ARCHIVES OF ACOUSTICS
31, 4 (Supplement), 319–324 (2006)

EFFICIENCY OF ATTENUATING HIGH-LEVEL ACOUSTIC IMPULSES WITH DOUBLE PROTECTION (EARPLUGS AND EARMUFFS USED SIMULTANEOUSLY)

J. ŻERA[(1), (2), (3)], R. MŁYŃSKI[(1)]

[(1)] Central Institute for Labour Protection – National Research Institute
Czerniakowska 16, 00-701 Warszawa, Poland
e-mail: jazer@ciop.pl

[(2)] The Frederic Chopin Academy of Music
Okólnik 2, 00-368 Warszawa, Poland

[(3)] Warsaw University of Technology, Institute of Radioelectronics
Nowowiejska 15/19, 00-665 Warszawa, Poland

(*received June 15, 2006; accepted September 30, 2006*)

The study aimed at attenuation obtained with simultaneously used earplugs and earmuffs (double protection) as opposed to hearing protective devices used singly. The measurements were conducted for high 170-dB peak SPL, 14-μs rise time, and 0.4-ms A duration acoustic impulses. Tests were conducted for light and heavy earmuffs, combined with foam and winged earplugs. The transmission loss method was used to assess the decrease in peak SPL and increase in A, C or D durations of waveforms of impulses recorded under the hearing protectors. The artificial test fixture (ATF, PN EN 24869-3) was used in the measurements modified to accommodate for conditions of double protection with a simultaneous use of an earmuff and an earplug. Results are discussed in relation to impulse noise damage risk criteria developed by CHABA, Pfander, and Smoorenburg. Double protection provides higher attenuation of peak SPL and a larger increase in the duration of impulses under hearing protectors, as compared to single protection of an earplug or an earmuff.

Key words: hearing protection devices, double protection, impulse noise, transmission loss.

1. Introduction

Various studies have shown that overall noise reduction under double protection of the ear obtained with earplugs and earmuffs worn simultaneously is not an algebraic sum of the noise reduction values of individual protectors [1–3, 5]. For continuous noise, considerable effort was devoted to establishing what was the increase in attenuation of double protection when noise reduction of both hearing protectors varied. These studies did not provide a simple answer. It is known that when both an earplug and an earmuff have high attenuation, the attenuation of double protection will not always have significantly higher value than attenuation of individual components [2].

In an earlier work, which was done for continuous noise, noise reduction was measured for energy-related parameters [4]. Under impulsive noise conditions the complicated structure of the hearing system, despite its own defensive mechanisms, can be damaged by a single impulse if peak level exceeds 140–150 dB, and impulse duration is sufficiently long. That is why, when evaluating the influence of impulsive noise on hearing, variables such as sound pressure level (SPL), attack and decay times of the impulse, impulse duration, and the number of and delay between consecutive expositions are considered. In particular, there are certain impulse noise hearing damage risk criteria developed by CHABA [6], PFANDER [8] and SMOORENBURG [10] which apply the peak pressure level and duration of impulses to assess their power to damage the ear.

In this paper, reduction of peak SPL of impulse noise obtained in double protection with earmuffs and earplugs is studied. The decrease in peak SPL at the double protected ear is compared to the reduction in peak SPL obtained when earplugs and earmuffs are used singly. Apart from a reduction in peak SPL, the change in time waveforms of impulses is assessed by comparing the duration of impulses, and the rise time for impulses outside the hearing protectors, under singly worn earplugs or earmuffs, and under earplugs and earmuffs used simultaneously. The data are compared against impulse noise hearing damage risk criteria.

2. Measurement set-up

Acoustic impulses were generated with the use of impulse noise sound source [13]. The source was capable of producing impulses of 150–170 dB peak SPL, and A duration of 0.4–1.1 ms (see Fig. 1). An acoustic impulse was produced with a blast of compressed air released suddenly from a cylinder after an elastic membrane was broken.

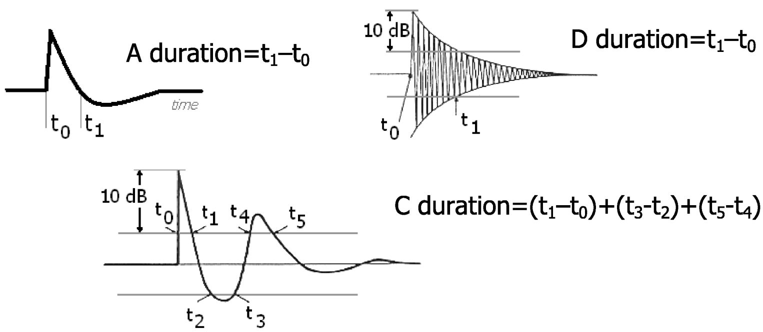

Fig. 1. Duration parameters of impulses: A-duration [6], D-duration [10], and C-duration [8].

Measurements were conducted in a sound-insulated rectangular room whose walls, ceiling and floor were covered with sound absorbing materials. An artificial test fixture (ATF) of external dimensions and acoustic isolation complying with the PN EN 24869-3 standard was used in the measurements. A horizontal distance between the impulse noise source and the ATF was 50 cm. The ATF was placed 30 cm higher than the blasting membrane of the impulse noise source.

The ATF, as recommended by the PN EN 24869-3 standard, is a flat-plate coupler suitable for testing earmuffs. This ATF, designed for testing double protection, was modified by adding an acoustic coupler suitable for inserting an earplug. The coupler consisted of a conical tube of diameter and length corresponding to the average dimensions of a human external ear canal [7, 11, 12].

The transmission loss method was used to evaluate the changes in the recorded impulses resulting from double protection or a single use of either an earmuff or an earplug. At each generation of acoustic impulse, microphone A (Bruel & Kjær type 4941) recorded impulse waveform outside the earmuff, and microphone B (Bruel & Kjær type 4192) recorded waveform under the earplug, earmuff, or earplug and earmuff used simultaneously. Microphone A was located outside the earmuff at a distance of about 10 cm from the side surface of the ATF. Microphone B was installed inside the ATF behind the conical tube. Both microphones were followed with Bruel & Kjær type 2669 preamplifiers. Signals were conditioned using a Bruel & Kjær type 2690 amplifier (Nexus), and delivered to Tucker Davies Technology System II A/D converters. The recorded waveforms were stored on a computer hard drive. Selected impulse parameters were calculated from the recorded waveforms using the Matlab programming environment. The parameters extracted from the waveforms were peak SPL, A, C and D duration of impulses. Definition of A, C and D duration as used in impulse noise damage risk criteria are given in Fig. 1.

Double protection obtained with a combination of two earmuffs and five earplugs was tested. The earmuffs were light, small-cup volume earmuffs $(\mathrm{SNR} = 21.2\ \mathrm{dB})$ and heavy, large-cup volume earmuffs $(\mathrm{SNR} = 33.9\ \mathrm{dB})$. Three types of foam earplugs were used; they were labeled foam1, foam2 and foam3 (SNR of earplugs was respectively 33, 31, and 34 dB). Two winged earplugs, labeled winged1 $(\mathrm{SNR} = 32\ \mathrm{dB})$ and winged2 $(\mathrm{SNR} = 28\ \mathrm{dB})$, were also tested.

3. Results

The principal aim of using double protection is to create a larger decrease in noise level at the ear than it is possible when using a single protector only. Due to decreased wearer's comfort (e.g. increased thermal discomfort) caused by inserting an earplug and wearing an earmuff, double protection is only justified when a significant increase in noise attenuation, possibly larger by 7–10 dB can be obtained in comparison to conditions in which earmuffs or earplugs are used individually.

An increase in noise reduction of peak SPL with double protection obtained with a combined use of foam or winged earplugs and light or heavy earmuffs is shown in Fig. 2. The ordinate in Fig. 2 represents noise reduction added in double protection to noise reduction of either an earplug or an earmuff, whichever provided higher noise reduction used as single hearing protection. Double protection using a light earmuff results in an increase in noise reduction of 0.7 to 5.2 dB for foam earplugs and 17.4 to 20.6 dB for two winged earplugs (9.3-dB average increase in noise reduction). In the case of a large-cup volume earmuff, noise reduction increases from 12.3 to 18.6 for foam earplugs and from 20.0 to 30.5 dB for winged earplugs (19.6-dB average increase in noise reduction).

As earplugs' SNR value increased, an additional attenuation obtained by using light or heavy earmuff systematically decreased (see Fig. 2). Attenuation introduced by the earmuff was thus more significant for earplugs of small SNR value. A contribution of light earmuff to the total noise reduction in double protection with foam earplugs decreased at a slope of about −1.5 dB/dB with an increase of earplug's SNR value ranging from 31 dB to 34 dB. A contribution of heavy earmuffs decreased at larger slope of about −2 dB/dB. For winged earplugs, whose SNR value was 28 and 31 dB, corresponding numbers are −0.8 dB/dB (light earmuff), and −2.6 dB/dB (heavy, large cup-volume earmuff).

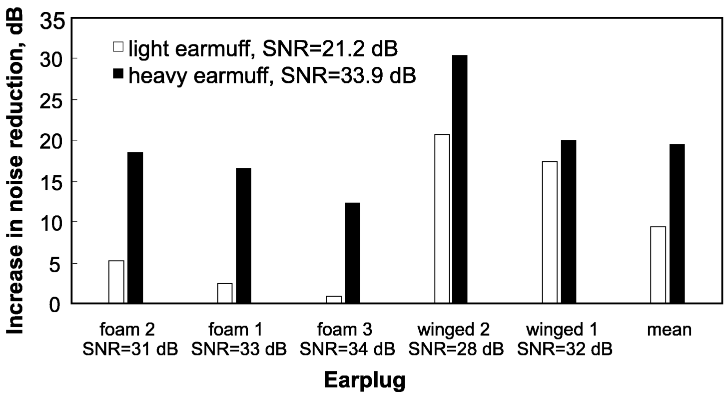

Fig. 2. Increase in noise reduction for double protection (additional decrease in peak SPL measured in transmission loss) as compared to noise reduction of better component (earmuff or earplug used singly).

Benefits of using double protection can also be discussed in the context of impulse noise hearing damage risk criteria. Impulses recorded in conditions of double protection, that is under an earplug and an earmuff are of lower peak SPL and display longer impulse duration as compared to impulses occurring under a single hearing protector. Selected results obtained for 170-dB peak SPL of impulses outside a hearing protector are shown in Fig. 3. An impulse noise damage risk criterion drawn in each panel is calculated using an assumption of single exposure to an acoustic impulse. In all graphs, impulses recorded outside the hearing protector, under the earplug or the earmuff, and under the double protector are plotted in peak SPL versus duration coordinates. A-duration is used for the CHABA criterion [6], C-duration for the PFANDER [8] and, finally, D-duration for the SMOORENBURG criterion [10]. All points lying above each of the criteria lines should be considered dangerous for human hearing.

Of the three criteria tested, only the CHABA criterion classifies impulses recorded either under an earplug or an earmuff as well as under doubly protected ear as not dangerous for hearing (Fig. 3a). A-duration of an outside impulse of about 0.4 ms is increased to about 3 ms for impulses recorded under an earmuff or an earplug (single protection). Using double protection is not associated with a significant increase of A-duration (Fig. 3a, squares). It is also apparent that a light earmuff used in combination with well protecting foam earplugs does not cause a large additional decrease in

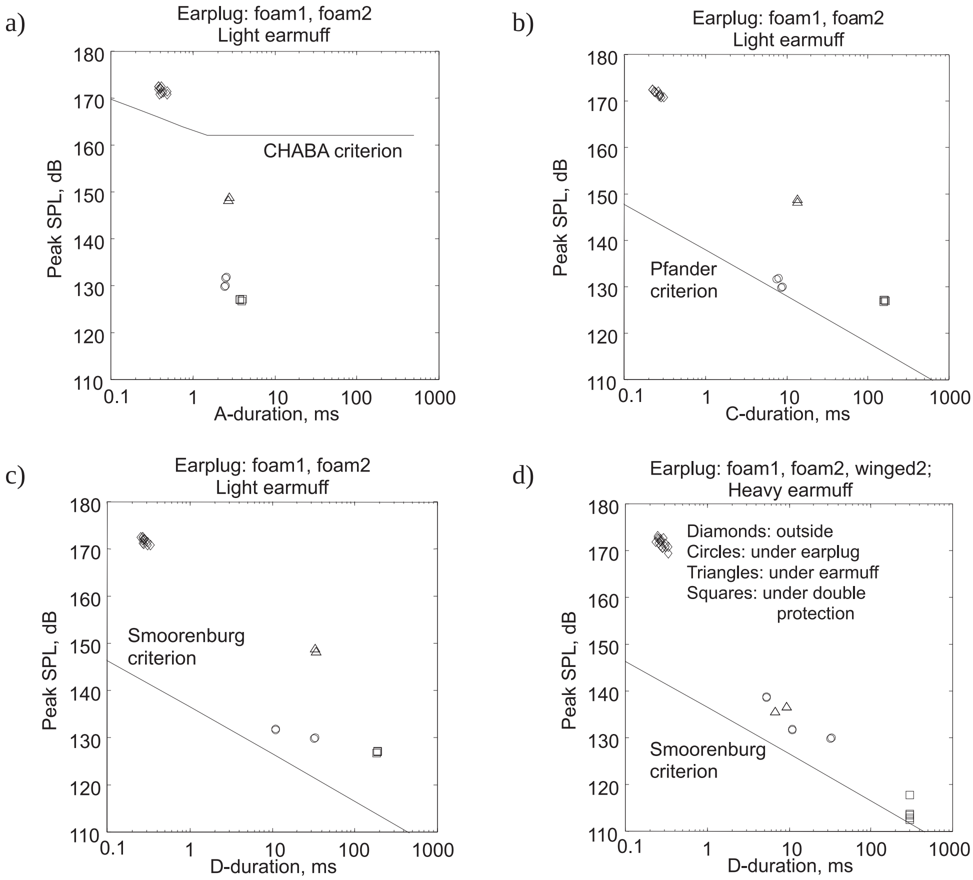

Fig. 3. Effectiveness of protection from impulses with single and double protection; a) the CHABA criterion, b) the Pfander criterion, c) the Smoorenburg criterion, light earmuffs, d) the Smoorenburg criterion, heavy earmuffs.

peak SPL. For C-duration (the Pfander criterion, Fig. 3b) and D-duration (the Smoorenburg criterion, Fig. 3c, d), there was a significant increase in duration of impulses under conditions of double protection. C-duration increased from about 0.3 ms for impulses recorded outside the earmuff (Fig. 3b, diamonds) to about 10 ms under an earmuff or a earplug used singly (Fig. 3b, triangles and circles). For double protection, there was a further increase in C-duration to about 200 ms (Fig. 3b, squares), whereas there was no significant decrease in peak SPL as compared to earplugs used singly. A similar pattern was observed for D-duration and double protection obtained with the use of light earmuffs (Fig. 3c). Figure 3d shows that most efficient double protection is obtained with the use of heavy earmuff combined with either foam or winged earplugs. Whereas D-duration of impulses recorded under either light or heavy earmuff is 10–20 ms (Fig. 3c, d, circles) D-duration for double protection with heavy earmuff is as large as 300 ms (Fig. 3d, squares). Moreover, peak SPL is decreased by as much as 12–20 dB for double protection as compared to earmuff or earplugs used singly.

4. Conclusions

A simultaneous decrease in peak SPL of an impulse and an increase in the duration of an impulse are advantages of double protection. In effect, an impulse reaching a doubly protected ear is softer than an impulse reaching an ear protected by a single hearing protector only.

The present study has shown that double protection is much more effective with the use of heavy earmuffs than light earmuffs as a component combined with foam or winged earplugs. Double protection with heavy earmuffs provides lowest peak SPL under an earmuff and a largest increase in D-duration.

Acknowledgments

Work supported by the Polish Ministry of Science and Higher Education, grant T07B00428, and the Ministry of Labour and Social Policy, grants SP03.1 and II-16.

References

[1] ABEL S. M., ARMSTRONG N. M., *The combined sound attenuation of earplugs and earmuffs*, Applied Acoustics, **36**, 19–30 (1992).

[2] BEHAR A., *Sound attenuation from combinations of earplugs and earmuffs*, Applied Acoustics, **32**, 149–158 (1991).

[3] BEHAR A., KUNOV H., *Insertion loss from using double protection*, Applied Acoustics, **57**, 375–385 (1999).

[4] BERGER E. H., *Methods of measuring the attenuation of hearing protectors devices*, J. Acoust. Soc. Am., **79**, 1655–1687 (1986).

[5] BERGER E. H., *Laboratory attenuation of earmuffs and earplugs both singly and in combination*, Am. Ind. Hyg. Assoc. J., **44**, 5, 321–329 (1983).

[6] DIXON W. W., *Proposed damage-risk criterion for impulse noise (gunfire)*, Working Group 57, NAS-NRC Committee on Hearing, Bioacoustics, and Biomechanics, NAS-NRC Committee on Hearing, 1–10 (1968).

[7] JOHANSEN P. A., *Measurement of the human ear canal*, Acustica, **33**, 349–351 (1975).

[8] PFANDER F., BONGARTZ H., BRINKMANN H., KIETZ H., *Danger from auditory impairment from impulse noise: a comparative study of the CHABA damage-risk criteria and those of the Federal Republic of Germany*, J. Acoust. Soc. Am., **67**, 628–633 (1980).

[9] PN-EN 24869-3: *Akustyka. Ochronniki słuchu. Część 3: Uproszczona metoda pomiaru tłumienia wtrącenia nauszników przeciwhałasowych do kontroli jakości*, 2001.

[10] SMOORENBURG G. F., *Damage risk criteria for impulse noise*, [in:] *New perspectives on noise*, HAMERNIK R. P., HENDERSON D., SALVI R. [Eds.], pp. 471–490, Raven Press, New York 1982.

[11] STINSON M. R., LAWTON B. W., *Specification of the geometry of the human ear canal for the prediction of sound-pressure level distribution*, J. Acoust. Soc. Am., **85**, 2492–2503 (1989).

[12] ŻERA J., MŁYŃSKI R., *Attenuation of high-level acoustic impulses by earplugs*, J. Acoust. Soc. Am., **115**, 5, 2379 (2004).

[13] ŻERA J., PUSŁOWSKI Z., *A foil blaster impulse noise source*, Proceedings of Noise Control, pp. 253–256, Kielce, Poland 2001.