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Transient Threshold Shift after gunshot noise exposure

B. Saedi[1], *M. Ghasemi*[2], *M. Motiee*[1], *M. Mojtahed*[3] *and A. Safavi*[3]

[1]Otolaryngology Department, Tehran University of Medical Sciences; [2]Occupation Medicine Department, Baghiatalah University of Medical Sciences; [3]Department of ENT, ENT Research Center, Tehran University of Medical Sciences, Tehran, Iran

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Abstract. *Transient Threshold Shift after gunshot noise exposure*. *Background*: Many people, such as soldiers, are routinely exposed to gunshot noise during target practice. It is suspected that this high-intensity noise may affect audition through repeated Transient Threshold Shifts (TTS); it can also mechanically alter auditory components such as waves. This study investigates the scope of gunshot noise from the AK-47 rifle (Kalashnikov) and the impact on the shooters' audition.

Methods: Forty soldiers (80 ears) were recruited in this study. They were all young and being exposed to gunshot noise for the first time. Gunshot characteristics were measured before exposure. The soldiers underwent auditory evaluation with Pure Tone Audiometry (PTA) and Oto-Acoustic Emission (OAE) once before exposure and immediately (less than one hour) after exposure.

Results: The AK-47 gunshot noise pressure level varied between L_{AIm} = 73.7 dBA to L_{AIm} = 111.4 dBA. Fourteen participants had subclinical hearing impairment in their pre-exposure evaluation; this number increased to 16 after the exposure. Six months post-exposure and later, the number of cases with impairment had fallen to eight (improvement in 50%). Both pre- and post-exposure OAE results were within normal values, while PTA results indicated a significant threshold alteration only at 6 kHz.

Conclusion: The results of this study confirm that exposure to gunshot noise with no ear protection can represent a significant hazard for auditory function, especially at higher frequencies.

Introduction

Many people, such as soldiers and military officers, are intermittently exposed to gunshot noise during routine target practice. Although many of them use hearing protection, many do not. The noise itself – a pulse wave noise – is intense enough to result in auditory sequels in shooters. Basically, this exposure can have a range of effects on auditory function. In first exposures, episodes of Transient Threshold Shift (TTS) can occur due to the overstimulation of the hair cells (auditory sensory units); during these episodes, sounds at lower pressure levels cannot be perceived. Situations leading to TTS episodes should be avoided[1] because these episodes, regardless of whether they are generated by pulse wave or fixed-level noises, can result in Permanent Threshold Shift (PTS),[1,2] the condition defined as the irreversible degeneration of hair cells.[1] On the other hand, these noises, as waves, can mechanically rupture the tympanic membrane, dislocate the middle ear bones or damage the organ of Corti.

Multiple studies have recently investigated the impacts of gunshot noises on the auditory system[2-8] and various results have been reported, ranging from no change in hearing status[3] to the significant deterioration of the mean auditory threshold.[8] These enormous variations may be explained by different types of rifles with different noise intensities, or by the use of hearing protection. Accordingly, the ultimate impact on audition seems to be directly dependent upon the noise-intensity level delivered to auditory structures.

TEOAE (Transient Evoked Oto-Acoustic Emission) is a widely acknowledged tool for functional hearing evaluation. The use of TOAE for the early detection of hair cell damage is also well established and has been used for monitoring ear injuries before they can be detected by conventional audiometry over the years. Some authors have reported that the tool is effective for TTS evaluation.[6,9]

The AK-47 rifle (Kalashnikov) is widely used in military training in many countries such as Iran, and soldiers are not routinely allowed to use hearing protection. This study aimed to evaluate the range of gunshot noise from AK-47 rifles and therefore to assess the impact on shooters' auditory status at their first gunshot noise exposure.

Although many authors have investigated the effect of noise exposure on TTS (Transient Threshold Shift),[2,5-7,10,11] there is still much debate about the relationship between TTS and PTS (Permanent Threshold Shift) and also about changes in the structures of the hearing system after noise exposure. The predisposing factors are also under investigation.[2,12-15]

Improving our understanding of the pathophysiology of TTS can be seen as a preventive measure. Accordingly, understanding the insidious damage caused by loud noise can make clear why protection is required during shooting practice.

Subjects and methods

Study Subjects

Forty participants (80 ears) entered this cross-sectional study. They were undergoing firearms training at the time of their first exposure to gunshot noise and they had normal hearing (hearing threshold of less than 20dB) before exposure. Moreover, they did not use hearing protection. Additionally, they had all qualified for military service and were considered to be generally healthy for the purposes of military service. None had either subjective or clinical auditory problems. Moreover, subjects with previous exposure to gunshot noise, a history of working in a noisy environment and a history of disease affecting auditory function were excluded from the study.

Pre-exposure evaluations

During the week before exposure was due, participants underwent a complete history-taking and a thorough physical examination focusing mainly on ENT problems. Data about age, eye colour, smoking, alcohol consumption, underlying disease, regular listening to loud music and ENT findings were recorded in data sheets. Auditory assessment was performed using Pure Tone Audiometry (PTA) as a subjective method and Oto-Acoustic Emission (OAE) as an objective method.

Measurement of variables

PTA was performed in an acoustic chamber and measured both air and bone conduction values using sound frequencies between 0.25 and 8 kHz. The normal auditory threshold was considered to be ≤25 db. Oto-Acoustic Emission was also used to objectively evaluate cochlear functionality for possible alterations. Consequently, these two methods used in conjunction detected both auditory conductive and sensorineural defects at an acceptable level.

Pure tune audiometry, including air and bone conduction, was performed in an acoustic chamber before and after exposure (mean values for 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz).

TTS (Transient Threshold Shift) was defined as temporary hearing deterioration after noise exposure which is fully reversible within 24 hours. Consequently, if there was not complete recovery after 24 to 48 hours, this condition was considered to be PTS (Permanent Threshold Shift).

Accordingly, TEOAE (Transient Evoked Oto-Acoustic Emission) was performed before and after exposure to gunshot noise. The stimuli for TEOAEs were 80 dB SPL 80 _s click, presented at a rate of 50/s in a nonlinear mode; the click intensity was automatically compensated in accordance with the size of the external auditory meatus and the responses were averaged after 260 repetitions. The analysis time was 2.5 to 20 ms and the TEOAE level was measured in 500-Hz intervals from 500 Hz to 5000 Hz at the frequencies of 1, 2, 3, 4, and 5 kHz. Only emissions of 3 dB above the noise background level were accepted, and this is if repeatability was 60%.

The AK-47 Kalashnikov rifle was the weapon given to soldiers for practice in an outdoor firing range. Before the soldiers entered the range, the gunshot noise characteristics were measured using a sound-level dosimeter (Cell, model 620), with the microphone attached in front of the tragus of the shooters' right ears. The levels measured were expressed in L_{AIm} (which conveyed the pulse wave noise weighing level in the scale of A (dB)).

Every soldier was provided with a 13-bullet cartridge: three bullets were used for calibration, five for semi-automatic firing and five for automatic firing. The soldiers shot in 12-shooter groups and so they could hear others firing at the same time. No ear protection was allowed in the range to simulate actual combat conditions and to allow the shooters to hear the commander's firing instructions.

Post-exposure evaluation

Immediately after the shooting practice, the soldiers were asked if they had tinnitus, dizziness, discomfort, or lightheadedness; moreover, vestibular function, speech comprehension, disequilibrium and disorientation were evaluated.

Auditory evaluations (PTA and OAE) were also performed at a tertiary health centre (Imam Khomeini Hospital, an affiliate of Tehran University of Medical Sciences) before and immediately (less than one hour) after exposure in order to detect both the Temporary Threshold Shift (TTS) and the possible Permanent Threshold Shift (PTS). Furthermore, auditory evaluations were repeated in the presence of any hearing problem after three months of noise exposure.

Ethical approval

The protocol for this study was approved by the Institutional Review Board of the Tehran University of Medical Sciences. All aspects of the study were conducted in accordance with the Declaration of Helsinki. Soldiers were asked to shoot with no ear protection by their instructors so they entered this study as part of their routine training and not at our request. Soldiers with emergency consequences of exposure to gunshot noise were immediately examined and stabilised by the medical staff at the range. Additionally, all the soldiers agreed to participate in our study voluntarily by signing informed consent forms.

Statistical methods

The outcome data were analysed using SPSS version 11.5. Comparative results were tested with chi-square testing, paired t-testing and the McNemar test. P values ≤ 0.05 were considered significant. Data was presented as mean ± standard deviation.

Results

Forty healthy males with no clinical auditory problems aged from 18 to 22 years (mean = 20.08 ± 2.61) entered the study. They were all junior soldiers with one to three (mean = 2.04) months of military training and it was their first exposure to gunshot noise. Table 1 outlines their baseline characteristics:

Table 1

Participants' personal characteristics and relationship with hearing loss

Characteristic	Amount (%)	P value
Eye colour		0.1
Brown	27 (67.5)	
Hazel	6 (15)	
Gray	3 (7.5)	
Green	3 (7.5)	
Blue	1 (2.5)	
Smoking	20 (50)	0.4
Alcohol consumption	0	0.0
History of ototoxic drug use		0.1
Tobramycin	1 (2.5)	
Gentamycin	1 (2.5)	
Erythromycin	5 (12.5)	
Furosemide	2 (5)	
Aspirin	4 (10)	
History of non-ototoxic drug use	10 (25)	
Listening to music	25 (62.5)	0.3
History of childhood diseases altering audition		0.2
Mumps	2	
Meningitis	1	

Twenty-three people reported previous medication use; 13 had used ototoxic medication and 10 had used non-ototoxic medication. No-one had taken any medication during the year prior to the exposure. Comparison of medication use with pre-exposure audiometry results showed no significant decline in auditory status (T-test, $P = 0.1$). Nobody reported taking chemotherapy drugs or exposure to heavy metals. Smoking was significantly correlated with post-exposure PTA impairment at 1 kHz frequency (T test, $P = 0.05$). Participants who routinely listened to music were found to spend an average of 1.79 ± 0.55 hours a day on this activity. Additionally, three participants reported childhood diseases with the potential to impair auditory function, but there were no changes in their audiometric profiles.

Furthermore, all participants were right-handed shooters.

Firing range characteristics and exposures

Gunshot noise frequencies were measured at between 250 and 8000 Hz, with the highest noise levels being mostly concentrated between 1000 and 2000 Hz. Accordingly, the Kalashnikov gunshot noise pressure level varied between $L_{Aim} = 73.7$ dBA and $L_{Aim} = 111.4$ dBA.

Immediately after, participants reported the following complaints: 21 had tinnitus, 13 had dizziness, 26 had hearing discomfort, 26 had word recognition problems, and 26 sensed an underlying noise. No-one reported light-headedness or was diagnosed with disorientation or disequilibrium. Vestibular function was also intact. Three subjects had pain in their ears with obvious tympanic membrane immobility and inflammation on otoscopy; only one of the three complained of a significant hearing loss in his right ear and physical examination of this subject revealed a tympanic rupture.

Auditory evaluations

Pure Tone Audiometry (PTA)

Fourteen participants (35%) had impaired pre-exposure results (subclinical sensorineural hearing defects) and this number rose to 16 (40%) after exposure. The mean hearing threshold results had not significantly changed after gunshot noise exposure (Chi2, $P = 0.2$).

PTA also revealed no significant change in auditory thresholds at frequencies of 0.5 to 4 kHz (Chi 2, $P>0.05$) while significant threshold changes were observed at 0.5 kHz (Chi 2, $P = 0.001$) and 4 kHz ($P = 0.029$). The participant with the clinical hearing loss in his right ear was also examined for any change in the contra-lateral ear at the same frequency but findings were not significant (Chi 2, P = 0.066) and favoured the conductive nature of the deficit.

The changes in the auditory status of the 16 participants with impaired post-exposure PTA results were also tested with the McNemar test and, once again, no significant difference was found ($P = 0.238$). Table 2 shows the pre- and post-exposure PTA results.

Table 2

Pre- and post-exposure audiometry results (values in db, tested with t-test)

Audiometric Frequencies	Mean and (SD) of pre-exposure values	Mean and (SD) of post-exposure values	Mean Difference	P values
Right				
500 Hz	0.2 (4.3)	2.5 (4.9)	2.3	0.001*
1000 Hz	2.7 (4.7)	3.6 (4.1)	0.96	0.096
2000 Hz	1.0 (4.5)	1.1 (4.1)	0.19	0.547
4000 Hz	10.6 (6.9)	12.1 (8.3)	1.5	0.029*
8000 Hz	10.8 (7.0)	11.9 (4.5)	1.15	0.313
Left				
500 Hz	0.9 (4.7)	1.9 (4.5)	0.96	0.134
1000 Hz	3.8 (5.2)	4.4 (5.2)	0.57	0.327
2000 Hz	0.4 (5.8)	0.4 (5.5)	0	0.999
4000 Hz	10.8 (9.5)	11.3 (7.7)	0.57	0.56
8000 Hz	10.2 (12.4)	11.9 (9.5)	1.7	0.185

*: significant.

Table 3
OAE results before and after gunshot noise exposure

Laterality	Mean and (SD) of pre-exposure values	Mean and (SD) of post-exposure values	Mean Difference	P value
Right				
WWR	75.3 (21.4)	66.4 (26.2)	8.9	0.019*
SNR 1	11.5 (7.5)	9.4 (7.4)	2.04	0.083
SNR 2	12.3 (5.6)	11.5 (5.9)	0.78	0.433
SNR 3	8.2 (5.4)	7.5 (5.8)	0.75	0.353
SNR 4	5.4 (5.1)	5.3 (4.8)	0.1	0.775
Left				
WWR	69.5 (24.4)	62.1 (33.6)	7.4	0.026*
SNR 1	10.1 (5.8)	7.7 (5.9)	1.4	0.012*
SNR 2	10.3 (6.1)	9.7 (6.7)	0.6	0.498
SNR 3	6.7 (4.7)	6.2 (5.7)	0.48	0.605
SNR 4	4.5 (5.7)	4.6 (5.7)	0.04	0.962

WWR: Whole Wave Reproducibility, SNR: Signal-to-Noise Ratio.
*: significant.

Oto-Acoustic Emission (OAE) results

As summarised in Table 3, OAE results showed significant changes in Whole Wave Reproducibility for both ears.

Follow-up results

At the end of the third month after exposure, the number of abnormal audiograms had fallen from 16 (40%) to eight (20%); the same results were noted at the end of the sixth month.

Discussion

Exposure to pulse wave noises can occur in some specific occupations like mine-workers, road and rail workers, recreational hunters, and the military. The military make up a major proportion of the population because, in addition to their usual employment, many people have to spend a period of their lives as soldiers in military service. So finding a way to protect this large population would seem to be quite important.

Our study took up this challenge and investigated the effect of gunshot noise impact on auditory function. The participants who entered this study were all exposed to gunshot noise for the first time; this characteristic eliminated the bias that might have resulted from any possible hearing damage prior to the gunshot noise. Moreover, all the subjects were young and it could therefore be assumed that there was no age-related hearing loss that interfered with the results. Auditory evaluation in this study was conducted using two methods: PTA and OAE. PTA was used to subjectively determine both conductive and sensorineural defects; OAE was used for the objective assessment of PTA results and cochlear outcomes were evaluated immediately after exposure. Accordingly, using these two methods together can result in the precise determination of possible auditory defects.

Furthermore, there are some differences between the methods of continuous sound measurement used in this study and similar approaches. There are accepted international criteria from the ISO (International Organization for Standardization) for continuous sound measurement. On the other hand, the criteria for the evaluation of impulse sound vary in different researches. However, these differences involve differences in the measurement instruments only and the final outcome of all of them is the determination of the auditory risk of loud noise from any weapon

Historical background

Although no-one was found to have clinical hearing impairment prior to exposure, the pre-exposure evaluation with PTA revealed 14 cases with defects in some frequencies. This finding shows that normal clinical hearing status in all participants (normal population) may conceal the hearing problems of a high percentage of the population (35% in our study). This is an important issue since people with pre-existing auditory impairments are more prone to further damage than those with normal audition.[3] The number of these cases reached 16 (40% of total) after exposure, which means that first exposure can result in a rise of 5% compared to pre-existing impairments.

The PTA results also showed that the hearing system was much more vulnerable at higher frequencies than lower ones. Other studies have frequently achieved the same outcome[3,5,8,16] and our study also showed a significant change at 4 kHz.[3]

This finding was also confirmed by our OAE results, which showed significant cochlear damage after exposure. On the other hand, it should be taken into account that the same noise intensity (if we disregard the actual cochlear damage) effectively ruptured a tympanic membrane and caused evident immobility and inflammation in two other pairs; this means that, if these intensities had reached the organ of Corti, a permanent threshold shift could have been reasonably expected. This consideration is a strong argument for using hearing protection, a recommendation found in many other studies.[4,6,7,17]

Routinely, military commanders order soldiers not to use hearing protection in firing ranges in order to simulate real combat conditions and to ensure that soldiers can hear instructions. However, this puts soldiers at risk of damage to hearing. One study[4] proposed a solution for this conflict by suggesting that soldiers should use hearing protection (ear plugs or earmuffs) unilaterally on the ear closer to the gun. The results of that study confirmed that this solution provided enough protection for the ear closer to the gun while allowing the soldiers to hear the instructors.[10]

One of the main differences between our study and others[4,10] is that participants did not use ear protection as part of a routine military protocol, and their circumstances therefore resembled real noise exposure in a combat situation. This probably explains some dissimilarities between the results of this study and others. It is important to ask what we can do for people exposed to gunshot noise to reduce the risk of permanent damage? Two methods have been suggested in this regard: one study reported that the administration of methyl prednisolone in the perilymph space could reduce the extent of hair-cell loss but not the permanent shift;[14] another study showed that the post-exposure administration of magnesium for seven days could reduce threshold shifts and that the continuation of magnesium for up to one month could even protect against hair-cell damage.[15] Our study also showed that up to 50% (eight cases) of auditory impairments could resolve spontaneously by sixth months after exposure.

Finally, Carter *et al*.[18] proposed that smoking could also contribute to hearing loss and also emphasised the predisposing effect of eye colour on the inducement of hearing damage by smoking and noise. However, our data did not support their hypothesis.

Our study also revealed that smokers had significant hearing impairment at low frequencies, although the average impairment in the whole group was at higher frequencies. This finding contrasts with the results of a study conducted by Virokonnas *et al*.[12] that reported more impairment at hearing thresholds of 3 to 4 kHz. However, our study and the study performed by Virokannas *et al*.[12] both suggest that smokers are prone to auditory alterations while exposed to noise.

Conclusion

The results of our study showed that exposure to gunshot noise with no ear protection could represent a significant hazard for auditory function, especially at higher frequencies. We therefore strongly recommend that shooters wear hearing protection.

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B. Saedi
Otolaryngology Research Center
Tehran University of Medical Sciences
Imam Khomeini Medical Center
Bagherkhan Street, Chamran Highway
141973141 Tehran, Iran
Fax: +982166581628
E-mail: saedi@tums.ac.ir