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THE EFFECTS OF GUN BLAST ON HEARING AND PERFORMANCE: A PRELIMINARY REVIEW

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PURPOSE

At the Third Tripartite Artillery Conference* it was recommended: "That an Ad Hoc Working Group on Blast Limits be organised..... ..... The general purpose of this Working Group would be to determine the acceptable blast limits for gun detachments". On January 8, 1962 at a meeting** held in Ottawa it was decided that a Canadian paper on Gun Blast Effects should be prepared. The Defence Research Medical Laboratories were asked to review the literature on the effects of gun blast on hearing and psychological aspects. This document summarizes the reports that were immediately available. A bibliography is included.

INTRODUCTION

The term blast describes the fluctuations in atmospheric pressure at a given point which arise from the very rapid combustion, explosion or detonation of material in the vicinity. Significant differences among blast phenomena are due to the rate at which the chemical

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*Memorandum: Ad Hoc Working Group on Blast Limits, HQS 8905-1-2 (D Arty), 12-12-61.

**Minutes of a Meeting to discuss the formation of the Tripartite Ad Hoc Working Group on Blast Limits for Gun Detachments, HQS 8905-1-2 (D Arty), 15-1-62 and supplementary notice, HQS 8905-1-2-1 (D Arty) dated 23 January, 1962.

transformation takes place (6). The sources of blast (pressure waves) generated by a gun are at the breech and muzzle. Breech blast is caused by the ejection of gas rearward to prevent recoil in a recoilless weapon while muzzle blast is produced by the combination of the bow wave (air pushed ahead by the projectile inside the barrel) with gas ejected from the muzzle behind the projectile (18).

BLAST DAMAGE TO HEARING

Damage to the ear mechanism resulting in temporary or permanent hearing loss is the most commonly reported injury to the body from blast energy transmitted through air. Such damage may include injury to the tympanic membrane (eardrum), the middle ear conduction apparatus and the cochlea (inner ear).

Injury to the eardrum and middle ear may not decrease hearing acuity permanently if the injury is properly cared for and infection avoided. Guild (9) suggests that rupturing of the tympanic membrane is produced by the rapid build-up of positive pressure in the initial phase of the blast wave, while Suggit (31) states that the rupture is caused by the longer rarefaction wave which follows the positive pressure phase. Hamburger and Liden (10) have suggested that the rupturing of the tympanic membrane prevents other and more serious injury. Investigations by Korkis (13) and Schwab (27), in which

tympanic membrane rupture was found to occur together with other auditory damage, do not substantiate this point of view. Muirhead (21) indicates that exposure to gun blast subjects the tympanic membrane to an oscillatory shock wave rather than a single transient pressure load, and the frequency range for which the hearing loss occurs is related to the frequency of this pressure oscillation.

Damage to the cochlea is usually the most serious injury. Intense blast may cause the destruction of the cells of the basilar membrane or the organ of corti or both, resulting in permanent hearing losses, while less intense blast may produce only temporary impairment of function. Suggit (31) reported that hemorrhage in the cochlear canal was accompanied by hearing loss for certain tones (frequencies). Lindquist, Neff and Schuknecht (15) found that cats with severe permanent hearing losses suffered degeneration of sensory cells in the upper nasal and lower middle cochlea. Less severe hearing losses were not always accompanied by definite damage to sensory elements in the cochlea. It is not known whether the hearing losses resulted from repeated exposure to sounds at a "sub-damaging" level or of occasional exposure to peaks of sound at intensities above the "damaging" level, nor is it known how important is the recovery period between the exposures.

Rosenblith and Stevens (26) indicate that cochlear damage due to continuous noise reflects a combined intensity and duration effect,

and Machle (16,17) states that such an effect may also apply to damage due to blast waves. Spieth and Trittipoe (29) point out that neither the hypothesis of equal relative importance of intensity and duration (equal-energy hypothesis) nor the hypothesis that duration is twice as important as intensity in producing a constant hearing threshold shift have been substantiated by investigation. Ward, Fleer and Glorig (32) found no difference in various characteristics (slope of audiogram, rapid tone decay, speech perception, or recruitment) of high frequency hearing losses in men exposed to either continuous noise or gunfire.

Satisfactory correlations between hearing loss and the physical parameters of blast and exposure duration have not been established. Murray and Reid (22) found that temporary hearing losses correlated best with peak pressures of the blast waves from artillery pieces. Repeated exposure to blast results in cumulative acoustic trauma, i.e., additional exposure to gunfire results in a greater degree of deafness. Machle (16,17) states that if recovery is to occur it will be complete within a few days. Other investigators have found that complete recovery may take up to two weeks (30,31).

Several investigators have found that the hearing losses suffered as a result of exposure to gunfire pertain to frequencies above 2,000 cycles per second (see Table I).

TABLE I

FREQUENCY RANGE OF HEARING LOSSES DUE TO EXPOSURE TO GUNFIRE

Investigator	Auditory Frequency Range (cycles per second)
Stewart and Barrow (30)	Between 2048 and 11,584
Collins (4)	at 8192
Meyrick (20)	at 4000
Boemer (2)	above 2896
Machle (16,17)	at 2496, 4096, 7292
Hendricks (12)	above 2048
Patt (23)	above 2896
Lindquist, Neff, Schuknecht (15)	between 2000 and 4000
Muirhead (21)	above 2000

Murray and Reid (22) have estimated that pressures between 6 and 8 pounds per square inch (psi) are required to rupture human tympanic membranes. Meade and Eckenrode (18) after a review of literature in 1955, concluded that pressures above 7 psi could cause damage to the auditory mechanism. Blair (1) reported that monkeys

exposed to blast waves suffered ruptured tympanic membranes at a pressure of 20 psi lasting for 200 msec. Murray and Reid (22) measured temporary threshold shifts following exposure to gun blast whose peak pressure was 3 to 4 psi and lasted from 4 to 8 milliseconds (msec), and found that the mean temporary hearing loss a few minutes after exposure was about 3 db for the frequency range from 512 to 8192 cps, with a mean low of 8 db between 4000 and 6000 cps. They also found that exposure during an interval of seven minutes to 9 gun blasts each with a peak pressure of 7 psi lasting 3 to 6 msec resulted in temporary threshold shifts of 20 to 85 db at frequencies above 2,048 cps. Repeated exposure at 15 minute intervals to gun blasts with a peak pressure of 3 to 4 psi lasting 4 to 8 msec resulted in small threshold elevations following the first exposure and hearing losses of 60 to 70 db a few minutes after a sequence of 10 or 12 blasts. They concluded that an overpressure of 0.25 psi can cause hearing losses of 40 db or more after 100 or more shots. They report that this peak pressure is produced at the ear when an 0.303 rifle is fired from the hip or shoulder. They further concluded that the recovery times are similar for hearing losses due to continuous noise and gun-blast exposures. One of the conclusions of the final Anehin report (24) was that "increased incidence of high-frequency hearing losses among noise-exposed personnel seems probably to be due more to gunfire than to jet noise". Spieth and Trittipoe (28) found that a

one msec burst of noise has considerably less effect than the equivalent amount of continuous noise on hearing thresholds at 3000, 4000, 6000 and 8000 cps. Noise bursts of 10 msec, 100 msec and 1 second caused no greater threshold elevation than the equivalent sound pressure level of continuous noise. There were no differences in recovery following exposure to either continuous noise or impulse noise.

Collins (4) found that men who had served in the Field Artillery, Anti-Aircraft Artillery or Coastal Defence Units had a significantly higher aural injury rate than did infantry men. Reid (25) found that gunners who had experienced no damage to their tympanic membranes had sustained permanent hearing losses of 30 or more decibels (db) for various tones. Patt (23) also found that artillery men and rifle coaches suffered significantly greater amounts of hearing loss than men not exposed to gunfire and that the greatest losses were for frequencies of approximately 4000 cps. Harbold and Greene (11) found that men who were exposed to small arms gunfire for two weeks suffered hearing losses for frequencies between 2000 and 8000 cps, with the greatest permanent losses between 4000 and 6000 cps. Temporary threshold shifts immediately following exposure showed a similar pattern. Gravendeel, Bowman and Pomp (8) found that men exposed to light arms fire suffered hearing losses of from 9 to 50 db, the left ear suffering the greater losses. The hearing loss increased with the

number of shots to which the men were exposed, but the greater the previous hearing loss the less was the amount of further hearing loss suffered and the more probable was the development of tinnitus.

PROTECTION OF THE EAR FROM GUN BLAST

The interaural muscles (stapedius and the tensor tympani) in the middle ear provide a protective mechanism for the ear for exposure to high-intensity continuous noise (7). In a reflex response to intense sound the tensor tympani pulls the drum inward, increasing its stiffness, while the stapedius muscle displaces the stapes and decreases its coupling to the inner ear. No protection against blast is provided by the interaural muscles, since the duration of the blast wave is less than the time necessary for the contraction of the muscles in response to the stimuli. It is indicated by Wever and Lawrence (34) that the latencies of the reflexes vary from 17 to 150 msec for the tensor tympani and 18 to 70 msec for the stapedius. Wersall (33) found that the interaural muscles can have a significant effect on sound transmission only after an appreciable tension has been reached, and that the attainment of final tension is independent of the sound intensity. In the cat the median value of muscle tension was attained after 68 msec by the stapedius and 96 msec for the tensor tympani, with the range of variation being 40-151 msec and 44-174 msec respectively. The investigations of Metz (19) indicate that reflex time is dependent on the intensity of the sound stimuli.

Fletcher (17) has recommended that either proper acoustic protective devices should be used by all men exposed to intense or prolonged gunfire or the interaural muscles should be activated artificially just prior to each blast exposure. Recent experimentation has indicated that with subjects exposed to 100 rounds of gunfire (.30 calibre machine gun) pre-stimuli activation of the acoustic reflex provided better protection than that afforded by the V-51R type ear plugs (similar to the Mine Safety Appliance Ear Defenders), up to 1000 cps. Above 1000 cps the V-51R type ear plugs were much superior.

Murray and Reid (22) reported in 1946 that nearly complete protection from gun blasts was provided by ear protectors that make an air-tight seal at the entrance to the ear canal. Harbold and Greene (11) in 1960 indicated that the use of conventional ear plugs was adequate in preventing hearing loss due to exposure to small arms gunfire. The use of cotton wool in the ear for protection from gun blast has been found by Patt (23) to be worthless.

Cohen (3) investigated temporary hearing losses at frequencies from 250 to 8000 cps in protected and unprotected ears, with exposures of 6, 12 and 18 minutes to recorded 30 calibre machine gun noise and a continuous wide-band noise of comparable energy. He found that hearing losses were confined to frequencies above 1000 cps after

exposure to either type of noise and that they tended to become greater with increasing exposure time. In the unprotected ear continuous noise caused greater hearing loss (and slower threshold recovery after exposure) than impulse noise. It was found also that the helmet used as a protective device gave significant protection against continuous noise but little protection against impulse noise. Gravendeel, Bouman and Pomp (8) found that greased cotton ear plugs provided hearing protection for exposure to small arms fire. In 1950 Kryter (14) stated that ear plugs which afford 20 to 30 db of sound attenuation for the middle range of frequencies would in practically all of the industrial and military situations in which noise and shock waves were then a problem afford sufficient protection to prevent deafness.

Little information is available upon which to make a judgement of the number of Canadian servicemen who suffered injuries to the hearing mechanism during peace time or in World Wars I and II. As indicated in Table II a total of 15,318 pensions are paid by the Canadian Department of Veterans Affairs for hearing injury. It may well be that an additional number of Canadian servicemen who suffered injuries to hearing are, for a variety of reasons, not drawing pensions.

TABLE II

NUMBER OF PENSIONS PAID CANADIAN VETERANS FOR HEARING INJURIES SUSTAINED IN WORLD WARS I AND II

Injury	World War I		World War II
Auditory Canal and Outer Ear	17		595
Middle Ear, Eustachian Tubes	3,296		4,963
Inner Ear,	777		3,380
Mastoid Process	88		175
Aero Otitis Media	2		12
Traumatic Rupture of Tympanic Membrane	270		1,524
Other Conditions	114	TOTALS	105
	4,564		10,754

PSYCHOLOGICAL ASPECTS OF EXPOSURE TO GUNFIRE

Meade and Eckenrode (18) suggest that blast intensities which are too small to cause serious physiological injury may be responsible for psychological difficulties. They concluded that exposure to blast with pressure above 2.5 psi may result in disrupted perceptual-motor activity.

Woodhead (35) found that bursts of noise at an intensity of 100 db increase the time of response to visual signals. In another study (36) she found that exposures to bursts of 1 second duration of low frequency 115 db noise caused a temporary deterioration in decision-making performance. This decrement was not evident with exposures to bursts of the same noise at 90 db. Further investigations (37) showed that people exposed to bursts of 110 db low and high-frequency noise of one second duration were more efficient in making decisions when they wore ear protectors than when they did not. Dreher (5) has shown that loud, unexpected, low frequency noise of 110 db for 2 seconds duration had no measurable effects on short-term memory, retrieval, or programming of auditorily presented information. Kryter (14) suggests that in difficult tasks the subject concentrates on the task and ignores the noise. For some tasks, such as aiming a gun, noise may encourage a greater concentration of attention than is achieved in average quiet conditions. Eldredge (6) points out that exposure to blast and noise of modern weapons could cause feelings of danger which could lead to changes in performance.

CONCLUSIONS

1. It is not possible to state definite levels of blast below which injury to the hearing mechanism will not be sustained nor adverse effects produced in performance or behaviour. The following generalities can,

however, be stated as a result of this literature survey.

(a) Few well-controlled investigations have been conducted into the effects of gun blast on personnel in relation to the physical parameters of exposure to blast, i.e., rates of rise and decay of pressure, peak pressure attained, repetition rate and time of exposure.

(b) The effects on performance of exposure to blast have not been related to peak pressure level, duration, repetition rate and other parameters.

(c) Damage to the cochlea usually affects hearing more seriously than damage to the tympanic membrane or the middle ear apparatus.

(d) Hearing losses, temporary or permanent, due to gun blast usually pertain to frequencies between 2000 and 8000 cps.

(e) The greater the exposure to gunfire the greater the amount of temporary or permanent hearing loss suffered.

(f) Individuals differ in their susceptability to hearing injury due to exposure to gun blast.

(g) Complete recovery from temporary hearing losses may take several weeks.

(h) Efficient sound attenuating ear protectors should be used to provide as much protection as possible to the hearing mechanism.

RECOMMENDATIONS

Before satisfactory protection criteria for exposure to gun blast can be determined more reliable information must be obtained. It appears unlikely that such information could be found by a more detailed survey of the literature. It could be obtained by experimental investigations of the relationship between measured physical characteristics of gun blast and their effects on hearing and performance, and the evaluation of the effectiveness of ear and whole-body devices for protection against blast.

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