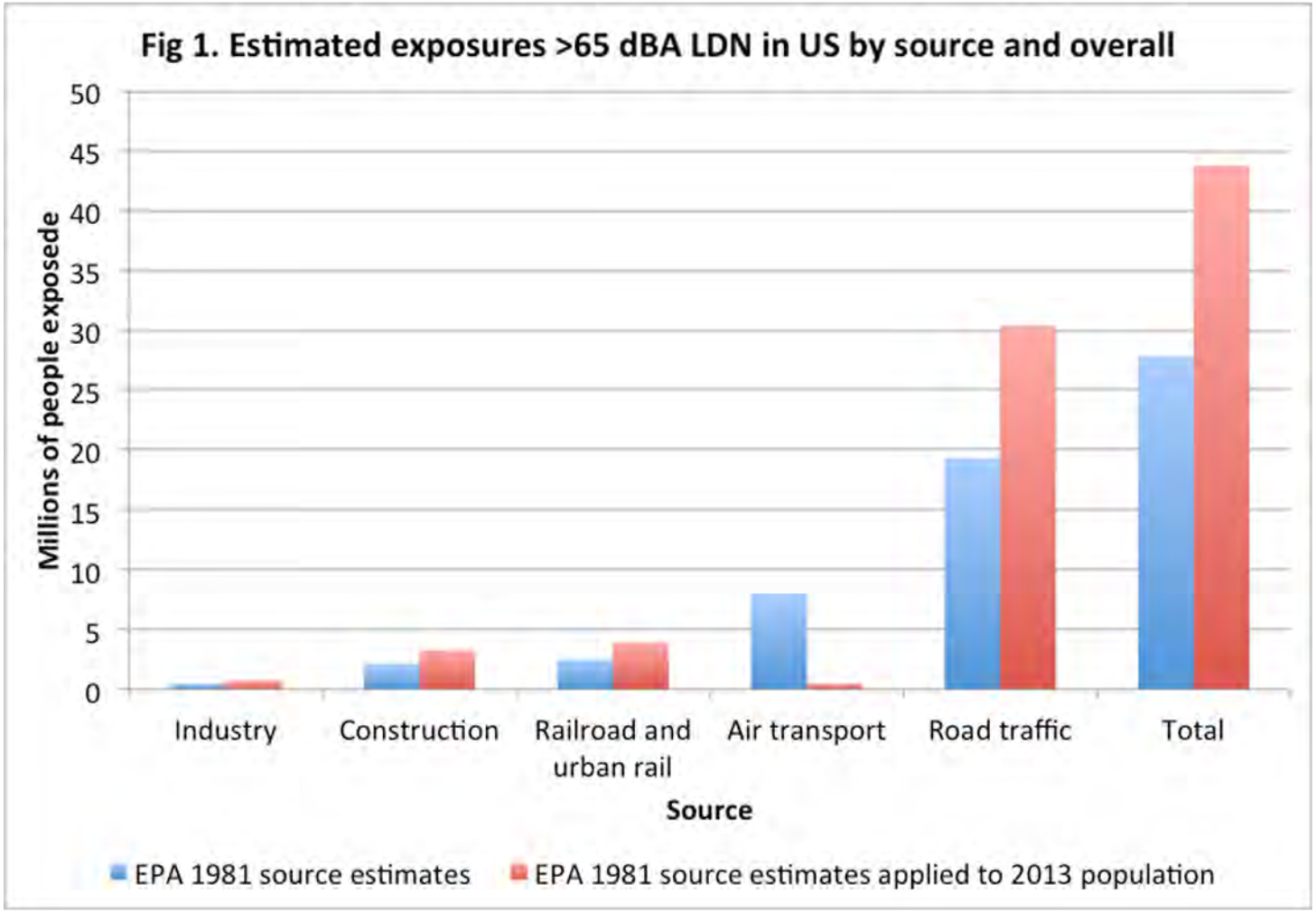
http://noisejem.sph.umich.edu/

Occupational noise exposures in US from NoiseJEM



N>1.2 million measurements

Community L_{DN} exposures: 1981 vs 2013



~104M Americans >70 dBA $L_{EQ(24)}$, at risk of NIHL – that's ~1 in 3!

(Rare) success: air transport

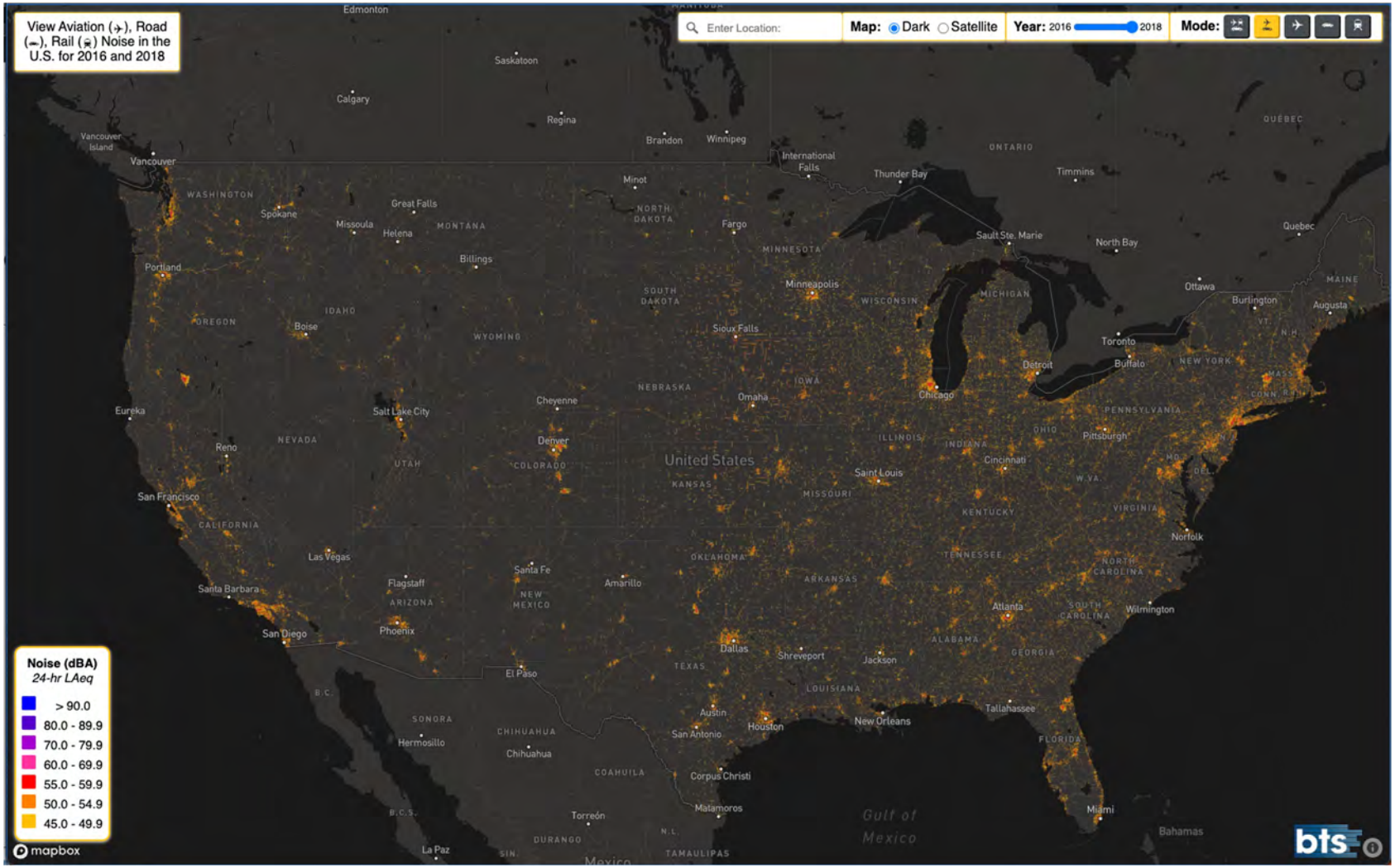
- Annual air transport exposures >65 dBA LDN down 90% (!) since 1981
  - From 4% of population in 1981 to 0.015% in 2007
  - Despite six-fold increase in person-miles travelled

- Due largely to quieter jet engines
  - Government requirements → technological improvements

https://en.wikipedia.org/wiki/Boeing_B-52_Stratofortress#/media/File:USAF_B-52_Stratofortress_Engines.jpg

Image © Rick Neitzel

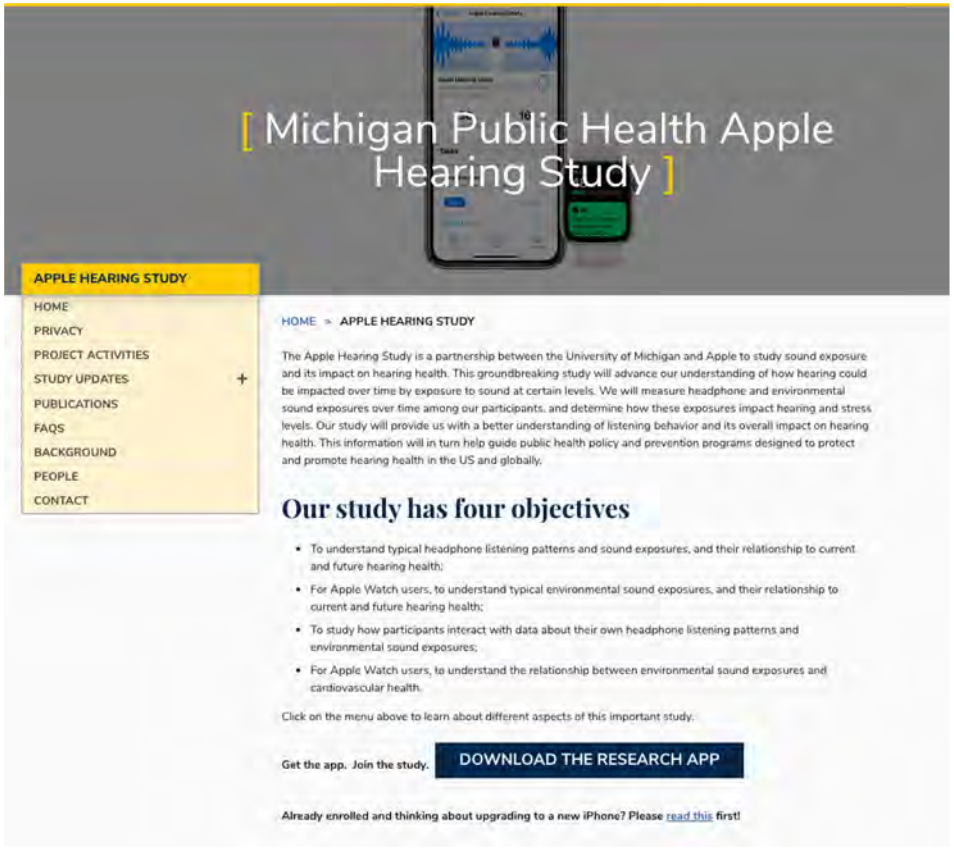
Speaking of transportation noise



https://maps.dot.gov/BTS/NationalTransportationNoiseMap/

But maps don't give personal level exposure information

- Enter the Apple Hearing Study (AHS)
- Study launched November 14, 2019
- Longitudinal, observational study



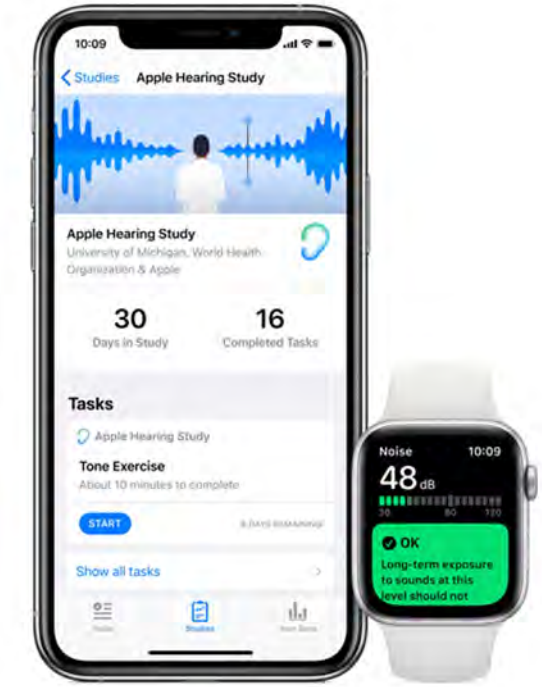
https://sph.umich.edu/applehearingstudy/

AHS primary study objectives

- To understand typical headphone sound exposures, and relationship of those exposures to hearing health

- Among Apple Watch users…
  - To understand environmental sound exposures, and relationship of those exposures to hearing health

- To understand how participants interact with their exposure data



https://sph-umich.shinyapps.io/ahs-inad-2023/

More on the AHS

- US participants download Research App
  - Participant interfaces with study via app
- Assigned randomly to 1 of 2 arms
  - Arm 1: can review headphone, environmental exposures in Health app
  - Arm 2: receive notifications to review data in Health app, take survey and brief tone audiometry test after loud exposure
- App gives “tasks” to complete

Image © Rick Neitzel

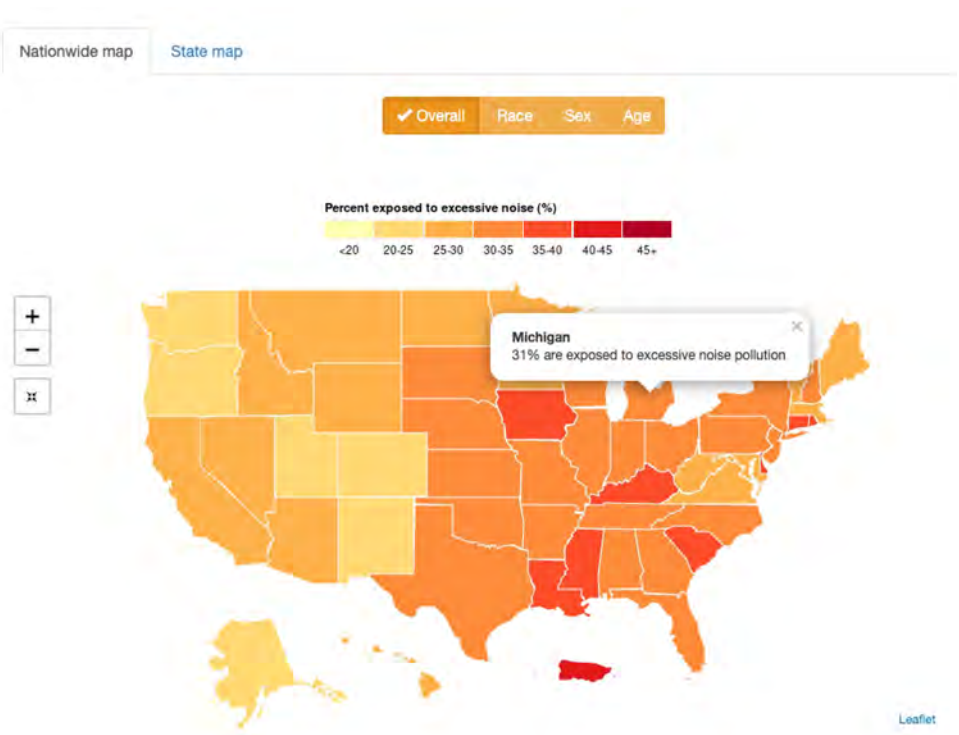
AHS study design

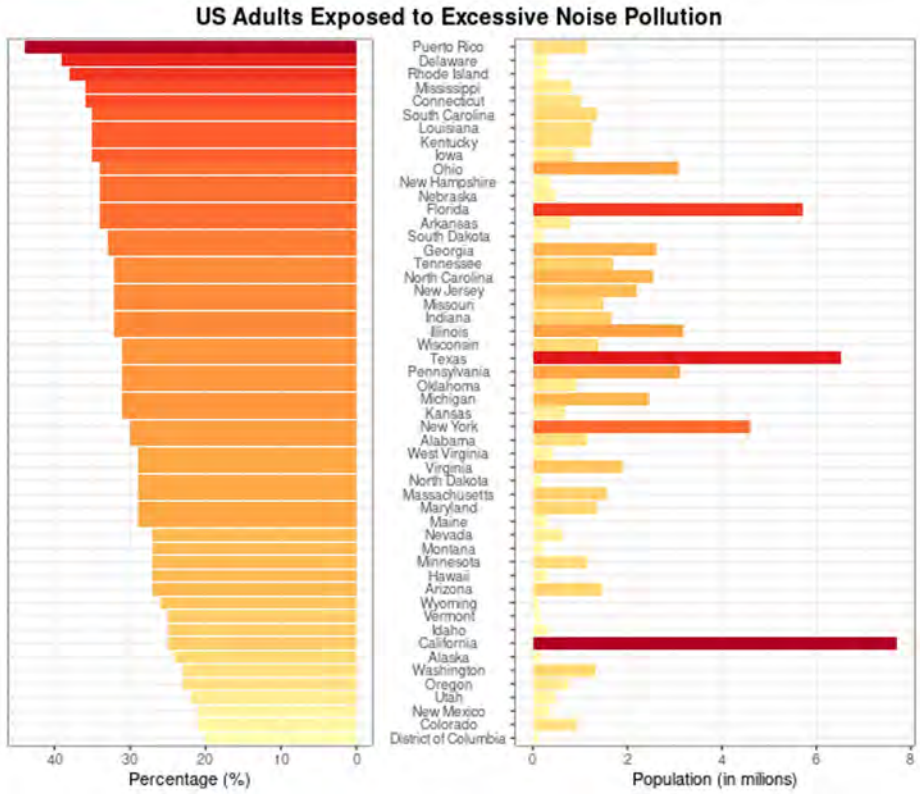
- Participants choose exactly which data types to share
  - UM can access all data
  - Apple has access to coded study data

- Data collected
  - Surveys
  - Hearing tests (pure tone audiometry, Speech in Noise, and tinnitus matching)
  - Sound exposures (duration and level)
  - Heart rate and heart rate variability

- www.clinicaltrials.gov (reg. NCT04172766)

AHS preliminary results: environmental noise exposure





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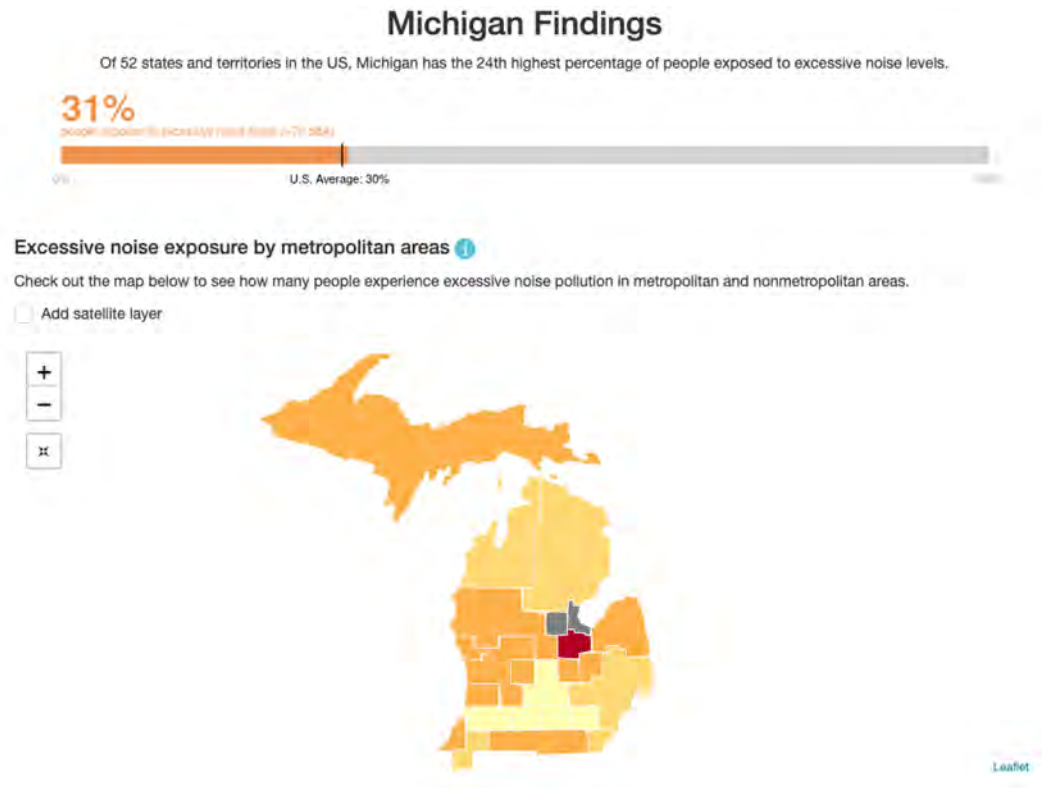
AHS preliminary results: environmental noise exposures

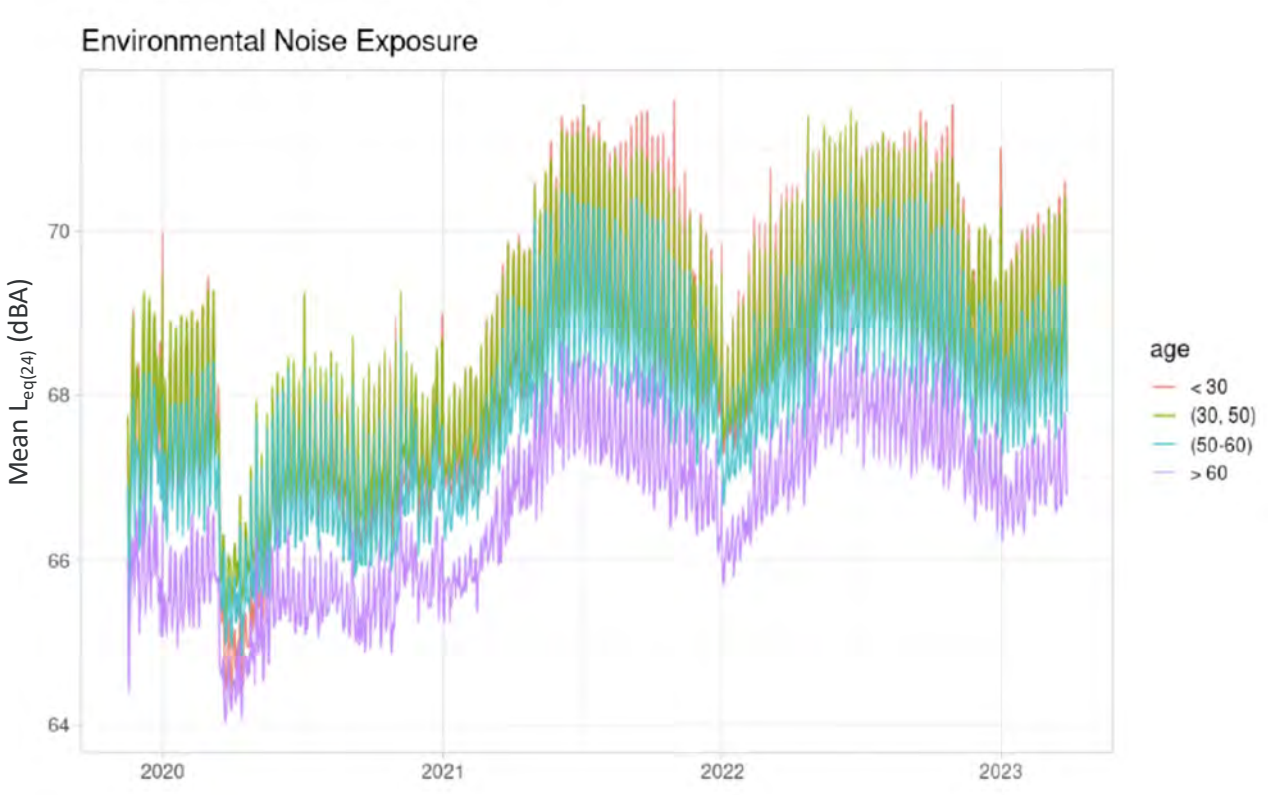
- Black and Hispanic Americans have highest exposures
- 35-44 year olds have highest long-term average exposures; 60+ year olds have lowest
- Exposures similar for males, females



https://sph-umich.shinyapps.io/ahs-inad-2023/

Preliminary study results: Environmental sound

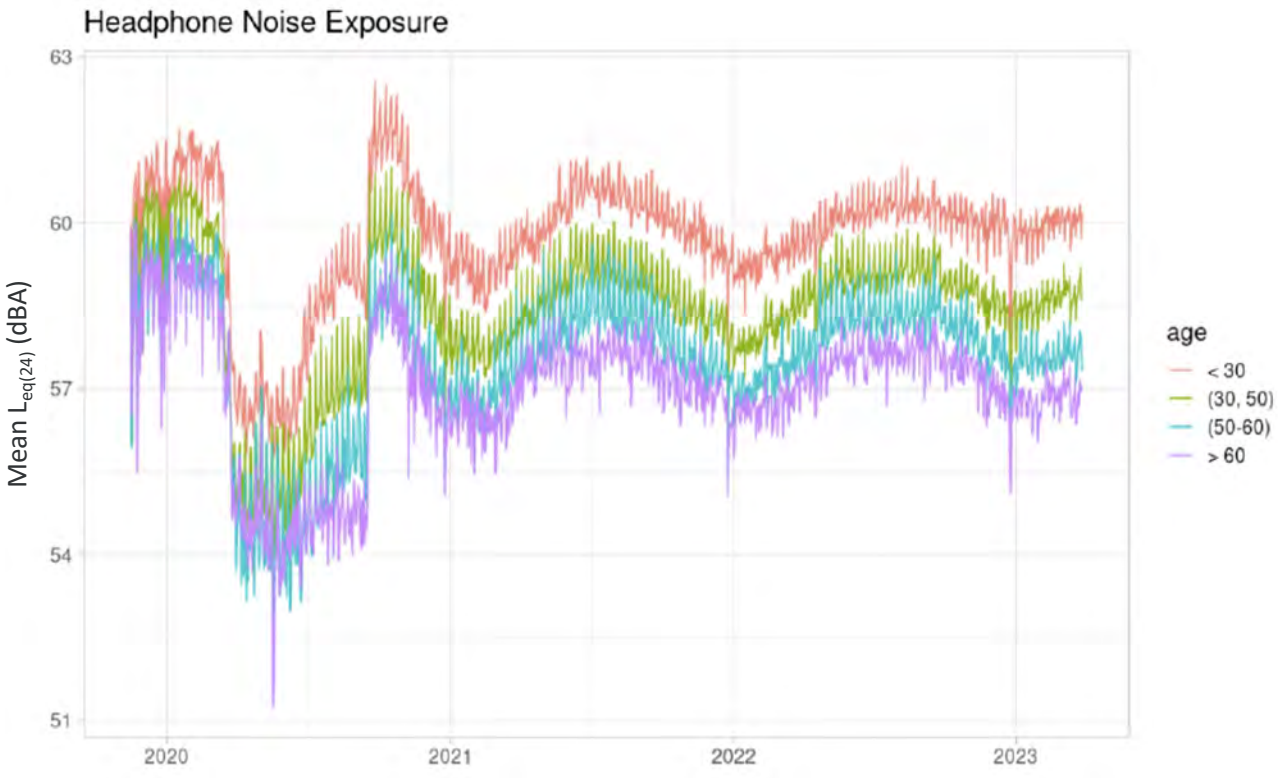
- Notable drop and quick recovery during COVID-19 lockdowns
- Highest exposures in <30, 30-50 year olds
- Lowest exposures in 60+ year olds



https://sph-umich.shinyapps.io/ahs-inad-2023/

Preliminary study results: Headphone sound

- Notable drop and prolonged recovery during COVID-19 lockdowns
- Highest exposures in <30 year olds
- Lowest exposures in 60+ year olds



Noise reduction options

1. Direct regulation
   - Source control and noise ordinances

2. Altering informational environment
   - Product disclosure and education
   - Noise mapping

3. Altering built environment
   - Building design and materials

Neitzel et al, *Environ Health Persp*, 2014

Noise reduction option I: Direct regulation

- Set maximum emission level for noise sources

- Only intervention that guarantees reductions
  - Within power of EPA
  - Also possible by states, but complicated

- Noise ordinances
  - Within power of local governments
  - Expensive, difficult to establish, enforce

https://www.yonkersny.gov/live/public-safety/code-enforcement-bureau/leaf-blower-ban

Neitzel et al, *Environ Health Persp*, 2014

Noise reduction option 2: Alter informational environment

- Product disclosures
  - Labels and warnings
  - Useless if consumer does not understand them
  - Need to be simple

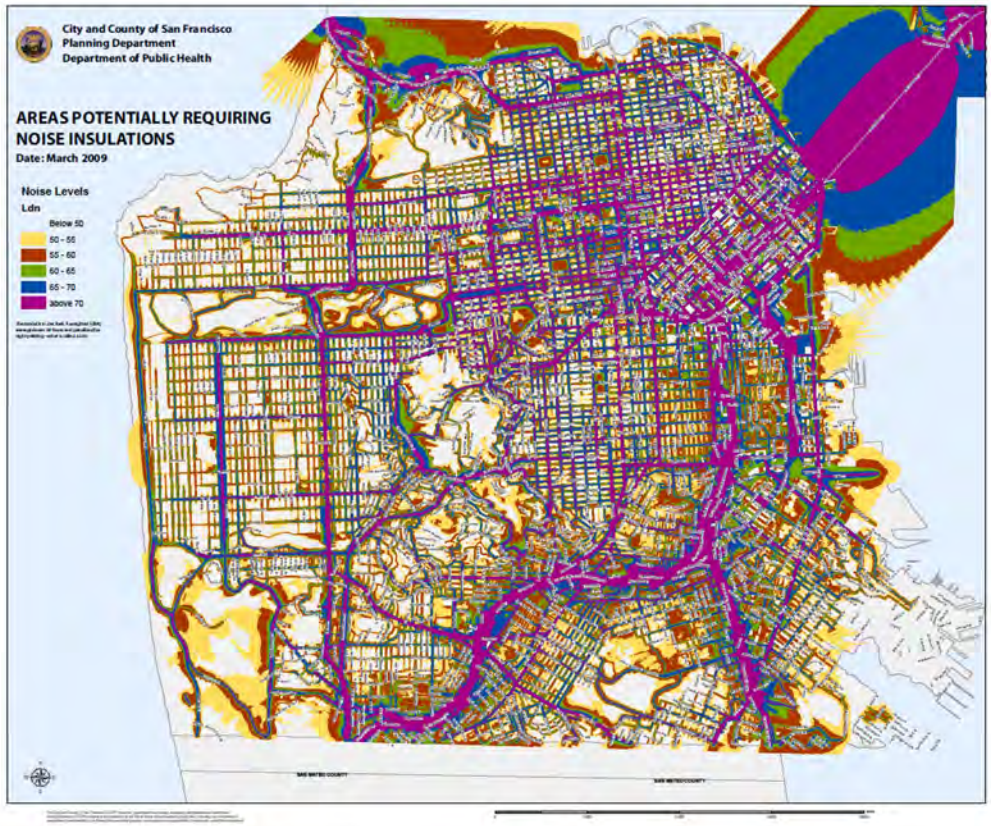
- Education
  - Needs to accompany product disclosures

Image © Rick Neitzel

Neitzel et al, *Environ Health Persp*, 2014

Noise reduction option 2: Alter informational environment

- Noise mapping
  - Assess spatial and temporal noise patterns
- Can be used to
  - Identify areas for intervention
  - Estimate population exposed
  - Predict noise changes

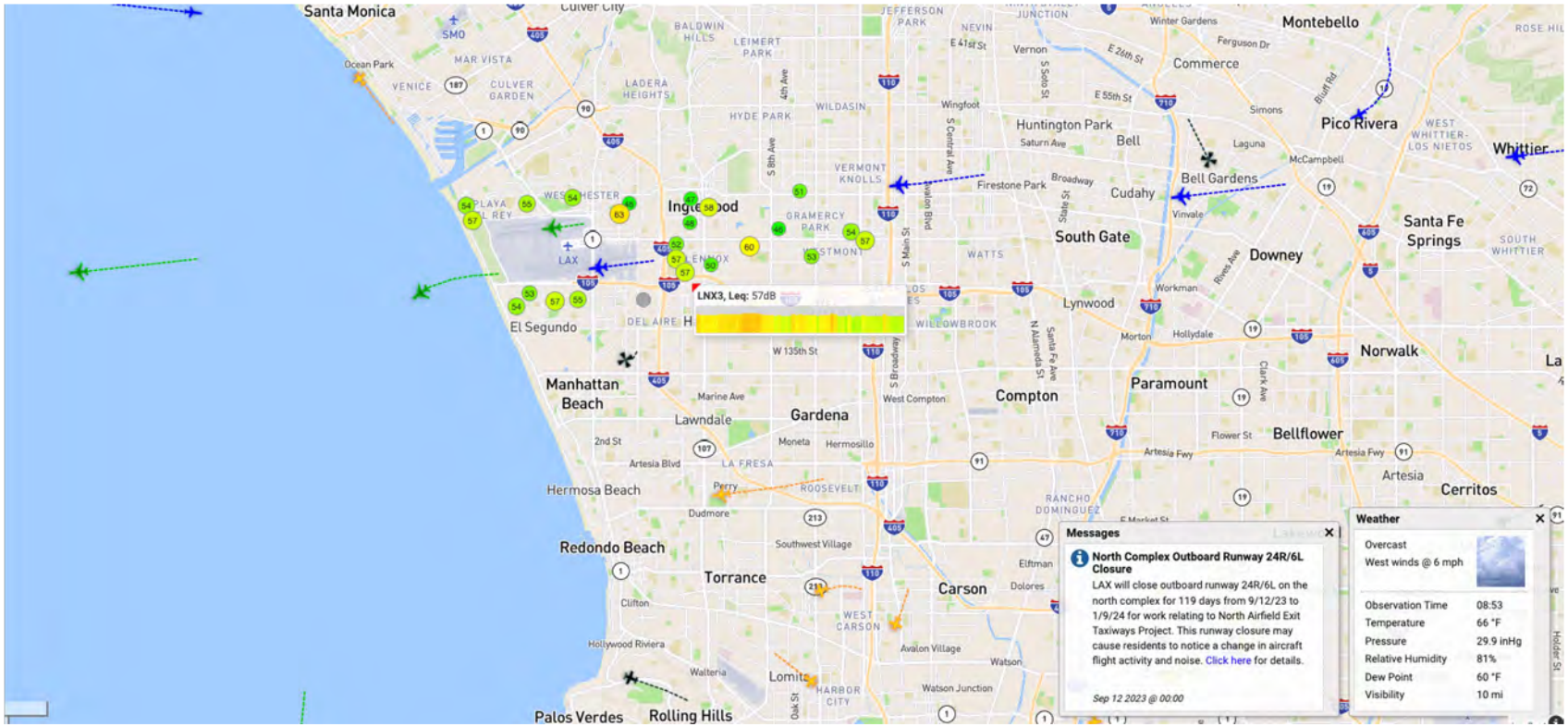


https://sfplanning.org/sites/default/files/resources/2019-09/Noise.pdf

Neitzel et al, *Environ Health Persp*, 2014

Community noise monitoring

- Real-time tracking of aircraft and noise levels around Los Angeles International Airport (LAX)



https://webtrak.emsbk.com/lax4

Noise control option 3: Altering built environment

- Building design
  - Meet consensus standards
  - ANSI standard for school acoustics
  - Add acoustics to LEED certification?

Figure 67. Noise wall behind cast-in-place retaining wall
photo #1745

- Building materials
  - Use attenuating materials
  - Insulation, multi-pane windows
  - Quiet pavement products
  - Noise barriers

Figure 68. Noise wall behind cast-in-place retaining wall
photo #1691

https://www.fhwa.dot.gov/environment/noise/noise_barriers/design_construction/design/design04.cfm

Public health ramifications

- Holistic approach needed to protect health
  - Exposures substantial, widespread
  - Cumulative across sources
  - Cumulative across lifetime
- Exposure assessment is challenging
  - Need assessment at individual and source level
- Interventions needed to prevent health effects

https://www.epa.gov/aboutepa

https://www.osha.gov/quicktakes/05272020

https://www.cdc.gov/about/organization/cio.htm

Questions?

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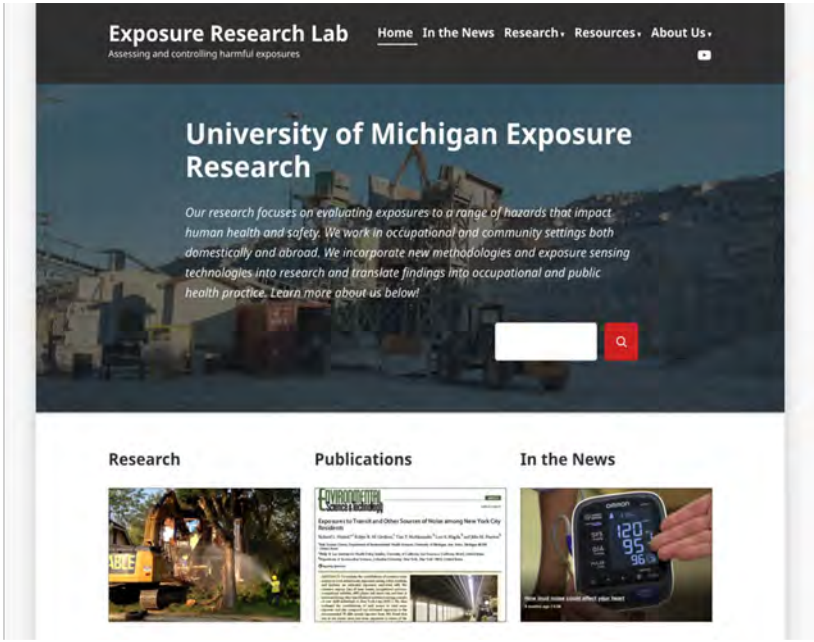

- For more information:
  - https://umexposureresearch.org/
  - www.hearingconservation.org
  - https://www.cdc.gov/niosh/topics/noise/noise.html