Hearing Loss Prevention Program in the Military Environment

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ABSTRACT

The military personnel regularly face a wide range of noise-hazardous situations, many of which are seldom encountered in other work environments. This paper reviews the essential elements of a hearing loss prevention program proposed for the Canadian Armed Forces. The program has been designed to meet the noise measurement and hazard investigation procedures, limits on noise exposure, use of hearing protection and other regulatory measures contained in the Canadian Occupational Health and Safety (COHS) Regulations (Part VII: Levels of Sound), while addressing the particular nature of the military environment. The focus of the paper is on the scientific basis and issues that are not typically found in other occupational environments (variable work schedules, excessive impulse noise, exposure over sustained durations, communications devices, etc.).

SOMMAIRE

Le personnel militaire doit régulièrement faire face à des conditions de bruit nocives, lesquelles ne se manifestent pas souvent dans les autres milieux de travail. Cet article couvre les éléments essentiels d'un programme de prévention de la perte auditive proposé pour les Forces Armées Canadiennes. Le programme a spécialement été conçu pour satisfaire les méthodes de mesure du bruit et d'évaluation du risque, les limites d'exposition, les exigences en matière d'utilisation de protecteurs contre le bruit et les autres mesures contenues dans le règlement canadien sur la santé et la sécurité au travail (Partie VII : Niveaux acoustiques), tout en tenant compte de la spécificité de l'environnement militaire. L'article traite plus particulièrement de la base scientifique du programme de prévention et des aspects qui ne sont pas généralement retrouvés dans les autres milieux de travail (horaires de travail variables, bruits impulsionnels excessifs, exposition sur de longues durées, casques protecteurs avec système de communication intégré, etc.).

1. INTRODUCTION

Noise can be particularly noxious to hearing in the military setting [1,2]. The personnel regularly face a wide range of noise-hazardous situations, many of which are seldom encountered in other work environments. High noise levels are associated with the operation of small arms and large calibre weapons, combat vehicles, fixed and rotary wing aircrafts, ships, vessels, and industrial equipment [3, 4].

It is well documented that hearing abilities are of utmost importance in offensive and defensive military operations [4]. Localization of snipers, determination of the position of the enemy, hearing of radio messages, and small arms identification are only a few examples of military tasks for which hearing is crucial.

Exposure to high noise levels, either continuous or impulsive, can cause permanent hearing loss in those exposed if no noise engineering or administrative controls are considered, or if hearing protectors are not worn when required. In addition, high noise levels can cause temporary loss of hearing, compromise speech communication, localization of sound sources and detection of warning sounds and thus, can jeopardize life or safety of the military and civilian personnel. Other physiological and psychological effects of noise affecting the personnel and work performance include sleep interference, increased stress and fatigue, and inability to concentrate [5, 6].

The Canadian Forces Health Services Group (CF H Svcs Gp) is currently implementing a comprehensive health care reform process, referred to as Rx2000, to review all aspects of health services in the Canadian Forces (CF) from clinical care to administration. One of the main objectives of Rx2000 is to "establish programs for the mitigation of preventable injuries and illnesses thereby protecting CF members and meeting requirements of DND/CF operations" [7]. In this context, the ultimate goal of a hearing-loss prevention (HLP) program in the Canadian Forces (CF) is to preserve hearing health as well as all hearing abilities necessary for effective operations.

The CF introduced hearing conservation procedures into its preventive medicine program in the early 1950s [8], and had a full program in place since 1968 [1]. The current policy (medical order CFMO 40-01 [9]) dates back from the early 1970s and now requires a thorough review as part of the Rx2000 process.

Several reports and studies throughout the 1980s and 1990s [1, 8, 10-12] addressed a number of shortcomings in CMFO 40-01, and provided recommendations on a number of areas including (1) noise monitoring and database, (2) audiometric testing, interpretation and record keeping, (3) hearing protection procedures, (4) use of special devices, and (5) training of personnel. In addition, a comprehensive study on the effects of impulse noise has just been completed by the Research and Technology Organisation (RTO) of NATO [13].

This paper reviews the essential elements of a new hearing loss prevention (HLP) program proposed for the Canadian Forces. The HLP program consists of the following elements: (1) hazard assessment and identification, (2) engineering noise control, (3) administrative controls, (4) hearing protection, (5) monitoring audiometry, (6) education, (7) program evaluation and (8) documentation. The program is based on evidence-based practices, reflects major findings from past reviews of CFMO 40-01, and is consistent with current federal regulations (Treasury Board OSH Directives, Canada Labour Code Part II, Canadian Occupational Health and Safety Regulations). The paper will focus on the scientific basis of the proposed HLP program and address issues that are not typically found in other occupational environments (variable work schedules, excessive impulse noise, exposure over sustained durations, communication devices). A draft policy based on this proposal is currently under review by DND/CF.

2. PROGRAM ELEMENTS

2.1 Hazard Assessment and Identification

2.1.1 Objectives

An effective hearing loss prevention program is based on accurate and up-to-date sound level measurements for all noise-hazardous areas, facilities and operational equipment. Valid decisions and actions regarding most program requirements are possible only with a systematic scheduling of noise surveys, proper data management, and timely and effective reporting of results.

2.1.2 Regulatory equipment and procedures

The instrument description, accessories and selection criteria to measure occupational noise exposure must comply with article 4 in CAN/CSA-Z107.56-94 (R 2001) [14] as specified under COHS regulations [15]. Sound level meters (SLM) and dosimeters must be of Type 2 tolerance or better.

- A sound level meter without integrating capability is to be used only when the noise field can be divided into one or more discrete time segments in which sound levels remain steady (±3 dB). The instrument must be set to the A-weighting scale and the slow response setting.
- An integrating SLM or noise dosimeter can be used in all environments. They are required in environments containing impulse sounds and/or when the noise field is fluctuating and cannot be divided into discrete time segments in which sound levels remain steady. The instrument must be set to the A-weighting scale and for a 3-dB exchange rate. The threshold level for noise dosimeters must be set at least 10 dB below the criterion level of 87 dBA specified in COHS.

All measurements must be carried out under the most realistic conditions possible. The acoustical environment and the work activities at the time of measurement must be representative of the normal environment and work patterns. All noise types present in the environment (including impulse sounds) must be included in the measurements. The exact procedures and information to be recorded must comply with articles 5 and 6 in CAN/CSA-Z107.56 [14].

2.1.3 Special equipment and methods

In addition to the regulatory provisions above, additional equipment and methods are necessary to specify the spectral characteristics of the noise field for engineering noise control and hearing protector selection purposes, and to measure intense transient sounds from weapons impulses.

To perform octave-band (or narrower bandwidth) frequency analysis of the noise field, the instrument will include filters complying with ANSI S1.11-1986 (R1998) [16]. For impulse noise exceeding peak levels of 140 dBC, the measurement methods will be based on ANSI S12.7-1986 (R1998) [17]. To measure the parameters and record the time variation of the sound pressure wave for single impulse sounds, a SLM with special characteristics as defined in ANSI S1.4-1983 (R2001) [18] is required. Special purpose microphones capable of handling very high peak sound pressure levels must be used.

2.1.4 Types of noise surveys

Different types of noise surveys are required to implement the elements fully effective HLP program from initial hazard assessment to detailed noise control and hearing protector selection.

Basic noise surveys:

- These surveys are conducted by CF Base/Wing or Area/Formation Preventive Medicine Technicians to provide an initial assessment of suspected noise hazard in all industrial-type and military environments characterized by steady state or fluctuating noises.
- Basic surveys are to be carried out immediately after the installation of new or retrofitted equipment or change in operations for existing equipment.
- Basic surveys are to be scheduled on an annual or semi-annual basis for periodic monitoring of noise-hazardous sites with the purpose of revisiting each noise-hazardous site at least once every three years.

- The occupational noise exposure ($L_{ex,T}$) or equivalent sound level ($L_{eq,T}$) in dBA will be measured.

Detailed and operational equipment surveys:

- Detailed surveys are conducted by internal or external acoustical experts when the results of basic noise surveys in a specific environment require the initiation of hearing loss prevention procedures (> 84 dBA).
- Operational surveys are conducted by internal or external acoustical experts to specify noise levels on-board ships, aircraft, army vehicles and other noise-hazardous military equipment. The results on a limited number of items for each piece of equipment can be applied to all others used in the different DND/CF military facilities, given the same technical specifications and operational conditions.
- The $L_{eq,T}$ in dBA and the frequency analysis of the noise in octave bands (or narrower bandwidth) will be measured along with any other parameter necessary for engineering noise control measures and/or detailed hearing protection device selection.

Impulse noise surveys:

- These surveys are conducted by internal or external acoustical experts, in collaboration with other NATO countries, and apply to all weapons systems or other equipment producing impulse or transient sounds with peak levels in excess of 140 dBC.
- In this type of survey, the results on a limited number of items for each weapons system can be applied to all others used in the DND/CF and NATO military facilities, given the same technical specifications and operational conditions.

The main measurement parameter is the single-event sound exposure level (SEL) in dBA. Recording of the instantaneous time variation of the sound pressure wave is recommended to derive additional impulse noise parameters as necessary, until widely-accepted damage-risk criteria are firmly established by the international community.

2.1.5 Hazard identification

In all cases, noise hazard must be assessed against the regulatory limits in COHS [15]. The maximum noise exposure limit from all sources is 87 dBA for an 8-hour work shift in any 24-hour period (or according to a 3 dB exchange rate or exposure schedule in Section 7.4 of COHS regulations for exposure durations other than 8 hours). Additional provisions beyond COHS regulations are also necessary to address the particular nature of the military environment. Noise exposures sustained over extended work shifts and damage-risk criteria for weapons impulse noise are discussed below.

General occupational noise regulations, like COHS, are based on a typical workday of about 8 hrs followed by a long rest period. In the military, sustained exposure largely exceeding an 8-hour workday can occur on a regular or irregular basis. For exposures lasting 12 hrs or more, a rest period at least as long as the exposure duration is recommended [19]. In all cases, the rest period should be sufficiently long to ensure that the temporary threshold shift (TTS) induced by the exposure has decreased to a value 2.5 dB or less, which is the residual TTS expected after an exposure to 87 dBA for 8 hrs and 16 hrs of rest. Data in [20] can be used to estimate such a minimum rest period, given exposure duration and level. The rest environment should be lower than 74 dBA.

An alternative method for assessing extended noise exposures is proposed by the Canadian Centre for Occupational Health and Safety [21]. The method is based on the Brief and Scala method sometimes used to calculate exposure limits for chemicals, which takes into account the decreasing period of recovery following extended work shifts. It gives a more conservative noise level limit than a 3 dB exchange rate for extended work shifts, especially for exposure durations beyond 10-12 hours. However, the validity of using the Brief and Scala method for noise exposure is unknown.

Noise hazard from weapons systems must also be assessed against the latest damage-risk criteria for impulse noise. Data from a recent RTO/NATO study (2003) [13] generally indicate that the risk from small calibre weapons (or short impulse duration) are under-estimated using current damage-risk criteria based on CHABA [22, 23], while the risk from large calibre weapons (or long impulse duration) may be over-estimated. Moreover, no simple trade-off relationship to establish exposure limits could be found between impulse exposure level and number of impulses (a 5 dB reduction was proposed in CHABA for each ten fold increase in the number of impulses). The use of the A-weighted SEL is also favored by RTO/NATO to describe impulses instead of the peak level proposed by CHABA.

The SEL is the level of a constant sound lasting 1 sec that would contain the same amount of acoustical energy as the impulse. The concept is illustrated in Figure 1. The A-weighted SEL avoids the sometimes difficult assessment of impulse duration and peak level [13] with standard equipment, and can be easily used to calculate the daily noise exposure ($L_{ex,8h}$) using the equal-energy principle as follows:

$$L_{ex,8h} = SEL + 10 \log (N/28800) \qquad (1)$$

where SEL is the sound exposure level in dBA per single impulse, N is the number of impulses and 28800 is the number of seconds in an 8-hour period.

The RTO/NATO study [13] points towards the concept of a critical level that should not be exceeded, even for a single impulse. Critical limits based on 95% of the exposed population not exceeding a temporary threshold shift or TTS of 25 dB (averaged over 4 and 6kHz) two minutes after exposure (TTS_2) have been derived. The critical SEL appears to depend on the impulse duration properties. For small-calibre weapons (e.g. rifle) with A-durations in the range from 0.2 to 0.3 ms, the unprotected SEL limit per single impulse measured in the free field at normal incidence is 116 dBA, for up to N=50 impulses at a rate of one every 5-10 sec. From equation 1, COHS daily noise exposure limit of 87 dBA would be exceeded for N=35 impulses at a SEL of 116 dBA. Thus, COHS limits ($L_{ex,8h} \leq$ 87 dBA) must be supplemented with an additional SEL limit of 116 dBA per impulse for small-calibre weapons for up to 35 impulses.

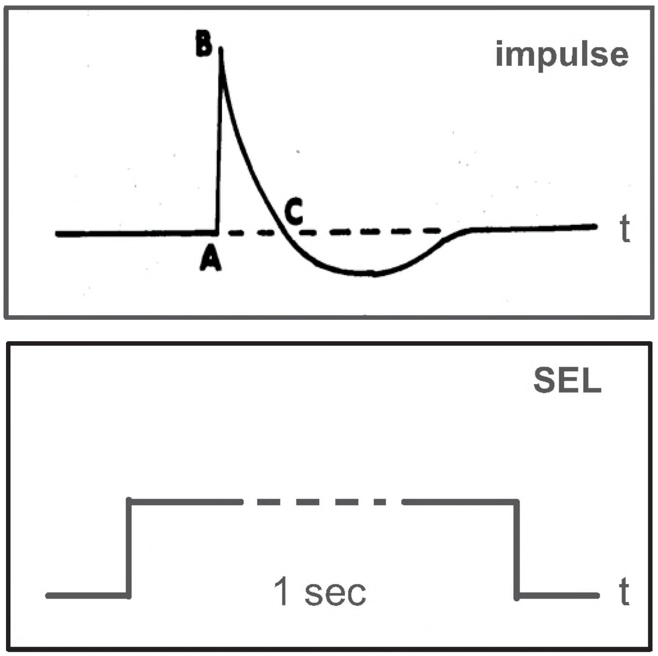

Figure 1: Example of a weapons impulse waveform (top) and equivalent SEL (bottom). The most common measure of impulse duration, the A-duration, is defined as the time from A to C.

For blast overpressures from explosions and large-calibre weapons with A-durations in the range from 0.9 to 3 ms, the protected SEL limit per single impulse measured at the ear under the hearing protector is 135 dBA, for up to N=100 impulses at a rate of one per minute [13]. From equation 1, only a single impulse at the critical level of 135 dBA under the protector would exceed COHS daily exposure limit. Thus, no additional provisions appear necessary beyond COHS limits ($L_{ex,8h} \leq$ 87 dBA) for large-calibre weapons.

2.1.6 Central noise database

Noise surveys related to all operational military equipment (ships, aircraft and vehicles) and weapons systems used at several DND/CF facilities should be included in a central noise database to be maintained and updated for access by all CF personnel involved in the implementation or evaluation of the HLP program.

- For ships, aircraft, army vehicles and other operational equipment characterized by steady-state or fluctuating noises, the equivalent sound pressure level (L_{eq}) in dBA and the octave-band frequency analysis in dB SPL will be included in the database for all measurement locations and operational conditions surveyed.
- For each weapons system, the sound exposure level (SEL) in dBA per single impulse will be included for all conditions of use and operator positions. It is also recommended to document the A-duration and instantaneous peak sound level in dBC until accepted damage-risk criteria are firmly established.

2.2 Engineering Noise Control Measures

Engineering noise control and abatement measures are the preferred method of reducing noise exposure to safe levels and are an integral part of an effective HLP program. No other prevention method can match the long-term health, safety and workplace communication efficiency benefits of a quieter environment. Noise control solutions can be achieved at the source (e.g. installation of silencers), along the transmission path (e.g. noise barrier, enclosure) and at the receiver (e.g. control booth around operator) [24].

Decisions and actions regarding the implementation of engineering noise control measures should be made immediately following recommendations from detailed, operational or impulse noise surveys (Section 2.1), and during the procurement process for all new and retrofitted equipment. When assessing the costs of engineering control measures, consideration must also be given to the long-term economic impact of not implementing them, and therefore having to address future compensation claims and rehabilitation measures for the exposed personnel.

The documentation for all new or retrofitted equipment and facilities should include noise performance specifications. The requirements should ensure that all state-of-the-art engineering control measures be considered to deliver the quietest possible products such that:

- Noise levels for all operators will not exceed 87 dBA during normal use, if technically feasible;
- Noise levels for all retrofitted equipment will not exceed levels before the retrofitting process; and
- All equipment exceeding the limit of 87 dBA will be supplied with: (1) measured noise levels in conformance with the detailed/operational or impulse noise surveys described in Section 2.1, (2) visible and permanent warning signs to indicate a risk to hearing; and (3) specific measures (e.g. hearing protectors) that must be taken to ensure exposure within safe limits.

2.3 Administrative Controls

Administrative controls refer to measures used to inform personnel of potentially noise-hazardous areas, and to staffing procedures used to further limit the duration and level of noise exposure once all engineering controls have been implemented.

The following procedures are required by COHS Part VII:

- Informing any personnel in writing of the potential risk to hearing whenever the daily noise exposure is likely to exceed 84 dBA;
- Evaluating the suitability of using hearing protectors when the daily noise exposure is from 84 to 87 dBA;
- The supplying of hearing protectors when the daily noise exposure is likely to exceed 87 dBA; and
- The installation of visible and permanent warning signs clearly identifying noise-hazardous areas where noise levels (slow weighting) are likely to exceed 87 dBA.

The following measures should also be considered:

- Restriction on the number of personnel required to enter noise-hazardous areas;
- Restriction on the time spent by the personnel in noise-hazardous areas and/or the adjustment or rotation of job schedules to lessen the exposure in a 24-hour or continuous period; and
- Increasing the distance between noise sources and the personnel whenever possible.

2.4 Personal Hearing Protection

2.4.1 Objectives

Personal hearing protection devices (HPDs) are to be used to reduce noise exposure only once all engineering and administrative control measures have been exhausted. HPDs must be carefully selected for optimal effectiveness in the workplace, taking into consideration the noise exposure, the attenuation achieved, the operational and environmental constraints, the auditory task requirements, and the user preferences.

2.4.2 Guiding principles

The calculation of the daily noise exposure ($L_{ex,8}$) for individuals at risks requires accurate noise level data from each hazardous site as well as duration of exposure data for each member [14]. In a working environment as complex as the military, the daily duration of noise exposures for each individual member in each hazardous site on a typical workday is very difficult or impossible to track down and estimate reliably. The work schedule is too variable from day to day, from month to month and from member to member to hope to obtain valid duration of exposure data (and thus valid $L_{ex,8}$ data) for each member or even for groups of members from which to base HPD decisions.

Instead, an approach based only on the level at each noise hazardous site is more suitable and practical for making HPD decisions in the military. In order to ensure that the daily noise exposure ($L_{ex,8}$) for all DND/CF personnel members do not exceed the regulatory limit of 87 dBA, the noise exposure ($L_{ex,T}$) at each noise-hazardous site should be made below 87 dBA by proper use of hearing protectors, irrespective of the duration of the exposure T. If noise exposure at each site visited during an 8-hr workday is below 87 dBA, then the daily exposure limit will not be exceeded. For working days longer than eight hours, the exposure level limit at each site needs to be decreased on the basis of a 3-dB exchange rate.

An approach to hearing protection by noise-hazardous site, as proposed here, is directly compatible with engineering and administrative noise control measures. Engineering noise control measures provide solutions to specific equipment or site facilities, not to specific individuals in a typical workday. Many administrative measures like warning signs and distance from noise sources also apply to specific areas or equipment.

2.4.3 Basic Methods and Application Issues

For steady-state or fluctuating noise, the selection of hearing protectors will be based on one of the three approved methods in Article 9.8 of CSA Standard Z94.2-02 [25].

Method 1: Grade or Class

Grades or Classes are assigned to hearing protectors based on attenuation data by the manufacturer.

- Grades (0-4) are assigned according to Appendix A in CSA Standard Z94.2-02 on the basis of attenuation data measured under Method B (subject fit) in ANSI S12.6-1997 [26].
- Classes (A-C) are assigned according to Table 3 in CSA Standard Z94.2-02 on the basis of attenuation data (experimenter fit) measured under ANSI S3.19-1974 [27]. It is to be noted that this standard has been withdrawn by ANSI. However, it is still widely used to calculate noise reduction ratings as required by the Environmental Protection Agency in the USA [28].

Selection based on grades or classes requires only the A-weighted noise exposure or sound level in the environment. The use of grades is preferred over classes. The latter are acceptable until a sufficient number of hearing protectors is tested under Method B in ANSI S12.6-1997.

Method 2: Single-Number Rating or SNR(SF_{84})

The single number rating (Subject Fit 84th percentile) or SNR(SF_{84}) provides a more accurate method based on a single value of attenuation (in dB) computed according to Appendix A in CSA Standard Z94.2-02 [25]. This number represents the protection achieved by at least 84% of users in a well-managed program.

The SNR(SF_{84}) rating can be used to calculate the resulting noise exposure after application of a hearing protector according to:

$$A = C - SNR(SF_{84}) \qquad (2)$$

where "A" is the A-weighted noise exposure or sound level in dBA when the hearing protector is worn, "C" is the C-weighted unprotected noise exposure or workplace sound level in dBC, and SNR(SF_{84}) is the hearing protector rating in dB.

Method 3: Octave-band (OB) computation

This method, described in Appendix B in CSA Standard Z94.2-02 [25], is the most complex method to select a hearing protector but it provides the best estimate of the A-weighted noise exposure or sound level in dBA when a hearing protector is worn. The OB computation is based on measurements of the one-octave band sound pressure levels describing the noise environment from 125-8000 Hz, and on the complete hearing protector sound attenuation data in third-octave bands from Method B in ANSI 12.6-1997 [26].

Table 1 lists the recommended HPDs to use according to the noise level. This table has been adapted from CSA Standard Z94.2-02 [25] to reflect the 87 dBA regulatory limit specified in COHS, instead of the 85 dBA limit assumed in the standard. When used, the SNR(SF_{84}) and OB methods should predict a resulting exposure level ≤ 87 dBA, and preferably in the range 77-82 dBA for optimal protection (i.e. 5-10 dB below the regulatory limit). Over-protection is not recommended as it can disrupt speech communication or detection/localization of important sounds [25]. Dual protection, where required for noise exposure ≥ 108 dBA, will consist of a minimum Grade 2 or Class B earmuff or helmet combined with a Grade 3 or Class A earplug. Unless measured dual protection attenuation data according to Method B in ANSI 12.6-1997 are available, the attenuation provided by dual protection can be assumed to be 5 dB higher than the highest attenuation of any of the two protectors in the combination [25].

Table 1: Recommended hearing protection devices (adapted from [25] to apply at each noisy site).

Level (dBA)	Recommended Hearing protection device(s)
≤ 84	not required
84-87	not required but shall be made available
88-92	Grade1/Class C **or** selected from SNR(SF_{84}) **or** OB method
93-97	Grade2/Class B **or** selected from SNR(SF_{84}) **or** OB method
98-102	Grade3/Class A **or** selected from SNR(SF_{84}) **or** OB method
103-107	Grade4/Class A **or** selected from SNR(SF_{84}) **or** OB method
108-112	Dual protection required; Exposure levels confirmed with SNR(SF_{84}) **or** OB method
≥ 112	Dual protection required Exposure levels confirmed with OB method Exposure duration limits may be required

Additional factors need to be considered when selecting and using hearing protectors to ensure optimal effectiveness in the workplace (Articles 10 and 11 in CSA Standard Z94.2-02) [25].

- The devices will be compatible with all other protective gear being used (e.g., hardhats, helmets, face masks, goggles);
- The physical durability and comfort of the devices will be compatible with the environmental constraints (e.g., extreme temperature, chemical agents);
- The devices will be compatible with the operational demands and auditory task requirements; and

All users will be provided with a range of devices to choose from, including different types and sizes of earplugs, to address comfort and preference issues

2.4.4 Special Measures, Devices and Methods

All CF weapons systems are potentially harmful to hearing, and permanent damage can occur from single impulses. This issue highlights the critical importance of proper use of HPDs in the field, so that their properties for protection against impulse noise from weapons do not render the wearer incapable of hearing shouted orders or radio/intercom communications.

- Hearing protectors will be used on all firing ranges and by all personnel in the vicinity of weapons systems;
- The area within which hearing protectors must be worn will be clearly indicated and enforced;
- The maximum number of daily rounds allowable per weapons system will be determined and limits will be adhered to, taking into consideration all other noisy activities during the day and the noise from other weapons systems on the firing range; and
- Special firing restrictions will be developed and enforced for each weapons system, where possible, to limit exposure (e.g., spatial locations or orientations of personnel that must be avoided with respect to the weapons system).

The actual protection achieved by hearing protectors against impulse noise from weapons systems may not be accurately reflected in the manufacturers' attenuation data (ANSI S3.19-1974 or ANSI S12.6-1997), as discussed in [13, 25]. The measurement procedures specified in the above standards are carried out with low-level continuous-type noises in a diffuse-field type environment, whereas weapons impulses may reach extreme peak pressures and strike at specific angles of sound incidence. Thus:

- Only a restricted set of approved hearing protectors will be used for protection against weapons systems; and
- The attenuation achieved by these protectors against specific weapons impulses will be confirmed under realistic conditions using special methods of assessing attenuation (see below). The recommended angle of incidence for assessing attenuation is 45° [13].

To determine the amount of protection achieved by special devices (e.g. active noise reduction, electronic sound restoration, level-dependent) or in special circumstances (e.g. impulse sounds from weapons systems), measurement methods based on ANSI S12.42-1995 (R1999) [29] are required. This standard specifies Microphone-in-the Ear (MIRE) and Acoustic Test Fixture (ATF) methods for measuring the attenuation of hearing protectors. Use of these special methods is warranted in situations where basic HPD selection methods (Section 2.4.3) are not suitable or cannot be used.

Communications headsets, with either passive or active noise-attenuation technology, pose a specific selection problem: How to account for the exposure that arises from the audio communication signal? Research at DRDC Toronto [30] shows the audio signal is typically set by the users to about 5-15 dB above the environmental noise permeating through the headset. The audio signal contribution to the overall exposure will also depend on the proportion of time that communications take place. Table 2 shows different listening scenarios at a signal-to-noise ratio of 10 dB during communications. The number in the second column is the additional exposure due to the audio signal over that from the environmental noise that is permeating through the communication headset or device. Thus, the second column indicates the additional attenuation required for the communication headset over that calculated from the environmental noise alone for the listed scenarios. Table 2 should only be used as a guide for initial assessment. The signal-to-noise ratio inside the headset set will depend on such factors as the quality of the audio signal, the spectrum of the noise and the hearing status of the user. Higher signal-to-noise ratios are typically required for individuals with hearing loss. Only CF-approved communications headsets will be selected in harsh environments after testing using realistic conditions of use.

Table 2: Estimated exposure from the combined audio signal and noise, assuming a signal-to-noise ratio of 10 dB during communications.

% Time Communicating	Exposure contribution over noise alone (dB)
100	10.4
50	7.8
25	5.4
10	3.0
5	1.8

2.4.5 HPD database

A central database of hearing protector data should be maintained and updated for access by all personnel involved in the implementation of the CF hearing loss prevention program and integrated with the noise database (section 2.1.6). The database will allow identifying proper HPDs given the environmental noise levels (either actual measurements or measurements from previous operational or impulse noise surveys).

- For steady-state or fluctuating noise: selection will be made according to one of the three methods in section 2.4.3.
- For impulse noise from weapons systems: selection will be restricted from a range of devices tested or approved by the CF for each weapons system. The maximum daily number of rounds (N_{max}) or events allowable will be included in the database. The latter will be calculated according to:

$$N_{max} = 28880 \times 10^{-(SEL-ATT-87)/10} \qquad (3)$$

where 87 dBA is the COHS noise exposure limit [15], SEL is the free-field sound exposure level in dBA per single impulse at the location of the noise-exposed personnel, and ATT is the measured or assumed attenuation (dB) of the hearing protector for the particular weapons impulse. When the SEL is measured under the protector, this SEL value is used instead of SEL-ATT in the equation above.
- For protection against small-calibre weapons (e.g. rifle), a minimum hearing protector attenuation (ATT) is necessary in addition to the N_{max} restriction in eq. (3) to ensure the critical level from RTO/NATO [13] is not exceeded for an impulse, as follows:

$$ATT \geq SEL - 116 \text{ dBA} \quad \text{(small-calibre)} \qquad (4)$$

where 116 dBA is the critical SEL limit for a single unprotected impulse. When the SEL is measured under the protector, then the protected SEL per single impulse will not exceed 116 dBA.
- For large-calibre weapons (e.g. blasts), the critical SEL limit of 135 dBA from RTO/NATO [13] per single impulse measured under the protector results in a daily exposure above 87 dBA, thus the N_{max} restriction in eq. (3) is sufficient to both meet COHS [14] and RTO/NATO [13] criteria.

2.5 Monitoring Audiometry

2.5.1 Objectives

Audiometric monitoring of the CF personnel at risk is needed to (1) identify and document the hearing status of individuals with hearing loss, (2) provide proper care, protection, employment follow-up for those who incur hearing loss, and (3) monitor the effectiveness of the HLP program. It important to note, however, that audiometric testing is not in itself a prevention method if there is no effective intervention to limit noise exposure, such as engineering and administrative control and hearing protection [24].

2.5.2 Reliability

There are reliability issues associated with the use of audiograms in occupational settings. Typically, the growth of permanent hearing loss is about 2dB/year for the first five years of exposure at 95 dBA/8hrs, 1dB/year for the next five years, and less than 1dB/year after 10 years [31]. Yet, the measurement accuracy for screening audiometry is around 10 dB in occupational settings [32], several times the potential yearly growth of permanent hearing loss in noise exposed individuals. Thus, noise-induced hearing loss may remain undetected for several years in an individual, and conversely, erroneous identification of hearing loss may occur despite any real change in hearing status.

Nonetheless, audiometric monitoring is required in the military setting, where the daily noise exposure of individual personnel is difficult to evaluate due to variable work schedules (Section 2.4.2), the efficiency of hearing protectors against weapons impulsive noise is poorly documented (Section 2.4.4) and the methods not yet standardized, and where permanent or temporary hearing loss can occur from a single intense acoustic event.

2.5.3 Procedures

Hearing examinations should consist of a recording of the noise exposure history (occupational and recreational) and an audiometric evaluation. There are three types of audiometric evaluations:

- A baseline audiogram will be conducted on all persons entering the CF, to serve as a reference for detecting any subsequent hearing threshold shifts. The baseline audiogram should always be conducted after at least 14 hours away from noise exposure (occupational or not), and within 30 days after initial noise exposure.
- A periodic audiogram will be conducted in conjunction with each periodic health evaluation (PHE) for the military personnel and upon request or following incidents that could potentially affect hearing. The periodic audiogram can be performed any time during the work shift (preferably late in the shift) so as to identify any TTS in hearing level before it becomes permanent. A "late-in-shift" audiogram is now often recommended as the best practice [6, 24]. Warning: The presence of TTS may only become apparent in noise exposed individuals with normal or near normal hearing. Individuals with hearing loss show decreased or no TTS for equivalent noise exposures [33]. Thus, the absence of TTS does not necessarily mean a safe workplace.
- A release audiogram will be conducted as part of the release medical for all persons leaving the CF. The release audiogram should be taken at least 2 weeks prior to departure from CF, to allow for follow-up.

Audiograms should be recorded with automatic audiometers to standardize the measurement process across CF facilities, and conducted by qualified personnel in quiet test environments not exceeding the maximum background noise levels specific in ANSI S3.1-1999 (R2003) [34]. Audiometers and calibration procedures should comply with CSA Standard Z107.4-M86 (R2001) [35].

The hearing thresholds must be determined by the Ascending method as described in CSA standard Z107.6-M90 (R1999) [36]. A trained physician, an audiologist, or an audiometric technician who has completed a certified military training comparable to the program certified by the US Council for Accreditation in Occupational Hearing Conservation must administer audiometric tests. Audiometric technicians must do the testing under the supervision of a trained physician or an audiologist. Upon completion of the audiogram, the examiner will explain the results of the hearing test to the personnel member.

2.5.4 Data interpretation and actions

A computerized record keeping system should be put in place to automatically identify hearing conditions requiring follow-up. It is highly recommended to use audiometers that allow automatic transfer of data in a format compatible with the computerized record keeping system, to minimize potential errors associated with manual transfers.

A standard threshold shift (STS) due to noise is to be defined as a change in the baseline audiogram of 15 dB or more at 500, 1000, 2000, 3000, 4000 or 6000 Hz, in either ear. This definition of STS calculation is the same as that recommended by NIOSH [37], but differs from other definitions based on averaging the threshold shift over a limited set of frequencies (typically at 2000, 3000 and 4000 Hz) as discussed in [24]. The criterion recommended here covers a wider range of frequencies and will generally be more sensitive in detecting early noise-induced hearing loss progressing from the higher frequencies to the lower frequencies.

Upon completion of an audiogram, the member and his/her supervisor are immediately notified in writing of any STS result. A follow-up audiogram is required as soon as possible but not more that 30 days after the first STS identification. This follow-up audiogram must be done after at least 14 hours away from noise:

- If the STS is confirmed after this second audiogram, the member and his/her supervisor are notified in writing within 21 days. In such cases, appropriate hearing prevention activities must be implemented to limit further hearing damage.
- If the STS is not confirmed after a rest from noise, the employee and the supervisor must be informed that the STS result identified after the first audiogram could have been the result of a temporary hearing loss. In such a situation, the monitoring of noise levels, the use of engineering and administrative noise control measures and the proper fit of the hearing protectors must be reassessed in order to avoid further temporary threshold shifts and prevent the future occurrence of a permanent hearing loss.

If a STS is detected and confirmed (or whenever the average hearing threshold levels at 1000, 2000, 3000 and 4000 Hz are greater than 25 dB HL in either ear), the member must be referred to a physician and an audiologist in order to fulfill a complete medical and audiological examination of his/her hearing system. As needed, hearing aids and rehabilitation services will be made available.

2.6 Education

An educational component is required (1) to ensure the CF personnel is aware of the effects of noise on health and safety, and (2) to explain the advantages and limits of each element contained in the HLP program.

Training should be provided to all personnel whose essential job requires working in areas where noise levels are in excess of 84 dBA. To ensure maximum effectiveness of the program, all personnel must be aware of the possible effects of exposure to hazardous noise and the correct procedures to follow to eliminate or minimize these harmful effects. The Education program should be provided annually and cover:

- The effects of noise on hearing;
- The purpose, advantages and limits of engineering and administrative noise controls;
- The purpose, advantages and disadvantages of the various types of hearing protectors;
- The selection, fit, care and use of hearing protectors;
- The interpretation of warning signs; and
- The purpose and procedures of audiometric evaluations.

The education program is a continuous process initiated at the recruit level and continued at the unit and base levels. In the military environment, a major challenge is to ensure continuity in the training process, given the mobility of the work force, the variable work schedules, and the distributed responsibility for the different elements mentioned above.

2.7 Program Evaluation

The objective of program evaluation is to assess or monitor the effectiveness of the HLP program in preventing hearing damage in the CF personnel. The use of general program evaluation tools based on audiometric databases [38] is questionable in the military environment, where exposure can vary widely across workers and is highly variable over time (Section 2.4.2). Instead, specific activities can include but should not be limited to (1) the identification of high-risk tasks or military occupations, (2) the field evaluation of the attenuation of hearing protectors, and (3) the validation of impulse noise damage risk-criteria and prevention measures.

2.8 Documentation

The critical documents (acoustical standards, regulations, etc.) necessary to implement the daily procedures contained in the HLP program should be easily accessible by the responsible base personnel. In addition to a copy of the HLP program, these include references [14, 15, 25, 35].

3. DISCUSSION AND CONCLUSIONS

In the military, the importance of accurate noise surveying, engineering and administrative noise controls, proper fit of hearing protection and regular audiometric monitoring of the hearing of exposed personnel cannot be over-emphasized. It is only through the utilization of all available methods that the hearing of the personnel will be protected.

The hearing loss prevention program described in this paper is based on current scientific knowledge of noise-induced hearing loss and damage-risk criteria, and on evidence-based practices for hearing conservation in industry. It also reflects major findings from past reviews of the current hearing conservation policy in the CF and complies with Canadian federal regulations. A draft policy based on this proposal is currently under review by DND/CF. Considerations of costs, operational constraints during military operations, and other implementation and personnel issues must be factored in a final policy.

The success of any hearing loss prevention program, such as the one proposed here, requires the contribution of a large number of civilian and military personnel for the implementation and interpretation of the various program elements. The program can only be fully effective if the personnel are given clear lines of responsibility for each task, and that provisions are made to coordinate their effort into a cohesive endeavour throughout the CF. Care must also be taken to ensure the program is regularly reviewed and kept up to date as new scientific evidence, regulatory documents and acoustical/noise standards are being published or reviewed.

Finally, the current proposal does not specifically address factors other than noise that can affect hearing in the workplace. These factors include excessive vibration and infrasounds, ultrasounds, and ototoxic agents like organic solvents, heavy metals and certain gases [39]. Likewise, the proposed hearing prevention program does not address the issue of fitness to work, only the prevention of hearing loss. The issue of hearing fitness is addressed elsewhere [40].

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