The Ototoxic Effects of Lead Exposure and its Implications for Firearm Users

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Introduction

This study aims to estimate the prevalence of hearing loss in the US population and investigate its association with blood levels of heavy metals from environmental exposure. Particular attention is given to lead (Pb), owing to its established ototoxicity and its heightened relevance to military populations, who face elevated exposure through firearm discharge and industrial processes.

Methods

Sample: 2,028 participants aged 20–69 years, 2015–2016 NHANES cycle, with complete data on covariates of interest
Outcomes — two hearing loss categories:

- **Low-frequency hearing loss (LFHL):** average threshold at 0.5, 1, 2, 4 kHz ≥25 dB in either ear.
- **High-frequency hearing loss (HFHL):** average threshold at 3, 4, 6 kHz ≥25 dB in either ear.

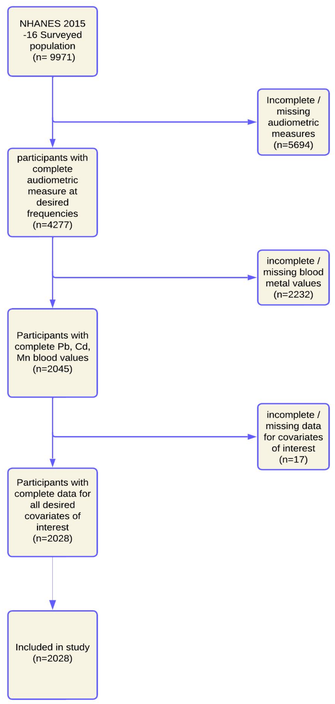

Figure 1. Study Sample Flow Chart

Exposures: blood cadmium, lead, and manganese concentrations (laboratory components)
Statistical analysis:

- Logistic regression (SAS survey procedures, accounting for complex survey design) to examine metal–hearing loss associations, adjusted for known demographic and clinical risk factors
- Group comparisons: design-adjusted Wald F-tests (survey-weighted linear regression, continuous variables); Rao-Scott modified χ^2 tests (categorical variables)
- Odds ratios estimated for blood metals as continuous measures and by quartile, to assess non-linear trends

Results

The estimated weighted prevalence of LFHL and HFHL were 14.97% (SE 1.4) and 33.56% (SE 8.8) respectively

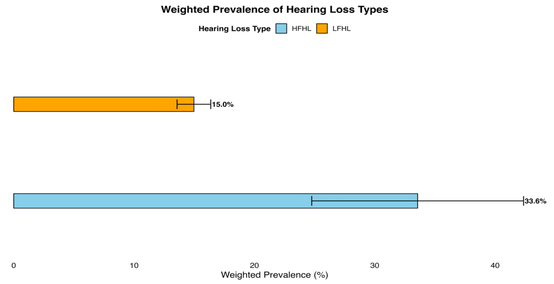

Figure 2. Weighted prevalence of LFHL and HFHL

- **Sample Characteristics**
- Weighted mean age, overall sample: 43.7 ± 0.6 years
- Age by hearing loss status:
  - LFHL: 55.7 ± 0.79 years vs. 41.6 ± 0.45 years without ($p < 0.001$)
  - HFHL: 53.8 ± 0.55 years vs. 38.6 ± 0.44 years without ($p < 0.001$)
- Comorbidities: both LFHL and HFHL groups had significantly higher rates of hypertension and diabetes
- BMI: not significantly associated with LFHL; significantly associated with HFHL ($p = 0.0252$)
- Noise/lifestyle exposures: significant exposure to occupational noise, smoking, firearm noise, and non-occupational noise
- Physical activity: lack of moderate work or recreational activity associated with higher LFHL vs. controls
- Education: less than high school associated with higher likelihood of hearing loss ($p < 0.001$)

Blood Metal Levels

- Mean blood levels: lead 1.10 ± 0.038 µg/L; cadmium 0.41 ± 0.01 µg/L; manganese 9.99 ± 0.11 µg/L
- Lead: significantly higher in both LFHL ($p = 0.0033$) and HFHL ($p < 0.0001$) vs. controls
- Manganese: significantly lower only in HFHL ($p = 0.0098$)
- Smoking: current smokers had higher blood lead and cadmium than former/never smokers

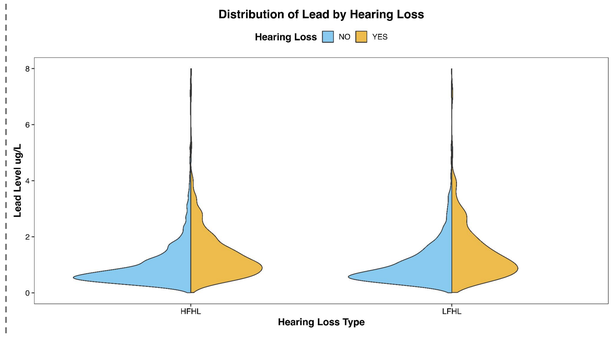

Figure 3. Blood Lead Distibution by HL status

Regression Analyses

- Lead (continuous), overall sample:
  - LFHL: OR = 1.17, 95% CI 1.02 - 1.35, p = 0.03
  - HFHL: OR = 1.16, 95% CI 1.01 - 1.34, p = 0.02
- Lead, stratified by sex: stronger HFHL association in males (OR = 1.27, 95% CI 1.06 - 1.52, p = 0.009)
- Cadmium, females: inverse dose-response with LFHL - Q3 vs. Q0 (reference), ORs ranging 3.76–2.50, decreasing at higher quartiles
- Manganese, females: higher odds of HFHL, quartile 2 vs. 1 (OR = 3.30, 95% CI 1.77–6.13)

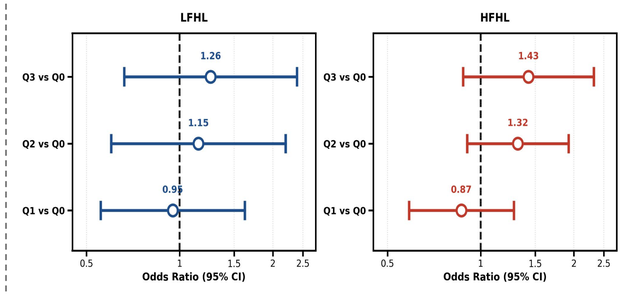

Figure 4.Adjusted Odds Ratio for HL by lead Quartile

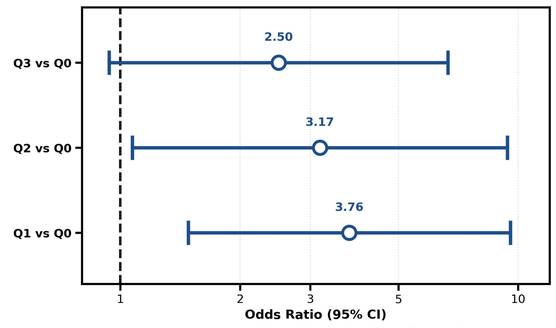

Figure 5. Cadmium Quartile Odds Ratios for LFHL in Females

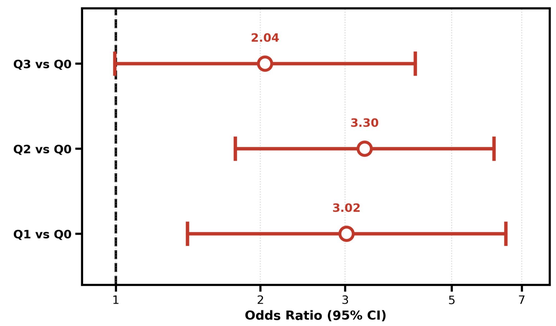

Figure 6. Manganese Quartile Odds Ratios for HFHL in Female

Conclusion

- Lead is a potent, independent risk factor for sensorineural hearing loss
- Males show linear high-frequency dose-response; females show non-linear low-frequency associations
- Lead is a common byproduct of ammunition and military environments, warranting auditory-toxicological surveillance to preserve service members' readiness

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