HEARING HAZARD FROM SMALL-BORE RIFLES

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At the beginning of this year articles appeared in national newspapers expressing concern at the damage to hearing said to be due to modern military small arms.

Simultaneously the National Small-bore Rifle Association received a private inquiry regarding a group of young men who had been rejected for flying training by the R.A.F. due to slight deafness, said to have been caused by rifle shooting.

Ever mindful of its duty to affiliated clubs and members, the National Small-bore Rifle Association organised a large-scale research project into this question by the Audiology Group of the Institute of Sound and Hearing at the University of Southampton. With the aid of a grant by the Medical Research Council and provision of ammunition and targets by the National Small-bore Rifle Association, this work has been completed and its conclusions appear below.

The thanks of all small-bore rifle shooters are due to the authors, the Institute of Sound and Vibration Research, to the Medical Research Council, to Southampton University and Highfield Small-bore Rifle Clubs, and to Dr. L.H.Lerman and our representative on the British Association of Sport and Medicine.

As a practical working paper for riflemen certain conclusions arise, and though they may seem self-evident this is the first time such self-evident truths have been exposed to scientific display.

Firstly, the importance of the environmental effects - shooting in the open air and in confined spaces of differing characteristics causing large differing in impulsive noise.

Secondly, the surprisingly high figure - 10 per cent - of the average exposed population who would be at risk on an indoor range.

Thirdly, ear protection. This section (Section 4) of the report needs to be studied most carefully by our administrators at national and club level. Club committees must take to heart the lessons incorporated in this section. They will welcome the view that they can protect their members so easily and so efficiently by fitting sound absorbent materials to certain selected parts of their premises as outlined in this paper. They will also be encouraged to do so by the comparative cheapness and availability of these materials.

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Committees should also give thought to drawing up rules for guidance of individual members so that they may protect their hearing even when not in the ambience of their own well-protected (!) club range in the same way as they draw up safety rules concerning the use of firearms.

It is unfortunate that the investigators were unable to extend their work to pistol shooting, which is now becoming increasingly popular amongst small-bore shooters. Their one conclusion, that in using a pistol outdoors the peak pressure level is five times as great as is the rifle, is very disturbing. The extrapolation of such a figure to indoor shooting is beyond the terms of this brief note, but their wise recommendations about personal ear protection should not go unheeded.

It is to be hoped that the National Small-bore Rifle Association can persuade the authors to carry out such further work on indoor pistol shooting and so arrive at some suitable remedy for this further hazard.

Hearing loss due to excessive exposure to industrial noise has been recognised for many years, and the hazards of heavy gun and small arms firing among service personnel is also well documented. Only recently, however, has the noise hazard of full-bore rifles been brought to the notice of sportsmen. In view of this, and the joint research programme on the effects of high intensity impulse noise on hearing between the Institute of Sound and Vibration Research and the Royal Naval Medical School, it was felt desirable to ascertain just what risk to hearing existed from unprotected exposure to the noise of small-bore weapons.

In studies of this kind two approaches are possible - either the noise can be measured and compared with other noises which produce a known effect, or the temporary hearing losses occurring after controlled noise exposures in a sample group of subjects can be measured. As the present knowledge of the effects of impulsive noises is largely based on measurements done with full-bore weapons and explosions, it was felt preferable therefore to adopt the second alternative approach. Besides being useful to small-bore riflemen, these experiments have also helped to fill a gap in the scientific knowledge of the effects of impulsive noise on hearing.

In planning these experiments, three variables which can affect the possible degree of hearing loss had to be taken into account:

- (1) Differences between the makes of ammunition.
- (2) Differences in the acoustics of various ranges. The reverberation of the range (i.e., the time taken for a sound to decay by a predetermined amount) and echoes will affect the degree of noise exposure experienced.
- (3) Variations in the individual susceptibility of the firers to damage from high-intensity impulsive sounds.

MEASUREMENT OF RIFLE NOISE

Due to their relatively long response time, conventional sound level meters are not suitable for measuring impulses. Hence the noise was measured with a calibrated Bruel and Kjaer Type 4135 $\frac{1}{4}$ in. condenser microphone and pre-amplifier. The output from this was displayed on a storage oscilloscope screen and the resulting amplitude/time trace recorded using a Polaroid camera. A second microphone and amplifier placed slightly closer to the rifle was used to trigger the oscilloscope.

A tendency towards a greater hearing loss in the left ear is known to exist among firers of full-bore weapons (assuming a right-handed firer), and this suggests that the sound pressure level reaching the left ear is greater than that reaching the right one. Consequently, a limited investigation of the sound field around the firer was made at the positions marked on Figure 1. These positions are described in Table, 1, together with the peak pressure levels measured. Lapua Championship was used as the standard ammunition fired by the subjects during the experiment. Differences in peak pressure levels reaching the left and right ears are apparent from this table, whilst the measurement taken at four feet to one side of the trigger shows the noise field experienced by an adjacent firer in a typical position.

TABLE 1-PEAK PRESSURE LEVELS MEASURED NEAR
A .22 RIFLE WITH THE FIRER IN POSITION

Position				Peak pressure level
Two feet left of muzzle	...	...	...	139 dB
Four feet left of trigger	...	...	...	132 dB
Close to firer's left ear	...	...	...	138 dB
Close to firer's right ear	...	...	...	130 dB

Figure 1. Positions of sound pressure level measurements.

For comparison of different ammunitions it was found more convenient to measure the peak pressure level at two feet to one side of the muzzle. Vostok, Lapua Championship and Match, Western Xpert and Eley Hundred were tested. Although most subjects agreed that there was a difference in loudness between the various makes of ammunition (decreasing in the order mentioned above), difference in the peak pressure level and duration, averaged between several rounds, were negligible.

The range acoustics will also affect the noise level reaching the firer's ear. In the open, most of the sound reaching the ear is directly radiated from the rifle, chiefly from the muzzle, although there may also be some ground-reflection, depending on the nature of the ground, or echoes from a nearby wall or roof. However, on an indoor range the sound is reflected from both walls and the same sound may be reflected back and forth many times. Because of the relatively small distances involved, the echoes follow one another too closely to be distinguished by the ear, and the shot merely sounds louder. The echoes can, however, be seen on the photograph of the oscilloscope trace in Figure 2a, which can be compared with the trace of a shot fired outdoors in Figure 2b.

Figure 2. Oscilloscope traces of (a) the multiple reflections of a rifle shot fired in an indoor range, (lower) a rifle shot fired outdoors.

The effect of the noise on the ear in an indoor range is therefore determined by the time taken for the noise to decay to a level which is small in comparison with the peak level. The worst type of range, from this point of view, has parallel surfaces of a non-absorbent material such as brick, stone or concrete, and with a minimum of 'furnishings', etc. (as in range C below). Such a range would be termed acoustically 'live'.

The different acoustics of three typical ranges are shown in Table 11 by the times taken for the peak sound pressure level to decay by 20 decibels with the microphone two feet to one side of the muzzle.

TABLE 11-ACOUSTICS OF THREE TYPICAL RANGES

Range	Peak pressure level (two feet to side of muzzle)	Time taken to decay 20 dB
A	139 dB	2.5 m/sec.
B	139 dB	30 m/sec.
C	139 dB	approx. 100 m/sec.

A-Open air, grass covered ground. B-Earth floor, parallel brick walls, corrugated iron roof. C-Prefabricated concrete construction, parallel floor and ceiling, parallel walls.

EVALUATION OF AUDITORY HAZARD

The first noticeable effects on the hearing due to excessive noise exposure are ringing in the ears and/or a temporary loss of hearing acuity which is measurable as a temporary threshold shift, usually centred around higher audible frequencies in the range 4 to 6 kc/s, but sometimes showing a maximum as low as 2 kc/s or as high as 8 kc/s. Given sufficient time, and provided the effects do not exceed certain experimental limits, the subject gradually recovers from these symptoms on removal from the noise and the hearing returns to its original level. If the exposure is sufficiently intense, or is repeated sufficiently often, particularly with short intervals between exposures, part of the threshold shift becomes permanent.

Because noise tends mainly to damage the higher audio-frequencies, there is little or no apparent diminution in the loudness of other people's voices - instead they become difficult to understand. In speech, vowel sounds contain most of the energy and this is in the low-frequency character and lower intensity. In cases of noise-induced hearing loss, the consonant sounds most important for intelligibility are not heard clearly, especially in conditions of background noise, for example, in crowds.

It is not usually until an advanced stage is reached that the slowly developing deafness becomes subjectively noticeable. A typical case of noise-induced hearing loss in a young person is shown in Figure 3.

Figure 3. Typical audiogram of a case of noise-induced hearing loss due to rifle fire.

A tentative hearing damage risk criterion for impulsive noise has been formulated in this Institute following experience with full-bore rifles and other sources of impulsive noise, Although care should be exercised in extrapolation from one kind of noise to another, application of this criterion suggested that up to about 10 per cent of an average exposed population would be affected by exposure to .22 rifle fire on an indoor range. In other words, anyone particularly susceptible to damage from impulsive noise might suffer a hearing loss, especially from repeated exposures.

The hazard was evaluated by measuring the temporary threshold shift produced by firing under controlled conditions. It was considered that any potential noise-induced hearing loss from repeated exposures would be predicted by a temporary threshold shift. In order to ascertain if the .22 rifle could in fact cause any such temporary threshold shift, a rather extreme exposure was adopted, each subject firing 100 live rounds evenly spaced over half an hour. To save time, and to simulate normal firing-point conditions, the subjects fired in pairs, lying about four feet apart. Each subject was therefore subjected to a total of 200 rounds, the report from the adjoining rifle being (for reasons beyond the scope of the article) of approximately equal potential hazard to that from the subject's own rifle.

The degree of temporary threshold shift produced was determined by measuring the subject's threshold of hearing (the faintest pure-tone sounds just heard) just before and commencing two minutes after the noise exposure. The threshold was measured at six frequencies between 500 c/s and 6 kc/s, which covered most of the frequencies at which temporary threshold shifts, if any, were likely to occur. This was done in a quiet room adjoining each range, using Rudmose ARJ-4 self-recording audiometers with earphones fitted into noise-reducing enclosures to minimise the effects of extraneous background noise. See Fig. 4.

Figure 4. Rudmose ARJ-4 self-recording audiometer with earphones fitted into noise-reducing enclosures.

A temporary threshold shift was not considered to be of practical importance unless it exceeded 10 decibels at two or more of the frequencies tested. Such shifts occurred in four out of nineteen subjects; in three cases in the left ear only, and in the other in both ears. Three of these were not members of a rifle club; two had never fired before and the third not since National Service. However, two of the subjects already had noise induced hearing losses exceeding 25 dB at 4 k/cs, and these could be traced to firing full-bore weapons or other noise exposure. These people were obviously noise sensitive, but any temporary threshold shift due to .22 rifle fire would have been reduced in amount because of the pre-existing hearing loss and, but for this, they might well have shown a larger temporary threshold shift.

Two subjects repeated the firing on an outdoor range, when there was only negligible threshold shift. One of these had shown a temporary threshold shift on the indoor range, and the other had had a 15 dB shift at 6 kc/s.

A summary of all the hearing tests has been produced.

ACOUSTIC IMPROVEMENTS AND EAR PROTECTION

Although the rate of firing, and the total number of rounds fired, were both in excess of those usual in normal practice, the experiment has served to demonstrate that there is some risk of slight hearing damage occurring in noise-sensitive individuals from indoor firing of the .22 rifle. Comparison with the noise measurements obtained outdoors and the apparent absence of auditory hazard there suggests that the indoor effect is due to reverberation. As most ranges are built of materials of low noise absorption coefficients, e.g., brick, concrete, stone, etc., it should be fairly easy, and not too expensive, to reduce the reverberation to within acceptable limits.

Wood-pulp trays, such as are used for packing eggs and sometimes fruit, have been shown to have some sound-absorptive properties if fixed to walls, ceilings and other reflecting surfaces and would probably be sufficiently effective in the .22 rifle range situation if used extensively. Commercially available acoustic tiles, however, offer considerably better absorption of reverberant noise, are aesthetically more pleasing and many types are incombustible. As the amount of noise reduction offered is proportional to the logarithm of the area of absorbent material installed, there must obviously be an optimum area beyond which it is not economical to install further material. In this instance it is suggested that only the firing end of the range need be treated, the treatment being continued along the side walls for a distance of some six feet or so beyond the firing line. If, on the grounds of economy, it is only possible to install material over some part of this total area, the available material should be evenly distributed around the surfaces requiring treatment. Liberal use of coconut matting on the floor is also beneficial.

The slight risk of hearing loss may alternatively be eliminated by the use of ear protection. Plugs fashioned from 'glass down' offer adequate protection in this instance, and are cheap, comfortable and disposable. Plastic or rubber ear plugs have to be rather uncomfortably tight to be effective and can give rise to infection of the ear canal if not kept clean. Ear muffs are comfortable, but cumbersome, and offer more than adequate protection against .22 fire. Even when tightly packed into the ear, cotton wool offers considerably less attenuation than do other ear plugs and has proved to be a very unreliable method of ear protection.

Although ear protectors do make communication less easy, they may also improve marksmanship by making it easier to concentrate, and the latter effect would also be achieved by acoustic treatment of the range.

PISTOL NOISE

Unfortunately, the range used for the audiometric investigation was not licensed for pistol shooting, but the report from a .22 pistol was measured on the outdoor range. The peak pressure level measured two feet to one side of the muzzle was found to be 153 decibels compared with 139 decibels from a rifle fired under similar conditions. This corresponds to a peak pressure level about five times as great.

The pressure at the ear is also greater, the right ear being more likely to be affected in pistol shooting. Ear protection should always be worn whilst firing pistols indoors.

SUMMARY

The investigation has shown that there is a possibility of highly noise-sensitive persons suffering some hearing loss through repeated exposures to noise of .22 rifles fired in reverberant indoor ranges. Acoustic treatment of the firing end of the range should be sufficient to prevent this, but if acoustic treatment is not feasible, suitable ear protection is recommended.

It may be appropriate here to re-emphasise the necessity for ear protection while firing full-bore rifles. Several studies have shown both temporary and permanent hearing losses in a considerably proportion of those using such weapons; while most of the recent work has been done using the 7.62mm. self-loading rifle, the noise from the .303 is nearly as great. The maximum sound pressure generated by such weapons is over ten times that for a .22 and the total duration of the pressure envelopes is longer. Ear protection becomes especially necessary when several riflemen are firing close together, or where there are reflecting surfaces, such as hard walls and/or a ceiling, near the firing point.

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