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TEMPORARY CHANGES IN HEARING AFTER EXPOSURE TO SHOOTING NOISE

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Abstract.
Objectives: Firearm is a common source of impulse noise that may potentially damage hearing organ. It has been suggested that otoacoustic emissions, particularly transient-evoked otoacoustic emissions (TEOAE), might be more sensitive than pure-tone audiometry (PTA) in the assessment of changes to cochlea caused by noise. The aim of this study was to: (i) evaluate exposure to impulse noise from small-caliber weapons, (ii) compare the post-exposure changes in hearing measured by PTA and TEOAE and correlate them with noise parameters. **Materials and Methods:** The study included 18 male hunters (group I) and 28 candidate policemen (group II) exposed to impulse noise from small firearms during target practices. Group I was unprotected during shooting, whereas group II used commonly available hearing protectors. PTA and TEOAE were performed before and 2–10 min after shooting. Exposure to impulse noise was evaluated by in situ measurements. **Results:** Groups I and II were exposed to 3–4 and 4–144 impulses of noise at mean C-weighted peak sound pressure levels of 154 dB and 156 dB, respectively. No post-exposure audiometric threshold shift was observed in group I. Significant reductions of TEOAE levels were found both for the whole response (-2.2 dB SPL) and for 1/2 -octave band responses in the frequency range of 1000–4000 Hz (from -1.6 to -3.0 dB SPL). These changes were not correlated with C-weighted peak sound pressure levels or equivalent-continuous A-weighted sound pressure level. Significant correlation was found for peak sound pressure and maximum sound pressure levels in 1/3-octave bands in the frequency range corresponding with the main part of the acoustic energy of impulses (correlation coefficients r from -0.58 to -0.77, $p < 0.05$). In group II neither PTA nor TEOAE showed significant hearing impairment after shooting. **Conclusions:** The results show that even short-term exposure to impulse noise from small-calibre firearms might cause temporary hearing impairment measured by TEOAE. Therefore, the use of earmuffs is strongly recommended, because most of them seem to effectively attenuate impulse noise from small-calibre firearms.

Key words:
Impulse noise, Noise measurements, Pure-tone audiometry, Transient-evoked otoacoustic emission, Temporary threshold shift, Hearing protectors

INTRODUCTION

Firearm is a common source of impulse noise that may potentially damage the hearing organ and can be made evident as a temporary threshold shift (TTS) or permanent threshold shift (PTS) by using standard pure-tone audiometry (PTA). Lately, it has been shown that otoacoustic emission (OAE), particularly transient-evoked otoacoustic emission (TEOAE), is more sensitive than PTA in the assessment of the subtle changes to the cochlea, either temporary or permanent, caused by noise or ototoxic agents [1–7].

Most of the literature data focus on hearing loss and related problems due to exposure to impulse noise in military service [8–13]. However, exposure to shooting noise

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from rifles and guns during professional training or in the leisure-time, also might cause hearing impairment [14].
The aim of the study was to evaluate the exposure to impulse noise from small firearms during target practice as well as to compare the audiometric hearing threshold shifts and TEOAE changes after shooting and correlate these changes with noise parameters.

MATERIALS AND METHODS

Subjects

The study included 46 males, 18 hunters (mean age, 46.2 ± 11.7 years) and 28 candidates for policemen (mean age, 25.2 ± 2.1), exposed to impulse noise produced by small firearms during their target practices. Hunters used rifles and, by choice, did not protect their hearing during the shooting, while candidate policemen used guns and applied commonly available hearing protectors (e.g., Peltor type H9A, H10A, H61F etc.). Each hunter was taking shots separately, whereas candidate policemen were practicing collectively. In addition, some hunters were occupationally exposed to noise. Thus, exposure to impulse noise and post-exposure changes in hearing were analyzed separately in both groups - hunters (group I) and candidate policemen (group II).
Otoscopy performed during the experiment was normal in all subjects selected.

Noise measurements

In order to evaluate shooters' exposure to impulse noise, the following parameters were determined according to Polish and international standards (PN-N-01307, ISO 1999) [15,16]: (i) C-weighted peak sound pressure level ($L_{C\ peak}$), (ii) A-weighted equivalent continuous sound pressure level ($L_{A\ eq,Te}$), (iii) maximum A-weighted sound pressure level with F (fast) time constants ($L_{A\ F\ max}$), (iv) maximum sound pressure levels in 1/3-octave bands in the frequency range 40–20 000 Hz ($L_{f\ F\ max}$), and (v) number of impulses (N). Additionally, positive and negative peak sound pressures (p_{peak+}, p_{peak}) were determined for hunters according to ISO 10843 [17].

Most of the parameters quoted above (i.e., $L_{C\ peak}$, $L_{A\ eq,Te,}$ $L_{A\ F\ max,}$ $L_{f\ F\ max}$) were measured directly *in situ*. The determination of the others (i.e., N, p_{peak+}, p_{peak-}) was based on the analysis of recorded signals.
The surveys were carried out using a measuring system consisting of a Bruel & Kjaer (B&K) type 4138 microphone plus a B&K type 2231 modular precision sound level meter and: (i) Svantek type SVAN 912 sound and vibration analyzer (measurement of $L_{A\ eq,Te,}$ $L_{A\ F\ max}$ and $L_{C\ peak}$), (ii) Hewlett-Packard type 3569A real-time frequency analyzer (frequency analysis), and (iii) B&K type 7005 tape recorder and B&K type 2133 real-time frequency analyzer (determination of p_{peak+} and p_{peak-}). The microphone was located approximately 0.1–0.2 m from the entrance to external canal of the ear.

Hearing tests

Standard PTA and TEOAE were performed before and 2–10 min after shooting. PTA was collected from all subjects, whereas TEOAE only from a part of them, i.e., 7 (39%) hunters and 13 (46%) candidate policemen. After exposure, PTA was performed first (before TEOAE) and the right ear was tested prior to the left ear.
Hearing tests were carried out in relatively quiet rooms of buildings placed in close vicinity of the rifle ranges.
Air conduction PTA at the frequencies of 1, 2, 3, 4, 6 and 8 kHz was performed using an Interacoustic AC 40 audiometer. The ILO 92 Otodynamics Analyser, hardware and software (Otodynamics, Ltd.), was applied for TEOAE recording and analyzing. The stimuli were unfiltered standard 80 ± 3 dB, 80-μs click, presented at a rate of 50/s in nonlinear mode. The responses were windowed from 2.5 to 50 ms post-stimulus and stored in two buffers after completion of 260 averages. The TEOAE level was calculated as the amount of signal above the noise base level at each 1/2-octave band frequency from 750 Hz to 6000 Hz.

Statistical analysis

The audiometric hearing threshold shifts and the changes in TEOAE after shooting were analyzed using the Wilcoxon matched pairs test. Relationships between the obtained data, particularly temporary changes in hearing, and impulse noise parameters were analyzed using Pearson's correlation coefficient (r). The statistical analysis was done with a significance level set at $p < 0.05$.

Exposure to noise

The results of noise measurements are summarized in Table 1 and Fig. 1. The hunters and candidate policemen were exposed to impulse noise at C-weighted peak sound pressure levels of 148.5−157.2 dB and 148.3−160.9 dB, respectively. In both groups the exposures to impulse noise were similar with respect to mean values of L_{Cpeak}, L_{AFmax} and $L_{Aeq,Te}$ levels. In contrast, they differed in the number of shots (3–4 in group I versus 4–144 in group II) and ranges of measured sound pressure levels, mainly because of separate shots taken by hunters, whereas candidate policemen were practicing collectively. Due to different types of weapon, both groups also differed in the shape of the frequency spectrum, but the main part of the acoustic energy of impulses included the frequency range of 100–1600 Hz.

Hearing protectors worn by candidate policemen reduced the real exposure to noise. Their attenuation parameters are summarized in Table 2. Predicted sound pressure lev-

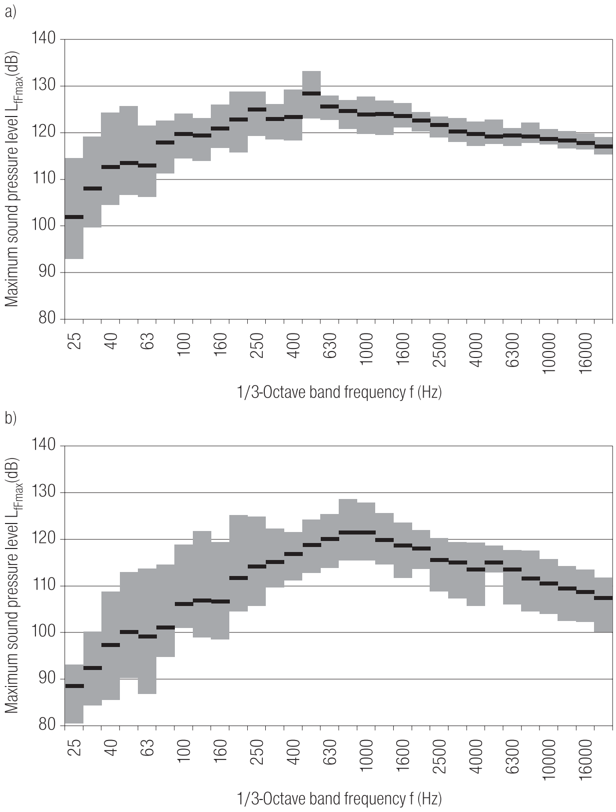


Fig. 1. 1/3-Octave frequency spectra of impulse noise in the study groups (in the chart, each bar represents the range of measured maximum sound pressure levels for each individual 1/3-octave band, dark lines mark the mean values): a) group I – noise emitted from rifles, b) group II – noise emitted from guns.

Table 1. Impulse noise parameters by study groups

Noise parameter	Group I	Group II
	Mean value ± SD (range)	
Number of impulses, N	3.1 ± 0.3 (3−4)	63.8 ± 49.4 (4–144)
C-weighted peak sound pressure level, L_{Cpeak} (dB)	154.2 ± 1.9 (148.5−157.2)	155.6 ± 4.8 (148.3−160.9)
A-weighted equivalent continuous sound pressure level, $L_{A\,eq,\,Te}$ (dB)	107.1 ± 1.9 (104.5−110.4)	108.2 ± 8.7 (112.6−143.8)
A-weighted maximum sound pressure level, $L_{A\,F\,max}$ (dB)	130.9 ± 1.3 (127.0–132.3)	130.9 ± 6.5 (120.9−138.9)
Positive peak sound pressure, p_{peak+} (Pa)	763.3 ± 129.0 (550.4−974.2)	–
Negative peak sound pressure, p_{peak-} (Pa)	746.9 ± 127.5 (547.2−977.4)	–

Table 2. Attenuation parameters of hearing protectors worn by group II

Frequency (Hz)	125	250	500	1000	2000	4000	8000
Sound attenuation (dB)	12.1 + 2.5	17.2 ± 3.8	28.9 ± 3.5	35.6 ± 3.0	34.7 ± 2.8	38.4 ±.7	36.3 ± 2.4

Data are presented as mean ± standard deviation.

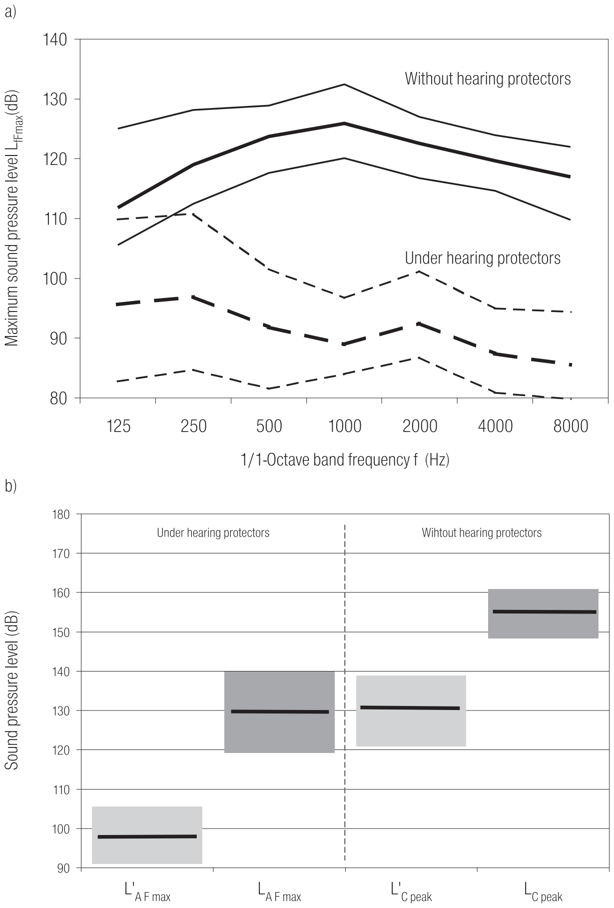


Fig. 2. Predicted sound pressure levels under hearing protectors compared to sound pressure levels measured at the shooter's ear (ranges and mean values) – group II only: a) maximum sound pressure levels in 1/1-octave bands, b) maximum A-weighted sound pressure level ($L'_{A F max}$, $L_{A F max}$) and C-weighted peak sound pressure level ($L'_{C peak}$, $L_{C peak}$).

els under ear-muffs, calculated according to ISO 4869 and EN 485 recommendations, are given in Fig. 2 [18,19]. The estimated attenuation of the maximum A-weighted sound pressure level and peak C-weighted sound pressure level was 30 ± 3 dB and 25 ± 4 dB, respectively.

Hearing tests

Group I

Mean values of pre-exposure PTA thresholds in hunters are presented in Fig. 3a. Only 2 (11.1%) subjects had pre-exposure normal or near normal bilateral audiometric thresholds (≤ 25 dB HL) and 3 (16.7%) had normal hearing on one ear (left one). Other hunters had hearing loss of up to 85–90 dB HL for 3, 4 and 6 kHz.

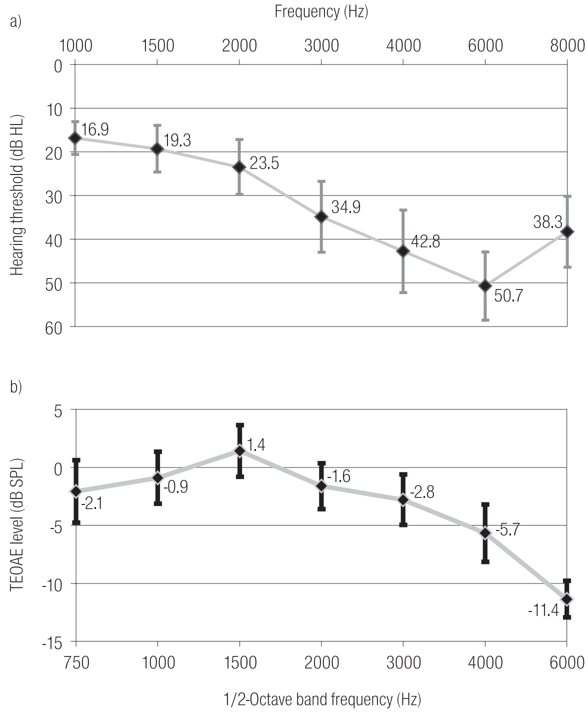


Fig. 3. Pre-exposure PTA thresholds (a) and TEOAE levels (b) in group I (mean values ± 95% confidence levels).

Pre-exposure TEOAE responses were present in all subjects tested. The mean whole response was 7.7±2.9 dB SPL. The amplitudes of TEOAE by frequencies are given in Fig. 3b.

No significant changes in PTA after shooting were found throughout all frequencies tested (Fig. 4a). Contrary to PTA, significant differences were noted between pre- and post-exposure levels of TEOAE. The significant temporary

Table 3. Pre- and post-exposure TEOAE levels in group I

		TEOAE amplitude (dB SPL)		
		Pre-exposure	Post-exposure	Difference
1/2-Octave band frequency (Hz)	750	-2.1 ± 4.7	-4.4 ± 4.1	-2.3 ± 4.0
	1000	-0.9 ± 3.9*	-2.5 ± 4.1*	-1.6 ± 2.3
	1500	1.4 ± 3.9*	-1.4 ± 4.8*	-2.8 ± 2.1
	2000	-1.6 ± 3.4*	-4.6 ± 4.7*	-3.0 ± 2.4
	3000	-2.8 ± 3.8*	-5.1 ± 5.1*	-2.3 ± 2.2
	4000	-5.7 ± 4.3*	-8.0 ± 5.2*	-2.3 ± 2.5
	6000	-11.4 ± 2.7	-13.6 ± 3.9	-2.2 ± 3.4
Whole response		7.7 ± 2.9*	5.5 ± 3.6*	-2.2 ± 1.5

* A significant difference in the Wilcoxon matched pairs test, $p < 0.05$.
Data are presented as mean ± standard deviation.

reductions of TEOAE levels (differences < 0 dB) were found both for the whole response as well as for 1/2-octave band responses in the frequency range of 1000−4000 Hz (p< 0.05) (Table 3, Fig. 4b). The greatest mean differences in TEOAE amplitudes occurred at 1500 Hz and 2000 Hz (-2.8±2.1 dB and -3.0±2.4 dB).

Group II

All candidates for policemen had pre-exposure normal bilateral PTA thresholds (up to 15 dB HL) (Fig. 5a). Pre-exposure TEOAE responses were obtained in all subjects (tested). The mean whole response was 11.1 ± 3.7 dB SPL. The TEOAE levels in 1/2-octave bands are presented in Fig. 5b. In PTA, a significant temporary threshold shift after shooting was noted only for the frequency of 3000 Hz, with the mean value of -1.7 ± 0.6 dB HL, which means that the post-exposure hearing threshold was better (lower) than the pre-exposure threshold. No significant differences were found for other audiometric frequencies. Nor were

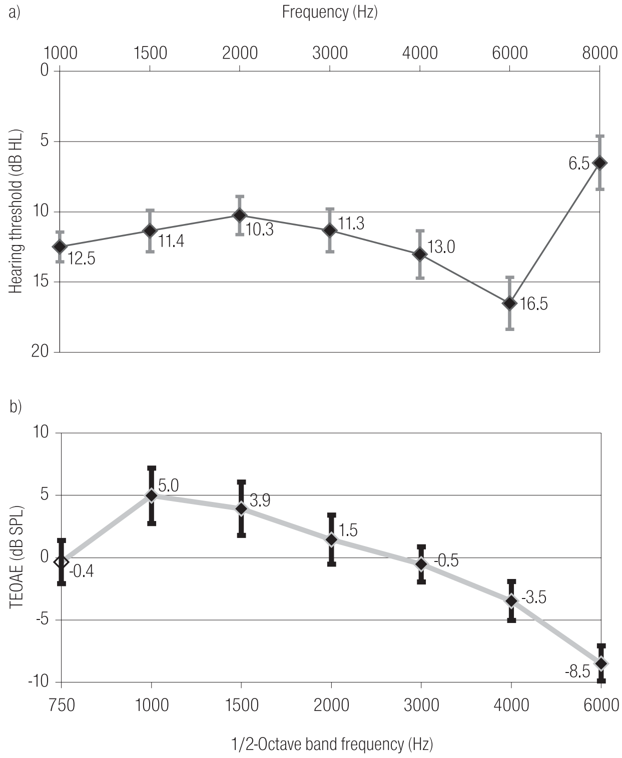
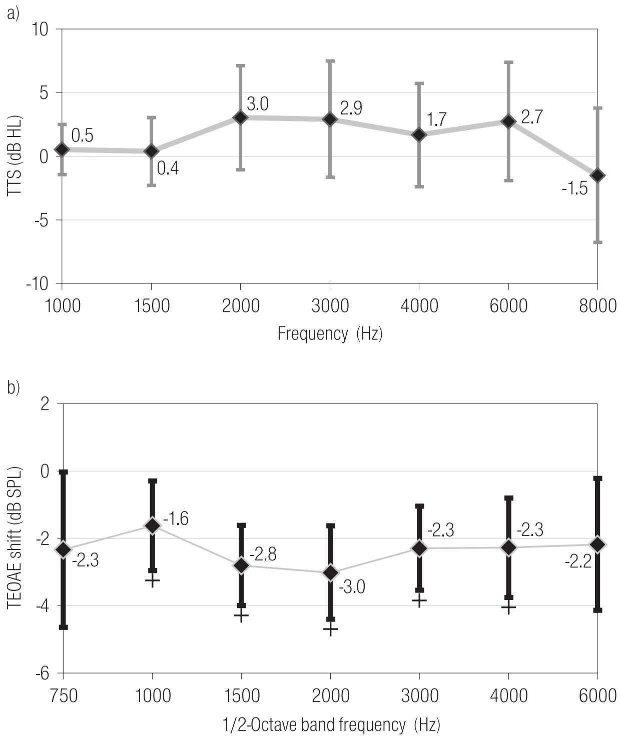
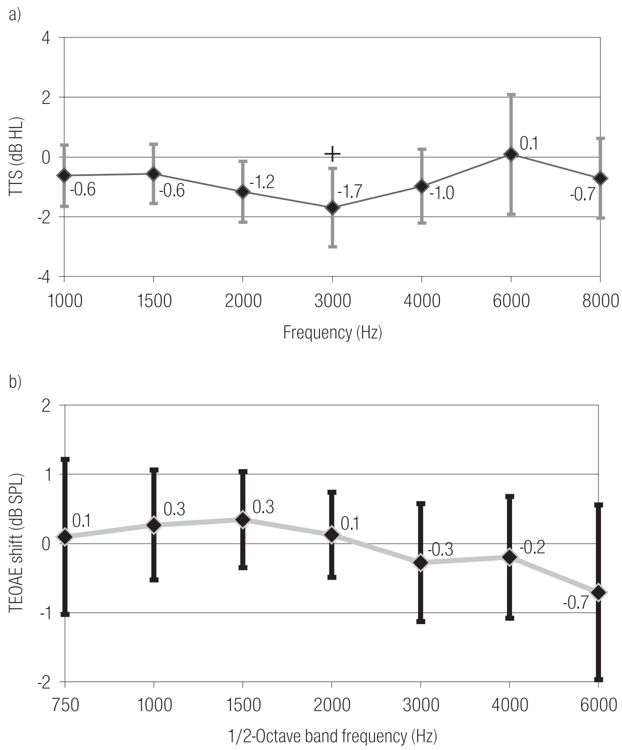


Fig. 5. Pre-exposure PTA thresholds (a) and TEOAE levels (b) in group II (mean values ± 95% confidence levels).



+ Significant differences (p < 0.05), post-exposure TEOAE level was lower than pre-exposure level

Fig. 4. PTA (a) and TEOAE shifts (b) after shooting in group I (mean values ± 95% confidence levels).



+ Significant differences (p < 0.05), post-exposure PTA threshold was lower (better) than pre-exposure threshold

Fig. 6. PTA (a) and TEOAE shifts (b) after shooting in group II (mean values ± 95% confidence levels).

noted significant post-exposure changes after shooting in case of TEOAE responses (Fig. 6b). Generally, both methods, PTA and TEOAE, did not show significant temporary hearing impairment due to exposure to shooting noise.

Relation between post-exposure changes in hearing and impulse noise parameters

The relations between post-exposure temporary changes in TEOAE and impulse noise parameters were analyzed on the basis of the results obtained in hunters without wearing hearing protectors. Temporary TEOAE shifts of the whole response and 1/2-octave band responses did not correlate with peak C-weighted sound pressure level $L_{C\,peak}$ or maximum and equivalent-continuous A-weighted sound pressure levels (L_{AFmax} and $L_{Aeq,Te}$).

The post-exposure changes in TEOAE level for the whole response were negatively correlated with peak sound pressure p_{peak+} ($r = -0.68$, $p < 0.05$) and maximum sound pressure levels in 1/3-octave bands at frequencies of 500 Hz and 630 Hz (Table 4), which means that the greater the values of p_{peak+} and $L_{f\,F\,max}$, the higher the post-exposure reduction of the TEOAE level.

Similar relations were also found for 1/2-octave band responses in the frequency range 1000–4000 Hz. The temporary shifts of TEOAE levels were correlated with positive or negative peak pressure and maximum sound pressure levels in 1/3-octave bands at frequencies of 40–63 Hz, 315–630 Hz, 1600 Hz and 2500 Hz (Table 4).

Table 4. Correlation coefficients between temporary changes in TEOAE levels and parameters describing exposure to impulse noise: results obtained in group I (only significant values. $p < 0.05$)

	Correlation coefficient r					
	Temporary changes in TEOAE level					
	Whole response	1/2-Octave band frequency (Hz) 1000	1500	2000	3000	4000
Positive peak sound pressure p_{peak+}	-0.68					-0.60
Negative peak sound pressure p_{peak-}			-0.74			
Maximum sound pressure level in 1/3-octave bands. $L_{f\,F\,max}$ 40 Hz			-0.64			
50 Hz			-0.77			
63 Hz			-0.75			
80 Hz					-0.58	
315 Hz			-0.58			
400 Hz			-0.76			
500 Hz	-0.66				-0.61	
630 Hz	-0.64	-0.65				-0.73
1600 Hz			-0.67			
2500 Hz					-0.58	

DISCUSSION

Firearm is a common source of impulse noise that may potentially damage the hearing organ.

Most of the literature data focuses on hearing loss and related problems due to exposure to impulse noise in military service. However, exposure to shooting noise from rifles and guns during professional training or in the leisure-time, also might cause hearing impairment [14].

Generally, impulse noise is described by many parameters, e.g., a linear or unweighted peak sound pressure level, C-weighted peak sound pressure level, type of waveform, impulse duration (A-, B- or C-duration), sound energy, sound energy level, sound exposure, rise and decay time, total number of impulses, repetition rate, maximum A-weighted sound pressure level (fast- or slow-weighted), or A-weighted equivalent continuous sound pressure level [8, 15–17].

According to ISO 1999 [15], the estimation of noised-induced permanent threshold shift, irrespectively of type of noise (steady, intermittent, fluctuating, irregular or impulse-type), is based on A-weighted equivalent continuous sound pressure level (i.e., on equal energy principle). In spite of its simplicity, the equal energy rule is not commonly accepted as a method for describing exposures that consist of both impulsive and continuous type noises. There is evidence that impulse noise effects do or do not conform to this rule [20]. However, the most important parameter of impulse noise from the point of view of hearing conservation is the C-weighted or unweighted peak sound pressure level [21].

In Poland, the permissible C-weighted peak sound pressure level at workplaces is 135 dB [22]. The previous European Union Council Directive (86/188/EEC) concerning occupational exposure established the permissible non-weighted peak sound pressure at 200 Pa (140 dB) [23]. A new Noise Directive preserves this admissible value. It sets exposure limit value at 200 Pa (140 dB(C) re 20 μPa), and upper and lower exposure actions values at 135 Pa (137 dB(C) re 20 μPa) and 112 Pa (C) re 20 μPa), respectively [24]. The peak sound pressure level of 140 dB is also assumed as appropriate for adults in case of environmental and leisure-time exposure to impulse noise [25]. Whereas within NATO and some NATO countries, the trend is to use the value limit of 160 dB as the peak level for military noise [9].

The small-calibre weapons (guns, miniature rifles, assault rifles, etc.) usually produce impulse noise at peak sound pressure levels of 132−165 dB (mean values at the shooter's ear). The spectral content of the main part of the acoustic energy is 150–2500 Hz (maximum 900–1500 Hz) [8–10]. In our study, the hunters and candidate policemen were exposed to impulse noise from guns and rifles at C-weighted peak sound pressure levels of 148−161 dB, significantly higher than occupational and environmental exposure limits. Thus, the results of our noise measurements during target practice did not differ from earlier observations.

One possible alternative to conventional pure-tone audiometry for screening and monitoring cochlear changes is the measurement of otoacoustic emissions. Particularly TEOAEs are becoming an important tool in assessing hearing in persons exposed to noise in industry and military service. The TEOAE method has been proved to be useful for hearing conservation purposes by enabling early detection of hearing impairment caused by industrial noise [5–7]. Also the high sensitivity and specificity of TEOAE as the screening method for the diagnosis of cochlear damage has been shown in military recruits [1,3,4,11].

For example Hotz et al. [1] found significant bilateral reductions in TEOAE levels in the frequency range from 2 kHz to 4 kHz among military personnel (117 male recruits and 30 male career cadets) after a 17-week training period that included exposure to noise from firearms. Santaolalla et al. [14] noted significantly lower amplitude of TEOAEs in male hunters (aged 30−45 years) compared to the control group.

In our study, we analyzed temporary changes in hearing due to short-time exposure to impulse noise from small-calibre weapons. We took into consideration two different groups. First, hunters without hearing protectors and second, candidate policemen using ear-muffs. The latter group was younger and had bilateral normal hearing. On the other hand, hunters' age was more diverse. Moreover, some of them had permanent hearing impairment. Occupational and/or leisure time exposure to noise and presbyacusis might be partially responsible for such a situation. By measuring PTA, in both groups, hunters without wearing hearing protectors and candidates for policemen using hearing protectors, we did not find significant post-exposure impairment of hearing. Significant reduction in TEOAE levels, both for the whole response as well as for band responses in the frequency range of 1000−4000 Hz were noted only in hunters. Moreover, a significant relationship was found between post-exposure differences in TEOAE levels, peak sound pressure and maximum sound pressure levels in 1/3-octave bands at frequencies of 40–80 Hz, 315–630 Hz, 1600 Hz and 2500 Hz, corresponding with the main part of the acoustic energy of impulses. Significant correlation between TEOAE shifts and peak sound pressure confirmed the legitimacy of choice of the unweighted peak sound pressure as a measure for impulse noise exposure from hearing conservation point of view [23,24].

Earlier, Konopka et al. [12,13] noted in soldiers reductions in amplitude of the TEOAE centered at 3 kHz (3.1 dB) and 4 kHz (5.1 dB) 10-15 min after shooting (15 single rounds of live ammunition at $L_{C\,peak}$ level of 155–156 dB). It is worth noting that in our study hunters were exposed only to 3–4 shots at mean $L_{C\,peak}$ level of 154 dB.

Actually in both groups, hunters without wearing hearing protectors (group I) and candidate policemen wearing hearing protectors (group II), the exposures to impulse noise were similar with respect to mean values of L_{Cpeak}, $L_{AF\,max}$ and $L_{A\,eq,\,Te}$ levels. They differed mainly in the number of shots. Subjects of group II were exposed to a larger number of shots and they were trained collectively, but neither PTA nor TEOAE showed significant post-exposure temporary hearing impairment.

It may be assumed that if noise exposure is not severe enough to cause either PTA temporary threshold shift or temporary reduction of TEOAE level, then it cannot produce permanent changes. Thus, it has been found that the use of hearing protectors safeguarded against short-time exposure to shooting noise during target practice. This confirms earlier observations that impulses from small-caliber weapons (guns and shotguns) are effectively attenuated by both small-volume and large-volume ear-muffs [9,10].

In conclusion, our results show that even short-term exposure to impulse noise from small-caliber firearms during target practice might cause temporary impairment of hearing measured by TEOAE. Therefore, the use of ear-muffs is strongly recommended, because most of them seem to sufficiently attenuate impulse noise from small-caliber firearms.

They also confirm that TEOAE might be more sensitive than PTA in the assessment of temporary changes in the cochlea caused by impulse noise. Moreover, the post-exposure temporary shift of TEOAE levels is correlated with peak sound pressure and maximum sound pressure levels in 1/3-octave bands in the frequency range corresponding with the main part of the acoustic energy of impulses.

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