TEMPORARY DEAFNESS DUE TO GUNFIRE

By N. E. MURRAY and G. REID (Captain A.A.M.C.)

1. Summary

1. EXPOSURE to gunblast which is not of sufficient severity to rupture the eardrums, causes inner-ear deafness which affects mainly the higher frequencies, but may, if the exposure is severe, extend as low as 256 c.p.s.

2. The magnitude of the exposure necessary to produce a given degree of hearing loss varies with the individual; but severe effects (i.e. with peak losses of from 55 to 85 Db.) were commonly caused by exposures which were mild compared with what may be expected in action.

3. Measurement of blast pressure in gun crew positions, indicated that the amount of damage to hearing a gun is liable to cause, runs parallel, roughly, with the peak blast pressure.

4. Of those guns which were tested, serious hearing loss was caused by the 17 Pr., the 18 Pr., in a concrete emplacement, the short 25 Pr., the 3·7 inch A.A. gun, and the mortars, especially the short 3 inch type. Peak pressures at the positions where this loss was caused, ranged from $1\frac{1}{2}$ to 8 pounds per square inch.

5. Rupture of the eardrum occurred in position 1 of the short 3 inch mortar, where the blast pressure was from 6 to 8 pounds per square inch.

6. Smaller pressures than these (e.g. about $\frac{1}{4}$ pound per square inch from the rifle) will also cause severe loss of hearing, when a sufficient number of rounds is fired.

7. Loss of hearing lasted from a few hours to several days.

8. It is well known that the effect on hearing of inner-ear deafness is more noticeable at threshold than at higher levels. Usually in civil life threshold hearing is not very important, but with sentries, impairment of threshold hearing is of great importance, because they may be required to hear and localize the faintest of sounds. Of course when the deafness is as severe as occurred after firing the 17 Pr. the hearing of speech at ordinary conversation level will also be impaired.

9. Cotton wool plugs are an inadequate form of ear protection. The Protector, Eardrum Aust. Mk. 1 designed by the Acoustic Research Laboratory, gave complete protection for as severe an exposure as may reasonably be expected in action.

2. Introduction

1. Although a considerable amount of work has been done in recent years on temporary deafness following exposure to aeroplane and tank

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noise, almost no observations have been made on temporary deafness following exposure to gunblast. Reports of severe deafness following firing of typical Australian Army jungle guns, the 25 Pr. short, and the short 3 inch mortar made a more detailed study, particularly of these guns, desirable.

2. This paper, which is the first of a series, is concerned with observations on *temporary* deafness occurring in members of guncrews, in experimental subjects exposed near guns, and in men firing small arms, together with the results of blast pressure measurements in gun crew positions. The amounts of temporary deafness resulting from the blast pressure from various guns and the practical aspect of these under operational conditions, are discussed. A second paper (see Ref. 1, Reid, 1945) is concerned with the results of laboratory experiments and the elaboration of certain aspects not fully dealt with in this paper, and a third paper will report the results of a survey of the incidence of permanent hearing loss in artillery personnel.

3. Historical

1. It has long been recognized that many artillery men and those who are exposed to blast become permanently deaf. The earlier papers have been reviewed by Bunch in 1937. In recent years a number of new reports have appeared; Passe (1940), Scott (1940), Davis (1940), Craig (1940), Guild (1941), Alexander (1941), Schilling and Everley (1942), Fox (1943), Collins (1944), Taylor (1944), and Silcox and Schenk (1944). Some of these papers are concerned mainly with the rupture of the tympanic membrane, and indeed when one reviews the literature it appears that some authors appear unaware of the occurrence of inner ear deafness, and regard the detrimental effects of gunblast largely in terms of ruptured drums.

2. Bunch (1937), published audiograms of men permanently deafened as a result of blast from both large guns and small arms. Audiograms of naval or military personnel exposed to gunfire were also published by Schilling and Everley (1942), and by Taylor (1944). Collins (1944) in the Western Desert, and Silcox and Schenk (1944) at Guadalcanal, described the hearing loss due to the effects of blast in battle casualties. These reports as well as others in the literature, show that, except when the middle ear is damaged by trauma or subsequent infection, the deafness is of the so-called, inner ear or nerve type, and involves mainly the higher frequencies.

3. Nearly all the reports on temporary traumatic deafness have been concerned with hearing loss following exposure to continuous noise. Dickson, Ewing and Littler (1939) and Campbell and Hargreaves (1940), published audiograms before and after exposure to aeroplane noise. Chamberlain (1942) examined four boilermakers before and after the day's work, and Schilling and Everley (1942) investigated the immediate

effect of exposure to Diesel engine noise in submarines. A more comprehensive investigation was carried out by Davis and his co-workers at Harvard (1942, 1943) on temporary deafness following exposure to loud tones and noise. This work, which was carried out under the auspices of the National Defense Research Committee of the U S.A., was related mainly to problems connected with the exposure of military personnel to the noise of aeroplanes and armoured fighting vehicles.

4. On the other hand, experiments in which human subjects have been examined before and after exposure to blast are almost non-existent. Wilson (1942, 1944), described the temporary hearing loss in recruits after their first rifle shooting ; but he was mainly concerned with determining, in any particular subject, whether the deafening effect of a pure tone would be a satisfactory method of predicting susceptibility to gunfire. Bunch (1938) described the onset of deafness after the explosion of a fire-cracker.

4. Scope of Investigations

1. *Location :* These Experiments were carried out at the Coastal Defence Batteries in the Sydney Area, the School of Artillery, Holsworthy, the Proof Ranges, Gellibrand and Port Wakefield, the Williamstown and Long Bay Rifle Ranges, and the Footscray Small Arms Factory. Acknowledgement is made to all who have facilitated the carrying out of observations in these places.

2. *No. of personnel examined :* Sixty four unprotected ears of 35 male subjects, were examined before and after firing artillery equipment, small arms and mortars. Twenty-eight of these subjects were army personnel ; besides ourselves (G.R. and N.E.M.) there was a laboratory assistant (subject E.P.S.) and four others were medical students, one of whom had served in the artillery. The ages of the subjects ranged from 20 to 38 years. With the exception of ourselves and E.P.S., the men were examined, after exposure to usually only one of the guns. When both ears were not being exposed simultaneously, the unexposed ear was protected by the ear plug designed by this laboratory (Protector, Eardrum Aust. Mk. 1) and described in report No. 5 of this laboratory by Eccles and Murray (1943). *This is a neoprene synthetic rubber plug of oval cross section to conform to cross section of the external auditory meatus.* A tube of antiseptic lubricant (*merthiolate in a lanoline base*) is included with the plugs to guard against ear infections, especially in tropical areas.

3. *Weapons investigated : subjective measurements.* Subjects, the number of whom appear in the parentheses, were examined, before and after the firing of the following guns :

1. 3·7 inch A.A. gun (2)
2. 18 Pr. in emplacement for coast defence (3)

3. 6 inch coast gun Mk. 7 on Mk. 2 mounting (4)
4. 10 cwt. 6 Pr. Twin on mounting 6 Pr. Mk. 1 (3)
5. Bofors 40 mm. A.A. gun (1)
6. 9·2 inch B.L. coast gun Mk. 10 on mounting 9·2 inch Mk. 7 (in turret) (2)
7. 9·2 inch B.L. coast gun Mk. 10 on mounting 9·2 inch Mk. 7 (outside turret) (2)
8 25 Pr. Mk. 2 (6)
9 17 Pr. Tank Attack Gun with muzzle brake (3)
10. Short 25 Pr. gun (3)
11. 4 inch Q.F. naval gun (3)
12 Service rifle firing from hip (4)
13. Service rifle firing from shoulder (1)
14. Service rifle firing in an enclosed space (2)
15. 9 mm. calibre Owen gun (1)
16. 9 mm. calibre special submachine gun (3)
17. Vickers machine gun (3)
18. Bren machine gun (5)
19. 2 inch mortar (4)
20. 3 inch mortar (3)
21. 3 inch short mortar (2)

4. *Weapons investigated : blast pressure measurements.* These were made at the ear positions of gun crews around the following guns :

1. 25 Pr. Short
2. 25 Pr. Mk. 2
3. 17 Pr. Tank Attack
4. 6 Pr. Tank Attack
5. 3 inch Mortar—Long
6. 3 inch Mortar—Short
7. 2 inch Mortar
8. 3·7 inch Anti-Aircraft
9. Rifle

5. Observations

(a) Subjective Measurements

1a. The threshold of hearing of the subjects was tested before and after firing, with a Western Electric 6B Audiometer. Those subjects whose ears were obstructed with wax were excluded, or the wax was removed. For most of the experiments the ear drums were examined, a Rinne test done, and in a few instances the bone conduction audiometer threshold was determined before and after firing. In most cases the audiogram was taken between 10 and 20 minutes after firing ceased, and in all cases within the first hour. Sometimes tests were commenced

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as early as 2 minutes after exposure, and in a large number of experiments the recovery was followed by a series of audiograms extending over several days. When figures for loss of hearing are unqualified as to time, they may be regarded as being at a stage between 10 to 20 minutes after exposure.

2a. The following frequencies were tested: 128, 256, 512, 1024, 2048, 4096, 5793, 9747 cycles per second, and other frequencies when it appeared specially indicated. They were tested in ascending order beginning at 1024 c.p.s. and the remaining frequencies in descending order beginning at 512 c.p.s. With practised subjects the whole test could be carried out, for one ear, in 5 minutes. Thresholds were approached from the region heard to the region not heard, and the intensities recorded in 5 Db. steps. In the tables and illustrations the loss of hearing is represented relative to the subjects' own pre-exposure threshold, and not, unless otherwise indicated, to the zero of the audiometer.

(b) "Average" and "Peak" Hearing Loss

1b. In the presentation of the results it was desirable to find a suitable value, which would express as simply as possible, the degree of hearing loss which had been produced in a subject, and which could be used for comparison purposes when hearing loss had been produced in one subject on separate occasions.

2b. It is discussed in a later paper, how with increase in the severity of an exposure to which an individual is subjected there is an increase in the loss of hearing as depicted in an audiogram, in both width and depth; that is, there is an increase in the maximum loss at any frequency, and the effect spreads to involve frequencies previously unaffected. Full details of these effects are shown in the figures included in this paper. (Ref. 1).

3b. To express simply in a single figure the magnitude of hearing loss involved, it is necessary to know how the hearing loss suffered reacts on the ability of the subject to hear orders directly, through earphones, or amplifying apparatus, and also on the ability to detect sounds, especially when he is used as a sentry in jungle warfare. The sounds for which it will be necessary to use threshold hearing acuity will, in general, be of high pitch, such as the snapping of a twig, brushing of leaves or undergrowth by approaching enemy. The effects on the hearing of speech are largely related to the "average" hearing loss in the range 500 to 4,000, although they are almost as closely related to the average loss in the range 500 to 8,000. Where the use of the hearing at threshold, such as for sentries, is taken into consideration, as well as the types and extent of hearing loss produced by gunfire, the best single parameter for "average" hearing loss is that taken over the range of

4 octaves from 512 to 8192 cycles. (This is a similar " average hearing loss " measurement to that used for calculating deafness following exposure to loud noise (Ref. 17).) Some comparisons can, therefore, be made with this work as to the relative severity of loud tones and gunfire in producing deafness.

4b. The maximum hearing loss produced at any frequency through the range 128 to 8196 cycles may also be used as a simple measurement of hearing loss; the point at which the maximum hearing loss occurs differing with different people as shown in the audiograms. This " peak loss " has an advantage in that the length of time required for recovery is a function of the maximum loss at any frequency rather than the extent of the loss in the frequency range. Its value is also of use in the study of the onset of permanent deafness, which is related more to the peak loss at any frequency than to the average loss over the whole range. Where a simple figure is necessary to explain the amount of hearing loss we have, in general, tabulated the " average hearing loss " and/or " peak loss " defined above.

(c) Blast Pressure Measurements—Apparatus

1c. The measurements were made by means of Piezo Electric Gauge similar to that used by the Road Research Laboratory, England. This is a Piezo Electric Gauge having a face of approximately an inch diameter mounted in a steel block. This gauge was mounted in a headpiece and held in position over the ear. The electrical impulses from the gauge were conveyed through the cable to an amplifier and cathode ray tube where the blast wave trace was photographed by a Contax camera with an F2 lens. The amplifier used was resistance capacity low frequency compensated; the time constant of the circuit, two seconds, was sufficient to pass the low frequency envelope of the blast wave; the upper frequency range extending approximately flat to 100 kc. Three stages of amplification were used to give a sufficient output voltage for full deflection on the face of the cathode ray tube.

2c. Initially the single sweep was actuated by a gun mount switch which operated immediately on recoil of the gun barrel. Later a pilot gauge was used ahead with the main gauge to initiate the sweep and switch on the beam of the cathode ray tube a few milliseconds before the blast wave reached the ear. Calibration of the gauge for blast pressures was carried out in the laboratory by means of a small pressure chamber carrying a calibrated pressure gauge. The pressure chamber was suddenly decompressed by bursting a diaphragm. Check calibrations were carried out, in the field, by means of a stable oscillator, the output of which was checked and impressed on the input circuits, with the cable and gauge attached, through a voltage dividing network. The frequency of the oscillator was chosen to facilitate its use also for time calibrations.

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6. Subjective Results

(a) Temporary hearing loss of men in the vicinity of guns.

1a. Audiograms of various subjects after exposure to most of the guns are illustrated in figure 1 (pages 99, 100, 101). These illustrations were chosen so as to show a selection as representative as possible of both weapons and ears. There were also many subjects who after exposure showed greater losses than those illustrated in figure 1 but these subjects had such permanent or unrecovered deafness before exposure that an audiogram showing the loss relative to the subjects' pre-exposure threshold would have been misleading. (See figure 2a, page 103).

2a. The hearing losses of the 35 unprotected subjects as well as of 2 others wearing cotton wool and one female subject are set out in table 5 in the appendix. Despite the variation in sensitivity from one subject to another, it can be stated that among the large weapons, which have been tested, the most serious effects were caused by the 17 Pr. with muzzle brake, the 18 Pr. in a concrete emplacement, the short 25 Pr. gun, the 3·7 inch A.A. gun, the mortars especially the short 3 inch type, and outside the turret of a 9·2 inch B.L. gun. With these guns comparatively few rounds produced in one or more subjects a peak loss of 55Db. or more at some frequency between 2048 and 8192 c.p.s. It will be shown later that these effects run roughly parallel with the magnitude of the peak blast pressure.

3a. The two worst positions at which subjects were exposed were at No. 2 position of the 17 Pr. T/A gun (7 rounds) and at No. 1 position of the 3 inch short mortar (2 rounds). In both cases peak losses of 85 Db. were produced, and the second of the two rounds from the mortar caused rupture of the eardrum. For the short 25 Pr., sensitive subjects were not exposed in the worst positions.

4a. It is likely that the other large weapons, particularly the 25 Pr., the 6 inch coast gun, the 4 inch Q.F. Naval gun, and the 40 mm. Bofors A.A. gun would produce greater degrees of hearing loss than were obtained in the experiments with these particular guns had exposures been more prolonged. The last named gun caused no effect in the one subject who was exposed ; but tests could not be made until one hour after exposure. Guns such as the 9·2 inch, the twin 6 Pr., and the 4 inch Q.F. Naval guns in which the crews or some of them are protected by turrets produced negligible effects. Such as were recorded, are due either to open hatches, or possibly to the general high noise level. Nevertheless circumstances may occur when men are exposed outside turrets, such as, for example, on the bridge of a ship, and it should be noted that when subjects were exposed outside the turrets, deafness was produced even after the few rounds which were fired.

5a. Turning to the small arms, it was surprising to find that peak hearing losses of the order of 50 to 70 Db. were commonly produced,

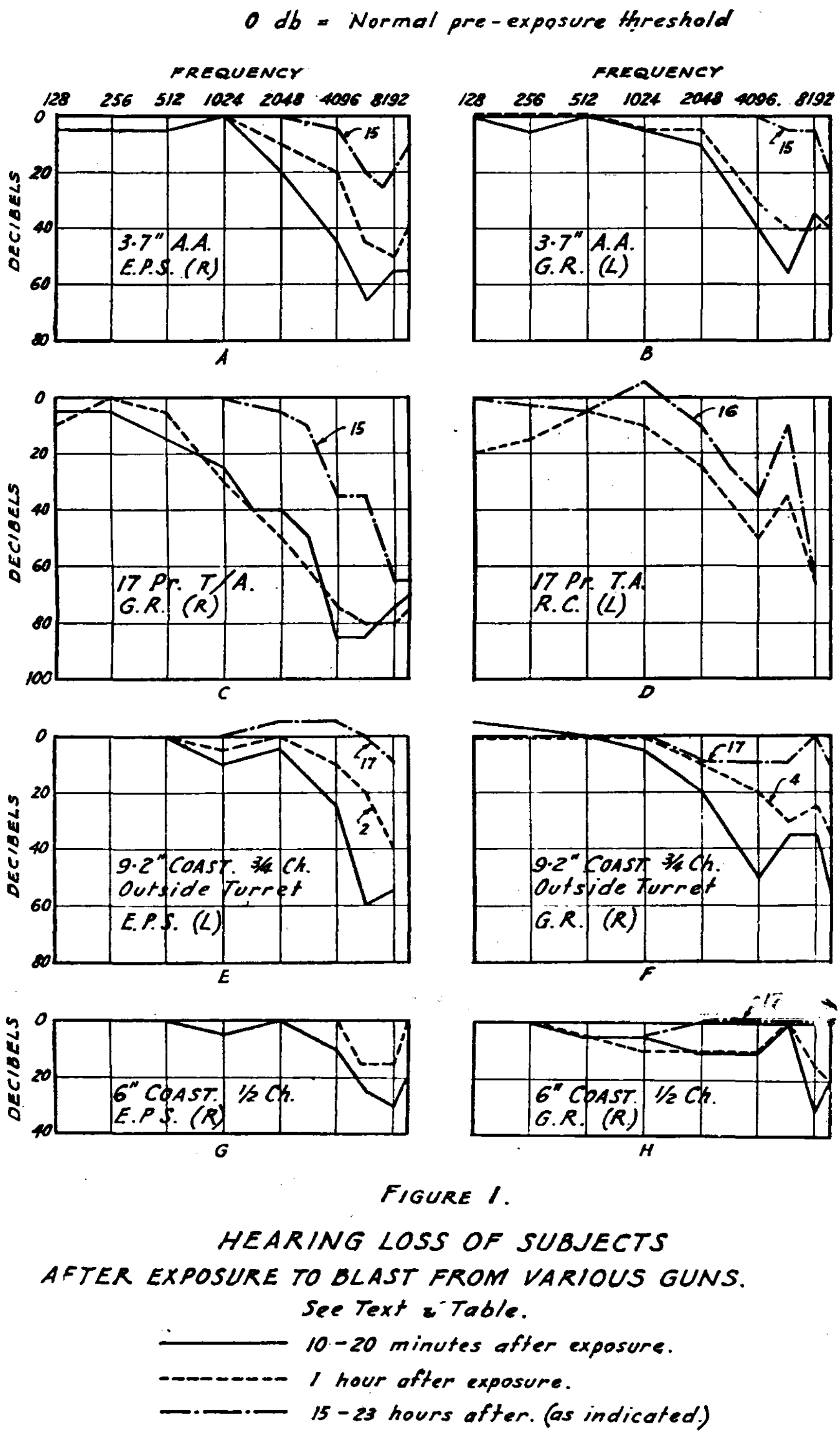

FIGURE 1.

HEARING LOSS OF SUBJECTS AFTER EXPOSURE TO BLAST FROM VARIOUS GUNS. See Text & Table.

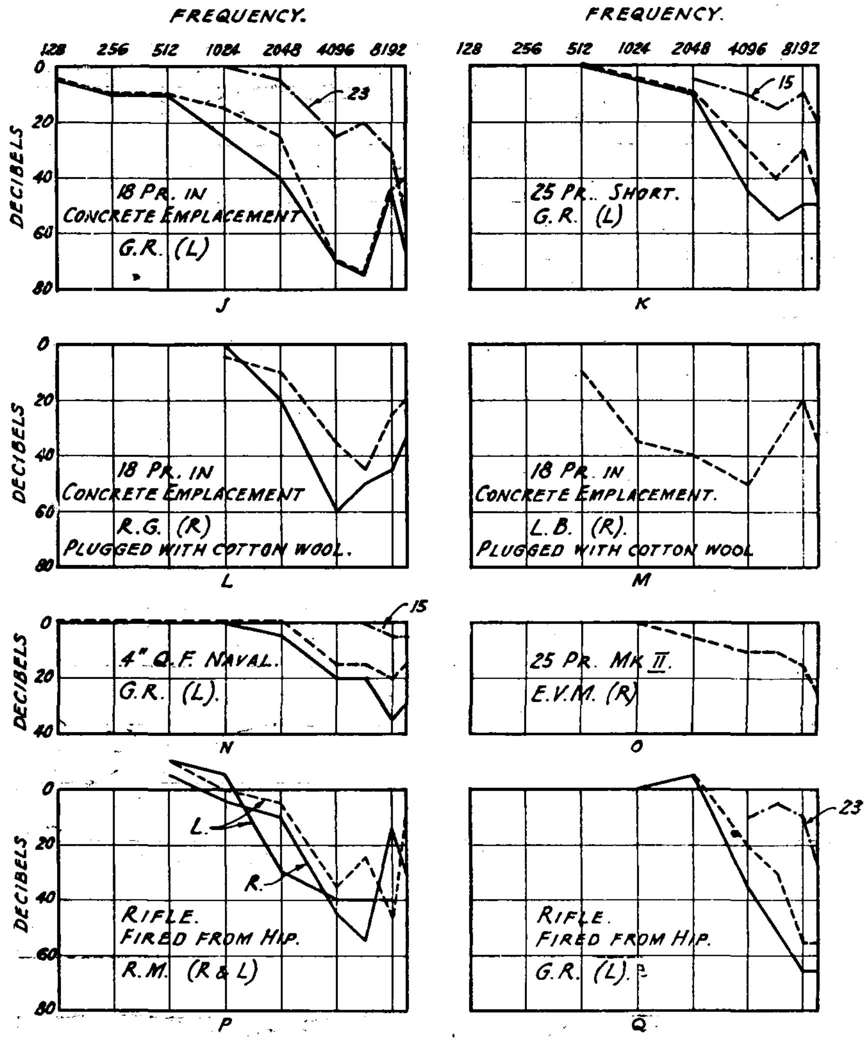

FIGURE 1. (CONTINUED)

HEARING LOSS OF SUBJECTS
AFTER EXPOSURE TO BLAST FROM VARIOUS GUNS.
See Text & Table.

———————— 10–20 minutes after exposure.
- - - - - - - - 1 hour after exposure.
—·—·— 15–23 hours after, as indicated.

0 db = Normal pre-exposure threshold.

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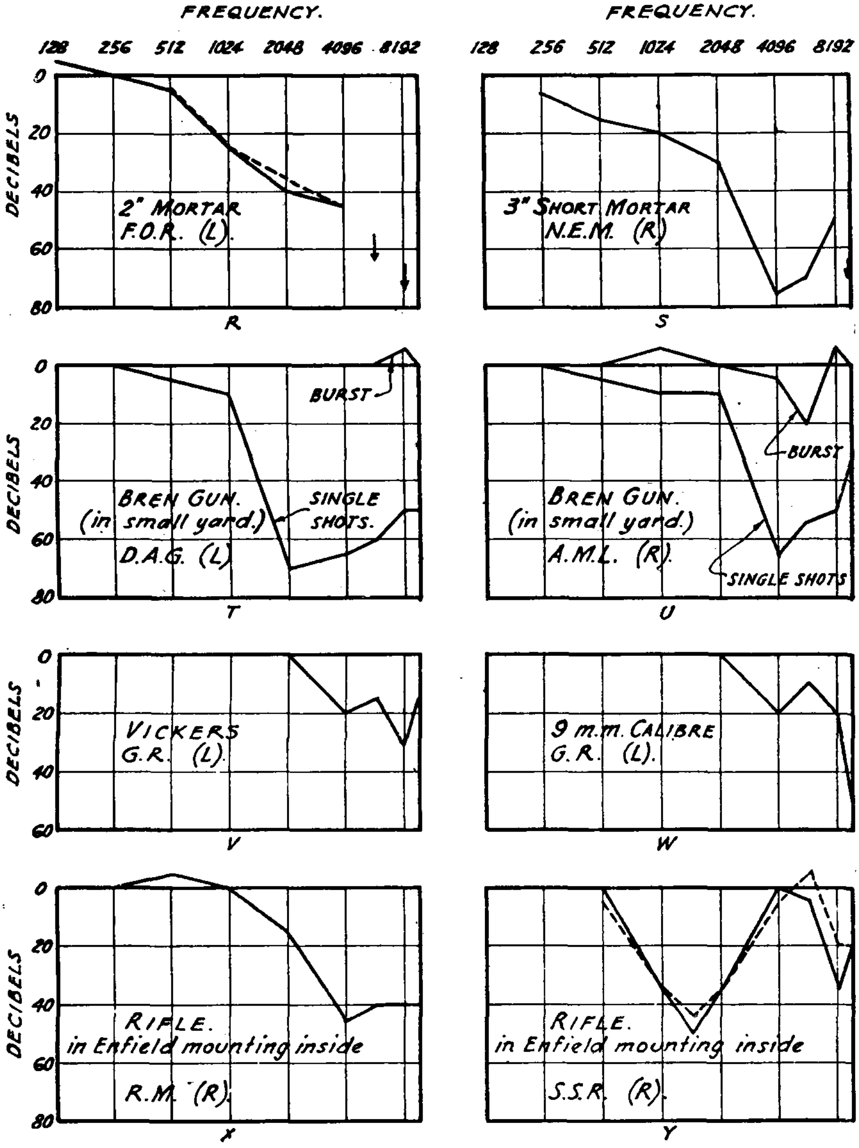

FIGURE 1. (CONTINUED).

HEARING LOSS OF SUBJECTS
AFTER EXPOSURE TO BLAST FROM VARIOUS GUNS

See Text & Table.

——————— 10.–20 mins after exposure

– – – – – – – 1 hour after exposure.

0 db = Normal pre-exposure threshold

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and that the rifle appeared for a given number of rounds more effective than a machine gun firing in a burst. One factor contributing to this result, is that when rounds are fired very rapidly (e.g. at 500/minute), the ear becomes protected after the first round of the series by means of the intra-aural reflex. When shots are separated by an interval of several seconds, each impulse reaches an ear which is unprotected, because the latent period of the intra-aural reflex is longer than the duration of the blast wave. These facts are illustrated by the audiograms of subjects exposed to firing of the Bren gun at two different rates of fire (see figure 1T and 1U).

6a. This study also shows that the small arms are particularly damaging when fired in a relatively enclosed space. In practice this occurs at proof ranges, but similar conditions may arise in action when there is house to house street fighting.

(b) Effect of Firing on Subjects already permanently deaf.

1b. Usually those subjects who had much permanent deafness were unsuitable as experimental subjects. Generally speaking such subjects were relatively insensitive to blast. Nevertheless some gunners, already permanently deaf were made even more so after exposure. Figure 2a (page 103) shows the audiogram of the right ear of subjects F.J.B. who had been an infantryman for two years, after which for the past year he had been an artificer at a proof range. The upper and lower curves are, respectively the audiograms of this subject, before and after firing from the hip, 350 rounds from the rifle in a period of five hours. These curves are drawn relative to the zero of the audiometer. Figure 2b shows the audiogram of the right ear of subject who had been in a 25 Pr. gun crew for two years. The lower curve was made 45 minutes after exposure in position 2, to 18 rounds (15 charge 1, and 3 charge 3) of the 25 Pr. Mk. 2.

(c) Frequencies involved and nature of the deafness

1c. It can be seen from figure 1 that with all of the guns the loss of hearing occurs mainly in the upper frequency range, usually with the peak loss between 4096 and 8192 c.p.s., sometimes between 2048 and 4096 c.p.s., and exceptionally between 1024 and 2048 as in figure IY. With severe exposures the effect spreads to involve lower frequencies. The variations in the shape of the audiogram which are met with are discussed more fully in a later paper. It suffices to state here that the variation depends on the subject himself and the number of rounds rather than on the type of gun (e.g. whether it causes subjectively, a "boom" or a "crack"). See section 8a.

2c. The Rinne test was always positive with the 512 fork, the result of this test as well as that of the bone conduction audiometric examinations, indicating that the deafness is of inner ear or nerve origin. When

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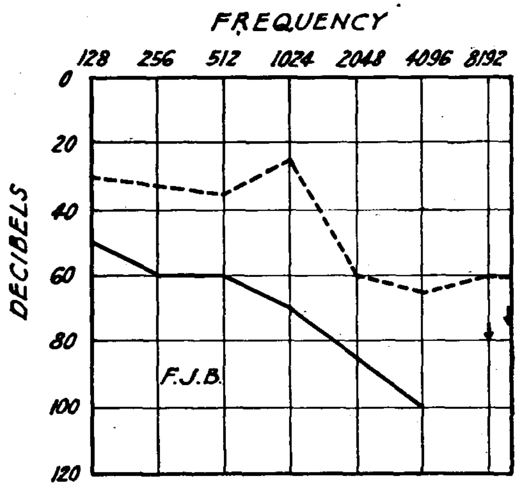

FIG. 2 a.

BEFORE & AFTER 350 ROUNDS OF RIFLE

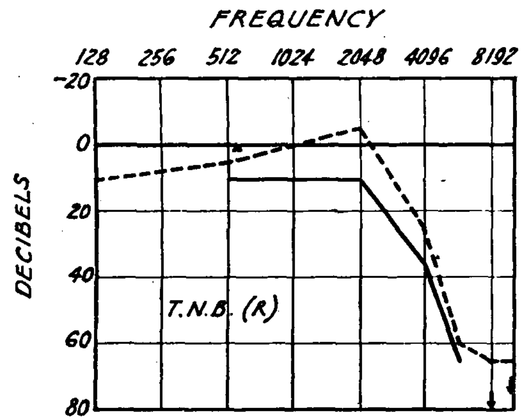

FIG. 2 b.

BEFORE & AFTER 18 ROUNDS OF 25 PDR.

EFFECT OF GUN BLAST ON SUBJECTS ALREADY PERMANENTLY DEAF.

----- BEFORE EXPOSURE ——— AFTER EXPOSURE deafness was produced in ourselves we observed the phenomenon of loudness recruitment which is so characteristic of this kind of deafness. This is discussed in section 9. Quantitative observations of this phenomenon are fully reported by Davis *et al.* (ref. No. 17b), in deafness following exposure to loud noise.

3c. Occasionally there was a slight loss of about 10 to 15 decibels at 128 or 256 c.p.s. unassociated with a loss at 1024 c.p.s. or with a great loss in the higher frequencies. This is possibly attributable to the congestion of the eardrum, particularly along the handle of the malleus, which was sometimes observed.

(d) Rupture of the eardrum

1d. Gunners and subject G.R. had, early in these investigations been exposed to blast pressures of the order of 6-8 pounds per square inch, without rupture of the eardrum. As our experience grew we became reluctant to expose subjects unprotected, to such high pressures because of the degree of deafness which was caused and because reports were common, of gunners who suffered ruptured eardrums in gun positions where blast pressure was probably not greater than this value. Measurements of blast pressure in Position 1 of the Short 3 inch mortar had indicated that the peak blast pressure here, was of the same order (6-8 pounds per square inch) as that caused in some positions of the 17 Pr. gun where subjects had already been exposed. To minimize possible damage, it was decided to expose the right ear of N.E.M. in position 1 of the short mortar, and fire one round only, examining the ear before firing further rounds.

2d. One such round caused considerable pain and very severe tinnitus; an audiometric examination begun 5 minutes afterwards showed a peak loss of 75 Db. at 4096 c.p.s. (see figure 3a, page 105). After 80 minutes, exposure was made to a second round, which resulted in a further loss of 15 Db. at 5793 c.p.s. bringing the peak loss to 85 Db. at this frequency. The audiogram is shown in figure 3a. There is no further change at 4096 or 2048 but there is a further loss of 10 Db. at 512 and 1024 c.p.s. This round resulted in rupture of the eardrum with bleeding from the ear, which may have accounted for the 10 Db. increase in the lower frequencies; but it is interesting to note that a Rinne test, 1 hour, 24 and 48 hours after exposure, was positive with a value of 20 seconds. The audiogram was roughly similar in shape to that following the first shot, and for some days the loudness recruitment characteristic of nerve deafness was clearly observable in the higher frequencies. In other words, in the absence of infection the deafness, despite the torn drum was largely of inner ear origin. Figure 3b shows the recovery curves from this exposure. The lag in the recovery from the lower frequencies (which usually are the first to recover, and recover in a few

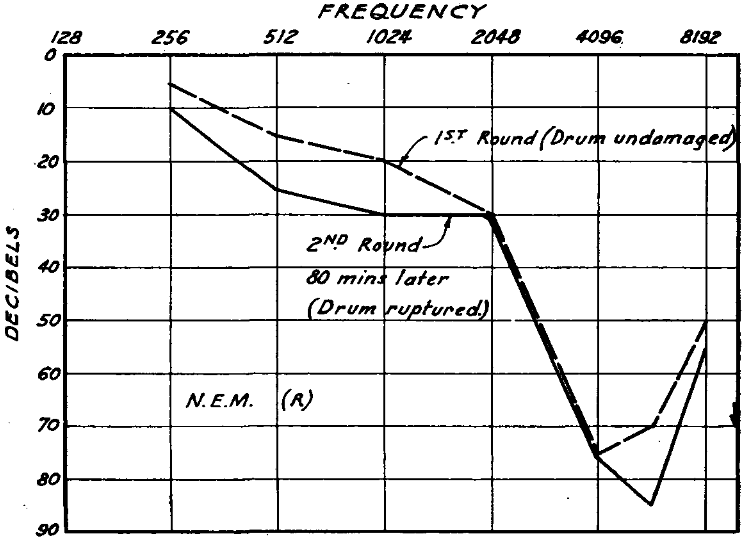

FIG. 3 a. DEAFNESS

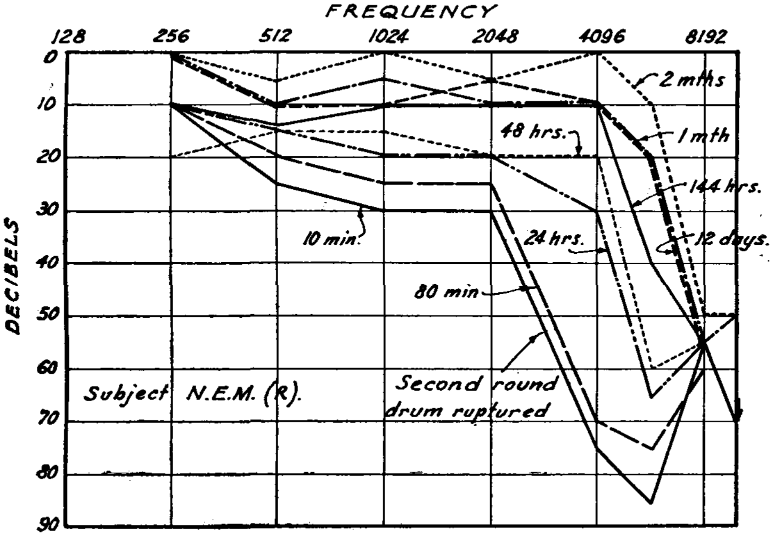

FIG. 3 b. RECOVERY.

RUPTURED DRUM

DEAFNESS & RECOVERY FROM 2 RDS OF 3" SHORT MORTAR.

0 db = Normal pre-exposure threshold.

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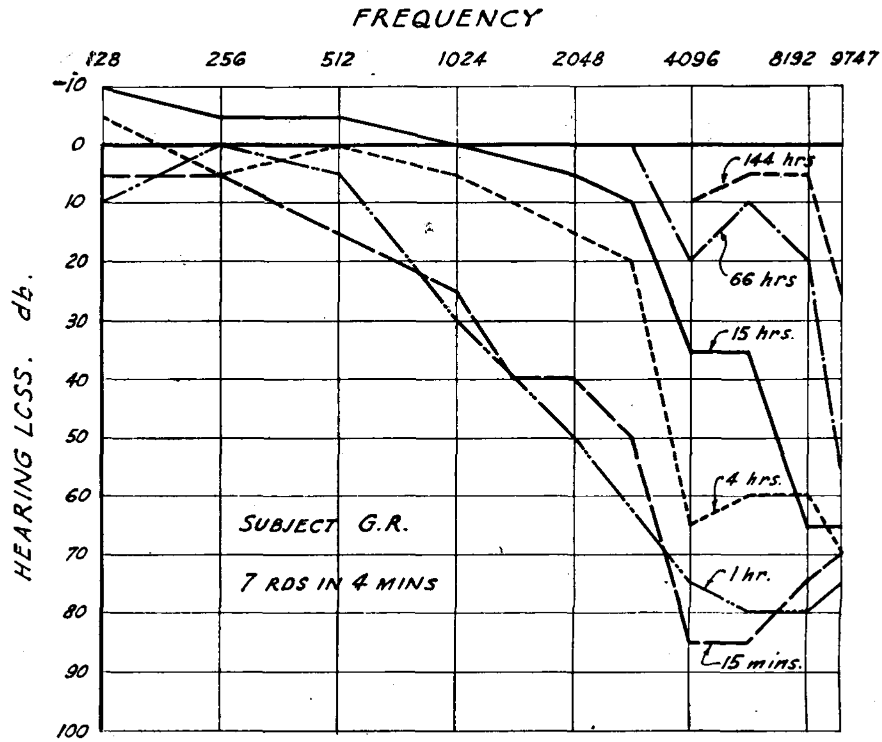

FIG. 4.

AUDIOGRAM AT VARYING PERIODS
AFTER EXPOSURE TO 17 PDR. T/A GUN
WITH MUZZLE BRAKE

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hours) is probably due to the ruptured eardrum. The upper curve of figure 3b shows the state of this ear 2 months after exposure. A peculiar feature is the complete lack of any real recovery at 8196 cycles, although there was almost complete recovery below this and some recovery at 9747. At the time of writing, two months after exposure, there remained a small clot on the eardrum sealing the rupture. The loss at 8196, shown persisting this time afterwards, may be considered permanent.

(e) Recovery

1e. This aspect is more fully discussed in a later paper. The curves in figures 1, 3 and 4, pages 99, 100, 101, 105, 106, indicate the way in which recovery occurs, and show that when the initial loss is severe, deafness is still appreciable 15 to 23 hours after exposure. The audiograms of subject G.R. after exposure to 7 rounds of the 17 Pr. T.A. gun with muzzle brake, and of N.E.M. from 2 rounds 3 inch Short mortar, show that recovery was still incomplete six days afterwards. (See figure 3 and 4.) The practical aspects of these recovery times are discussed in Section 11, page 118.

(f) Variation in sensitivity from subject to subject

1f. It is apparent from an examination of table 5 in the appendix that there is considerable variation in sensitivity among different subjects. For example the figures for hearing loss from the Long 3 inch mortar (see Appendix) are unimpressive, despite the fact, as will be shown later, that the blast pressure was of an order comparable with that which had caused considerable hearing loss in other subjects. The subjects available in the more severe positions for this experiment were relatively insensitive, and only four rounds were fired. In contrast to this result, the 2 inch mortar (see Appendix) caused considerable loss of hearing in the sensitive subjects who happened to be available on that occasion, despite the much lower blast pressure which is produced.

2f. For this reason and because of the fact that the number of rounds and rate of fire were not standardized, it was not possible to compare the effects of various guns and at various gun positions, except in a general way. With the exception of ourselves and E.P.S., subjects were usually exposed to only one of the gun positions. Sufficient data, however, was accumulated, from the records of hearing losses of these and other suitable subjects, to clearly indicate which were the effects likely to be caused by the various weapons, and to correlate such observations with blast pressure measurements. By this means it becomes possible to state that a weapon, such as the 3 inch Long mortar, will commonly produce serious loss of hearing, despite the fact that the experimental subjects exposed to the blast from it, were unaffected in the particular experiment reported here.

(g) Hearing loss from various guns for same subject

19. A comparison of the effects of a large number of exposures can most satisfactorily be made from the study of the records of a single subject. In table 1, below, the average and peak losses sustained by subject G.R. are set out. It should, however, be noted that a decrease in

TABLE I

Hearing Loss from various guns for same subject (G.R.)

Gun, Position and Ear	Rounds per time	Hearing Loss Db. Average 512–8196 c.p.s.	Hearing Loss Db. Peak	Date
17 Pr. with muzzle brake Pos. 2, R. ear	7/4 mins.	49	85	29·6·44
18 Pr. in concrete emplacement Pos. 1, L. ear	20/40 mins.	32	75	17·6·44
25 Pr. short Pos. 1, and 4, L. ear	10/110 mins.	22	55	7·7·44
9·2″ B.L., outside turret, L. ear	10/90 mins.	22	50	21·6·44
3·7″ A.A., Pos. 4 L. ear	11/8 mins.	20	55	29·5·44
Rifle from hip, L. ear	80/15 mins. 80/30 mins.	19 18	65 55	10·10·44 20·10·44
6″ coast (½ charge), behind facing sideways, R. ear	6/5 mins.	14	30	20·6·44
4″ Q.F. Naval, outside turret, L. ear	6/2 mins.	10	35	13·7·44
Vickers M.G., opposite 2, facing sideways, L. ear	60/10 mins. in bursts of 15	8	30	12·10·44
9 mm. submachine gun	30/10 mins. in short bursts	7	20	18·10·44
Rifle firing from shoulder	10/2 mins.	6	25	26·10·44
25 Pr. (17, ch. 1 ; 3 ch. 3), Pos. 6, L. ear	20/75 mins.	5	15	28·6·44
Bren gun in small yard, partly roofed, next to firer L. ear	28/8 mins. singly 125/1 mins. in 5 bursts	5 1	20 15	2·11·44 26·10·44
Owen gun, R. ear	250/10 mins. in short bursts	1	10	10·10·44
Vickers Pos. 1	120/20 mins. in burst of 15	1	5	12·10·44
Bren gun as above L. ear	28 in one burst	1	5	2·11·44

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susceptibility with repeated exposures may have contributed to these results, and for this reason the dates of each exposure are set out in the table. The question of decrease in susceptibility is discussed in a later paper (Ref. 1).

2g. Some of these figures do not give a true impression of the damaging effect of some of the guns, because there are gun positions likely to be more injurious than those occupied by this subject. However, as pointed out above, after the severe effects following exposure to the 17 Pr. and the 18 Pr. in the concrete emplacements had been produced it was felt to be unwise to repeat such exposures. Thus with the short 25 Pr. the position least likely to affect hearing was occupied. Four groups of two rounds were fired with intervals between each group of 18, 15 and 23 minutes. The peak loss in Db. at 4096 c.p.s. after each group was 20, 25, 30 and 40 respectively. After 50 more minutes position 4 was occupied, after which, the peak loss at 4096 c.p.s. was 50 Db. but this position caused so much pain that continuation of the exposure after two rounds was not practicable.

7. Blast Pressure Measurements

(a) Tabulation of Blast Pressures of Typical guns and Mortars

1a. Figures for the maximum positive pressures, taken at the ear position of the subject, are presented in the following table, each figure representing a single measurement. The positions occupied are set out in figures 5, 8, 9 and 10.

(b) Blast Pressure Photographs

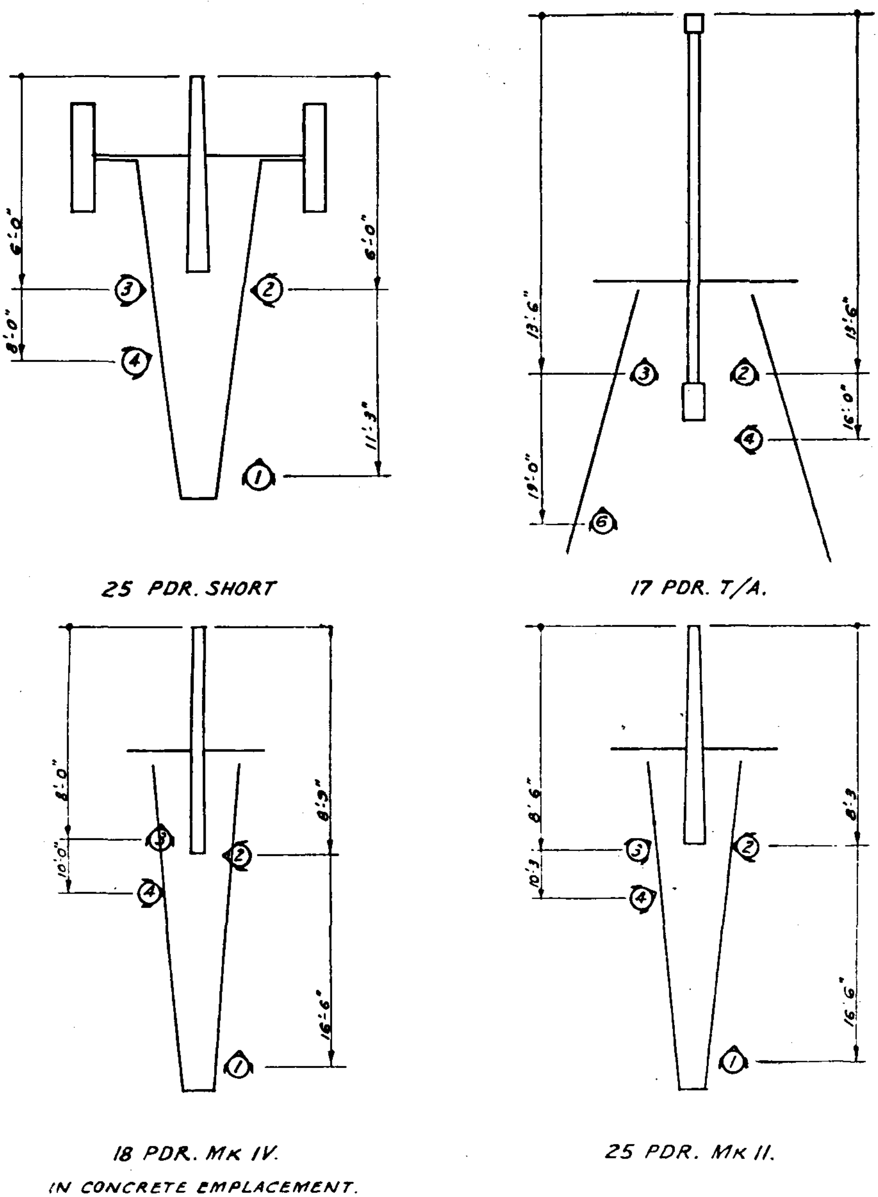
1b. Photographs of the oscillograph tracings of the blast pressure curves are reproduced for the short 25 Pr., (figure 6), 18 Pr. in concrete gun emplacement (figure 7), 3 inch Short mortar (figure 8), 3 inch Mortar (figure 9), 2 inch Mortar (figure 10) and the rifle (figure 11).

2b. A feature of the pressure curves of the large guns and the mortars is the presence of several pressure peaks in the record. The initial peak is not usually the greatest. This is characteristic in general of flashing propellants and would be enhanced when normal charge is fired from a shortened standard gun as occurs with the Short 25 Pr. and the Short 3 inch Mortar. The presence of several peaks is particularly marked in the records obtained when the mortars were fired. It would appear from our observations that the closer to the muzzle the gauge is placed, the greater is the number of peaks. Further away the pressure/time curve of the blast wave becomes simpler in form. The two distinct phases seen in the mortar records are due possibly to incomplete detonation within the barrel of the weapon, a considerable secondary

TABLE 2

BLAST PRESSURES AT EAR POSITIONS AROUND GUNS

Gun	Position	Ear	Subject facing:	Maximum positive Blast Pressure (lbs/sq. inch)			
25 Pr. short (charge 3)	2	Right	Sideways	6·0	7·5	6·7	
	4	Left	Sideways	3·8	6·7	4·9	
	1	Right	Sideways	3·3	2·6		
	2	Left	Forwards	5·7	6·9		
	2	Right	Forwards	7·6			
3 inch mortar short (Bombs Mk. 3, 95 gr. ballistite and 12 sec. charges each 115 gr. cordite W.M.107)	1	Right	Forwards	7·0	5·7		
	2	Left	Forwards	7·8	8·4	7·5	7·3
	3	Left	Sideways	5·7			
	4	Left	Sideways	5.0			
3 inch mortar long (Amm. as above)	1	Right	Forwards	3·5	2·8		
	2	Left	Forwards	4·7	3·2		
	3	Left	Sideways	3·5			
	4	Left	Sideways	1·3			
17 Pr. T.A. gun with muzzle brake (A.P. Shot A.C. Service Charge)	2	Right	Sideways	6·9	7·9		
	4	Right	Sideways	7·4			
	6	Left	Sideways	6·8			
18 Pr. in concrete emplacement as coast gun	To R. of 2	Right	Forwards	6·9	7·0	7·0	
	1	Left	Forwards	3·8			
		Right	Forwards	4·6			
(Car. Q.F. 18 Pr. H.E. plugged)	Amm. No.	Right	Forwards	3·8			
	Behind 1	Right (close to	Forwards wall)	4·7			
				(Charge 3)		(Super Ch.)	
25 Pr. Mk. 2	2	Right	Sideways	2·7	3·4	2·6	3·4
	2	Left	Sideways	1·6		1·2	
	2	Right	Forwards	2·1		2·4	
	2	Left	Forwards	2·8		2·1	
	1	Right	Forwards	1·1	1·3	0·9	0·8
	4	Left	Sideways	2·3	2·1	2·3	1·6
2 inch mortar Bombs M.E. Mk. 1 55 gr. Ballistite blue cart. paper	1	Right	Forwards	1·3	1·5	1·6	
	to R. of 1	Left	Forwards	1·8	2·0		
Rifle	Hip	Right	—	0·3	0·25	0·21	0.15
	,,	Left	—	0·18	0·25	0·25	
	Shoulder	Left	—	0·15	0·21	0·15	
	,,	Right	—	0·21	0·25	0·15	



GUN POSITIONS

FIG. 5

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flash taking place outside. It is interesting with reference to these observations that the relatively simple curve shown for the rifle is replaced by a record showing a rapid series of positive and negative waves when the gauge is placed within a few inches in front of and to the side of the muzzle.

3b. In the 18 Pr. record there is a late secondary peak, possibly attributable to reflection from the roof or wall of the emplacement. The investigation of blast waves from guns in relatively enclosed spaces required further study. It is clear that the 18 Pr. gun when used as a coast gun in its emplacement with roof, rear and side walls, is much more detrimental to hearing than when used in the open as a field gun.

8. Relation of Blast Pressure Measurements to Aural Effects

(a) FEATURES OF BLAST WAVE LIKELY TO AFFECT THE AMOUNT OF AURAL DAMAGE

1a. When we attempt to find features of the blast wave which are most important in relation to hearing loss caused, we may consider the following :—

(*a*) Maximum positive blast pressure.
(*b*) Maximum positive impulse, i.e., the integration of the blast pressure-time curve over the positive impulse.
(*c*) Number of peaks in blast wave of harmful magnitude.
(*d*) Time between peaks in blast wave curves.
(*e*) Frequencies involved and their relative magnitude.

2a. From American data, which we have, it appears that the maximum energy is found in the region of 100 c.p.s. If we consider that the effect on hearing from a blast wave is similar to that from noise or loud tones we would expect the hearing loss to be mainly in the lower frequencies at about 128-256 cycles (ref. 17). This would be modified by the fact that higher frequencies are more effective in producing hearing loss than lower frequencies. An examination of our results of hearing loss in figure 1 and table 5 appendix showed that peak hearing loss most commonly occurred in octave 2048-4096 or 4096-8192. Also types of audiogram were more consistent from gun to gun on the one person than from person to person on the one gun. Detailed analysis of the frequency spectrum from gun blast was not considered useful for our purpose of relating blast pressure measurement to hearing loss. There are considerable physical differences between loud noise and blast waves of the order we are interested in here. The loud noise is only approximately ·001 lb./square inch maximum pressure. Also blast waves are shock fronted.

3a. Effects from (*c*) and (*d*) are inter-related. When it was observed from our hearing loss diagrams that bursts of gun fire were

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No. 2 position.
Right Ear.
Facing sideways.

No. 2. Position.
Right Ear.
Facing forward.

No. 2 Position.
Left Ear.
Facing forward.

No. 4 Position.
Left Ear.
Facing sideways.

No. 1 Position.
Right Ear.
Facing forward.

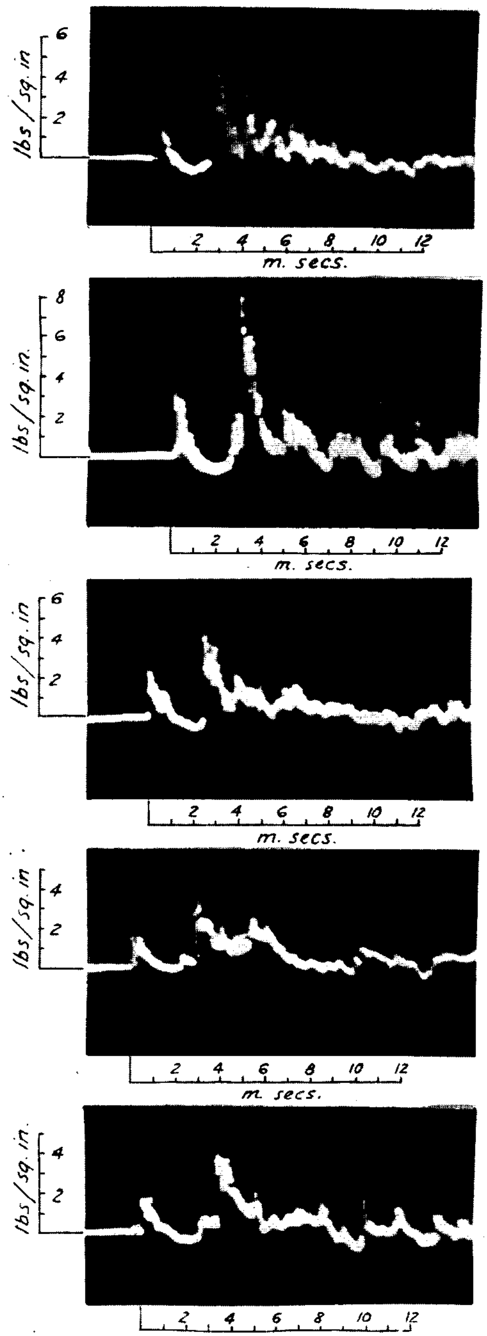
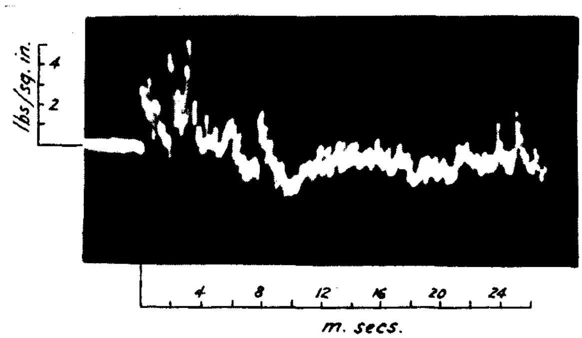
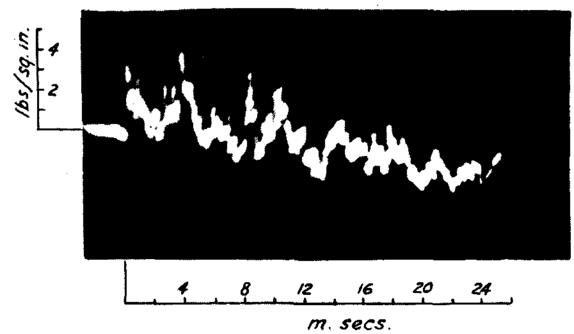


FIG. 6.
25 Pdr. short gun. Grade III propellant charge.

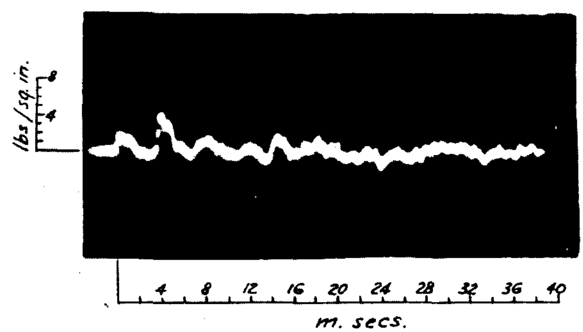
Beside No. 2.
Right Ear.
Facing forward.



Ammunition No.
Right Ear.
Facing forward.



Position No. 1.
Right Ear.
Facing forward.



Behind 1.
Immediately in front of rear wall.
Right Ear.
Facing forward.

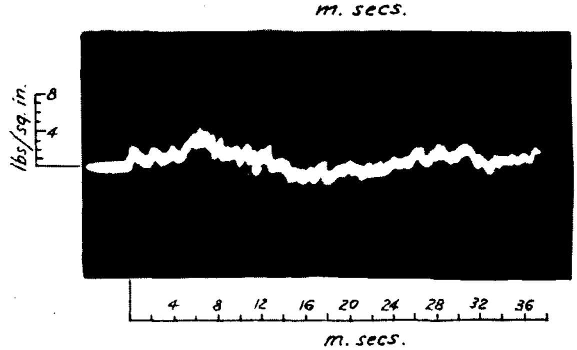


FIG. 7.
18 Pdr. gun in concrete emplacement.

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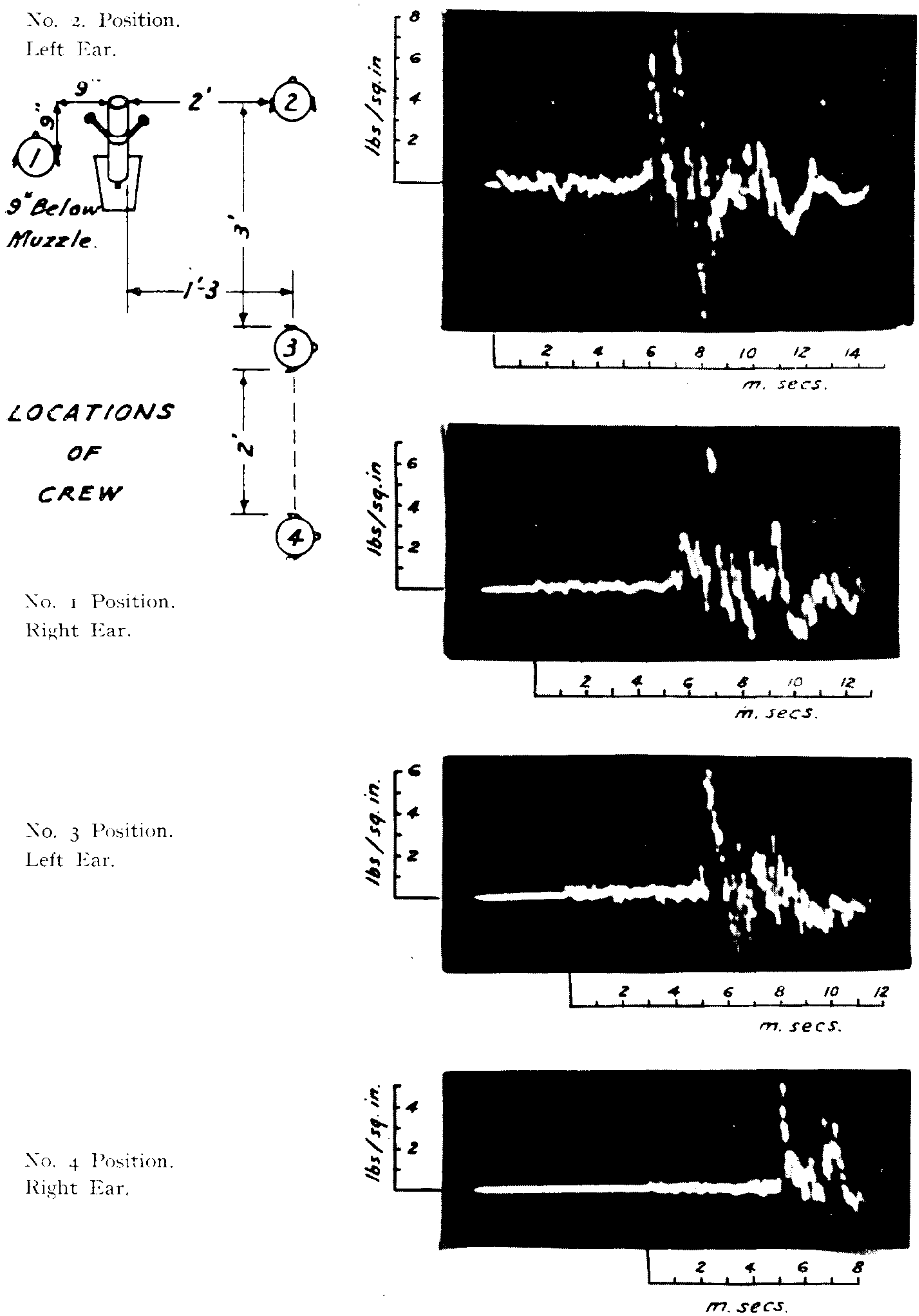
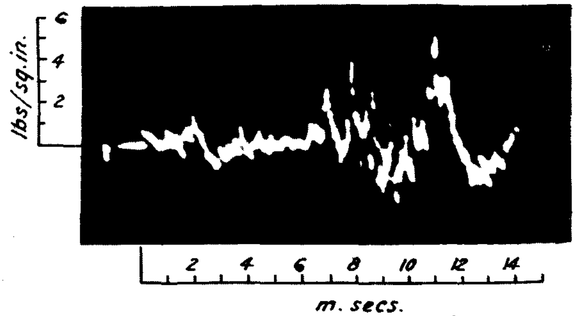
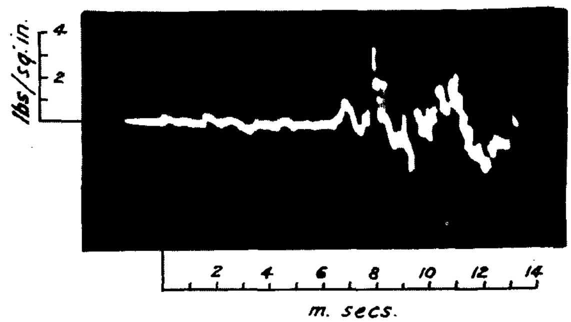


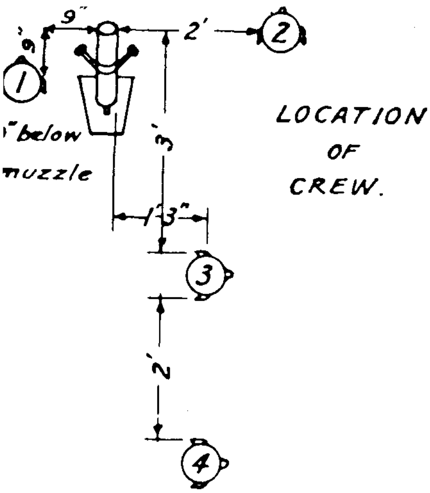
FIG. 8.
3 in. short mortar.

No. 2 Position.
Left Ear.

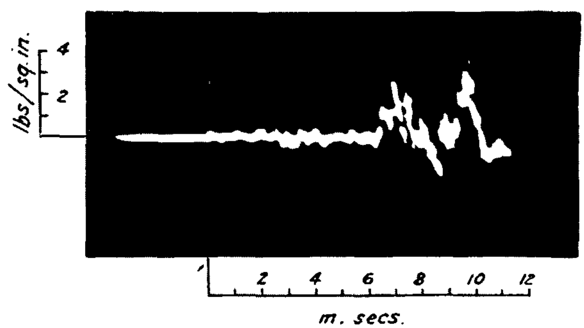


No. 1 Position.
Right Ear.





No. 3 Position.
Left Ear.



No. 4 Position.
Left Ear.

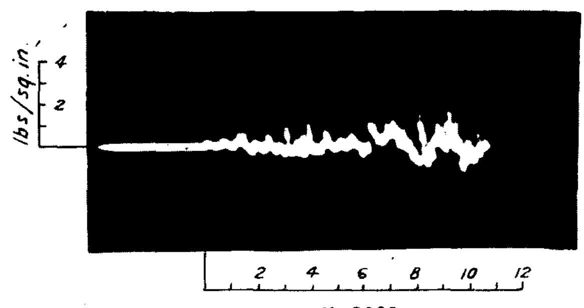


FIG. 9.
3 in. long mortar.

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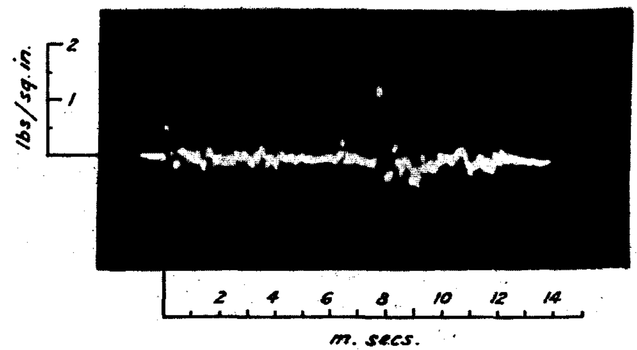
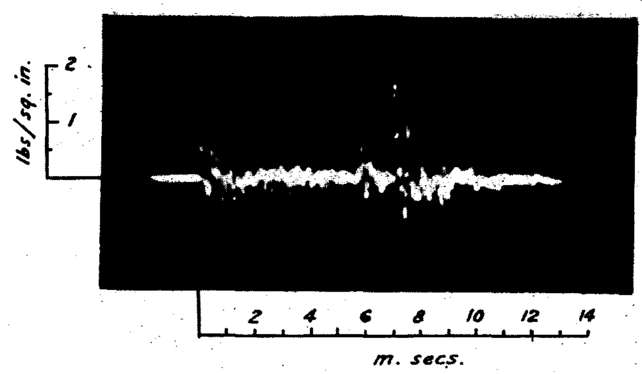
No. 1 Position.



No. 2 Position.
Left Ear.



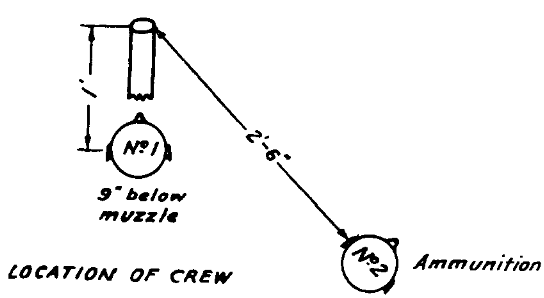


FIG. 10.
2 in. mortar.

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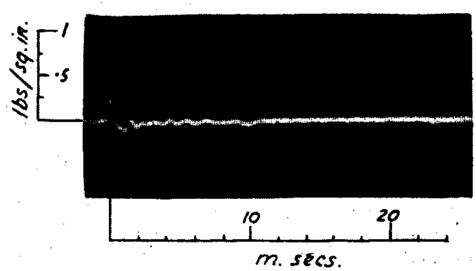
Left Ear.
Firing from hip.



Left Ear.
Firing from shoulder.

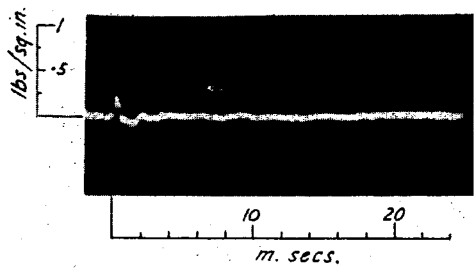


FIG. 11.
Rifle. 303 short Lee-Enfield.

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nuch less effective than single rounds (see section 6, paragraph 5a, page)8) a further laboratory study was made confirming and elaborating his aspect (ref. 1). Within the period of a blast wave curve the time between various peaks, see figures 6, 7, 8, is much less than that between uccessive shots in bursts from a machine gun and, in fact, all of them vill pass in less time than the latency of the intra-aural reflex. The number of peaks, however, was not found to be of major importance n relation to hearing loss produced.

4a. The maximum positive blast impulse may be considered as of nore importance than maximum pressure when we are interested in the effect on buildings or something having considerable mass, where it may be, in general, the best criterion for damaging effect. For a light damped nechanism such as the human ear which is capable of following rapid pressure changes, the peak blast pressure might be expected to have a closer relationship to the amount of deafness than the impulse. The naximum positive pressure is also much simpler to read from the blast pressure curve than is the impulse.

5a. For the reasons outlined in section 8a, paragraphs 1a-4a, the relationship sought was, therefore, the amount of deafness produced by various maximum pressures as indicated by the blast wave photographs.

(b) Hearing loss versus peak blast pressure

1b. Generally the greater the peak pressure the greater the aural effect. Endeavours to find a quantitative relationship between the two from all records of all individuals such as table 5 appendix, were masked by large individual variations in susceptibilities of the persons exposed. As most of this work was carried out in conjunction with practice shoots arranged for other purposes great differences in exposure regarding number of rounds and the position around guns was also unavoidable.

2b. We have, however, records for subject G.R., for the hearing loss, for a number of rounds giving an approximate equivalent exposures, over a range of pressures directly measured by ourselves. In a series of subsequent experiments (ref. 1, Reid 1945) to show the effect of number of rounds (blank charge from rifle muzzle at a distance giving response pressures of approximately 3 lbs. per square inch) on the average hearing loss over a number of subjects it was found that subject G.R. was of approximately average sensitivity. Further, no real increase in average hearing loss occurred between 7 and 15 rounds. Table 3, page 114, sets out the hearing loss for this subject for various blast pressures, the number of rounds varying from 7 to 20. The Table may, therefore, be considered as representing the hearing losses likely to occur in a subject of average sensitivity from an exposure of approximately ten rounds fired at short intervals. Results of this table are plotted on figure 12, page 115.

3b. It should be possible to use the curves of figure 12 to give a reasonable measure of the hearing loss to be expected in other sensitive subjects from these or other guns, from an exposure of approximately ten rounds. This number of rounds (10) is sufficient to even out large individual differences in resultant hearing loss likely to occur if comparisons are made from exposure to single rounds.

It is suggested therefore that the best subjective criterion for measurement of hearing loss from gunfire is the hearing loss caused by exposure to 10 *rounds.* This could be known as the "*Ten Round Hearing Loss*".

Care should be taken that on guns, known from measurements of blast pressure as being able to rupture eardrums in the worst positions, experimental subjects are only exposed in the less severe positions where the pressure is less than 4 lbs. per square inch.

4b. The increase in hearing loss with number of exposures has been studied in a subsequent paper (ref. 1, Reid 1945), so that approximate figures can also be obtained for the exposure to a different number of rounds.

TABLE 3

HEARING LOSS FROM VARIOUS BLAST PRESSURES FOR A SUBJECT OF AVERAGE SENSITIVITY (G.R.)

Gun	Rounds	Loss Db. Average—Peak		Mean Peak Blast Pressure at Position occupied Lbs. per sq. in.
17 Pr. T.A. with muzzle brake	7*	49	85	7
18 Pr. in emplacement	20*	42	75	4·5
Short 25 Pr. (Pos. 1)	8*	17	45	3
25 Pr. Mk. 2	20*	5	15	1·8

* This subject is approximately constant for hearing losses from exposures between 7 and 20 rounds (see 8b.3).

5b. From the above curves and from blast measurements taken of the worst positions of the Short 25 Pr. we would expect this gun in the worst position to cause particularly severe hearing losses although no subjects were actually exposed in these positions. We have no records of the loss of hearing of the 6 Pr. T.A. gun when fired. Blast pressures, however, were measured at the right ear of No. 2 and were for three readings 3·1, 3·4, and 3·3 lbs. per square inch respectively. Considerable hearing losses, are therefore, to be expected from this weapon.

6b. While table 3 and figure 12 have been drawn for a number of rounds, so as to get an approximate equivalent exposure, it is to be noted that severe hearing loss can occur from a single round from the higher pressures; thus N.E.M. suffered an average hearing loss of 38 Db. with a peak of 75 Db. from a single round of a 3 inch Short Mortar, (figure 3a, page 105).

(c.) "OTOLOGICALLY SAFE" LIMITS

1c. (*a*) *To prevent Deafness.* It has been stated in the past, that in order to prevent loss of hearing peak blast pressures should not exceed 2·5 pounds per square inch, and when the ear is plugged with dry cotton wool this limit is 7 pounds per square inch. Our results show that lower

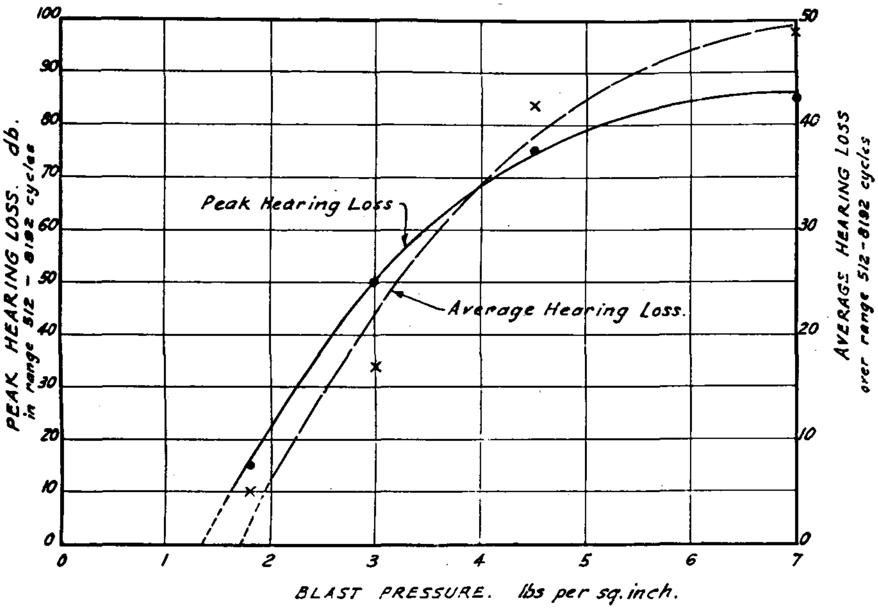

FIG. 12.

BLAST PRESSURES v HEARING LOSS

SUBJECT OF AVERAGE SENSITIVITY.

EFFECT OF TEN ROUNDS AT SHORT INTERVALS

("Ten Round Hearing Loss.")

pressures than these will deafen, even though no discomfort be experienced. For example, the rifle which produces a peak pressure about one quarter of a pound caused loss of hearing in several subjects, firing from 80 to several hundred rounds. Cotton wool did not protect subjects exposed to pressures of the order of 4-7 pounds per square inch. (See section 10, page 116.)

2c. (*b*) *To Prevent Rupture of the Eardrums.* The work of

Zuckerman *et al.* at the time of the air raids on Great Britain indicated that peak blast pressures of the order of 15 to 50 lbs. per square inch will cause rupture of 50 per cent. of human eardrums. Some instances are also recorded there of drum rupture from blast pressures from bombs estimated to be as low as 2-4 lbs. per square inch. It is known, however, both from evidence in the literature and from conversations with artillery officers, that ruptured eardrums occur in gun crew members (exposed probably to blast pressures of the order of 6-8 lbs.). It is important, therefore, to record rupture of the tympanic membrane when the pressure was fairly accurately known—that is, 6-8 lbs. per square inch at position 1 of the Short 3 inch mortar. (See section 6d, page 104.)

9. Classification of Weapons in Respect to Aural Effects

1. The relationship between peak pressure in hearing loss makes it possible to tabulate the various guns in the following order with reference to need for protection of hearing.

(a) *Peak Pressures of* 4-8 *lbs. per square inch. Protection imperative :—* to prevent rapid hearing loss, and ruptured ear drums in some subjects.
Short 3 inch Mortar.
Short 25 Pr.
17 Pr. T.A. gun with muzzle brake.
18 Pr. in concrete emplacement.
3 inch Long Mortar.

(b) *Peak pressures of* $1\frac{1}{2}$-4 *lbs. per square inch. Protection essential :—* to prevent hearing loss.
6 Pr. T.A. gun.
3·7 inch A.A. gun.
25 Pr. Mk. 2.
2 inch Mortar.

(c) *Peak pressure less than* $1\frac{1}{2}$ *lbs. per square inch. Need for protection varies with circumstances.*
Protection essential :—
Bofors, 2 Pr. guns, and small arms, at proof ranges.
Protection desirable.
Bofors, 2 Pr. guns.
Protection doubtful.
Inside gun turrets.

10. Means of Protection from Gun Blast

1. In no case, when one ear was exposed and the other ear protected by the Acoustic Research Laboratory earplug (ref. 24) known in the

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Army as Protector Eardrum Aust. Mk. 1, was deafness detected in the protected ear. In order to test the protection given by these plugs in as severe an exposure as may be expected in action, the following experiment was made. The 18 Pr. in a concrete emplacement was used, because it is known to cause in these circumstances, very high blast pressures of the order from 4-7 lbs. per square inch, and it was possible to be present when several hundred rounds were fired from this gun. Six ears of four subjects, protected by cotton wool and seven ears of four subjects protected by the Protector were examined before and after firing. The results are set out in the following table :—

TABLE 4

Exposure to blast pressures of 4·7 lbs. per square inch.
Effect of Cotton Wool and Protector Eardrum Aust. Mk. 1

Subject	Position		No. of Rounds	Protection	Hearing Loss Av.	Hearing Loss Max.	Remarks
R.G.	Left	2 & 3	160	Cottonwool	nil.	nil.	
	Right	2 & 3	160	,,	26	52	See fig. 1 L page 100
G.R.Y.	Right	Amm. No.	130	,,	7	20	
T.R.E.	Right	Various	130	,,	nil.	nil.	Complained of pain
	Left	,,	130	,,	,,	,,	,, ,,
L.B.	Right	1	200	,,	36	50	See fig. 1 M page 100
G.R.	Right	Various	250	Protector Eardrum Aust. Mk. 1	nil.	nil.	
	Left	,,	250	,,	,,	,,	
E.P.S.	Right	1	220	,,	,,	,,	
	Left	1	220	,,	,,	,,	
N.E.M.	Right	1	80	,,	,,	,,	
	Left		80	,,	,,	,,	
R.B.R.	Right	2 & 3	96	,,	,,	,,	

2. That cotton wool is an unreliable form of ear protection has long been recognized (Passe 1940, Guild 1941 and Taylor 1944). It is illustrated here by the audiograms of R.G. and L.B. in figures 1L. and 1M., page 100. On the other hand subject G.R., protected by Protector Eardrum Aust. Mk. 1 suffered no discomfort or loss of hearing after exposure to 250 rounds although 20 had caused considerable loss in the unprotected ear. (See figure 1J., page 100.) The only effect noticed with the plugs, was ringing, which occurred rarely and lasted never more than a few seconds after each shot.

3. In these experiments the cotton wool was inserted by the wearers and appeared well inserted. They were experienced gunners and were accustomed to the use of cotton wool.

4. It is clear from the above remarks, as well as from other evidence extending back to the first world war, that cotton wool is insufficient ear protection, and that artillery personnel require adequate protection such as is provided by Protector Eardrum Aust. Mk. 1 in order to prevent hearing loss.

5. To what extent infantrymen firing rifles or sub-machine guns require protection cannot at present be stated. This study shows that deafness commonly follows small arms fire ; but the answer to the problems (that is, protect the ears) is not so simple as with large guns, except in proof ranges. This is because the infantryman requires good threshold hearing, not only when he is on sentry duty after a day's action but during the whole period he is on patrol using his weapons. The question of how seriously the infantryman is deafened by small arms requires further exploration in the field.

11. Significance of Deafness following Gunfire

1. The figures given and the graphs drawn represent threshold hearing losses. Thus a threshold loss of 30 decibels at, say, a frequency of 4096 c.p.s. means that a tone of that frequency which is *just* heard by a normal ear must be raised in intensity 30 Db. in order to be just heard by a deaf ear, that is, its energy value must be increased 1,000 times.

2. This does not mean that a tone of greater intensity (say 50 Db. above threshold) must be raised by a similar amount, that is 30 Db., in order to sound equally loud to the ear with a loss of 30 Db. at threshold. Actually it is characteristic of the deafness due to noise or gunfire that the loss of perceived loudness is not constant but is variable in the sense that it diminishes rapidly as the intensity of sound is increased. Consider, for example, a normal and a deaf ear differing in acuity at threshold by a given number of decibels. With sounds at the level of ordinary speech (60-70 Db.) the difference in the sensation of loudness between the two ears may be considerably reduced from the original difference at threshold intensity, and reduced even more so at the level of the noise in planes and tanks. The extent to which this occurs will depend on the size of the threshold loss.

3. The deafness produced by gunfire may be, therefore, of importance in :—

(a) affecting the ability to hear sounds at threshold level,

or

(b) affecting the ability to hear speech at various levels of intensity.

As pointed out above, the first of these effects is much more obvious than the second and it must be added that in everyday civil life threshold

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hearing is not usually of great importance. This should not be taken to belittle the importance of a threshold loss due to gunfire because in conditions of quiet, when an enemy may betray his presence by the slightest noise, threshold hearing acuity, at once becomes of the greatest importance. Moreover, many of the sounds which it is important to detect may contain a lot of high frequency components, that is, the rustle of leaves. It is for this reason that the importance of protecting hearing should be impressed on men exposed to gun and mortar fire. With many of the hearing losses recorded in these experiments the individuals would be impaired as sentries for several days. Where the men were again exposed before recovery the deafness would tend to become incremental and ultimately very great. There is also much evidence, not presented here to indicate that deafness ultimately becomes permanent, especially where exposure again occurs without complete recovery.

4. One other point requires emphasis. Usually one ear is more affected than the other. This means that not only will a subject have a threshold hearing loss but his localization of faintly audible sounds may be seriously impaired. The importance of this to a sentry is too obvious to require further elaboration.

5. So far as the ability to understand speech is concerned, much of the hearing loss particularly when the effects of gunfire were slight, lies outside the range which is of chief importance for the hearing of speech. When the exposure is more severe as in figures 1, C, D, J, M, R, T, Y, pages 99, 100 and 101, the speech range is involved. The maximum losses in these figures for the frequencies 512, 1024, 2048, and 4096 were respectively 15 Db., 35 Db., 70 Db., and 85 Db. Subject G.R. found considerable difficulty in hearing ordinary conversation in his right ear after the experiment of figure 1C., page 99, and subject F.J.B. after the experiment of figure 2a, page 103, was deaf to all but loudly shouted conversation.

6. How then does the way in which loudness is recruited as described above affect the hearing of speech in deafness of the type under consideration? A rapid decrease in the difference between the loudnesses perceived by a normal and a deaf ear as the intensity of the source is raised does not mean that there will be a corresponding reduction in the difference between the articulation scores for the two ears, at various intensity levels. (Steinberg and Gardner 1937, 1940.) This is largely because some of the speech sounds, that is, " th " are faint and remain below the threshold of the deaf ear. Davis *et al.* (ref. 17b) investigated the articulation efficiency of subjects during the temporary deafness after exposure to noise and found in subjects with hearing losses comparable to the worst of our own, moderately large articulation losses at the 40 and 70 Db. level, but because of the wide scatter of the points, no

quantitative relation between hearing loss and articulation loss could be established. Articulation loss at the 100 Db. level was never severe.

7. Practically, the effect on hearing of conversation at the ordinary speech level of 60-70 Db. may be summarized as follows. When loss is as severe as obtained after firing the 17 Pr. there will be considerable impairment of hearing of speech whereas with mild losses (as in figures 1. G. H. N, and O, pages 99 and 100), the impairment of hearing at ordinary speech levels will be slight and the subject not appear obviously deaf to his fellows.

8. These facts have a bearing on the question of protection and the way orders are given to gun crews. If the drill is such that orders reach the members of a gun crew at say 60 Db., then if plugs are worn, naturally there will be a difficulty in hearing them. On the other hand, without plugs, there will be a loss of hearing due to the gunblast which, at that level of intensity, will of itself impair the hearing of orders. If the wearing of plugs is part of the normal gun drill, then it should be possible to transmit orders so that they will be properly heard, despite the overall 30 Db. loss which a good plug gives. This loss, moreover, will remain constant over a period of action. The intensity level at which orders should be given and the articulation loss caused by plugs or gunfire deafness at this and other intensities, particularly in battle noise requires further exploration in the field.

9. To what extent, apart from its effect on hearing, gunblast impairs efficiency, is undetermined. It is undoubtedly true, however, that when the ears are properly protected, the gunner's attention and activity are no longer directed towards protecting his ears—by raising his hands, by tilting his head or by other tricks. For these reasons our impression is that the wearing of comfortable plugs not only prevents hearing loss but improves the general efficiency of the gunner. To what extent, also, the " tenseness " associated with waiting for the gun to fire, contributes to fatigue is unknown. It may become less with experience. At all events, the most unpleasant features of gunfire is removed when the ears are protected and subjects lose most of that tenseness and apprehension.

10. The facts in this discussion emphasize the importance of impressing upon gun crews during their training that it is not effeminate to wear ear plugs, but that the care of their ears is as important as the care of their weapons.

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APPENDIX—TABLE 5

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :— 512	1024	2048	4096	5793	8192	9749
G.R. (R)	17 Pr. T.A. with brake muzzle	2	7/4 m.	15 m.	15	25	40	85	85	75	70
C.T. (R)	,,	3	9/7 m.	55 m.	−5	5	0	10	60	60	55
C.T. (L)	,,	3	9/7 m.	55 m.	5	0	5	5	15	50	70
R.C. (R)	,,	4	9/7 m.	45 m.	0	0	5	20	20	15	15
R.C. (L)	,,	4	9/7 m.	45 m.	5	10	25	50	35	65	15
G.R. (L)	18 Pr. in concrete emplacement as coast gun	1	20/40 m.	15 m.	10	25	40	70	75	45	65
R.G. (R)‡	,,	2 & 3	160/5 hrs	15 m.	0	0	20	60	50	45	35
L.B. (R)	,,	1	200/5 hrs	30 m.	10	35	40	50	—	20	35
G.R. (L)	25 Pr. short	1	8/60 m.	10 m.	0	0	10	35	45	40	50
		1 & 4	8& 2/110 m.	10 m.	0	5	10	45	55	50	50
K.K. (R)	,,	1	16/4 hrs	15 m.	−5	10	5	0*	—	10*	—
K.K. (L)	,,	1	16/4 hrs	15 m.	0	5	0	10*	—	10*	—

* Initial hearing 30 Db. or more below audiometer zero. ‡ Ear plugged with cotton wool.

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :— 512	1024	2048	4096	5793	8192	9747
F.J.B. (R)	Rifle from hip		350/5 hrs	15 m.	25*	45	25*	35*	35* +	25* +	20* +
F.J.B. (L)	,,		,,	15 m.	20*	–10*	15*	30*	—	5* +	10* +
R.M. (R)	,,		110/30 m.	15 m.	–5	5	10	45	55	15	30
R.M. (L)	,,		,,	15 m.	–10	–5	30	40	40	40	20
L.W. (R)	,,	Firer Vicinity	100 / 400 } 90 m.	15 m.	–1	–10	–5	0	—	15*	—
L.W. (L)	,,	Firer Vicinity	100 / 400 } 90 m.	15 m.	—	–5	10	10*	—	N.H.	N.H.
G.R. (L)	,,	(On right in corr. pos. to firer)	80/30 m.	10 m.	0	5	0	45	55	35	40
G.R. (L)	,,	,,	80/15 m.	15 m.	0	0	–5	35	50	65	65
E.P.S. (R)	3·7″ A.A.	3	11/8 m.	12 m.	5	0	20	45	65	55	55
G.R. (L)	,,	4	11/8 m.	17 m.	0	5	10	40	55	35	40

* Initial hearing 30 Db. or more below zero of audiometer.

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TABLE 5 (CONTINUED)

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :— 512	1024	2048	4096	5793	8192	9747
B.R. (R)	9·2″ B.L. (¾ch.)	Amm. No Rammer	10/90 m.	40 m.	5	5	0	0	0	25	20
B.R. (L)	,,	,,	10/90 m.	40 m.	0	0	−5	0	5	20	0
H.F. (R)	,,	Layer for elevation	10/90 m.	25 m.	0	5	5	0	0	0	0
H.F. (L)	,,	(port open)	10/90 m.	25 m.	−5	5	5	5	0	0	0
E.P.S. (L)	,,	Outside turret	10/90 m.	15 m.	0	10	5	25	60	55	—
G.R. (R)	,,	,,	10/90 m.	10 m.	0	5	20	50	35	35	55
R.M. (R)	Rifle in Enfield	On right	15/15 m.	15 m.	−5	0	15	45	40	40	40
S.S.R. (R)	support for accuracy	in corr. pos. to	32/30 m.	15 m.	0	35	35	0	35	35	20
S.S.R. (L)	calibration in shed	firer	32/30 m.	15 m.	−5	−5	10	10	5	5	25
R.H.L (L)	4″ Q.F. Naval	Layer (port open)	6/2 m.	10 m.	−5	5	0	5	—	−5	−5

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Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at:— 512	1024	2048	4096	5793	8192	9747
G.R. (L)	4″ Q.F. Naval (contd.)	Outside turret	6/2 m.	20 m.	0	0	5	20	20	35	30
C.B. (R)	,,	Layer (port open)	6/2 m.	15 m.	—	0	0	0	—	−10	0
E.P.S. (R)	6″ coast (½ charge)	Setter in Pit	6/5 m.	15 m.	0	5	0	10	25	30	20
G.R. (R)	,,	1 (side on)	6/5 m.	20 m.	5	5	20	20	0	30	15
C.E.C. (R)	,,	Amm. No	6/5 m.	25 m.	0	0	−5	0	10	25	10
J.K. (R)	,,	R.B.L. in Pit	6/5 m.	10 m.	0	0	0	−5	5	5	−5
J.K. (L)	,,	R.B.L. in Pit	6/5 m.	10 m.	0	0	0	−5	0	0	0
M.R.F. (R)	Vickers M.G.	1 or 2 or in vicinity	1000 rds. 4 hrs.	15 m.	0	0	20	20*	—	15*	—
M.R.F. (L)	,,	,,	(bursts of 15)	15 m.	10	0	5	5*	—	5*	—

* Initial hearing 30 Db. or more below audiometer zero.

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TABLE 5 (CONTINUED)

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at:— 512	1024	2048	4096	5793	8192	9747
Mc.S. (R)	Vickers M.G. (contd.)	1 or 2 or in vicinity	1000 rds. 4 hrs. (bursts of 15)	25 m.	5	0	10	15*	—	5*	—
Mc.S. (L)	,,	,,		25 m.	—	10	5	15	—	-5*	—
G.R. (L)	,,	1	120/20 m. (bursts of 15)	15 m.	0	0	0	0	5	5	0
G.R. (L)	,,	Opp. 2 in corr. pos.	60/10 m. (bursts of 15)	15 m.	0	0	0	20	15	30	15
G.R. (L)	9 mm. special sub-machine gun	Firer	30/2 m. (short bursts)	10 m.	0	0	0	20	10	20	50
S.M.W. (R)	,,	,,	100 in short bursts	10 m.	0	0	5	10	—	-5	5
S.M.W. (L)	,,	,,	,,	10 m.	0	0	0	5	—	5	0
C.H. (R)	,,	,,	30/2 m.	15 m.	0	-5	0	0	0	5	—
C.H. (L)	,,	,,	,,	15 m.	0	0	0	0	0	5	—
G.R. (L)	Rifle from shoulder	Firer	10/1 m.	10 m.	0	0	0	10	20	25	35

* Initial hearing 30 Db. or more below audiometer zero.

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Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at:— 512	1024	2048	4096	5793	8192	9747
A.L. (R)	Bren M.G. in small yard partly roofed	firer	125 in 5 bursts	10 m.	−10	−15	0*	−5*	0*	N.H.*	—
A.L. (L)		,,	,,	10 m.	0	5	0	−5*	0*	N.H.*	—
D.A.G. (L)		to L. of firer	28 in a burst	10 m.	0	0	0	0	0	−5	0
D.A.G. (L)	,,		28 single shots	10 m.	5	10	70	65	60	50	50
G.R. (L)	,,	to R. of firer	28 in a burst	10 m.	0	0	0	0	5	0	0
G.R. (L)	,,		125 in 5 bursts	10 m.	0	0	0	5	15	0	5
G.R. (L)	,,	,,	28 singly	10 m.	0	0	0	10	15	20	5
A.M.L. (R)	,,	to L. of firer	28 in a burst	10 m.	0	−5	0	5	20	−5	0
A.M.L. (R)	,,		28 singly	10 m.	5	10	10	65	55	50	35
J.M. (R)	,,	,,	28 singly	5 m.	−5	−5	−5	−10	0	0	10
G.R. (L)	25 Pr. Mk. 2	6	20/75 m. 17 : Ch. 1 3 : Ch. 3	20 m.	−5	0	0	15	15	10	20
T.N.B. (R)	,,	2	(18/90 m. 15 : Ch. 1 3 : Ch. 3)	45 m.	5	10	15	10	5	10* +	5* +

Initial hearing 30 Db. or more below audiometer zero.

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TABLE 5 (CONTINUED)

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :— 512	1024	2048	4096	5793	8192	9747
T.N.B. (L)	25 Pr. Mk. 2 (contd.)	2	18/90 m. 15 : Ch. 1 3 : Ch. 3	45 m.	10	5	20	10	10* +	0* +	N.H.
E.V.M (R)	,,	2	25/90 m.	60 m.	0	0	5	10*	10	15	25
E.V.M (L)	,,	2	25/90 m.	60 m.	0	0	0	10	0	10	0
R.A.C. (R)	,,	4	12/90 m.	55 m.	0	0	10	5	15	10	—
R.A.C. (L)	,,	4	12/90 m.	55 m.	10	5	10	5	5	5	5*
F.L. (R)	,,	5	28/75 m.	65 m.	0	0	0	5	5*	5*	0*
F.L. (L)	,,	5	28/75 m.	65 m.	5	5	−5	0	—	−5	0
J.T. (R)	,,	2	10/7 m. All ch. 3	30 m.	5	15	5	0	5	5	−5*
J.T. (L)	,,	2	,,	30 m.	5	10	10	5	—	0	5*
G.R. (L)	Owen, 9 mm.	Firer	250/10 m. (short bursts)	10 m.	0	0	0	5	10	0	15
E.P.S. (L)	40 mm. Bofors	2	19/	60 m.	0	0	0	0	10	−5	0

* Initial hearing 30 Db. or more below audiometer zero.

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :— 512	1024	2048	4096	5793	8192	9747
R.A.S. (R)	Twin 6 Pr. Coast	Layer for line	73/10 m.	10 m.	5	20	20	20	5*	10	—
R.A.S. (L)	,,		73/10 m.	10 m.	10	10	5	5	20*	5	5
E.P.S. (L)	,,	Amm. No	200/30 m.	15 m.	0	0	0	0	0	0	0
H.L.J. (R)	,,	5	50/6 m.	20 m.	0	5	0	5	5	10	0
H.L.J. (L)	,,	5	50/6 m.	20 m.	5	5	0	0	0	—	0
K.K. (R)	2″ Mortar	Firer	30/10 m.	20 m.	0	5	10	15*	—	15*	—
K.K. (L)	,,	,,	,,	20 m.	0	0	5	25*	10	0*	—
F.O.R. (L)	,,	to R. of firer	,,	30 m.	5	25	40	45*	55+	65+	70+
B.C.E. (R)	,,	to L. of firer	,,	15 m.	0	5	10	15	15	20	15
C.E.V. (R)	,,	Firer	9/30 m.	15 m.	5	−5	45	20*	40	40	25
C.E.V. (L)	,,	Firer	12/40 m.	15 m.	—	−5	35	20*	15*	50	20

* Initial hearing 30 Db. or more below audiometer zero.

TABLE 5 (CONTINUED)

Ear	Gun etc.	Pos.	Rds/time	Time after	Hearing loss in Db. at :—						
					512	1024	2048	4096	5793	8192	9747
L.S.P. (R)	3″ long mortar	1	4/2 m.	10 m.	5	5	0	0	-5	5	10
S.T.E. (R)	,,	2	4/2 m.	5 m.	0	0	0	0*	0*	0*	
S.T.E. (L)	,,	2	4/2 m.	5 m.	0	0	0	0*	0*	0*	
G.R. (L)	,,	3	4/2 m.	15 m.	0	0	0	0	5	10	20
L.S.P. (L)	3″ short moratr	3	3/3 m.	15 m.	—	0	10	20	30	25	25
N.E.M. (R)	,,	1	1 m.	10 m.	15	20	30	75	70	50	70+
		1	1 (80 m. later)	10 m.	25	30	30	75	85	55	70+

* Initial hearing loss 40 Db. or more below audiometer zero.