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Main Article

Temporary threshold shift due to recreational firearm use

U Bapat, N Tolley

Abstract

Objective: To assess whether a temporary threshold shift occurred after recreational firearm use.

Design: An observational study of 25 subjects using ear protection in an indoor rifle range. Hearing was evaluated before and after shooting five rounds with a 0.22 calibre rifle over 10 minutes. A threshold shift of 5 dB was found to be statistically significant, while a shift of 10 dB was clinically significant.

Results: Twenty-four candidates had a statistically significant threshold shift, while 12 had a clinically significant threshold shift. Two subjects with previous industrial noise exposure had threshold shifts at more frequencies than other subjects. There was no significant preference for either ear. One subject showed no changes.

Conclusion: This small study sheds some light on impulse noise behaviour in an indoor shooting range, but no definite conclusions can be drawn. The side of shooting did not influence threshold changes in either ear.

Key words: Noise Induced Hearing Loss; Firearms

Introduction

Loud noises can cause hearing loss by damaging the delicate hair cells in the inner ear. A temporary threshold shift is defined as a temporary neurosensory hearing loss that recovers almost completely once the noxious stimulus is removed.[1] A temporary threshold shift may occur after exposure to impulse noise, as it does after exposure to any loud noise, and usually recovers over 24 hours. Such a temporary threshold shift is typically related to the traumatising stimulus spectrum and to the exposure level and duration.

Temporary threshold shift is anatomically correlated with decreased stiffness of the stereocilia of the outer hair cells, which become disarrayed and floppy, perhaps due to metabolic exhaustion. Consequently, it is sometimes referred to as 'auditory fatigue'. This may account for the well described clinical fact that intermittent noise is much less likely to produce permanent injury than continuous noise at the same intensity level.

The extent of a temporary threshold shift is predictable from the noise that causes it, on the basis of intensity, frequency, content and the temporal pattern of exposure (i.e. intermittent or continuous). Basilar membrane mechanics appear to be largely responsible for noise-induced temporary threshold shift. The maximal temporary threshold shift is generally seen one octave above the peak frequency of the stimulus.

There appears to be a critical intensity level for noise exposure. Below the critical level, little or no hearing damage will develop regardless of exposure time. Beyond the critical level, extensive damage will be caused even after a short exposure time.

Sound in one ear may also influence the susceptibility of the other.[2] Factors other than the physical properties of the fatiguing sound contribute to the degree of temporary threshold shift.[3] A clinically important feature of temporary threshold shift is that it is rarely apparent to the subject because of its relatively low magnitude and relatively high frequency.

Repeated temporary threshold shifts suffered over weeks, months and years eventually fail to recover completely and thereby become a permanent threshold shift. This is associated with fusion of adjacent stereocilia and loss of stereocilia. Permanent threshold shift is related to a number of factors, including exposure duration, subject's age, exposure to other ototoxic factors, presence of impulse noise components, etc.[4]

Temporary and permanent threshold shifts represent the most common hearing effects of acute and chronic high-level acoustic stimulation. More severe injury results in a range of pathology, from

From the Department of Otolaryngology and Head and Neck Surgery, St Mary's Hospital, London, UK.
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loss of adjacent supporting cells to complete disruption of the organ of Corti.

Tinnitus will present when there is a temporary threshold shift in which the hair cells are damaged and are trying to recover, or when there is a permanent threshold shift in which the hair cells have been destroyed. These hairs produce ongoing 'sounds'; that is, they are constantly stimulated because they are irritated. The brain perceives this constant irritation as sound. Individuals who reliably experience ringing in their ears after noise exposure probably have experienced an injury to the auditory system in the form of at least a temporary threshold shift.

Since repeated temporary threshold shift slowly converts to permanent threshold shift, post-exposure tinnitus and temporary threshold shift serve as warning signs of impending permanent noise-induced hearing loss. By comparing pre-exposure audiograms with audiograms taken immediately after exposure and again 24 hours later, the presence or absence of temporary threshold shift or permanent threshold shift can be established. Pure tone audiometry at the usual octave intervals should be performed, with the inclusion of 3000 Hz, which is a sensitive area for noise-induced hearing loss and is a frequency that contributes significantly to speech understanding.

An impulse noise is a transient noise stimulus which is usually due to blast effect and the rapid expansion of gases. It is often the consequence of an explosion. Gunfire may be categorised as an impulse noise. Sounds over 85–90 dB can lead to permanent hearing damage when heard without hearing protection. The US National Institute for Occupational Safety and Health criteria document states that exposure to impulse noise should not exceed 140 dBA.[5] Firearms can produce noise levels of up to 170 dB. Thus, the use of hearing protection to reduce the harmful effects of impulse noise is recommended, even if the weapon is fired only once, since virtually all of the structures of the ear and hearing system can be damaged from gunfire noise.[6] Most non-occupational noise-induced hearing loss is the result of firearms. The noise-induced hearing loss associated with firearm noise in right-handed rifle shooters has been described as a bilateral, high-frequency sensorineural hearing loss affecting the left ear more than the right. This is because the left ear faces the barrel while the right ear is tucked into the shoulder and in the acoustic shadow of the head.

Indoor and outdoor firing ranges for recreational firearm use are popular. Such firing ranges may allow the use of a variety of rifles and pistols of different calibres, or they may restrict the type of weapon used, depending on the location and size of the range. Impulse noise from firearms behaves differently in indoor firing ranges because of the reverberation effect when the sound reflects off hard surfaces.

Ear protection in the form of earmuffs is compulsory in the practice area, and this attenuates the sound heard by the subject to safe levels. Earplugs and earmuffs are available with attenuation levels from 10 to 32 dB, although they are not frequency selective. An advantage of earmuffs is that they are easy to place correctly and are especially useful when exposure to noise is relatively intermittent. For shooters, a key indication of ear protection inadequacy is ringing of the ears or a feeling of fullness in the ears after an episode of shooting.

The aim of this study was to evaluate the effect of recreational firearm noise on a small group of individuals using an indoor rifle range. We specifically aimed to determine whether or not temporary threshold shift occurred after short duration exposure to impulse noise.

Materials and methods

Test subjects

Twenty-five shooting enthusiasts (members of an indoor rifle club) underwent pure tone air conduction audiometry before and after their shooting session. The group consisted of 18 men and seven women, with an age range of 21 to 69 years (median 51 years). Routine demographic data was collected, along with specific information related to otologic history, general illness, past noise exposure (occupational or other), handedness and use of ear protection (Table I). All except two subjects were right-handed. Seventeen subjects had a history of other previous noise exposure, in the army or as members of a rock band in their younger days. Two had a history of industrial noise exposure and were aware that they had suffered noise-induced hearing loss from the same, prior to retirement. None of the subjects had any significant otoscopy findings. All the subjects wore protective earmuffs while inside the range. These were not frequency specific but attenuated the sounds by 20–30 dB (manufacturer's recommendations).

Firing range

This was a five lane, 25 m long indoor range. It was situated in the grounds of a secondary school and was too far from any other building for external sounds to be heard or to have any significant effect. The bullets used were all of 0.22 calibre only.

TABLE I

SUBJECTS' CHARACTERISTICS

Characteristic	Subjects (*n*)
*Age** (years)	
21–30	1
31–40	5
41–50	5
51–60	8
61–70	6
Sex	
Male	18
Female	7
Dominant hand	
Right	23
Left	2
Previous noise exposure	
Military/leisure	15
Occupational/industrial	2

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Instruments used

A PCWerth Kamplex TA155B diagnostic audiometer (Kamplex TA155 Diagnostic Audiometer, Serial No. 2040, manufactured by Interacoustics, Assens, Denmark and distributed by PC Werth Ltd, UK) was used. Only air conduction audiometry was performed as the temporary threshold shift was being studied. Since both the pre- and post-shooting audiometric tests were conducted in the same place and the background conditions were relatively constant, the lack of a soundproof room (providing ideal conditions for testing) was not considered essential. Each individual acted as his or her own control. The frequencies measured were 250 and 500 Hz and 1, 2, 3, 4, 6 and 8 kHz on both ears, i.e. a total of 16 frequencies were tested.

A fast sound level meter (Kamplex SLM3) measured the sound pressure level at the time of shooting. The peak level was 110 dBA (dBA denotes a decibel measure made with a filter that adjusts for human auditory sensitivity) inside the range, measured at the level of a shooter's left ear in a right-handed person while shooting from a rifle.

All equipment was calibrated before the study.

Test conditions

Each candidate underwent air conduction pure tone audiometry prior to shooting five rounds over 10 minutes with a 0.22 calibre rifle. This was followed within 10 minutes of the shooting by the post-exposure hearing test. The tests were carried out in a quiet room in the firing range.

Analysis

A threshold shift was recorded whenever an average 5 dB or greater shift occurred in the threshold at any of the frequencies tested for either ear. A series of paired *t*-tests was performed to determine if there were any statistically significant differences (i.e. $p < 0.05$) between hearing thresholds before and after the shooting episode. The US occupational safety and health act defines a standard threshold shift as an average 10 dB or greater shift from the baseline audiogram at 2, 3 and 4 kHz for either ear.[7] This was used as a guide in our study; a threshold shift of 10 dB or greater at any frequency was considered clinically significant.

Results

Twenty-four out of the 25 subjects had at least a single frequency threshold change of 5 dB or more. Out of 16 frequencies tested, 22 subjects had a 5 dB or more threshold change over two to seven frequencies, one subject had changes at 10 frequencies and another at 15 frequencies. Both of these latter subjects had a history of industrial noise exposure. Only one subject had no change in any threshold following exposure. None of the test group reported tinnitus or hearing loss following the noise exposure. These shifts, of a minimum of 5 dB, were statistically significant ($p < 0.05$) using the paired *t*-test at all frequencies except 250 Hz and 2 kHz on the left side.

TABLE II

SUBJECTS WITH CLINICALLY SIGNIFICANT THRESHOLD SHIFTS

Frequency (Hz)	Subjects with clinically significant TS (*n*)	
	Right ear	Left ear
250	0	1
500	0	0
1000	2	2
2000	0	1
3000	0	1
4000	3	1
6000	3	1
8000	3	0

TS = threshold shift

Clinically significant threshold shifts of 10 dB or more were observed at all frequencies except 500 Hz (Table II). These were seen in a total of 12 subjects (48 per cent) (Table III). Four subjects had changes at two frequencies and one subject at three frequencies. Eleven clinically significant threshold shifts occurred in the same ear as the dominant shooting hand, and seven occurred in the opposite ear (no effect of the head shadow was seen in this study).

On the other hand, prior history of noise exposure correlated well with threshold shifts (Table IV). A history of noise exposure was reported by 10/12 subjects (83.3 per cent) who showed a clinically significant threshold shift, compared with only 7/13 subjects (53.8 per cent) who showed no clinically significant threshold shift. The greatest changes were seen in the two subjects who had noise-induced hearing loss from previous industrial noise exposure.

Discussion

Exposure to impulse noise has been studied in military and recreational settings. A study on the effect of impulse noise from a howitzer and a rifle on cats' ears found that although most ears recovered

TABLE III

SUBJECTS WITH CLINICALLY SIGNIFICANT THRESHOLD SHIFTS: DETAILS

Subject	Noise exposure?	Handedness	TS frequency (Hz)	
			Right ear	Left ear
1	Y	R	1000	
3	Y	R	6000	
4	N	L	1000	1000
6	Y	R	4000 8000	
10	N	R		1000
11	Y	R	8000	2000
12	Y	R	4000	6000
15	Y	R		4000
19	Y	R		3000
22	Y	R	6000	
23	Y	R	6000	
24	Y	R	4000 8000	250

TS = threshold shift; Y = yes; N = no; R = right; L = left

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TABLE IV

SUBJECTS' CLINICALLY SIGNIFICANT THRESHOLD SHIFTS AND HISTORY OF NOISE EXPOSURE

Clinically significant TS?	History of noise exposure? (*n*)		Total (*n*)
	Yes	No	
Yes	10	2	12
No	7	6	13
Total	17	8	25

TS = threshold shift

about 50 per cent of their loss, some showed continued deterioration.[8] Observations on long-serving soldiers frequently exposed to impulse noise showed that temporary threshold shifts can develop into a permanent threshold shift if the noise exposure continues.[9] A study of the hearing thresholds of Eskimos showed evidence of impulse noise trauma from rifles and shotguns, which is the major source of noise for this population. In recreational firearm users, high frequency hearing loss and hearing handicap was seen to vary with age and occupation.[10–12] A case–control study on exposure to leisure noise during an aerobics class (mean noise level 91.8 dB) showed temporary threshold shifts occurring in all those exposed to the noise for an hour.[13]

Impulse noise has been shown to result in significant temporary threshold shift, and cumulative exposure to the impulse noise can also lead to noise-induced hearing loss.[14–20] As mentioned earlier, exposure to impulse noise should not exceed 140 dBA.[5] In our study, the maximum intensity was 110 dBA, which is within the accepted range. To our knowledge, there has been no study to assess whether temporary threshold shift occurs due to impulse noise from indoor recreational shooting, even though this is a well known leisure activity and adequate ear protection is used.

This study was thus undertaken to investigate the effect of impulse noise on the hearing thresholds of 25 recreational shooting enthusiasts. In all, 24 subjects (96 per cent) demonstrated an elevation of their air conduction thresholds following exposure to impulse noise. However, only 12 subjects (48 per cent) had clinically significant threshold shifts of 10 dB or more. Of the 16 frequencies tested, there were statistically significant threshold shifts in 14. These changes occurred mainly at and above 1 kHz.

We found a positive correlation between history of noise exposure and significant threshold shift following impulse noise exposure (10/12 subjects). Two of these subjects, with a history of industrial noise exposure, had threshold shifts observed in at least 10 frequencies.

No subject complained of any loss of hearing or reported any tinnitus. This absence of tinnitus does not indicate the absence or presence of temporary threshold shift. Repeated testing 24 hours after impulse noise exposure may be helpful in demonstrating the return to normal thresholds.

A study of the temporary effect of fatiguing noise on hearing showed that temporary threshold shift may be a useful measure of individual sensitivity to noise. However, it seems doubtful that any prognosis of presumed permanent threshold shift could be made based on the evaluation of temporary threshold shifts.[21]

We found that a temporary threshold shift did occur, even after exposure to impulse noise for a very short duration. In our study, there was no significant difference in the temporary threshold shifts seen in the right and left ears, irrespective of the dominant hand. This is in contrast to some previous studies, which found that the ear opposite to the dominant hand sustained more pronounced hearing loss.[22–24] In another study, the audiograms of 644 French army officers were analysed for left–right asymmetry of hearing thresholds and any relationship to the subject's shooting posture. The results suggested that each ear has different intrinsic characteristics, as lower frequency thresholds were better for left ears whereas higher frequency thresholds were better for right ears.[25]

Otoacoustic emissions have been used in some recent studies to assess cochlear changes during recovery from impulse noise exposure.[26] A comparative study of pure tone averages and otoacoustic emissions before and after impulse noise exposure in 10 soldiers indicated that emissions seem to be more sensitive for monitoring early cochlear changes.[27]

- **Temporary threshold shift can result from impulse noise in recreational or military settings**
- **Cumulative exposure to impulse noise can lead to noise-induced hearing loss**
- **Following firearm use, the ear opposite the dominant hand has more pronounced hearing loss**
- **This was a study of the effect of impulse noise in a small indoor shooting range**
- **Temporary threshold shift may occur from exposure to indoor firearm noise**

Our small study population imposes limitations on the conclusions drawn from this study. As only approximately half the study population (48 per cent) had clinically significant threshold shifts of 10 dB or more, the results were equivocal. Repeated testing after a few hours may add further information regarding temporary threshold shift, and repeated testing after 24 hours may show a return to normal thresholds. Further studies to characterise the effect of impulse noise on hearing would enable a more thorough understanding of the mechanisms of hearing. In our study, we did not notice any influence of side of shooting on the threshold changes. Only industrial noise exposure correlated with increased sensitivity of the ears to loud noise, while other noise exposure did not affect results in the present study.

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Address for correspondence:
Mrs U Bapat,
123 Turney Road,
London SE21 7JB, UK.

Fax: 020 7014 0431
E-mail: urmibapat@yahoo.com

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