NOISE AND THE INFANTRYMAN

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"... of 100 infantrymen who regarded their hearing as normal ... 54 of these men were found to have audiometric evidence of acoustic trauma". *J. roy. Army med. Corps* (1965). 111, 193."

Introduction

FOR several years now there has been a growing concern about the increase in noise-induced deafness in officers and men of all arms. This concern has been reflected in the studies undertaken by the Army Personnel Research Establishment (A.P.R.E.) of the sound pressure peaks and durations generated by weapon firing and of the sound pressure levels to which personnel are exposed when travelling in Armoured Fighting Vehicles (A.F.V.), Armoured Personnel Carriers (A.P.C.), helicopters and other forms of military transport, as well as the hazard caused by noisy engines in military workshops. Advice given to the Defence Council resulted in the issue of Defence Council Instruction (D.C.I.) (Army) 19 of 1966 which defined hazardous noise and authorised the individual provision of V51R ear defenders. The D.C.I. also forecast the need for more sophisticated devices such as ear muffs and combined ear muff and communication head-sets in special circumstances.

The military hazard

Hearing acuity may be damaged by noise in the course of a short, intense, exposure such as from gunfire, or it may suffer a gradual deterioration over periods of months or years of exposure to high levels of continuous noise as in vehicle workshops or travelling in noisy vehicles.

Apart from difficulties in inter-communication which defective hearing can cause, the major problem of aural detection and identification of the presence of enemy personnel is exacerbated when soldiers have been deafened (Black 1958), albeit temporarily, by exposure to gunfire or long periods of travel in noisy vehicles. Increasingly, 'intellectual' (e.g. vigilance) tasks are being required of the modern infantrymen especially in the senior ranks, and studies by Broadbent (1958), Lazzaroni (1962) and Wundt (1893) have shown that accuracy in an 'intellectual' task diminishes in noisy conditions.

Scientific evaluation of the hazard

Basic principles

Although the human ear is sensitive to sound frequencies between 20 and 20,000 Hz (cycles per second), maximum sensitivity is obtained around 4000 Hz and the frequencies which are important for special intelligibility lie between 500 and 4000 Hz.

The ear recognizes as sound, variation of pressure from less than 1/1000th part of a dyne per sq cm to more than 1000 dyne/sq cm which is recognised as the pain threshold for continuous noise. Because of this wide range, and also because the ratio of two different pressures is more nearly related to the change in human sensation than pressure difference on a linear scale, it is convenient to use a logarithmic scale. Sound pressure levels are therefore measured in decibels (dB) and are commonly related to a pressure

of 0.00002 dynes/sq cm (2×10^{-5} N/M²) which is the lowest sound pressure discernable by the normal human ear. In other words, where a sound is said to have a value of "X" decibels, it has a pressure of "X" decibels above the specified reference pressure.

Measurement of continuous noise

In dealing systematically with noise problems, sound measuring instruments are essential. The two main techniques used for the measurement of continuous noise are by recording microphone to an oscilloscope or by using a Sound Level Meter. For practical purposes, the use of an oscilloscope in this situation is unnecessarily precise and cumbersome. Modern Sound Level Meters with inbuilt Octave Band Analyses are by far the most useful tool at this stage.

Sound energy is picked up by a microphone system which converts it into electrical energy; this is then measured in microwatts and expressed on a comparative logarithmic scale in decibels. Measurements of sound pressure level are not taken for academic interest, they are intended to be used for the estimation of hearing damage risk, annoyance, or acoustical insulation efficiency. Consequently, an instrument giving data which could be immediately related to subjective impressions of loudness would be desirable. Attempts have been made to design such an instrument. In view however of all the difficulties involved in simulating the human hearing system for all types of noise it has been internationally decided that the most practical solution is to standardise an apparatus by which the root mean square sound pressure can be measured under closely defined conditions so that results obtained by different users can be compared.

Provided that it has been properly calibrated, and checked for stability of calibration before use, a simple sound level meter will indicate whether a continuous noise problem exists in, for example, a workshop where engines are being tested. Reference to available criteria (Burns 1965 and 1968) for overall sound pressure exposure time will rapidly indicate whether a problem exists or does not. If an overall sound pressure of some 85 dB or more is found in such a situation where personnel may be employed for many hours a day, further investigation is warranted. This further investigation would involve an accurate analysis of the noise and relating this to the known criteria for exposure to continuous noise—with appropriate allowances for on off time—in comparison with the average daily exposure of the personnel involved (Burns 1965, Kryter, Ward and Miller 1966 and Kryter 1965).

Measurement of impulsive noise (gunfire)

Because of the comparatively short time at which an impulsive type noise, such as gunfire, stays at its peak level (e.g. U.K. L.I.A.I. Rifle) the 'A' duration (which is the time required for the initial pressure wave to rise to its positive peak and return momentarily to ambient) is of the order of 330 microseconds. A sound level meter would be quite inappropriate for measurement of such a rapid transient, and the only practical methods of measurement are by microphone or piezo-electric blast gauges connected to a recording oscilloscope.

By means of a suitably calibrated microphone/oscilloscope system, the peak sound pressure from gunfire of all calibres can be measured and the 'A' and 'B' durations of the pressure wave determined. The 'A' duration has already been defined. The 'B'

duration is the total time that the envelope of the pressure fluctuations (+ive and -ive) is within 20 dB of the peak pressure level. Included in this time would be the duration of that part of any reflection pattern that is within 20 dB of the peak level. In the case of the U.K. L.I.A.I. rifle, the 'B' duration when fired in the open air is about 5 milliseconds. In indoor ranges, owing to reflections, this would obviously be longer. The reason for measuring peak sound pressure and the two durations will become clear when we consider current damage risk criteria for impulsive noise.

Unfortunately, although some attempts have been made to produce a portable "Impact Noise Analyser", the storage oscilloscope method is, at present, the only accurate means of measuring this type of noise.

Some examples of the hazard

Collins (1948) described work carried out on acoustic trauma in 108 military subjects at the National Hospital, Queens Square, London. At the time of acoustic trauma, deafness was a symptom complained of by all his patients; rather more than one third of these considered that their deafness was now aggravated by gunfire to a greater extent than had previously been present. In 88 per cent of the subjects, tinnitus was present. It was usually acute at the time of injury and in 47 per cent of cases also continued to be present at the time of examination. Pain was experienced by some 37 per cent of the patients at the time of injury but in rather less than 10 per cent did this symptom tend to recur on aggravation by further exposure to gunfire. About 50 per cent of the patients had both eardrums ruptured, but they healed well. Collins pointed out that, although the eardrums healed quite well, there was a residual deafness of a permanent character.

More recently, Drettner (1963) showed that 18.7 per cent of 235 recruits showed a hearing decrement after small arms firing but there was a significant decrease among similar recruits wearing ear defenders.

In a paper on "War deafness and its prevention" Guild (1941) stated "I wish to point out that to prevent war deafness, it is necessary not only to have the required technical information but also *to have suitable action taken by those in authority*". While this is true it must also be remembered that all the scientific measurements and recommendations, backed by those in high authority, are of little use if the officer and N.C.O. in charge of the range or firing party does not implement the provisions laid down for their protection.

Korkis (1952) in a paper on "Blast injuries of the ear" sounded a warning note of caution which is true today. He concluded that a soldier must be allowed a reasonable standard of hearing to carry out his orders. Solid ear plugs must have a damping effect on the acuity of hearing and it will not be easy to insist on men wearing ear plugs—human nature being what it is. He also pointed out that the constant use of ear plugs is likely to lead to a certain number of cases of otitis externa, especially in tropical climates. This last point is particularly true today when each soldier is issued with his own ear plugs, and care should be taken to see that these are regularly cleansed in soap and water.

The scientific and medical literature abounds in examples of temporary and permanent deafness due to unprotected exposure to gunfire but this very short survey

would be incomplete without mention of a paper by Meyrick (1946) on the incidence of acoustic trauma in the training of infantrymen. A total of 195 males between eighteen and a half and twenty years of age were studied, and a control group of 178 civilians were used for comparison. During their infantry training, the military subjects fired the rifle, Bren, Sten, 2 inch Mortar and "Piat" guns. A marked deterioration in hearing acuity, especially in the higher frequencies and at 4000 Hz was observed. The effect was more marked in the left ear than the right, and the author suggested that an efficient ear plug should be inserted in the left ear only so that the subject could still have unimpeded auditory facility in the right ear for orders. This conclusion may well be valid for individuals firing singly on ranges but where two or more men are firing from the same location, the right ear of the left hand man will probably be as much affected as the left ear of his neighbour unless an unreasonable distance is allowed between them.

A paper by Stewart and Barrow (1946) highlights a most significant feature of deafness caused by gunfire. Some 100 small-arms instructors of average age of twenty five years were studied. They instructed personnel on the shotgun and 50 calibre machine gun ranges. It was noted that gunfire produced a definite loss of hearing, beginning in the high tones (2000—11000 Hz) and that when this loss was severe, all tones were affected. They also noted a wide variation in individual susceptibility to impulsive type noise. This problem of individual sensitivity to impulsive noise was recently investigated at A.P.R.E. (Elwood et al 1967).

The most significant statement made, however, was that this hearing damage occurs insidiously and, since damage to the conversational or speech range of frequencies is late, few people appreciate their handicap until it is far advanced. They concluded that routine pre-arranged surveys of auditory acuity are necessary. Cotton wool plugs were used in this study and the authors drew a further valid conclusion that they were ineffective in preventing loss of hearing. By following up the 100 subjects for six months they also concluded that the hearing losses observed were permanent.

Damage risk criteria

It will be seen that the two different types of noise exposure require two types of Damage Risk Criteria (D.R.C.).

For the continuous noise situation, Burns (1968) and Kryter (1965) have established a relationship between exposure times to octave-band noise and the risk of hearing damage. Burns has produced a table of maximum (unprotected) exposure times to continuous noise (Fig. 1). A recent study in R.E.M.E. workshops has shown that at certain locations a man can only work for seven minutes (unprotected) with 3 x K60 engines, 1 x B81 and 2 x G.M.C. V8 engines running, whereas if wearing ear muffs he can operate quite safely for eight hours. The principle therefore is to measure the noise, assess the total stay-time and apply the D.R.C., making whatever recommendations for protection as may be necessary for the man to complete the task.

A committee of the National Academy of Sciences—National Research Council on Hearing, Bio-acoustics and Biomechanics has recently produced a Proposed Damage Risk Criterion for Impulsive Noise (Gunfire) (Ward 1968) (Fig. 2). In this D.R.C., peak sound pressure is related to both 'A' and 'B' durations. If the limits prescribed are exceeded, or likely to be exceeded, then hearing protection should be mandatory.

CRITERIA FOR CONTINUOUS NOISE EXPOSURE

VALUES OF SOUND PRESSURE LEVELS IN SPECIFIC
FREQUENCY BANDS WHICH INDICATE A HAZARD TO
HEARING AT STATED TOTAL DAILY DURATIONS

OCTAVE BAND CENTRE FREQUENCY Hz(cps)	7min	15min	30min	1 hour	2 hours	4 hours	8 hours
63	122	116	110	106	103	100	97
125	116	110	104	100	97	94	91
250	112	106	100	96	93	90	87
500	109	103	97	93	90	87	84
1000	107	101	95	91	88	85	82
2000	105	99	93	89	86	83	80
4000	104	98	92	88	85	82	79
8000	103	97	91	87	84	81	78

Figure 1. Damage Risk Criteria—Continuous Noise.

Basic Limit for 95% of unprotected ears exposed
at normal incidence to impulsive noise,
after Ward

Figure 2. Damage Risk Criteria—Impulsive Noise.

The maximum peak pressure level permitted is 164 dB (without ear protection) for the shortest pulses of any practical interest (.025 milliseconds). If we revert to the example of the U.K. L.I.A.I. rifle, the peak pressure level at the firer's ear was 161 dB, the 'A' duration 0.33 milliseconds and the 'B' duration 5 milliseconds. The maximum peak pressure, for the unprotected ear, at 0.33 milliseconds is about 157 dB according to both the 'A' and 'B' durations. It is clear therefore that adequate hearing protection must be provided in order to avoid damage in this case.

The principle is similar to that adopted in the case of continuous noise exposure; to measure the peak sound pressure and durations and decide whether hearing protection is necessary or not. If it is found to be necessary, the attenuation required to prevent hazardous exposure is determined, and the type of protection to enable the man to do his job is recommended.

Methods of protection

Entry of sound into the ear canal can be reduced by wearing some form of plugs in the ear canal or external cups usually known as ear muffs. The most widely used plug in the Services is the V51R or Sonex plug. The plug is issued in three sizes at present, large, medium and small and D.C.I. 19/66 requires them to be fitted under medical supervision. The requirement is important since some people have dissimilar sized ears and often require different sizes of plug for each ear. Furthermore, unless the plug is correctly fitted its attenuation value will be greatly reduced.

For use with D.R.C.'s, the average attenuation afforded by correctly fitting ear plugs of the Sonex type is approximately 20 dB but is considerably lower at frequencies below 1000 Hz. Higher attenuation and greater comfort are combined in "fluid seal" earmuffs in which a close fit to the head is obtained by the fluid-filled annular tube. The average attenuation afforded by a correctly applied ear muff is approximately 40 dB but is lower at frequencies below 1000 Hz.

While D.C.I. 19/66 provides for the universal issue of V51R (Sonex) plugs, the higher attenuation of the ear muffs might be supplied in specially hazardous situations for example, where firing a weapon was known to cause such a peak sound pressure at the firer's ear that a Temporary Threshold Shift would be inevitable even when wearing Sonex plugs.

It is appreciated that only three sizes of plug may not completely cover the range of ear sizes in the Services and a recommendation has been made for the range to be increased to five sizes.

It may be properly observed here that the very fact the external sounds seem less loud, whilst the wearer's voice sounds to him different and louder, results in a tendency to talk more quietly. What is needed for conversation between people wearing ear protection in noise is to talk loudly, and this should always be emphasized.

The other problem in the military situation is the necessity for good communication even when wearing ear plugs or muffs. Where possible orders should be given through an amplifier e.g. loud hailer on the range, and ideally there should be an audio-visual signal for safety orders.

A novel idea to cope with the communication problem whilst still providing a good degree of sound attenuation was originally designed by E.R.D.E., Waltham Abbey.

The device, known as the "Erdefender", maintains normal directional hearing ability at ordinary sound levels by the provision in each earpiece of a muff-type defender, of an electronic sound reproducing system and extension microphones. The amplifiers in the system are designed to saturate at a fixed sound level (85 dB) so that at higher levels, the protective attenuation of the headset becomes effective. The acoustic attenuation of the "Erdefender" is nominally 50 dB but is lower at the lower frequencies. Each ear muff is individually powered by a self-contained mercury battery and includes a push-on and push-off switch.

Conclusions

All weapon noise can damage hearing, from small arms of the lowest calibre to the largest guns in use.

The sound pressure created by firing most weapons is known, and adequate protective devices exist.

Even the most sophisticated ear protector can be rendered almost useless if its use is not mandatory in the presence of noise and it is not fitted or worn correctly.

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ACADEMIC ACHIEVEMENTS

F.D.S.

F.F.R.

D.R.C.Path.

D.C.H.

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