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The impact of gender and risk factors for hearing impairment on audiogram changes in military cadets during shooting exercises

Uticaj pola i faktora rizika za oštećenje sluha na promene u audiogramu kod vojnih kadeta u toku gađanja

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Abstract

Background/Aim. Military personnel are frequently exposed to high levels of noise, where hearing loss can affect their combat performance. The aim of this study was to assess the impact of impulse noise produced by firearms during shooting exercises, analyze the effect of noise through pure-tone audiometry, and correlate it with sex differences and risk factors for hearing impairment. **Methods.** The study included 105 cadets, 75 men and 30 women, aged 19 to 25 years, who underwent regular firearm shooting as part of their military training. We observed the results of audiometric examinations conducted at three time points: 24 hrs before noise exposure, immediately after the noise exposure [shooting with a "*Crvena Zastava*" 99 pistol, i.e., CZ99], and 24 hrs after the shooting. Data on risk factors were obtained from a questionnaire with anamnestic data of the cadets. **Results.** Immediately after noise exposure, there was significant sensorineural hearing impairment at 2,000 Hz and 4,000 Hz, with complete recovery after 24 hrs. Our study revealed that male participants are more susceptible to this type of noise exposure compared to female participants. Additionally, we found that 22.9% of the respondents had risk factors for post-shooting hearing impairment, which included smoking, noise exposure within the last 7 days, field work within the past 72 hrs, and hereditary hearing loss in the family. **Conclusion.** Despite the regular use of hearing protection, hearing impairment after acute acoustic trauma caused by shooting in military personnel remains inevitable and is more pronounced in men than in women. Our results suggest that the presence of risk factors for hearing impairment contributes to an increase in the temporary threshold shift, i.e., a decrease in hearing.

Key words:
audiometry; hearing loss; hearing loss, noise-induced; military medicine; risk factors; sex factors.

Apstrakt

Uvod/Cilj. Vojno osoblje je često izloženo visokim nivoima buke, gde gubitak sluha može uticati na njihove borbene sposobnosti. Cilj rada bio je da se proceni uticaj impulsne buke koju proizvodi pucanje vatrenim oružjem tokom vežbi gađanja, analizira uticaj buke tonskom audiometrijom i poveže sa polnim razlikama i faktorima rizika za oštećenje sluha. **Metode.** U studiju je bilo uključeno 105 kadeta, 75 muškaraca i 30 žena, uzrasta od 19 do 25 godina, koji u sklopu svog školovanja obavljaju redovna gađanja iz vatrenog oružja u toku vojne obuke. Posmatrali smo rezultate audiometrijskog ispitivanja sprovedenog u tri termina: 24 h pre izlaganja buci, neposredno nakon izlaganja buci [gađanje iz pištolja „Crvena Zastava“ 99, tj., CZ99] i 24 h nakon izvršenog gađanja. Podaci o faktorima rizika dobijeni su iz upitnika sa anamnestičkim podacima kadeta. **Rezultati.** Neposredno nakon izlaganja pucnju, dolazilo je do značajnog senzorineuralnog oštećenja sluha na 2.000 Hz i 4.000 Hz, uz kompletni oporavak nakon 24 h. Naša studija je pokazala da su ispitanici muškog pola osetljiviji na ovakvo izlaganje buci u odnosu na ispitanice ženskog pola. Takođe, ustanovili smo da je 22,9% ispitanika imalo faktore rizika za oštećenje sluha nakon pucnja, što uključuje pušenje, izloženost buci u poslednjih 7 dana, rad na terenu u poslednja 72 h i nasledni gubitak sluha u porodici. **Zaključak.** Uprkos regularnom korišćenju zaštitnih sredstava za sluh, oštećenje sluha nakon akutne akustične traume izazvane pucanjem kod pripadnika vojne populacije ostaje neizbežno i izraženije je kod muškaraca u odnosu na žene. Naši rezultati ukazuju da postojanje faktora rizika za oštećenje sluha doprinosi privremenom povećanju praga sluha tj. smanjenju sluha.

Ključne reči:
audiometrija; sluh, gubitak; sluh, gubitak izazvan bukom; vojna medicina; faktori rizika; pol, faktor.

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Introduction

Hearing plays a crucial role in a soldier's performance and is essential for effective communication. Noise-induced hearing loss (NIHL) is a significant impairment in the military and can affect combat performance. Unlike civilians, military personnel are frequently exposed to intense noise levels and often have no choice but to remain in noisy environments in order to complete specific tasks and missions [1]. The harmful effects of noise depend on its characteristics (type, intensity, constancy or intermittence, impact) and the duration of exposure, directionality, and individual sensitivity of the person exposed to the noise [2]. Occupational NIHL is the most prevalent work-related illness globally [3], particularly affecting professions exposed to high levels of noise, such as military personnel [4–7]. Gunshot noise ranks as a fourth-degree noise, with measured sound pressure levels ranging from 140 A-weighted decibels [dB(A)] to 180 dB(A) upon using firearms [8]. Audiometry has shown the greatest hearing loss at 4,000 Hz following high-intensity impulse noise in occupationally exposed individuals, occurring in 86.7% of cases, even at lower noise levels measured during shooting from pistols and revolvers, with a maximum measured value of 113.1 dB for a 0.40 calibre pistol and 116.8 dB for a 0.38 calibre revolver [9].

Inner ear injuries caused by acute acoustic trauma can be classified as temporary threshold shift (TTS) or permanent threshold shift (PTS) [10], depending on the duration and intensity of noise exposure. Generally, hearing recovers after TTS within 24–48 hrs [10–13], hence it is often not recognized as a potential issue. Nevertheless, if the noise exposure that induces TTS is repeated, it may evolve to PTS. This is a common mechanism of hearing impairment in occupational exposure to noise [14]. Mechanisms by which intense noise induces hearing loss include physical injury of structures in the inner ear, inflammation, ischaemia, oxidative stress, and excessive activity of nerve endings in the cochlea, resulting in functional hearing impairment [6]. Brief exposure to high-level impulse noise induces physical disorganization and damage of stereocilia as well as direct injury of both supporting cells and sensory neurons [15], resulting in functional hearing impairment. For such an injury, the major factor is the maximum sound pressure, while the duration of exposure is less important [16]. The most vulnerable structure to noise is the basal cochlea. This finding is responsible for pronounced sensitivity for noise-induced hearing impairment at high frequencies (both TTS and PTS). The individual's audiometric tests may vary; hence, the smallest measurable values of TTS and PTS are not well defined. This led to the development of various standards for defining significant hearing impairment, commonly referred to as "standard threshold shift" (STS). According to the Occupational Safety and Health Administration (OSHA), the accepted STS in the given ear is established at an average value of 10 dB increase in threshold compared to the individual's baseline audiogram (or recently obtained) measured at 2,000, 3,000, and 4,000 Hz [17]. Ryan et al. [14] in their review of basic and clinical observations of noise-induced TTS and PTS also stated that STS for work-related injury should be set at least at 25 dB when hearing impairment is confirmed on repeated tests within 30 days.

The aim of this study was to examine whether the presence of risk factors for the occurrence of hearing damage in the subjects, such as smoking, previous exposure to noise, and genetic predisposition, affects the recovery of the hearing threshold following exposure to gunfire from a "*Crvena Zastava*" 99 pistol, i.e., CZ99. Additionally, the study examined whether gender could have an influence on hearing impairment after acute acoustic trauma, as well as a difference in hearing recovery after shooting, measured by audiometry.

Methods

The study was conducted at the Military Academy and the Military Medical Academy, the Institute of Occupational Medicine, and the Institute of Medical Research, Belgrade, Serbia, from November 2022 to April 2023. Approval for this study was obtained from the Ethics Committee of the Faculty of Medicine of the Military Medical Academy, University of Defence (No. 1/2022). All participants signed informed consent.

In this interventional prospective study, 105 cadets of both genders were enrolled (75 males and 30 females). The participants performed regular shooting exercises with the CZ99 pistol at a semi-enclosed shooting range, using earplugs for hearing protection. The intervention in this study is related to exposure to noise and diagnostic testing through audiometry [18]. The criteria for exclusion, shooting conditions, and terms of audiometric investigation are described in detail in our previous study [19].

Pure-tone audiometry was performed using the Bell Plus audiometer (Inventis, Padova, Italy). The device is suitable for field use and determines both air and bone conduction sound transmission. Calibration on an audiometer was done every 12 months. For assessment of air conduction, the pure-tone thresholds were determined at the following frequencies: 125, 250, 500, 1,000, 2,000, 4,000, 6,000, and 8,000 Hz, and for bone conduction at 250, 500, 1,000, 2,000, and 4,000 Hz [18].

For data analysis, we used SPSS version 26.0 software (IBM, USA, 2019). Continuous variables are presented as mean ± standard deviation or as median with interquartile range (25th and 75th percentiles), while categorical variables are presented as frequencies of individual categories. For between-group comparison, we used the Mann-Whitney *U* test, and for paired comparison within a group, we used the Wilcoxon test. For continuous variables, comparisons within groups at three different time points were performed using analysis of variance (ANOVA) for data with a parametric distribution. The correlation between variables of interest was tested using Spearman's correlation. The value of $p < 0.05$ was considered significant throughout all analyses. Results are presented as mean ± standard deviation.

Results

A total of 105 participants were included in the study, of whom 72.4% were men and 27.6% were women. Among them, 22.9% had risk factors for hearing impairment after shooting. These risk factors included smoking, noise exposure in the past 7 days, field work in the past 72 hrs, and a family history of hearing loss. Additional participant characteristics are shown in Table 1.

Average audiometric test values of the right and left ear before shooting at 2,000 and 4,000 Hz showed no significant difference (2,000 Hz: 10.38 ± 1.50 dB right vs. 10.57 ± 1.74 dB left, $p = 0.348$; 4,000 Hz: 10.95 ± 2.51 dB right vs. 10.81 ± 2.61 dB left, $p = 0.604$) (Figure 1).

Immediately after shooting, audiogram analysis at 2,000 Hz demonstrated significant average hearing loss both in the right (10.38 ± 1.50 dB vs. 12.14 ± 3.46 dB, $p < 0.001$) and left ear (10.57 ± 1.74 dB vs. 12.81 ± 3.73 dB, $p < 0.001$) (Figure 2).

Table 1

Basic characteristics of examinees

Parameters	Yes	No
Smoking	20 (19.0)	84 (81.0)
Alcohol consumption	10 (9.5)	95 (90.5)
Previous noise exposure	2 (1.9)	103 (98.1)
Hay fever	5 (4.8)	100 (95.2)
Infection	2 (1.9)	103 (98.1)
Hereditary	2 (1.9)	103 (98.1)
Total risk factors	24 (22.9)	81 (77.1)

All values are given as numbers (percentages).

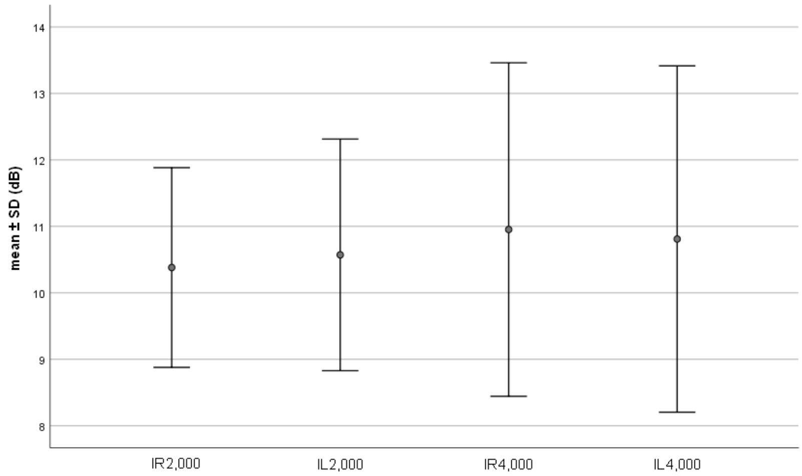

Fig. 1 – Audiometric test of the right and left ear before shooting
R – right ear; L – left ear; I – first time point at 2,000 Hz and 4,000 Hz; SD – standard deviation.
***Note*: The y-axis shows the level of audibility, i.e., hearing before shooting, as well as the shift in hearing threshold after shooting.**

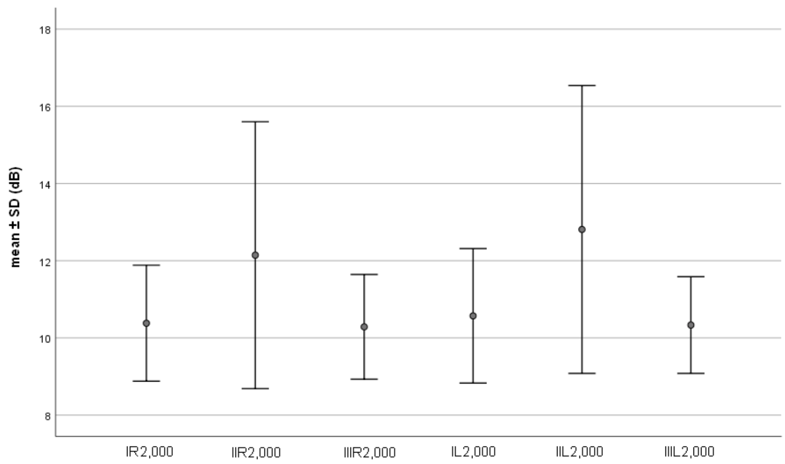

Fig. 2 – Comparison of average audiometric values of the left and right ear before shooting, immediately after shooting, and 24 hrs after shooting at 2,000 Hz.
R – right ear; L – left ear; I, II, III – first, second, and third time points at 2,000 Hz; SD – standard deviation.
***Note*: The y-axis shows the level of audibility, i.e., hearing before shooting, as well as the shift in hearing threshold after shooting.**

Comparison of values obtained 24 hrs after shooting with pre-shooting levels revealed no significant difference in either ear.

Analysis of hearing at 4,000 Hz demonstrated significant difference of average values again both on the right ear (10.95 ± 2.51 dB vs. 12.52 ± 4.45 dB, $p < 0.001$) and on the left ear (10.81 ± 2.61 dB vs. 13.19 ± 5.15 dB, $p < 0.001$) before/immediately after shooting (Figure 3).

Analysis of audiogram differences by gender revealed significantly increased values only in male participants on the right ear at 4,000 Hz immediately after shooting (Table 2).

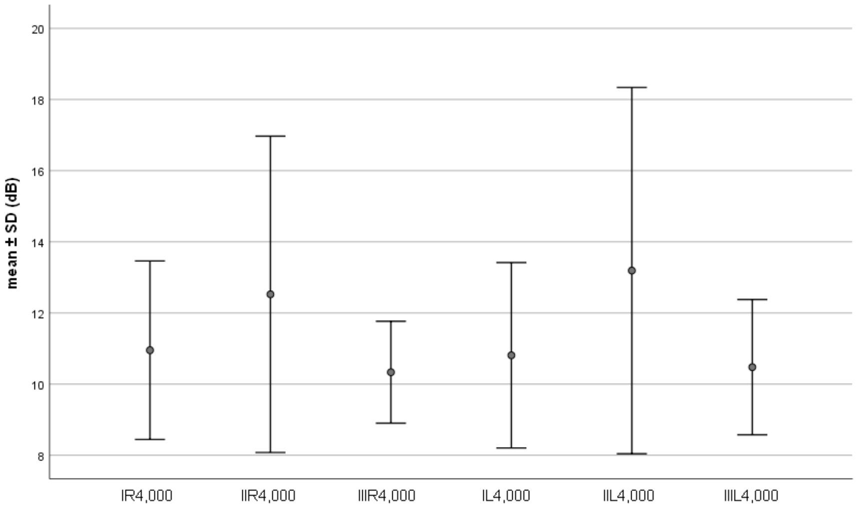

Fig. 3 – Comparison of average audiometric values of the left and right ear before shooting, immediately after shooting, and 24 hrs after shooting at 4,000 Hz
R – right ear; L – left ear; I, II, III – first, second, and third time points at 4,000 Hz; SD – standard deviation.
***Note*: The y-axis shows the level of audibility, i.e., hearing before shooting, as well as the shift in hearing threshold after shooting.**

Table 2

Gender difference analysis and average audiogram values according to time of acute acoustic trauma exposure at 2,000 and 4,000 Hz

Frequency	Ear	Time	Gender	Mean ± SD (dB)	*p*-value
2,000 Hz	Right	I	male	10.26 ± 1.12	0.195
		I	female	10.69 ± 2.21	
		II	male	12.43 ± 3.70	0.163
		II	female	11.38 ± 2.64	
		III	male	10.33 ± 1.49	0.599
		III	female	10.17 ± 0.93	
2,000 Hz	Left	I	male	10.59 ± 1.82	0.845
		I	female	10.52 ± 1.55	
		II	male	13.03 ± 3.92	0.337
		II	female	12.24 ± 3.16	
		III	male	10.33 ± 1.25	0.954
		III	female	10.34 ± 1.29	
4,000 Hz	Right	I	male	11.12 ± 2.78	0.274
		I	female	10.52 ± 1.55	
		II	male	13.29 ± 4.94	**0.004**
		II	female	10.52 ± 1.55	
		III	male	10.46 ± 1.67	0.141
		III	female	10.00 ± 0.86	
4,000 Hz	Left	I	male	11.05 ± 2.98	0.122
		I	female	10.17 ± 0.93	
		II	male	13.68 ± 5.68	0.112
		II	female	11.90 ± 3.11	
		III	male	10.59 ± 2.15	0.314
		III	female	10.17 ± 0.93	

All values are given as mean ± standard deviation (SD).
The bold value indicates the significance level of *p* < 0.05.

Participants with identified risk factors demonstrated a significant increase in the average audiogram on the right ear at 2,000 Hz before shooting (Table 3).

Examination of the correlation between cumulative risk factors in males and females and audiometric findings before shooting, right after shooting, and 24 hrs after shooting (measured at 2,000 Hz) showed statistical significance in females. A strong statistical correlation was observed between the cumulative number of risk factors and audiometric results for the right ear at all three measurement points: before, immediately after, and 24 hrs after the shooting (Table 4).

Discussion

Despite the use of personal hearing protection, a large number of professional soldiers and officers experience disability and hearing loss, both gradual and sudden [20, 21].

In our investigation, when we observed all participants together, we found statistically significant hearing impairment measured at 2,000 Hz and 4,000 Hz in both ears immediately after noise exposure. The hearing of our subjects has completely recovered 24 hrs after the shooting, i.e., we found no statistically significant differences between the results before

Table 3

Average audiogram values of the right and left ear before, immediately after, and 24 hrs after shooting at 2,000 and 4,000 Hz according to the presence of risk factors

Frequency	Ear	Time	Risk Factors	Mean ± SD (dB)	*p*-value
2,000 Hz	Right	I	no	10.19 ± 0.95	**0.013**
		I	yes	11.04 ± 2.54	
		II	no	12.16 ± 3.53	0.924
		II	yes	12.08 ± 3.27	
		III	no	10.31 ± 1.45	0.752
		III	yes	10.21 ± 1.02	
2,000 Hz	Left	I	no	10.56 ± 1.77	0.865
		I	yes	10.63 ± 1.69	
		II	no	12.72 ± 3.80	0.639
		II	yes	13.13 ± 3.55	
		III	no	10.37 ± 1.32	0.580
		III	yes	10.21 ± 1.02	
4,000 Hz	Right	I	no	10.86 ± 2.34	0.511
		I	yes	11.25 ± 3.04	
		II	no	12.16 ± 4.54	0.125
		II	yes	13.75 ± 3.97	
		III	no	10.37 ± 1.54	0.629
		III	yes	10.21 ± 1.02	
4,000 Hz	Left	I	no	10.80 ± 2.68	0.960
		I	yes	10.83 ± 2.41	
		II	no	13.15 ± 5.50	0.878
		II	yes	13.33 ± 3.81	
		III	no	10.49 ± 1.87	0.862
		III	yes	10.42 ± 2.04	

All values are given as mean ± standard deviation (SD).
The bold value indicates the significance level of *p* < 0.05.

Table 4

Correlation of audiogram values to cumulative risk factors in all participants (males and females)

Frequency	Ear	Time	Female		Male	
			rs	*p*-value	*rs*	*p*-value
2,000 Hz	Right	I	**+0.640**	**0.000**	+0.118	0.310
		II	**+0.381**	**0.041**	-0.110	0.344
		III	**+0.556**	**0.002**	-0.146	0.209
2,000 Hz	Left	I	+0.256	0.179	-0.023	0.846
		II	+0.166	0.389	+0.032	0.787
		III	+0.354	0.059	-0.164	0.157
4,000 Hz	Right	I	-0.115	0.551	+0.044	0.705
		II	+0.256	0.179	+0.182	0.115
		III	/	/	-0.073	0.530
4,000 Hz	Left	I	-0.064	0.741	+0.014	0.906
		II	+0.000	1.000	+0.084	0.471
		III	-0.064	0.741	-0.067	0.563

Spearman's correlation (*rs*) was used.
Bold values indicate the statistical significance (*p* < 0.05).

and 24 hrs after the shooting. This can be explained by the fact that all the respondents were completely healthy and belonged to the young population. The frequency of hearing impairment increases with age [22–24].

When we investigated the gender impact, we found a trend of higher sensitivity to noise in males compared to females, with statistical significance at 4,000 Hz in the right ear. Consistent with our findings, Villavisanis et al. [25] reported in their research that gender is a significant biological variable influencing hearing sensitivity; it significantly affects hearing loss on both sides, more in men compared to women.

Several studies have pointed out the specific gender-dependent organization of the cochlea, as well as other components of both classical and non-classical auditory pathways in the brain [26–28]. Therefore, it is believed that the auditory system in males and females is not equally sensitive to every type and frequency of sound and that the auditory regions in females are more resistant to damage caused by prolonged noise compared to males [29]. Considering this, the American National Institute of Health recommended the inclusion of gender as a biological variable in future research regarding hearing assessment [30, 31].

In addition, Villavisanis et al. [25] confirmed the impact of sexual hormones on hearing, emphasizing the protective effect of estrogen. In addition to its role in promoting female reproductive functions, estrogen, with its most potent endogenous form, estradiol, plays a protective role in auditory function [32, 33]. Estrogen synthesis is mainly located in the ovaries. However, several other tissues and organs, including adipose tissue, brain, skin, and bone, also produce estrogen [32]. Regardless of gender, those tissues convert androgen hormones into estrogens through the enzyme aromatase. The role of these local estrogens is to improve cardiovascular or neurological functions and to protect the local environment against degeneration and injuries [34]. Among tissues that express the enzyme aromatase and hence are able to produce estrogen locally is the auditory cortex. This production enables the better processing of auditory stimuli in the central nervous system [35]. In accordance with the previously reported influence of estrogen on hearing function, Delhez et al. [33] reported the relation between fluctuation in estrogen concentrations during the menstrual cycle and hearing sensitivity in women.

In our study, we hypothesize that the non-genomic pathway of estrogen effect in female cadets may be activated, given their brief exposure to intense noise. The non-genomic mechanism acts by binding to estrogen receptors (ER) in the cell membrane [36, 37], activating ionic channels and cytoplasmic kinases within seconds or minutes. Other authors established that in the inner ear of human adults, there are two types of ER – ERα in the spiral ganglion and ERβ in the stria vascularis [38], which highlights the importance of gender.

In addition to the hypothesis of better adaptation to acute exposure to noise in women, some authors found similar resilience in long-term exposure. A Norwegian study that investigated the influence of gender on hearing loss showed that men's hearing improved after cessation of occupational noise exposure, while that was not so significant in women [39, 40].

While no significant differences were observed between the left and right ear before the shooting, a significantly greater hearing impairment was found in men compared to women immediately after the shooting, specifically in the right ear at 4,000 Hz. The position of the firearm could not be associated with this finding, since the gun was at an equal distance from both ears while shooting (cadets fired while standing with arms outstretched). These findings are in accordance with a study that included as many as 95,000 industrial workers professionally exposed to noise, where it was determined that there is a more pronounced hearing loss in men, with greater sensitivity of the right ear [41]. Although our study focused on acute noise exposure, contrary to the study mentioned above, our results are partially in agreement with theirs, considering that in males we also found more expressed hearing impairment in the right ear. These results can be explained by the fact that the majority of our subjects were right-handed. Despite the pistol being positioned at an equal distance from both ears, military training involves various shooting exercises with different types of weapons, in diverse body positions, using stationary and mobile targets. This could serve as an explanation for the higher sensitivity of the right ear.

Regarding risk factors, although data remain limited, existing studies indicate that smoking is associated with an elevated risk of hearing loss, and that the risk increases the longer someone continues with this habit. It has been concluded that the risk may decrease over time after quitting smoking [42]. In our investigation, smoking was the most prevalent risk factor, reported by 19 male participants and 1 female. Alcohol consumption was the second most frequent, observed in 10 male participants, 6 of whom also reported smoking. Other risk factors, including prior noise exposure, infection, and heredity predispositions, were rarely recorded. In the entire study group (males and females together), we found a statistically significant difference in baseline levels of audiometry at 2,000 Hz between the group with risk factors and the group without. The presence of risk factors increases sensitivity to noise.

Other authors also found a similar correlation. In their research, Rocha et al. [43] analyzed audiometry values in two groups of military personnel: those with a history of noise exposure as a risk factor and a control group without prior exposure. They observed that the noise-exposed groups, regardless of age, showed changes in their high-frequency thresholds when compared to the control group.

Recent studies have identified a group of genes associated with susceptibility to NIHL, suggesting that genetic predisposition plays a role in its development, along with environmental factors. These genes influence processes such as oxidative stress progression, deoxyribonucleic acid damage repair, apoptosis, as well as the structure of the cilia themselves [44]. However, in our study, only two participants reported a positive family history of hearing loss, so our data are insufficient for research in that direction.

Among the female participants, risk factors were identified in only three individuals, each presenting with one of the following: smoking, hay fever, or previous noise exposure. However, results of audiometry at 2,000 Hz showed statistically significant correlation with the presence of risk factors across all three time points. Such a result is somewhat unexpected and certainly deserves further research.

In this sense, it is important to monitor hearing at high frequencies using the conventional audiometry method for the early detection of noise-induced hearing loss.

Limitations of the study

In this study, we had to look at all risk factors cumulatively rather than individually, as we are dealing with a young, healthy population where the frequency of risk factors is low. Therefore, a significantly larger number of respondents should be included in subsequent research, so that we can evaluate the individual impact of risk factors. In addition, audiometry was performed immediately after shooting nearby the shooting theatre in a silent room. That is why the conditions were somewhat different compared to the first and third measurements.

Conclusion

The results of our research suggest that, in a population of young and healthy military personnel, acute noise exposure from gunfire leads to hearing impairment at 2,000 and 4,000 Hz, with full recovery observed after 24 hrs. Audiometric data indicated a higher hearing sensitivity to impulse noise in male subjects. They also showed that the presence of risk factors for hearing damage was associated with higher baseline hearing levels. Such results support the idea that the harmful effects of high-intensity acute impulse noise cannot be completely avoided, despite the regular use of earplugs, and that hearing protection in military service should be improved in the future. In this way, the cumulative harmful effects of noise during mandatory periodic shooting exercises should be minimized, both during cadet training and later during military service.

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Conflict of interest

The authors declare no conflict of interest.

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