Canadian Audiologist

The Official Publication of the Canadian Academy of Audiology

Summary Paper – Auditory Changes Following Firearm Noise Exposure, A Review*

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Published September 7, 2022

Editor's Note: We wish to thank the authors for this summary of an important review paper recently published in the Journal of Acoustical Society (2022): Sonstrom Malowski K, Gollihugh LH, Malyuk H, Le Prell CG. Auditory changes following firearm noise exposure, a review. Mar;151(3):1769. doi: 10.1121/10.0009675. Supporting references from this summary can be found in the full published manuscript.

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Firearms produce peak sound pressure levels (peak SPL) that can range between ~130 and 175 dB peak SPL, creating a significant risk for auditory dysfunction for exposed populations. Noise-induced hearing loss (NIHL), commonly presented as a notch on the audiogram between 2–6kHz, is one of the best-known consequences of firearm noise exposure. NIHL can accompany related auditory symptoms, including tinnitus and difficulty understanding speech in noisy environments. NIHL and other auditory deficits are highly prevalent among populations exposed to occupational, recreational and/or military firearm exposure(s). This has increased interest in developing ways to assess and prevent NIHL within these populations. However, research and clinical trial design challenges exist due to the significant variability of existing data within the literature. In addition, variability exists for endpoint definitions, protocol development, and methodologic approach for assessment. Key findings and recommendations from our review concerning auditory changes following firearm noise exposure are presented.

Populations

Populations at increased risk for NIHL include service members, safety/police officers, and recreational firearm users. As is well known for U.S. service members, the monitoring, prevention, intervention, and treatment for NIHL generates significant economic costs.

Pathology

Auditory changes following noise exposure are often the result of compromised function of cochlear outer hair cells (OHCs), though other pathologic etiologies are possible, including, for example, reticular lamina and strial cell density damage.

Threshold Shift

Temporary Threshold Shifts (TTS) are changes measured at short post-noise exposure times, whereas Permanent Threshold Shifts (PTS) are threshold changes measured at longer post-noise times, commonly 2-4 weeks following noise exposure, with little additional recovery expected. The most common assessment used to document Significant Threshold Shift (STS) following noise exposure used by regulatory (e.g., OSHA (1983); NIOSH (1998)) and professional (e.g., ASHA (1994); AAA (2009)) organizations are permanent changes in pure-tone detection thresholds on the audiogram. Additionally, the effects of noise exposure are cumulative, and some 20-40% of outer hair cells can be damaged before seeing threshold changes on the audiogram. Therefore, an auditory injury may be missed only using the audiogram, particularly when measurements are obtained following a single shooting episode instead of measurements of long-term cumulative effects. Importantly, when using the audiogram, a variety of operational definitions are used for STS, creating ambiguity with study design and validation studies for research and/or clinical trial studies investigating NIHL.

Distortion Product Otoacoustic Emissions

Distortion product otoacoustic emissions (DPOAEs) and transient evoked otoacoustic emissions (TEOAEs) are sensitive to auditory dysfunction immediately following noise exposure as they reflect changes in OHC function even if the damage is not sufficient to alter the audiogram. Primarily this happens because changes in otoacoustic emissions (OAEs) reflect changes in outer hair cell active processes.

Other Auditory Deficits

Additional assessments have been used to measure functional changes that may be valuable in detecting auditory change following noise exposure even in the presence of a normal audiogram, including Speech-In-Noise (SIN) testing, extended high-frequency audiometry (EHFA), and evoked potential measurements to detect neural pathology. Another common consequence of firearm noise exposure that has been well-documented is tinnitus.

Scoping review

Our scoping review identified overall trends regarding assessing and interpreting TTS and/or PTS resulting from firearm-noise exposure (Sonstrom Malowski et al., 2022). For inclusion, the study needed to describe subjects enrolled in firearm training without blast exposure beyond that of firearm use alone. Secondly, articles needed to include a pre-exposure audiogram and follow-up audiogram that assessed either TTS or PTS. Finally, subjects with any type of prophylaxis or therapeutic intervention were excluded; however, data for placebo groups were used if clearly separated from that of the intervention group.

A total of 39 articles/reports were reviewed; 20 met the inclusion criteria, and 19 were excluded from the analysis. The most common reason for exclusion was blast exposure in parallel with firearm exposure. The second most common reason for exclusion was a lack of baseline testing, which prevented explicit measurement of TTS or PTS. Other reasons articles were excluded included a lack of participants following instructions, long-term firearm noise exposure, and pharmaceutical intervention studies in which data from the placebo group was not clearly separated from the intervention group.

Five areas of interest were reviewed, including: (1) Criteria/definitions for TTS/PTS, (2) Population and demographic criteria, (3) Firearm specification and detail, (4) Hearing protection devices, and (5) Primary and secondary outcomes, such as audiometric shifts for TTS/PTS, OAEs, EHF. Criteria for TTS or PTS were only defined in 30% of the articles reviewed, and this criterion was not consistent. For example, 20% used criteria of a ?10 dB HL at any frequency to define a TTS and/or PTS, whereas others provided differing TTS definitions. A similar trend was found for the studies that included OAE measurements (n=13/20), in which only 15% of studies provided explicit criteria to define what constituted a significant shift in amplitude following exposure. These studies used a criterion of ?6 dB SPL shift for DPOAEs and ?4 dB SPL shift for TEOAEs; no other studies provided clear definitions. Regarding participant demographics, the criteria for eligibility were variable across the literature. Only 60% of studies required that participants had hearing within normal limits. Within that subset, definitions for what constituted normal hearing were inconsistent across studies. A plethora of additional population/demographic exclusion criteria was used across studies (e.g., use of ototoxic medications, middle ear pathologies, acoustic/head trauma, neurological/mental disturbances, and significant past noise exposure). Surprisingly, 25% of the studies reviewed did not report any population and/or demographic eligibility criteria. Common inclusion criteria consistent across studies included subject age range and occupation (e.g., military). Firearm type and shots fired varied substantially across studies, with rifles being the most common firearm used in 70% of studies. Sound level measurements were obtained in 80% of studies; however, there was variability in measurement weighting and overall sound pressure levels obtained, with the range generally falling between 110 to 172 peak SPL and weighting varying between A and C or not reported at all. The location of SPLs were recorded also varied across studies, with only 3 studies reporting both internal (in-the-ear) and external sound measurements. Hearing protection devices (HPDs) were used by shooters in 60% of studies included. However, the type and attenuation levels of HPDs used were also variable. Regarding primary and secondary outcomes, all studies included pure-tone audiometry, and 65% included audiometric and OAE results. Pure tone audiometric threshold shifts of 10 dB HL or greater at any frequency were found in at least some participants in 60% of studies. Several authors reported OAE shifts following noise exposure and suggested that OAEs were sensitive to noise-induced outer hair cell damage and/or more sensitive than audiometry. A probable explanation is that OAEs are affected initially from less noise exposure than is needed to cause a significant audiometric shift. However, confidence in these findings is reduced due to a lack of definitions provided for TTS and/or PTS. From our review, only 10% of studies reported on EHFA; none included SIN and/or evoked potential measurements.

This review provides clear evidence that variability exists for (1) overall study design, (2) criteria for auditory change(s) following exposure, and (3) primary and secondary outcomes. Challenges regarding study design for future studies and comparing data across the literature exist due to inconsistent test protocols and ambiguous or lack of criteria/definitions. Protocols should be carefully evaluated for future studies to avoid shortcomings identified in this review. We specifically advocate protocols that include not only conventional audiometry, but also OAEs, EHFA, and SIN testing, with a priori criteria specified for what will be considered a significant shift(s) on each measure. Standard definitions for clinically significant shift refer to changes in function detectable to the patient. There is ongoing discussion regarding what constitutes a clinically significant shift not only for the audiogram, but also for assessments beyond the audiogram, such as SIN and tinnitus. Sub-clinical pathology, including biomarkers for noise injury that can be measured using OAE or EHFA shift, should serve as a red flag for intervention. Only by providing comprehensive testing to patients at risk for firearm noise exposure will early signs of injury be detected in high-risk populations.