IMPULSE NOISE ATTENUATION: HEARING PROTECTION AND COMMUNICATION IN A MILITARY ENVIRONMENT

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Abstract

Military training creates unique noise hazards including high impulse noise content. The need for hearing protection needs to be considered alongside the need for effective voice communication. This requires a hearing protector with high impulse protection that minimally impedes low intensity voice communication. These level dependant devices are called non-linear hearing protectors. A range of commercial plugs both linear and non-linear and one home made non-linear plug (a modified commercial plug) were tested to determine the suitability of each against the criteria stated above. Two commercial plugs were identified as possibly suitable and interestingly the home made plug performed comparably to these plugs. This study provides direction for future research to determine the best hearing protector for military situations taking into consideration level of protection, need for communication, operational suitability and cost.

Introduction

In both training and combat-like operations land based military units are exposed to unique noise hazards. The levels and types of military noise exposure are variable, ranging from steady state noise in vehicles to high intensity impulses from a variety of weapons. Steady state noise can reach up to 90 dB (A) during an infantry contact, with impulses from small arms peaking in the range 140 - 160 dB (C)[1].

Since these activities are the 'bread and butter' of land based military units, the associated exposures generally cannot be engineered out. Thus, the solution is found in the last step of the hierarchy of occupational noise exposure controls, that of personal protective equipment (PPE). The use of PPE for hearing protection in military training is an issue of great contention. It is of some benefit to briefly examine the debate to provide the context for the current study.

One popular attitude within the military argues that training must simulate battle as accurately as possible, including loud noises. This means that the most realistic training involves hazardous noise exposures. The counter argument is that why risk the hearing of service personnel when not necessary. This entails effective noise hazard control preserving the hearing of service people until it is operationally impracticable to do so. Bearing this in mind, the Australian Defence Force (ADF) has, in line with current occupational health and safety legislation, made a commitment to reduce noise exposure. Due to the Occupational Health and Safety principle of "duty of care" the need for personal protection must prevail.

Legal obligations and current exposure standards

In order for the ADF to fulfill its statutory obligations under the Occupational Health and Safety (Commonwealth Employment) Act 1991 it needs, where reasonably practicable, to protect the health and safety of its employees[2]. This means that the ADF must reduce the noise exposure of its soldiers, sailors and aircraftmen and women to acceptable levels.

The noise exposure limits for ADF personnel are set out in *Occupational Noise Management in the Defence Organisation*[3]. This states that the noise exposure limits are 85 dB eight-hour equivalent continuous, A-weighted sound pressure level ($L_{Aeq,8h}$) for continuous noise and 140 dB C-weighted sound pressure level ($L_{C,Peak}$) for impulse noise[3, p 3].

There is some debate surrounding the appropriateness of such standards for military noise exposure. The current standard is modeled on a civilian full time worker, working an eight hour day, having 16 hours of relative quiet and two days of rest a week[3,p 1]. This is in many cases not the kind of work routines service personnel experience, in peacetime or in operational situations. There is a similar debate regarding the appropriateness of such standards for civilian shift workers. One hypothesis suggests that military noise exposures need to be averaged not over eight hours like normal workers, but perhaps over a whole year, as military activities usually have a yearly cycle[4]. This would lead to an improved model of informed occupational exposure limits for military environments. Since no such exposure limits exist, the ADF is left no choice but to use the current, albeit imperfect, exposure standard. This must suffice as a first approximation until an improved or more appropriate noise exposure standard can be developed.

Current conventional hearing protection

Due to the differences in exposure levels the Australian military environment requires either many different types of hearing protectors or alternatively a multi-purpose hearing protectors catering for all needs.

Conventional linear hearing protectors operate by attenuating the noise levels outside the ear by a certain amount dependant on the design. The rating of these hearing protectors is derived from the level of attenuation that the device offers the wearer. The level of attenuation of these types of hearing protectors does not vary greatly, if at all, as a function of amplitude. In contrast, non-linear hearing protectors have different levels of attenuation dependant on both the frequency and amplitude of the noise. These devices are of great interest to the military.

The ideal hearing protector for the ADF would be one which has zero attenuation at low continuous noise levels, permitting effective communication, but increasing attenuation as the level of the noise grows, with maximum attenuation for impulsive noise. Current technology can meet this goal but it tends to be expensive.

This type of hearing protector would not be limited in application to the military. Many other industries and groups could benefit, such as recreational and sports shooters, or occupations involving explosive powered fastening tools.

Speech intelligibility and hearing protection

One of the biggest drawbacks of hearing protectors in military environments is the reduction in speech intelligibility. This is important as instructions and orders must be clearly understood in exercises involving live weapon fire. If hearing protectors interfere with communications, there is a risk that the hearing protector will be either poorly fitted or not worn by the individual[5]. With this in mind a hearing protector that reduces exposure to impulse noise to acceptable levels and allows effective communication would be of advantage. The balance is between effective protection and communication.

Study Aim

This study examined the properties of a number of different types of hearing protectors (earplugs) in impulse and continuous noise, and was divided into two test groups. Group One examined: a commercial non-linear (level dependent) earplug (which also has a solid side which will be tested) ('CAE non-linear' and 'CAE solid' respectively); a commercial solid foam earplug currently in use in the ADF ('Classic'); a home-made version of the non-linear plug ('HM'); and a commercial audiological test plug insert ('Insert'). Group Two briefly examined the plug range of commercial linear ('solid') and non-linear ('1mm', '680 Ohms', '1500 Ohms', '2200 Ohms', '4700 Ohms') personally moulded plugs.

Methodology

Due to time and project constraints the plugs were tested only for continuous and impulsive noise. No octave or 1/3 octave band testing was carried out.

Each plug type was tested for its performance at a number of different amplitudes of continuous broadband noise and also tested for performance in high-intensity impulse noise. The levels against which the hearing protectors were evaluated are those stated in *Occupational Noise Management in the Defence Organisation* [3, p 3].

The attenuation measure used in the testing is Insertion Loss (IL). IL is the attenuation of the noise level in the ear canal without and with the hearing protector. This provides a good indication of effectiveness.

Test Plugs

- Combat Arms Earplug (CAE): The commercial Combat Arms Earplug is a double sided plug designed for military applications. The design is based on the flanged EAR Ultra Fit plug. The solid side (olive) is designed for use in high continuous noise for the highest level of attenuation. The non-linear side (yellow) is designed for use where the primary noise hazard is impulsive and where communication is necessary.
- Homemade (HM) non-linear plug: A standard EAR Classic foam plug which has a 1mm internal diameter silicon audiological tube through its centre.
- EAR Audiological Insert: An audiological plug for testing hearing in high noise backgrounds. A foam plug with a rigid tube with an internal diameter of approximately 2mm.
- EAR Classic: A foam plug currently in service in the ADF.
- Phoenix Solid: A tapered version of a personally moulded solid plug.
- Phoenix 1mm: A tapered version of a personally moulded plug with a 1mm tube through its centre
- Phoenix with filters: Tapered versions of personally moulded plugs, each with a different filter (rated 680 Ohms, 1500 Ohms, 2200 Ohms and 4700 Ohms)

Continuous noise was measured using a B&K model 2231 SLM with a B&K 4165 microphone. The “in-ear” measurements were conducted using the Knowles Electronics Mannequin for Acoustical Research (KEMAR) and Zwizlocki coupler together with a B&K 4134 measuring microphone, a B&K 2804 microphone power supply connected to a B&K 2231 SLM.

Test conditions for each group are listed in *Table 1*. Different sample sizes were used for the two test groups as the Phoenix devices were only made available after the main testing had been completed. Time limitations mean that the Group Two devices were only tested at a single level of continuous noise 90 dB(A) and for only five impulses.

The continuous levels were chosen to represent typical noise exposures to soldiers during training. Continuous noise levels can reach up to 90 dB (A) during an infantry contact and speech is around 65-70 dB (A) (louder for shouting). The levels chosen reflect both these situations.

A starting pistol was used to simulate impulse noises to which soldiers are exposed, primarily small arms fire. Small arms generally produce peak noise levels at around 140 - 160 dB(C) at the shooter's ear.

Condition		Group One	Group Two
Plugs tested		-CAE non-linear side ('CAE non-linear') -CAE solid side ('CAE solid') -Home made non-linear plug ('HM') -EAR Insert ('Insert') -EAR Classic ('Classic')	-Phoenix solid -Phoenix 1mm -Phoenix 680 Ohms -Phoenix 1500 Ohms -Phoenix 2200 Ohms -Phoenix 4700 Ohms
Impulse Noise	**Type**	Cap pistol	Cap pistol
	Levels	134 to 146 dB (un-weighted) (Mean =142 dB, SD = 2.0)	136 to 143 dB (un-weighted) (Mean =141 dB, SD = 1.5)
	Sample size for each plug	10	5
Continuous Noise	**Type**	Broadband pink noise	Broadband pink noise
	Levels	70, 80 ,90, 95, & 100 dB (A-weighted)	90 dB (A-weighted)
	Duration	60 seconds	60 seconds

Table 1
Test conditions

Results

Group One

The mean IL for group one plugs at each level of continuous noise are illustrated in *Figure 1*.

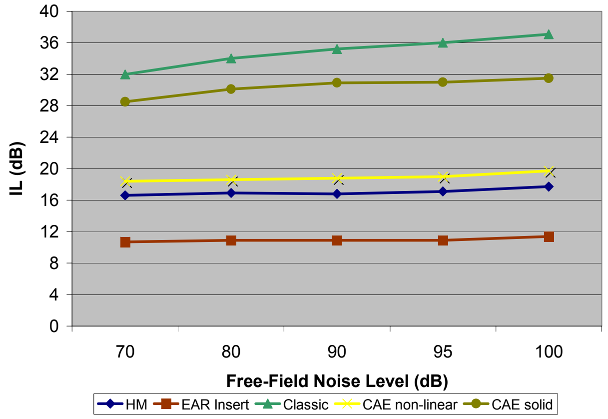

Figure 1
Mean insertion loss for Group One devices for continuous A-weighted noise

The mean insertion loss attenuation values for the impulsive noise response for Group One devices are:-

Device	**Mean IL** (dB)	**SD** (dB)
HM	31.1	1.4
EAR Insert	19.5	1.7
Classic	54.4	0.8
CAE non-linear	31.4	1.6
CAE Solid	44.7	1.5

Group Two

The mean insertion loss and attenuation for impulsive noise and continuous noise presented at 90 dB(A) for Group Two devices are:-

GroupTwo Device	**Mean IL** (dB) Impulse noise (SD)	**Attenuation**(dB) Continuous noise
Solid	40 (1.2)	37
1 mm tube	25 (0.8)	18
680 ohms	14 (1.4)	18
1,500 ohms	20 (1.4)	22
2,200 ohms	20 (2.5)	24
4,700 ohms	22 (0.8)	28

Discussion and conclusions

The hearing protectors in Group One performed generally as expected. The most interesting finding from these results is in the comparison between the CAE non-linear and the HM plugs. The CAE non-linear plug achieved an IL range of 18-20 dB over 70-100 dB(A) and the HM plug achieved only slightly less than this (17-18 dB over 70-100 dB(A)).

The plugs in Group Two provided interesting and unexpected results in 90 dB(A) continuous noise. As would be expected the solid plug had the highest IL, with the filter plugs having IL values proportionate with their rating. However, the lowest rated plug (680 Ohms) had an almost identical IL with that of the Phoenix 1mm plug.

The impulse performance of the Group One plugs was comparable to the continuous performance. The mean IL for the CAE non-linear and the HM plugs were practically identical.

Group Two impulse results did not show the same pattern as for the continuous results. The most obvious difference being the 1mm plug having higher IL than the filtered plugs.

*(**Note**: it must be remembered that filtered plugs are designed to achieve specific performance at particular frequencies, for example when used in hearing aid applications. Hence comments on their performance are limited to the specific testing carried out during this project)*

A summary of results suggests the following preliminary conclusions which could direct future research:

- The 1 mm plug was closest to the desired performance (i.e. low continuous IL with high impulsive IL). Both the HM plug and CAE non-linear plug performed comparably with the 1 mm plug.
- The Classic, CAE solid and Phoenix solid all performed well in impulse noise, with high IL also for continuous noise.
- The EAR Audiological Insert performedrelatively poorly with low IL for both continuous and impulse noise.

Other issues of concern are cost and operational suitability. The HM plug is a simply modified Classic, which could be cheaper to produce than the CAE double plug. However, the CAE has an advantage in that when high continuous noise exposures can be expected, such as travel in aircraft or armoured vehicles, the solid side offers more protection, provided speech recognition is not a crucial factor. However, the CAE protrudes more from the ear than the other plugs when fitted properly, which may impede operational effectiveness.

The Phoenix 1 mm has the same benefits as the HM plug, but would again cost more as it is a personally moulded plug.

There are a number of factors which limit broad conclusions being made:

- The sample sizes are small to achieve statistically significant results.
- Conclusions made regarding speech intelligibility must be preliminary, as a better way to measure speech recognition would be by human trials.
- Frequency variation has not been taken into account in this research. Broad band frequency was chosen for the continuous noise because of the wide variation of noise frequency to which a soldier would be exposed.
- The impulse noise used has a high frequency component, which may not be similar to that of some small arms fire or other typical impulse noise exposures of soldiers.
- The Phoenix plugs are designed to be personally moulded, but the test plugs used were plain tapered plugs so that they could fit the Zwizlocki coupler. The fit may have been imperfect in the parallel sides of the coupler resulting in a lower mean IL.
- Doubt still exists surrounding the suitability of test mannequins such as KEMAR for hearing protector testing and research at high noise levels.

One final issue worthy of mention is the difference between small diameter apertures and filter type hearing protectors. The HM, EAR Insert and Phoenix 1mm plugs all have small diameter holes though the centre of the plug. In contrast the CAE non-linear and all the other Phoenix plugs except the solid plug are fitted with special filters. The performance of the plugs according to the criteria used in this study raise many questions as to whether a hole is just as effective as a filter. This has interesting implications for further research, since plugs with filters cost more and often are more frequency specific than just the hole in a plug.

Where to from here?

These results have identified some interesting properties of the hearing protectors tested and indications for the direction of further research in this area. Other research which could stem from this project includes a more detailed octave band frequency analysis of the plugs, human trials examining practical speech perception and perceived hearing protection and field testing in common training situations.

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