

## THE ATTENUATION OF HEARING PROTECTORS AGAINST HIGH-LEVEL SHOOTING IMPULSES

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The acoustical attenuation of five different hearing protectors were investigated using real impulses and miniature microphone technique in field conditions from a 23 mm anti-aircraft cannon, from 122 mm howitzer and from an explosion of 1 kg of TNT. The measurements were carried out using voluntary military officers exposed to similar impulses in their work. The combination of earmuffs and earplugs proved to give the best attenuation. The attenuation of the earmuffs was related to the size of the cup. Light protectors gave practically no protection against the highest impulses from howitzer and TNT-blasts.

### 1. Introduction

Impulse noise is mainly generated by three different ways: by hitting a plate (i.e. hammering), by gas expansion (i.e. shooting) and electric shocks (i.e. MIG-welding). Most of the exposures to high level impulses occur in metal industry. The exposure to impulse noise is growing in construction industry due to the increasing use of nail gunners. Moreover most of the Finnish young men are exposed to impulse noise during their military service.

The risk of hearing damage of impulse noise cannot be assessed by the energy principle like steady state noise [4]. The impulse noise is evaluated by the peak level or by the peak level and the duration of the impulse. The CE directives have adopted the approach where the peak level shall not exceed 140 dB [1]. According to PFANDER [10] and CHABA [3] the maximum allowed peak depends on the duration of the impulse. Pfander's and CHABA's recommendations are used only the evaluation of risks related to explosives and gunshots. At industrial sites the impulses are more complex, varying in peak level and in duration, and they require statistical methods for the analysis.

The energy of industrial impulse noise is located to frequencies over 1 kHz. Thus hearing protectors (HPD) can provide similar to steady state noise an attenuation of 30–40 dB depending on the HPD's type. The peak levels of industrial noise is almost

without exception below 140 dB. The peak levels of hand held firearms are from 120 to 160 dB and also at high frequencies, which means that for them an attenuation of 30–40 dB can be obtained too. This attenuation is sufficient to protect the shooters from NIHL. The problem arises from large calibre weapons, because the impulses are very intense, peak levels may exceed 180 dB, and the energy is mainly distributed to low frequencies, where the attenuation of HPD's is low. Additionally the protectors may become non-linear at these levels, even resulting to a lower performance of the protectors than laboratory test results would indicate.

Among the professional soldiers noise induced hearing loss (NIHL) is the most frequent occupational disease. In the eighties annually over 300 new compensated cases have been reported. Due to improved safety regulations in the nineties the number of cases was reduced to about 50 and has remained in this level [5, 17]. On overall hearing loss statistics the soldiers have been among the five most risky occupations (Table 1).

**Table 1.** Number of compensated NIHL-cases among military officers in Finland.

1987	1992	1997	2001
362	56	38	41

In the sixties about 57% of officers had NIHL [11]. The number of new cases have declined constantly during the last years. With the conscripts the risk has remained the same from early sixties [6, 8] to 1995 [12]. Despite of new regulations and new practices in noise controlling measures, at present about 200–300 conscripts will annually have changes in their hearing due to military shooting exercises [14]. Most of the occurred in situations where the conscript was not protected by HPD's, like rehearsals in the forest, guardian shooting for alarm etc. Thus 78% of the changes are due to hand arm shots and only 22% due to large calibre guns.

The purpose of the study was to evaluate the efficiency of hearing protectors against low frequency high peak impulses. The data was also applied to evaluate health risks of the soldiers and conscripts when HPD are worn and to find the best protection against impulses.

## 2. Material and methods

The attenuation of three ear muffs and two combinations with ear plugs were measured against impulses of three high level sources. Two muffs (Peltor H61FA/V and Silenta Supermil) had small cup volumes (60 cm<sup>3</sup>, 187 g and 67 cm<sup>3</sup>, 137 g) and one a large cup volume (Silenta super, 165 cm<sup>3</sup> and 258 g). The measured combinations were Peltor Blue with Peltor H6 and EAR with Silenta Supermil. The impulse sources and their properties are shown in Table 2.

To measure the attenuation of each protector 10 test persons were used. For every impulse source and protector the same test persons were used. For every test combinations two impulses were revealed. Thus a test person was exposed to 30 impulses.

**Table 2.** Properties of the impulse sources.

Impulse source	Peak level (dB)	A-duration (ms)
Antiaircraft cannon (23 mm)	165	~ 0.2
Explosive (1 kg TNT)	172	< 5
Howitzer (122 mm)	178	> 5

This kind of exposure may cause the risk of permanent hearing loss. This is why all test subjects were voluntary army officers, who were extremely resistive to NIHL. As a criterion it was demanded, that all test subjects had been exposed during several years to same kind of noise without having a severe hearing impairment. To ensure that the test did not cause any NIHL, the hearing of all test persons were monitored after each set of shots with audimetry to see weather any changes had occurred.

Ten test subjects were selected by the garnison hospital on the basis of audiograms. The purpose of the test and the possible dangers in it were explained to all the test persons. During the tests the both ears were always protected with double protection. As an on line check the inside peak level was monitored to prevent from risks caused by poor setting of hearing protectors.

The positions of the test person during the test was selected to resemble that of a training officer in rehearsals for each gun (Fig. 1). The test subject sat on a bench, face towards the gun. The explosive was taken into the tests to verify if it can be used to simulate a large calibre gun, which would make the testing easier and cheaper. With explosives the sitting position corresponded to that training officer of a 122 mm cannon. When blasting the air pressure could throw in the air small stones and pebbles. To protect the test subject against these particles, he was wearing a bullet proof west and a visor. The explosives were located at the height of 1 m to minimise the sand rain. In addition there was a thick steel plate between the test subject and the explosive.

The attenuation of earmuff and combinations with earplugs were performed using two microphone techniques. One microphone was located outside the ear muff and another inside the ear muff. The high peak levels of the guns were too high to all miniature microphones available for the measurement. Thus the measurement of the inside level was recorded with an quarter inch microphone (B&K4135) for which a hole was drilled in the ear muff. The hole was sealed with tube tightener to prevent any air leakage [16]. The inside level for the combination of earmuff and earplug was measured with a probe microphone (B&K 4136) techniques [7].

The outside microphone was mounted on the bench in order to avoid the recording of the movements made by the test subject when the air pressure wave hits.

Both signals were conducted to signal analyser (B&K2032), which was used as a transient analyser. For each impulse 2048 points were recorded with an interval of 0.61 ms. Thus the whole record lasted 125 ms and the frequency range of the analysis was 8192 Hz. The data was windowed with a rectangular window. The shots were triggered with a delay of -10 ms. The dynamic range of the measuring equipment was over 75 dB. The time records were stored on disk in a HP9816 computer. For analysis the data was transferred to a data base (Metrica, Leading technology inc.).

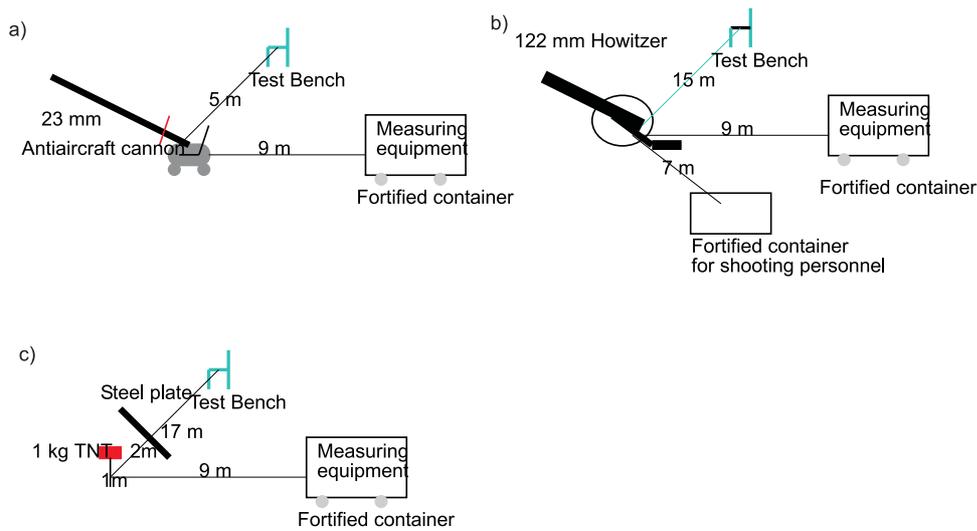


Fig. 1. Location of the subject in the measurements with: a) antiaircraft cannon b) 122 mm howitzer, c) explosive.

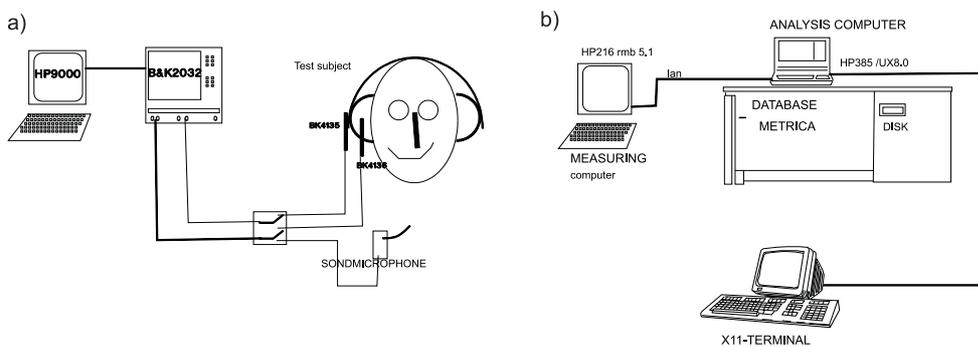


Fig. 2. Data processing: a) the measurement set-up, b) the analysis set-up.

### 3. Results

The hearing threshold of test subjects before and after the test did not show any change.

The best attenuation was obtained against the impulses from the antiaircraft cannon and the worst against 1 kg TNT (Fig. 3). The small volume protectors (Peltor, SuperMil) gave a lower attenuation (5–11 dB) than the large volume (Silenta Super) protector (11–18 dB) or the combinations of ear plug and ear muffs (16–25 dB).

The inside peak level of the protectors were evaluated according to Pfander's criteria and criteria of directive 2003/10/EC (Fig. 4).

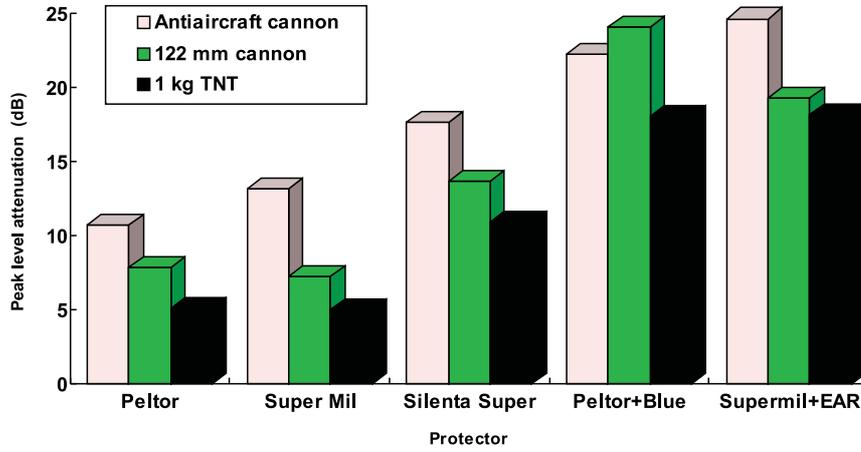


Fig. 3. Peak level attenuation of HPDs for different impulses.

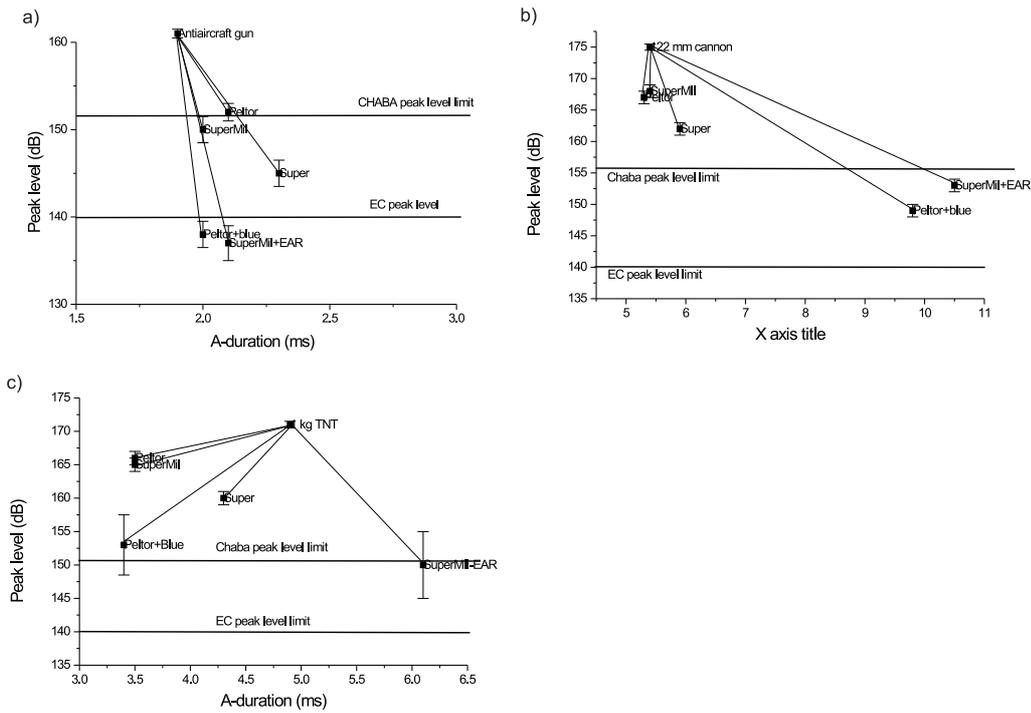


Fig. 4. The change in peak levels and in A-duration caused by different protectors against a) impulse from an antiaircraft cannon, b) impulse from a howitzer, c) impulse from an explosion of 1 kg TNT.

#### 4. Discussion

Studies with high level impulses involve ethical problems and instrumentation problems. Moreover the applicability of the results must be analysed with precautions.

The ethical problems are due to fact that a single impulse may destroy the hearing of a test person or cause permanent hearing disease. In the other hand this kind of study is required to evaluate the performance of possible hearing protection solutions. All the personnel prioritised this research and volunteered even when knowing of risks. The measuring techniques did not allow, that the measurements are performed during normal rehearsals. The concept of choosing people resistant to noise, showed to be a very good approach to the problem. The hearing threshold did not change due to the experiments.

The dynamic range was in practice reduced due to two factors. First the need to minimise the exposure prohibited the use of test shots to set up optimal ranges. Secondly the large variation in the inside level reduced further the true dynamic range by forcing the use of large safety margins. In practice the dynamic range of the measuring setup was over 50 dB. Also other instrumentation problems are present when measuring with high impulse levels. The measurement should be done by putting a miniature microphone in the ear canal. This is not possible, because there is not available miniature microphone with such dynamical performance. The error made by the system we used is not significant. The results measured in the ear canal differ mainly from the results measured at the open end of ear at frequencies above 4 kHz. The dominant frequencies of impulses in the study were well below 200 Hz.

One should keep in mind that hearing loss is not the only risk when working large calibre weapons and explosives [11]. The minimisation of risks like gun malfunctioning, people in the target area requires a good communication between all people participating to the shooting. Traditionally this is done by speech, which means that the attenuation of hearing protectors cannot be extended. Already the test subjects warned that the combination protectors, cannot be used in real situation, just because of the need to communicate. This means that the hearing conservation programmes must be based on some other concept than maximising the attenuation of hearing protectors.

The results show that the attenuation of the hearing protectors depend strongly on the impulse duration and frequency contents. Thus it is somewhat difficult to compare our results to previous results. By assuming that duration is depending on peak level Table 3 can be made between two models of hearing protectors. The comparison emphasizes the dependence of attenuation of the cup volume. Silenta super has almost three times larger cup volume than the Silenta mil.

According to the directive the combination protectors gave satisfactory protection against the impulses from antiaircraft gun. In all other cases the protection was not satisfactory.

According to Pfander all hearing protectors give satisfactory protection against impulses from antiaircraft gun. Against the explosive only combinations give satisfactory protection and against impulses from 122 mm cannon none of the protectors gave satisfactory protection.

**Table 3.** Comparison of results.

Protector	Peak level attenuation				
	30 mm cannon (176 dB) <sup>1</sup>	1 kg TNT (172 dB)	122 mm cannon (178 dB)	105 mm cannon (153 dB) <sup>2</sup>	antiaircraft cannon (162 dB)
Silenta mil	4.0	5	7.3	15.2	13.2
Silenta Super	11.9	10.9	13.7	17.4	17.6

1 – Starck *et al.*, 1987; 2 – Liu *et al.*, 1989.

## 5. Conclusions

The high level impulses generated by explosions and large calibre guns cannot be attenuated enough with hearing protectors, but additional protective measures are required to bring the exposure to an acceptable level.

## References

- [1] 2003/10/EC, Council directive on the minimum health and safety requirements regarding to the exposure of workers to the risks arising from physical factors (noise) European Commission, Brussel 2003.
- [2] Annual Report of the Committees on threshold limit values and biological exposure indices, American Conference of Governmental Industrial Hygienists, 2003.
- [3] CHABA Proposed Damage-risk Criterion for Impulse Noise (Gunfire). Report of Working Group 57, National Academy of sciences. National Research Council. Washinton DC: Committee of Hearing, bioacoustics and biomechanics, 1968
- [4] EVANS W. A., MING H. Y., *Industrial noise-induced hearing loss in Hong Kong – a comparative stude*, Ann. Occup. Hyg., **25**, 63–80 (1982).
- [5] KARJALAINEN A., AALTO L., JOLANKI R., MÄKINEN I., SAALO A., Ammattitaudit 2001, Työterveyslaitos 2002.
- [6] LAHIKAINEN E., SALMIVALLI A., *Korvan detonaatiovammoista varusmiehillä*, SotA, **37**, 140, 1962.
- [7] LIU C., PEKKARINEN J., STARCK J., *Application of the probe microphone methods to measure attenuation of hearing protectors againsts high impulse sound levels*, Appl. Acoustics, **27**, 13–25 (1989),
- [8] OLAISON C. F., *Bullerskador hos rekryter*, Nord Audiol, **5**, 85 (1962).
- [9] PEKKARINEN J., STARCK J., *Hearing protection against high level shooting impulses in relation to hearing damage risk criteria*, J. Acoust. Soc. Am., **91**, 196–200 (1992).
- [10] PFANDER F., *Das Knalltrauma*, Springer Verlag, Berlin, Heidelberg, New York 1975.
- [11] Puolustusvoimat, Varomääräykset kuulonsuojaamisesta [in Finnish], 1993.
- [12] RIIHIKANGAS P., ANTONEN H., HASSI J., SORRI M., *Hearing loss and impulse noise during military service*, Scand. Audiol. Suppl., **12**, 292–297 (1980).

- [13] SALMIVALLI A., *Acoustical trauma in regular army personnel – clinical and audiological study*, Thesis University of Turku, 1967.
- [14] SAVOLAINEN S., LEHTOMÄKI K., *Hearing protection in acute acoustic trauma in Finnish conscripts*, *Scand. Audiol.*, **25**, 1, 53–58 (1996).
- [15] STARCK J., PEKKARINEN J., *Industrial impulse noise: crest factor as an additional parameter in exposure measurements*, *Appl. Acoustics*, **20**, 263–274 (1987).
- [16] STARCK J., PEKKARINEN J., *Objective measurements of hearing protector attenuation for weapons's noise exposure*, [in:] *Proceedings of hearing conservation conference*, OES publications, Anderson Hall University of Kentucky, 1987.
- [17] VAARANEN V., VASAMA M., JOLANKI R., TOIKKANEN J., *Ammattitaudit 1991*, *Katsauksia* 118, Työterveyslaitos 1992.