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THE HAZARD OF IMPULSE NOISE

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THE HAZARD OF IMPULSE NOISE

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ABSTRACT

At the Ninth Commonwealth Defence Conference on Clothing and General Stores, Canada presented a paper (CDA 3A and 3B) which discussed the policy and implementation of a Hearing Conservation Programme for the Canadian Forces, the conduct of sound surveys and the measurement of noise with particular reference to steady state noise. The introduction of certain new weapons has been accompanied by very high levels of impulse noise. The present paper discusses the measurement of impulse noises, damage risk criterion for impulse noise and the use of protective devices by personnel.

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INTRODUCTION

1. The immediate effect of high intensity impulse sound upon the auditory system is a threshold shift, sometimes referred to as auditory fatigue. The shift is measured in terms of the difference of an individual's hearing level before and after the sound exposure. That is, the shift is the change in the sensitivity of the ear to just detect a pure tone of a given frequency.

2. The magnitude of the shift depends on the peak pressure of the impulses, the pressure-wave or pressure-envelope duration, and the number of impulses per exposure. The rise time (i.e. spectrum energy) of the impulse is also a potentially significant variable. It is hardly necessary to add that the threshold shift varies considerably among individuals, and from time to time for any given individual.

3. After the sound exposure, the elevated hearing level usually returns to its pre-exposure level. Shifts of this type, for obvious reasons, are termed temporary threshold shifts, or TTS. The recovery time-constant is such that TTS not greater than about 40 dB will disappear in less than 24 hours. For a TTS greater than this, recovery time can extend into several days, or even weeks.

4. Daily exposure over a period of years to sound of sufficient intensity will eventually result in the inability of the ear to recover its pre-exposure hearing level; that is, the TTS gradually becomes

permanent. Mind you, a single exposure to sound of sufficient intensity can produce an immediate permanent threshold shift (PTS).

(1) DCIEM Research Paper No. 836

DAMAGE RISK CRITERION FOR IMPULSE NOISE

5. The National Academy of Sciences-National Research Council (US) Committee on Hearing, Bioacoustics, and Biomechanics (commonly referred to as CHABA) has attempted to protect individuals exposed to high intensity impulse and steady-state sound by specifying safe limits for such exposures. In so doing, it has assumed that exposures that produce equal amounts of TTS (measured 2 minutes after an exposure) eventually produce, if repeated on a near-daily basis over a course of about ten years, approximately the same amount of PTS. This assumption, while difficult to test, is not at all unreasonable.

6. The proposed CHABA criteria for impulse noise specifies acceptable exposure levels for two types of waveform duration. A pressure-wave duration, termed A-duration in the criteria, is the time required for the initial or principal pressure wave to rise to its positive peak and return momentarily to ambient pressure. An ideal pressure wave is shown in Figure 1; the time duration is given by the distance on the time axis (C-A) (CHABA, 1968).

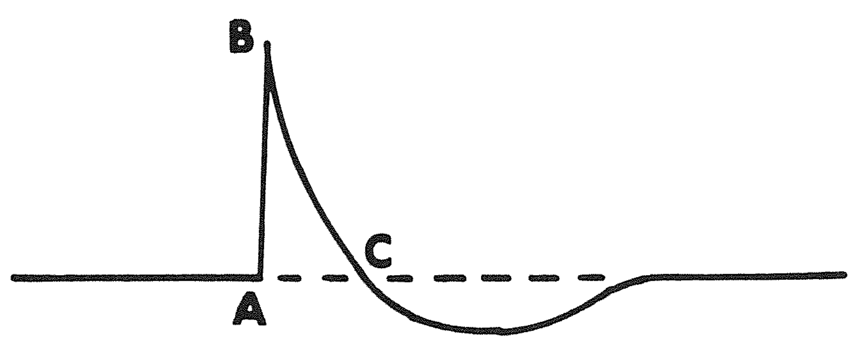

Figure 1

7. A pressure-envelope duration, termed B-duration in the criteria, is the total time that the envelope of the pressure fluctuations, both positive and negative, are within 20 dB of the peak pressure level. Included in this time is the duration of that part of any reflection pattern that is within 20 dB of the peak level. In Figure 2 an ideal pressure-envelope is illustrated; the B-duration is the time (D-A) (F-E). When pressure reflections are present therefore, the B-duration is the appropriate pulse duration to consider; it is the sum of the incident and reflected pressure-envelope durations.

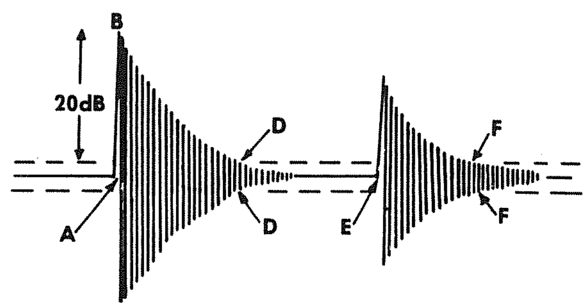

Figure 2

8. The proposed CHABA criteria are shown graphically in Figure 3, and sets acceptable peak-pressure exposure limits for a sound wave impinging on the ear at normal incidence, as a function of either the A or B pulse duration. It is considered that below these limits, 95 percent of the exposed normal-hearing population will not sustain a temporary (TTS) or permanent threshold shift greater than 10 dB at or below 1 kHz, 15 dB at 2 kHz, and 20 dB at or above 3 kHz. Exposures that exceed any of the specified limits may be considered as potentially dangerous in the long term for the majority of exposed individuals.

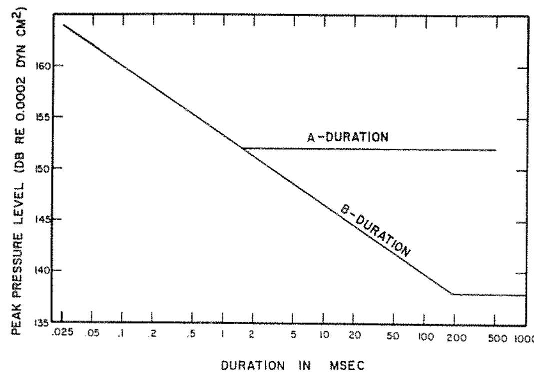

Figure 3

9. Impulse sounds that arrive at the ear of an exposed individual at normal incidence are more dangerous than those arriving at grazing incidence. With grazing incidence exposure, 5 dB may be added to the permissible peak pressure level of an impulse of a given duration. When an individual is firing a weapon on a range for example, his ear receives the impulse from his own fire at grazing incidence; he receives the impulse from his neighbour's fire at about normal incidence. Thus, greater damage frequently occurs to an individual's hearing from weapons other than his own.

10. The acceptable limits of exposure that are shown in Figure 3 are based on an exposure of 100 impulses per day. When the number of impulses is different than this, the CHABA criteria allow an adjustment of 5 dB in permitted level for each ten-fold change in the number of pulses. An exposure of 1000 impulses per day would therefore reduce the permitted levels by 5 dB. An exposure to a single impulse per day would permit the appropriate peak pressure level to be increased by 10 dB.

11. It has been suggested more recently that this correction is too conservative for exposures of less than 100 impulses, and not safe enough for impulse exposures exceeding 100 (Coles and Rice, 1970). A more realistic correction would reduce the permitted levels by about 20 dB (instead of 5 dB) for an exposure of 1000 impulses, and increase the permitted levels by 15 dB (instead of 10 dB) for a single exposure per

day. The corrections are shown in Table 1 and should be added to the permissible peak pressure level of the impulse.

TABLE 1

CORRECTIONS FOR ACCEPTABLE LIMITS OF IMPULSE EXPOSURE WHEN DAILY EXPOSURE IS MORE OR LESS THAN 100 IMPULSES

Number of impulses per day	Correction in dB
1	+ 15 dB
10	+ 11 dB
20	+ 10 dB
50	+ 5 dB
100	0
200	- 5 dB
300	- 10 dB
500	- 15 dB
1000	- 20 dB
2000	- 25 dB
5000	- 30 dB

IMPULSE NOISE MEASUREMENT

12. The measurement of certain of the parameters upon which the CHABA damage-risk criteria are based is not a trivial task, and in effect requires the determination of the pressure-level time-history of the impulse. The peak pressure of the impulse which one measures with an impulse sound level meter cannot be used by itself to provide all the required data.

13. The recommended method of determining the required impulse waveform is shown in Figure 4 (Coles and Rice, 1966; Coles et all, 1968). Two transducers, which may be piezo-electric free field incident

pressure gauges or condenser microphones of appropriate sensitivity and frequency response (Garinther and Moreland, 1965), are employed in this procedure.

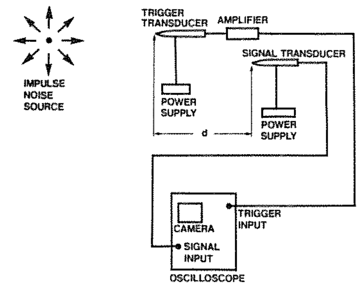

Figure 4

14. The transducer nearest the noise source (the trigger transducer) provides a trigger pulse for the oscilloscope. Amplification of this signal may result in improved trigger stability. The second transducer (the signal transducer) provides the vertical input voltage for the oscilloscope. A processed photographic record of each impulse can be obtained immediately after a weapon firing by employing an oscilloscope camera with Polaroid film.

15. The variable distance d between the trigger and signal transducers produces an optimal oscillosgraphic display as required. For each foot of separation, approximately .9 msec of delay occurs between the start of the triggered oscilloscope sweep and the leading edge of the displayed impulse waveform on the screen. The required delay value is determined by the desired time scale of the display (i.e. the horizontal sweep rate of the oscilloscope) and the impulse duration of the signal.

16. A typical impulse-noise pressure waveform is shown in Figure 5. The weapon producing the impulse is a 105mm Pack Howitzer with muzzle brake, using stock 105mm HE ammunition at charge 7. The pressure transducer employed was a Susquehanna Type ST-7 lead metaniobate gauge, located

40 ft from the weapon breech on a line 135 degrees from the line of fire (Forshaw and Crabtree, 1971). The weapon was fired from inside a test firing bay, the side and back walls of which produced the three large reflections occurring 10, 25 and 40 msec after the incident impulse, and the multiplicity of small reflections occurring well beyond 200 mes.

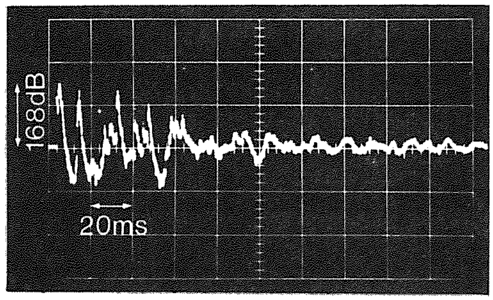

Figure 5

IMPULSE-NOISE HEARING PROTECTION - OPERATIONAL CONSIDERATIONS

17. When an impulse sound exceeds a relevant safe limit, as specified by accepted damage risk criteria, the peak pressure reaching the inner ear of an individual should be reduced to an acceptable level by some type of hearing protection device. The amount of protection provided against impulse sound by an ear plug or circumaural earmuff is not precisely known. Estimates range from about 20 to 35 dB, depending on the effectiveness of the fit (Coles et al, 1968).

18. The use of these devices is often unacceptable in combat situations, however, because the loss in hearing sensitivity that they produce cannot be tolerated. Patrol and sentry activities, particularly at night, require an optimum level of hearing. In operations dependent upon effective voice communications, verbal commands must be correctly understood when given during the low ambient-noise periods between the high level impulses. Moreover, it is not always practical to remove protection devices during such low-noise intervals.

19. At the same time, however, it is operationally desirable to protect combat personnel from TTS. This loss in hearing sensitivity lasts for many hours and is potentially as dangerous as might be the attenuation of a hearing protective device.

20. An ideal device should protect the wearer against high intensity sound capable of producing significant TTS, and yet permit low level ambient sounds to be perceived normally. One such device (the Gundefender ear plug) has been developed at the Royal Naval Medical School, Alverstoke, England, and is a modified V-51R ear plug with a 0.025-inch diameter opening into the wearer's ear canal (see Figure 6).

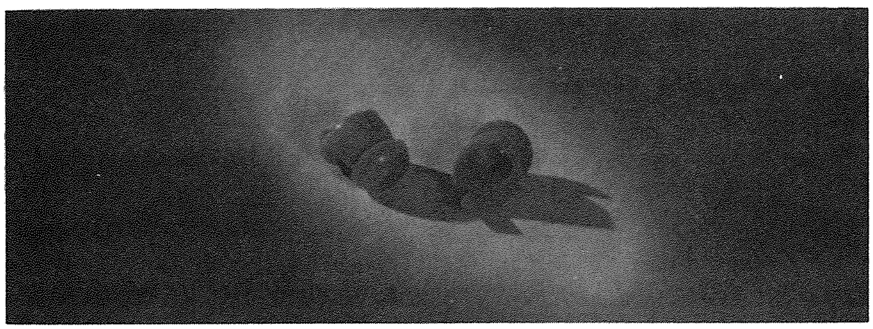

Figure 6

The combined opening and ear canal volume act as a Helmoltz resonator at low sound intensities. Sound attenuation should therefore not occur below the cut-off frequency of the system (in this case 1000Hz), and attenuation above this frequency can be expected to increase at a rate of 12 dB per octave to some limiting value (in this case about 20 dB).

21. At sound pressure levels above about 110 dB the acoustical impedance of the small opening in the ear plug increases progressively (the laminar flow through the opening becomes turbulent), resulting in a decrease in the acoustical energy entering the ear canal. Measurements made in a cadaver-ear preparation indicate that the peak pressure reduction of sound impulses by the device increases from 10 to 20 dB as the peak

pressure level increases from 140 to 180 dB (Forrest and Coles, 1970).

22. Recent field evaluations by Forrest and Coles indicate, in fact, that the Gundefender ear plug is as effective as the V-51R in preventing TTS from short-duration impulse noise at least, and may be used successfully in such impulse-noise environments in which steady-state noise levels do not exceed 90 dBA.(2) Unfortunately there is one limitation to the uses of the device at present; it is not available in extra large and extra small sizes. Consequently not all personnel can be fitted adequately with the Gundefender ear plug and these persons will require alternative protection.

(2)A weighting network is an electrical network incorporated in the amplifying circuits of measuring instruments (e.g. sound level meters) to produce a specified electro-acoustical frequency response. The "A" weighting network of the sound level meter, for example, approximates the 40-phon loudness contour, while the "C" weighting network approximates a uniform response over a specified range of frequencies. The sound pressure level of a sound, expressed in dB, is assumed to be C-weighted unless specified otherwise. Sound pressure levels with A-weighting are expressed as dBA.

NOISE EXPOSURE GUIDELINES

23. Clearly, the CHABA damage-risk criteria for impulse noise does not lend themselves as such for use in the military environment where personnel are not always trained in the use of precision instrumentation and measuring equipment.

24. Rather, it is more convenient for military users to consult non-hazardous exposure guidelines, specified in terms of the maximum number of

rounds per day with standard-issue hearing protection devices, as a function of exposure location around each weapon or class of weapon currently in the arsenal.

25. Exposure guidelines of this type were first published by the Army Personnel Research Establishment in England (Elwood, Brasher and Croton, 1970) and included daily exposure limits for both steady-state and impulse noise. Similar guidelines have also been published for the Canadian Forces (Forshaw, 1970), and are based on weapon-impulse and vehicle steady-state noise measurements, and currently estimated limits of non-hazardous exposure.

26. Typical exposure limits presented in the guidelines are listed in part as follows:

(1) 88mm CARL GUSTAV Anti-Tank Recoiless Rifle

An individual wearing adequate hearing protection (properly fitted ear plugs at the very least) may not be exposed to more than five rounds in a two-minute interval. Such an exposure must be followed by a two-hour recovery period in an area where the ambient noise level does not exceed 90 dBB (or equivalent), and the total exposure in any 24-hour period must not exceed 20 rounds.

(2) 105mm Tank Gun

Crewmen, instructors, and observers in close proximity to the tank, when properly protected, may not be exposed to more than 100 rounds of fire per day. When a number of tanks are firing simultaneously, the tank commander is in a particularly hazardous position in the hatch of his vehicle. He is not only exposed to the sound impulses from his own weapon, but also from those of neighbouring weapons. During such operations, tanks should be spaced not less than 100 feet apart and should not be within 50 feet of built-up areas and structures that can reflect blast waves back onto the vehicle.

27. These guidelines have been distributed to the Command Surgeons and other interested persons in the Canadian Forces, particularly the commanders of operational training units. Realistically we do not expect a document of this nature to be received with overwhelming enthusiasm by operational people. Quite reasonably, their attitude towards a task or mission is governed by considerations for its success, and men who are trained and dedicated accordingly will permit or tolerate noise exposure when necessary, regardless of its potential hazard.

28. Moreover, and this is probably one reason why there has been difficulty in selling hearing conservation in many civilian as well as military operations, when a deafened individual is working in the noise environment, his hearing loss does not (for most occupations at least) handicap his performance. Unless it can be demonstrated that temporary or permanent hearing loss does compromise the effectiveness of a military operation, the cost and effort necessary to control noise or minimize its effect on personnel will not usually receive high priority.

NOISE HAZARD REDUCTION

29. For the moment, at least, we must therefore accept the fact that combat personnel in the Canadian Forces may be subjected to noise levels in excess of currently estimated limits of non-hazardous exposure. At the same time, however, there are a number of measures that can be reasonably adopted to at least minimize the risk of noise induced hearing loss.

(1) The noise hazard associated with each weapon or vehicle can, for example, be identified and defined explicitly (Forshaw, Coffey and Stong, 1972). For if there is any flexibility at all in a training operation and the unit commander or course director wishes to minimize its inherent noise risk, he must have the relevant information with which he can realize the most effective reduction in the risk at the least cost and disruption to his program.

During tank-gunnery training, for example, one can limit the daily exposure of personnel to noise (particularly instructors) either by increasing the number of instructors at a school (thereby restricting the firing-range noise-exposure of each instructor to a one-half or one-quarter day, as suggested by the given weapon noise-exposure guideline), by extending the length of the courses (thereby limiting the required daily noise exposure of personnel to certain weapons), and/or extending the weapons range facilities to increase the distance between weapons that are firing simultaneously.

(2) Further, an individual who is subjected to excessive levels of noise must be provided with hearing protection/communication equipment that is both effective and compatible with the operation or task he is required to perform. If a soldier must maintain an optimum level of hearing and yet be protected from the TTS that results from exposure to high levels of impulse noise, he must have special purpose

equipment such as the Gundefender ear plug.

(3) More important, the individual must be made aware of the nature and effects of noise exposure and instructed in the correct use of the equipment provided to protect him from the effects of that exposure. The importance of effective and continuing programs of instruction and education in these matters cannot be over-emphasized. A soldier must understand, for example, that when he arrives on the firing range without his ear plugs, he cannot expect to receive effective protection when he borrows his buddy's ear plugs unless they are the same size. He must understand that when his artillery tank or anti-tank weapon has completed firing, he must continue to wear hearing protection at least as long as neighbouring weapons on the range continue to fire. He must realize that modified ear plugs such as the Gundefender do not provide protection from the steady-state noise generated by helicopters, armoured personnel carriers, diesel generators, etc.

MONITORING AUDIOMETRY

30. When considering any program of hearing conservation, one must realize that it is almost impossible to specify practical maximum-noise levels and exposure times that will ensure safety for everyone. In any group of persons subject to the same average noise environment, a small percentage will develop relatively large amounts of permanent hearing loss, even though the group average itself is acceptably small. A few individuals are highly susceptible to noise-induced hearing loss, and as yet there are no accurate and simple tests available by which such persons can

be identified in advance.

31. In the industrial and military environment where noise exposure is more or less controlled within some accepted non-hazardous limit, it is considered desirable to identify personnel who nevertheless sustain significant and irreversible hearing damage. In the combat situation where soldiers may be routinely exposed to noise levels in excess of the CHABA non-hazardous limits, it is crucial that the overly susceptible individual be identified as early as possible in his career.

32. At the moment, this can only be done with a program of pre-enlistment and monitoring audiometry. That is, the hearing thresholds of all personnel exposed to hazardous noise should be checked periodically. At the first sign of a significant deterioration of a person's hearing level, that person should either be provided with more effective protection, or be removed from the noise environment. As long as we are forced to accept excessive noise-exposure risks in our routine training and operational activities, a safeguard program such as monitoring audiometry is the only way to protect those individuals who will otherwise end their military careers with permanent and significant hearing impairment.

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