This document presents a review of existing evidence on risk of noise induced hearing loss due to exposure to sounds in recreational settings. The evidence will be used to stimulate discussion for determination of exposure limits to be applied to standards for personal audio devices. The review has been undertaken by Dr Richard Neitzel with inputs from Dr Brian Fligor, in collaboration with WHO.
What’s in an exposure limit?

- **Question addressed:**
  - Are existing exposure limits for occupational noise exposure suitable for determination of risk due to recreational sound?

- **Best measure of noise-induced hearing loss (NIHL) risk**
  - Equivalent continuous average sound pressure level, $L_{EQ}$.
  - $L_{EX}$: 8-hour $L_{EQ}$ for occupational noise exposure (in dBA)
  - $L_{EQ(24)}$: 24-hour $L_{EQ}$ for environmental noise exposure (in dBA)
Current occupational and environmental exposure limits

- **Most occupational limits** are 85 dBA $L_{EX}$
  - E.g., US National Institute for Occupational Safety and Health
  - NIHL <5 dBHL at 1, 2, 3, 4 kHz in median individual after 40 yrs
  - 8% excess risk of NIHL $\geq$25 dBHL at 1, 2, 3, 4 kHz after 40 yrs at 85 dBA $L_{EX}$, 1% at 80 dBA
  - No margin of safety

- **Most environmental limits** are 70 dBA $L_{EQ(24)}$
  - Equivalent to 75 dBA $L_{EX}$ and $\leq$60 dBA for other 16 hours
  - $<$5 dBHL shift at 4 kHz in 96% of people after 40 yr exposure
  - Includes 5 dB margin of safety (EPA 1974; WHO 1999)

- **EU directive 80 dBA $L_{EX}$**: WHO/EPA without safety margin
NIHL risk from occupational noise and music

- Classical music produces less TTS than equivalent noise (Lindgren & Axelsson, 1983; Strasser et al, 2003)

- Classical music TTS resolves faster than equivalent noise (Strasser et al, 2003; Strasser et al, 1999)

- Music and noise of same energy and duration caused significant TTS at 4 and 6 kHz (Swanson et al, 1987)
  - More TTS from disliked music (cognitive factors in audiometry)

- TTS from noise may be worse than equivalent music
  - But variation in types/patterns of music listening warrants adoption of exposure guidelines that presume equal hazard
Lifetime durations of occupational and nonoccupational exposure

- Current NIHL risk models derived from occupational noise exposures (ISO 1999, ANSI S3.44)
  - Greatest rate of NIHL in first ten yrs of exposure

- Maximum duration for NIHL risk estimates: 40 yrs
  - Appropriate in 1960s/1970s (life expectancies in high-income countries 65-70 yrs, noise exposures primarily occupational)
  - Untenable assumption today (children may be exposed from early age to high levels of music, life expectancies now >80 years in high-income nations)

- Exposure duration of 60 yr (ages 10-70) more realistic
Daily durations of occupational and nonoccupational exposure

- Occupational exposures historically ~8 hrs/day
  - Music exposures have potential to exceed this
  - Appears most listen to music one to several hrs/day

- Majority of 4500 people in NYC estimated to receive most of exposure through music (Neitzel et al, 2012)
  - Listened to music 2.2 hours per day on average
  - Music was primary source of exposure for 59% of people

- Risk of any NIHL in NYC study greater from music than any other source assessed (Lewis et al, 2013)
  - Greatest impairment in those with high occupational exposure
NIHL in young individuals

- Evidence of NIHL in young people entering workforce

- Worse baseline hearing in young construction workers (mean age 27 yrs) compared to student controls
  - NIHL exceeded ANSI predictions even after accounting for baseline (Seixas et al 2004)

- 20% of young workers (mean age 22 yrs) entering workforce each year for 20 years in manufacturing company had audiometric notches consistent with NIHL
  - Greater rates of NIHL with worse hearing at baseline
  - No change in prevalence over time (Rabinowitz et al. 2006, 2007)
Differences in occupational and nonoccupational exposure levels

- Various studies have evaluated maximum output of personal music players
  - Possible exposure levels far exceed recommended limits
  - Studies establish potential for NIHL, but do not quantify risk

- Listening levels and estimated $L_{EX}$ exposures for children/young adults using portable music players.
  - Jiang et al. 2016 systematic review of 26 studies
  - 3-58% subjects per study had daily music exposure >85 dBA $L_{EX}$
  - Average music $L_{EX}$ exposures ranged from 61.6-87.2 dBA
Relevance of standards for predicting NIHL

- ANSI S3.44, ISO 1999 specify 75 to 100 dBA range

- ANSI S3.44 description of relevant exposures:

  “...equivalent continuous A-weighted sound pressure level for a normal 8-h working day from 75 to 100 dB... and periods of exposure lasting from 0 to 40 years. Extrapolations to higher levels are not supported by quantitative data.”

- Given range of music $L_{EX}$ in literature, ISO and ANSI NIHL prediction models appropriate for assessing risk from music exposures
Identifying an appropriate exposure limit

- Guidance from ANSI S3.44:

  “The selection of maximum tolerable or maximum permissible noise exposures and protection requirements, as well as the selection of specific formulae for impairment risk assessment or compensation purposes, require consideration of ethical, social, economic, and political factors not amenable to international standardization.”
Identifying an appropriate exposure limit

- Must specify dB of HL at specific audiometric frequencies that constitutes meaningful NIHL
  - Critical for setting acceptable risk, exposure limit

- For example:
  - American Academy of Otolaryngology - Head and Neck Surgery: audiometric frequencies 0.5, 1, 2, and 3 kHz
  - NIOSH: audiometric frequencies 1, 2, 3 and 4 kHz

- WHO has previously stated
  - HL > 10 dBHL average audiometric hearing threshold at 2 and 4 kHz in both ears impacts speech comprehension (WHO 1999)
  - HL > 30 dBHL average at 2 and 4 kHz in both ears results in noticeable social hearing handicap (WHO 1999)
Identifying an appropriate exposure limit

- WHO appears to lack definition of what constitutes NIHL
- Any exposure limit inherently a political compromise
  - Requires definition of acceptable risk of NIHL
  - Explicitly acknowledges some individuals will suffer NIHL
  - Exception: exposure limit with zero risk of NIHL (i.e., 75 dBA $L_{EX}$, equivalent to 70 dBA $L_{EQ(24)}$)
- Consider “hidden hearing loss” from noise?
  - Damage to auditory periphery, e.g., cochlear synaptopathy, that does not manifest as elevated audiometric thresholds
  - Not possible to establish dose-response relationship
Conclusions

- Without WHO definition of maximum acceptable NIHL...
  - Cannot determine risk of individuals exceeding that definition from exposure to music
  - Cannot determine acceptable level of risk of NIHL

- Establishing maximum acceptable NIHL must be priority for WHO
Recommendations for WHO exposure limit

- Two logical options

- Option 1: 70 dBA $L_{EQ(24)}$, equivalent to 75 dBA $L_{EX}$
  - Includes margin of safety for susceptible individuals
  - Zero risk of NIHL$>5$ dBHL at any frequency in essentially any individual

- Option 2: 75 dBA $L_{EQ24}$, equivalent to 80 dBA $L_{EX}$
  - Current EU occupational lower exposure action value
  - Protective against substantial HL for virtually everyone
  - Small fraction of individuals may get material HL after 40 yrs
Recommendations for WHO exposure limit

- 75 dBA $L_{EX}$ limit (zero risk of NIHL) appropriate for
  - Young children (no autonomy to make informed health decisions)
  - Pre-existing hearing loss (NIHL or another cause)
  - Pre-existing tinnitus
  - Increased susceptibility to NIHL or noise-induced tinnitus (e.g., use of ototoxic medications or exposed to ototoxic chemicals)

- 80 dBA $L_{EX}$ may represent optimal limit for others
  - Sufficiently protective vs. technically/socially feasible

- If 80 dBA $L_{EX}$ too restrictive, consider “liberal” limit
  - 83 dBA $L_{EX}$ (i.e., 78 dBA $L_{EQ(24)}$; 92 dBA 1-hour $L_{EQ}$)
  - Risk of some NIHL to individuals, but protective for vast majority
Final conclusions: health impacts beyond NIHL

- Cannot recommend exposure limit based on dose-response relationship between noise exposure, tinnitus
  - Noise-induced tinnitus may precede measurable NIHL
  - More stringent exposure limits may be necessary to protect against noise-induced tinnitus

- Exposure limits to prevent NIHL may not protect against other impacts, e.g., hypertension, heart attacks
  - More appropriate limit might be <55 dBA 24-hr Day-Evening-Night level, $L_{DEN}$
  - 60-65 dBA $L_{EX}$
Questions and discussion