THE PROBLEM OF NOISE IN THE ROYAL NAVY AND ROYAL MARINES

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THE Navy is in much the same position as the other armed services and industry in a tendency for its operations to become increasingly noisy. This trend has led to widespread research in the field of noise-induced hearing loss, and to increasing activity in the fields of noise reduction and hearing conservation.

As none of the major noise problems are fundamentally different from those in industry and civil life, an account of how they are being tackled in the Royal Navy and Royal Marines and of the research that has been carried out is likely to be a matter of considerable interest to many civilian otologists and industrial health officers.

By way of introduction, some of the more important Service noise sources are illustrated in Fig. 1. As depicted, the main problems are with jet engines, diesel engines, guns and small-arms. These and other noise-hazardous situations have been studied during the period 1957 to 1964 in a series of audiometric surveys carried out by the authors for the R.N. Personnel Research Committee of the Medical Research Council.

The surveys have employed manual methods of pure-tone audiometry, using a single Amplivox Model 61 audiometer of accurately-known calibration (Knight and Coles, 1960) and constant output. After clinical examination and detailed interrogation, the men were given hearing tests in the R.N. Mobile Audiometric Unit (Coles, Heron and Knight, 1963). This Unit, under most conditions of external ambient noise, gives a sufficiently quiet environment for valid measurements of air-conduction thresholds in the frequency range 250 to 800 c/s down to 10 decibels more sensitive than British Standard normal threshold (B.S. 2497: 1954).

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† Part of the work described was submitted by Dr. Knight in January, 1962, to the University of London in a thesis entitled "Effects on Hearing of Auditory Hazards", which was approved for the award of the Ph.D. degree.

(a) Aircraft engines (official Navy photograph).

(b) Diesel engines (official Navy photograph).

FIG. 1.
Some sources of hazardous noise.

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(c) Guns (official Navy photograph).

(d) Small-arms.

FIG. 1.
Some sources of hazardous noise.

Noise of Turbo-Jet Engines

The flight deck of an aircraft carrier, with its close concentration of many powerful jet aircraft, the intensive flying operations and the technique of bringing the aircraft to full power before catapulting, is one of the worst jet noise situations in existence. It has therefore been closely studied.

Contrary to what might be expected, because of the intermittency of the noise as compared with the usual 8-hour exposures in industry permanent hearing loss attributable to jet noise is rare. Indeed, coincidental gunfire noise exposure was assessed in the U.S. Navy (Ward, 1957), as the major flight-deck noise hazard. British studies, however (Coles, and Knight, 1959; Knight, 1963), based on two surveys—the first, retrospective, and the second, prospective—revealed an additional low-frequency type of hearing loss resulting from jet-noise exposure in sound fields which approached 150 decibels S.P.L. This loss is illustrated in Fig. 2. Clearly, in these men, increasing amounts of jet noise exposure (from Grade I to Grade III) resulted in greater low-frequency loss. A fourth group of men, who had also experienced intense levels of gunfire noise, showed the classical high-frequency loss as well as the effect on hearing of low tones.

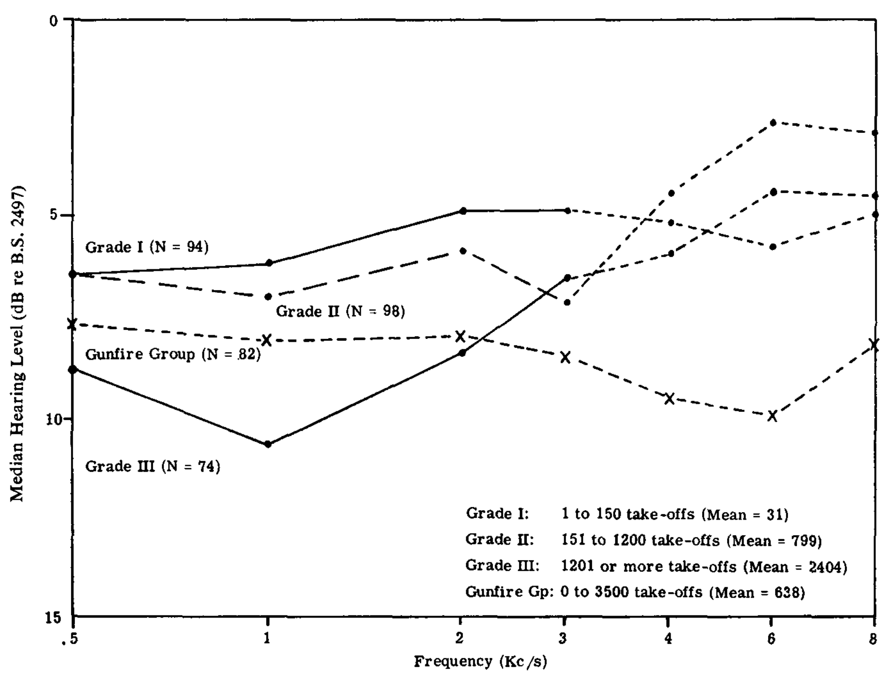

FIG. 2.
Hearing level of groups of men with jet aircraft noise exposure.

Consideration has been given to the possible causes of these low-frequency hearing losses and two factors are believed to have been responsible. First, jet noise is somewhat different from most other engine and industrial noises in that it has a wide distribution across the frequency spectrum with intense components in the lower frequency bands and also that it is not of impulsive character. As with pure tones, the average effect on hearing may therefore be expected to occur maximally at frequencies about half an octave above the chief components of the stimulating noise.

Secondly, all ear muffs and earplugs produce a greater attenuation of high-frequency sounds than of the lower frequencies. The result is that, when ear protection is worn, the noise that reaches the ear, though reduced in level at all frequencies, becomes relatively richer in the lower frequencies as compared with the higher frequencies. If the protection used is of inefficient type, as was the case at the time of the authors' surveys, the attenuation of the low-frequency components of the noise will be particularly feeble.

The threshold shifts attributed to jet noise were measured some 4 to 6 weeks after the last noise exposure. The rest period therefore greatly exceeded the criterion of 40 hours used by Davis, Hoople and Parrack (1958) to distinguish between categories of threshold shift which they described as "temporary" and "persistent". Concerning this distinction, they wrote that "some slight further improvement in hearing may occur after 40 hours, but seldom is it very much". These authors, with others, in the report on the "Relations of Hearing Loss to Noise Exposure" (A.S.A., 1954), showed a group with less than 15 decibels hearing loss at any frequency, when measured 48 hours after exposure. They recovered on average about 2 decibels at 4,000 c/s and more than 10 decibels at 6,000 c/s between 48 hours and 6 weeks after cessation of a particular noise exposure. Their data indicated that the greater the existing loss, the less the temporary effect. Opportunities for measurement of the recovery process such as this, which involved lengthy repairs to a noisy plant, are rare; normally investigations of this sort are confined to measurements after a holiday or, more commonly, after a week-end. For example, Atherley (1964) has obtained thresholds of a group of workers with a mean hearing loss of 30 decibels at 4,000 c/s, measured on a Monday morning after a week-end's rest, and found thresholds 7 decibels better on a second occasion after 16 days away from noise. As far as assessment of any disability in industrial workers is concerned, it can be argued that it is the mid-week audiogram containing a temporary component which gives the more accurate representation of the general hearing level during the working life rather than the somewhat artificial end-of-holiday level. When more results are available on the temporary component of hearing loss measured at stages during the working week, it will be possible to apply the data to reduce all measurements to an equivalent Monday morning value for purposes of comparison.

In the aircraft carrier situation, many of the subjects of the prospective survey have now been re-tested after an average interval of approximately 2 years. The latest hearing tests have shown that, with a few partial exceptions, individual threshold shifts of 15 and 20 decibels at 500 and 1,000 c/s, which persisted 4 to 6 weeks after exposure, have recovered during an interval of 2 years. This finding leads to the question of whether the eventual long-term recovery from the effects of jet-aircraft noise is exceptional or whether the same principle applies to the more usual high-frequency notches which occur from exposure to other noises. There is a scarcity of accurate measurements of the stages of recovery from persistent threshold shift, and, until more results are produced, there are grounds for doubting that threshold shifts obtained after 48 hours, or even several weeks, away from noise truly represent the extent of a permanent disability, except perhaps in the case of severe and longstanding effects.

On the other hand, the losses would probably have been permanent or more severe had the previous level of noise reaching the ear continued. It is significant and most satisfactory that recovery of hearing was found to have taken place in spite of continuing employment of the men on aircraft carrier flight decks since 1960. This finding demonstrates the efficiency of the fluid-seal ear muffs (designed in Canada by Shaw and Thiessen, 1954, 1958)* which have been available to these men for the last 3 years, and of the measures employed to ensure their proper use.

To summarize, in the current situation where jet noise exposure reaches levels of 150 decibels there need be little risk of permanent auditory damage if the best type of ear defender is used. Up to now the efficiency of ear defenders appears to have kept ahead of rising noise levels, but warning must be given that the limit of possible attenuation of any ear defender has almost been reached by the Shaw and Thiessen type of muff (the limitation being imposed by entry of noise by bone conduction through the rest of the head). If jet noise levels continue to rise, then further surveys or audiometric monitoring programmes will be needed for the detection of possible effects on hearing anywhere in the range 250 to 8,000 c/s.

Diesel Engine Noise

Apart from their frequent use driving electric generators, diesel engines form the main propulsion machinery of many modern ships, both naval and mercantile. Frequently for military use, the most powerful and noisy engines are squeezed into very confined spaces (Fig. 1). The

* These ear muffs are manufactured as "Eargards" by Denis Ferranti Meters Ltd., Bangor. They are known in the R.N. and R.A.F. as "Ear Defenders Mark 3".

result is an undoubtedly noise-hazardous situation, in which the noise reaches overall levels in the region of 120 decibels. Although continuous in character the noise has impulsive components, which accounts for the high-tone type of hearing loss which results from exposure to it.

An investigation into the hearing state of engine-room personnel in British submariners revealed the more usual high-tone type of noise-induced hearing loss. Fig. 3 illustrates the way in which with increasing duration of exposure to diesel noise the notch in the audiogram grows both deeper and wider. Similar results were found in submarine engine-room personnel of the U.S. Navy (Webster and Solomon, 1955), and in dockyard men working in diesel engine test beds (Coles and Knight, 1960). There can be little doubt but that they also occur in merchant ships and in many industrial situations.

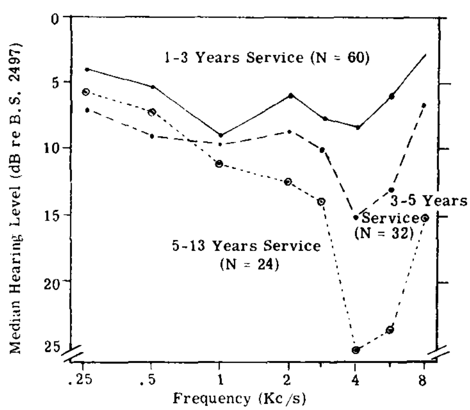

FIG. 3.
Hearing level of submariners grouped according to length of engine-room service.

Hearing conservation measures should always be considered for men working close to a powerful diesel engine. In the Royal Navy, "Eargard" muffs are used to prevent hearing loss from this cause. As shown in Fig. 1, telephones (fed from a transistorized magnetic induction loop receiver) may be included within the muffs. By this means a great improvement in communication has also been achieved, both in this and in the aircraft noise environment.

Gunfire Noise

This has been recognized as a cause of deafness for several centuries and no further elaboration is necessary here except, perhaps, to comment on the way in which the hazard is still all too frequently disregarded. An attitude of bravado or "it can't happen to me" seems often to prevail. Unfortunately, a degree of hardness of hearing tends to be accepted almost as the "trademark" of gunners. Alternatively, the gunners who are relatively noise-resistant and seemingly unaffected are sometimes quoted as examples justifying non-use of ear protection. By education, example and disciplinary measures the position in the Royal Navy is now gradually improving.

Guided Missile Noise

Missile systems are gradually taking over from the gun and, with their novelty, a more healthy but perhaps less necessary respect for their noise-making potentialities is evident. The noise is similar to that of a jet engine in its physical characteristics and, though exposure is for much shorter and infrequent periods, men may be sufficiently near the noise source for its intensity to be at a dangerously high level.

However, there are hazards other than noise which limit the proximity of exposure. The result is that exposure levels much in excess of 150 decibels, which would cause non-auditory effects such as vertigo and pain in the face, chest or abdomen, do not occur, and an efficient means of ear protection is all that is needed to safeguard hearing.

Small-arms Noise

The introduction of the self-loading rifle (S.L.R., a British modification of the Belgian F.N. rifle) has further emphasized the fact that auditory damage occurs from exposure to the noise of small-arms.

Certainly the S.L.R. is noisier than its predecessor, the Number 4 (Lee-Enfield, ·303-inch) rifle. Peak positive pressures at the ears of marksmen firing these weapons have been measured and found to be 168 and 162 decibels respectively (Elliott and Thurlow, 1962). The effects of S.L.R. noise on hearing have also been measured (reported by Coles, 1963). One-third of a squad of Royal Marine recruits, who failed to make use of the ear plugs issued to them, developed persistent* hearing losses in the 3,000 to 8,000 c/s frequency range during their training. As a result, disciplinary enforcement of ear protection has been instituted.

Whilst our interest has been focussed on the S.L.R. and action has been taken to prevent auditory damage resulting from its noise, the acoustic hazard from the ·303-inch rifle and the 12-bore shotgun continues to be somewhat overlooked. No surveys with the naval personnel exposed to the noise of the ·303 have been carried out, but there is ample evidence, from the experience of those performing routine and other audiometric tests on new-entry personnel, that it is a frequent cause of hearing loss. After defective vision, the next commonest cause of medical rejection of civilian candidates for the Fleet Air Arm is high-tone hearing loss. In the majority of these young men the cause of their hearing loss

* Measured at least 3 weeks after their last noise exposure.

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(as judged by history of exposure and of subsequent pronounced tinnitus) has either been use of 12-bore shotguns or the firing of ·303-inch rifles in Cadet Force training, competitions, etc.

More attention should be paid to the hazardous noise exposure of the small-arms noise to which many schoolboys are exposed. Otologists could do much to help by means of their expert advice as and when cases come to their notice. For gunfire noise of any type, the American V51R-type* plugs are probably the best form of ear protection, though glass-down† has advantages in being disposable. Cotton-wool soaked in petroleum jelly or in liquid paraffin is a cheaper but somewhat inconvenient alternative. Dry cotton-wool should never be used as it provides very little attenuation and leads to a false sense of security. Ranges should be designed so as to avoid reverberation, which can greatly increase the noise hazard. Any form of enclosure, roofing or a nearby wall at the firing point should be viewed with disfavour in this connection. Finally, marksmen should not be placed within about 8 ft. of one another because, if they are closer than this, a man will be exposed to a higher noise level from his neighbour's weapon than from his own.

Fig. 4 gives some examples of the auditory effects of the noise of the S.L.R. and other infantry weapons, and also of the wide range of variation in noise susceptibility of individuals. There is at present no reliable test of noise sensitivity (Summerfield, Glorig and Wheeler, 1958).

On the other hand, it has been shown by the authors, and others (e.g. Gravendeel, Bouman and Plomp, 1957; Solomon and Fletcher, 1958; Harbold and Greene, 1961) that some indication of noise sensitivity and hazardous noise exposure can be gained from occurrence of temporary symptoms of tinnitus or dullness of hearing, especially if they persist longer than, say, 5 minutes after exposure. Unfortunately, absence of such symptoms does not mean lack of sensitivity or of hazardous exposure.

The Protective Action of the Intra-tympanic Muscles

These muscles probably play an important part in determining noise sensitivity. They contract involuntarily in response to exposure to sounds of sensation level of about 90 decibels (range, 70 to more than 110 decibels). This action, by reducing the conduction of sound across the middle ear, is protective and is known as the acoustic reflex. Its efficacy against temporary threshold shifts (T.T.S.) induced by non-impulse noise has been demonstrated by Fletcher and Riopelle (1960).

In 2 per cent. of the general population (Reger, 1960), or in a larger proportion after suitable noise training (Fleer, 1963), the muscles may be

* Earplugs of this type are manufactured under the trade name of "Sonex" by Amplivox Ltd., Wembley.

† Glass-down is marketed as "Anti-Noise" by Ardente Industrial Services Ltd., London.

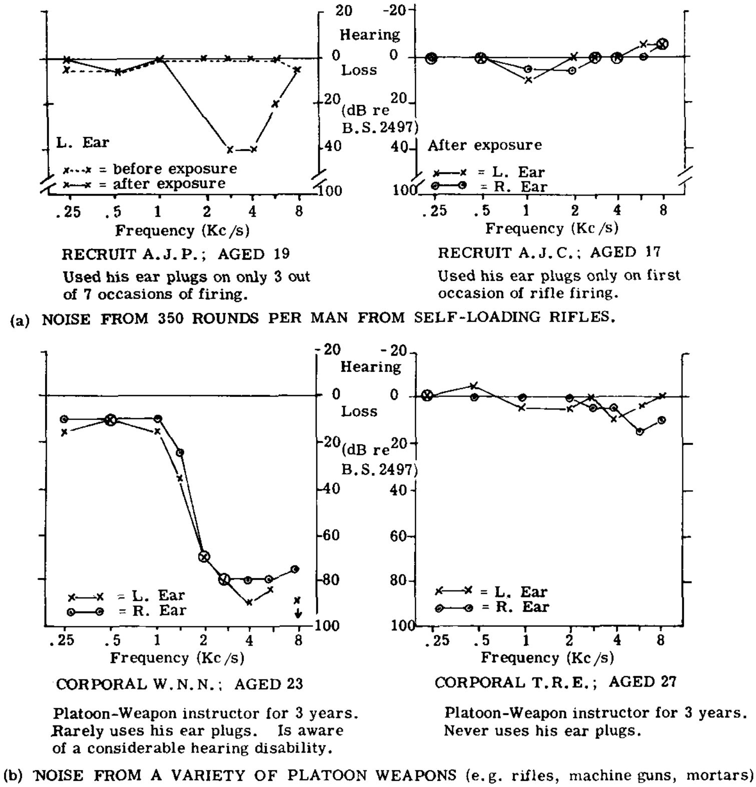

FIG. 4.
Audiograms illustrating the effects on hearing of small-arms noise and the wide range of individual variation in noise sensitivity.

contracted voluntarily. Such voluntary contraction has been shown by the latter to give a useful degree of protection against impulse noise-induced T.T.S.

A state of increased tone of the muscles (Mendelson, 1963) or of their anticipatory contraction (Reid, 1946) may arise as result of experience of the noise. Further evidence for such an alteration of intra-tympanic muscle activity is provided by two series of observations made by the authors.

The acoustic reflex threshold at 1,000 c/s and 4,000 c/s, defined as the minimum intensity level of these pure-tone stimuli needed to evoke the reflex, was measured in a group of 40 Royal Marines who had just completed their training without having used ear plugs during weapon firings. A Madsen acoustic impedance meter, an instrument described by Terkildsen and Scott Nielsen (1960), was employed for this purpose. The men were sub-grouped according to the state of their high-tone hearing, and the average acoustic reflex threshold was then calculated for each sub-group (Fig. 5). The reflex thresholds were not believed to have been affected by the hearing losses themselves for a variety of reasons, some of which have been described in more detail elsewhere (Coles, 1963). There appeared therefore to be a connection between

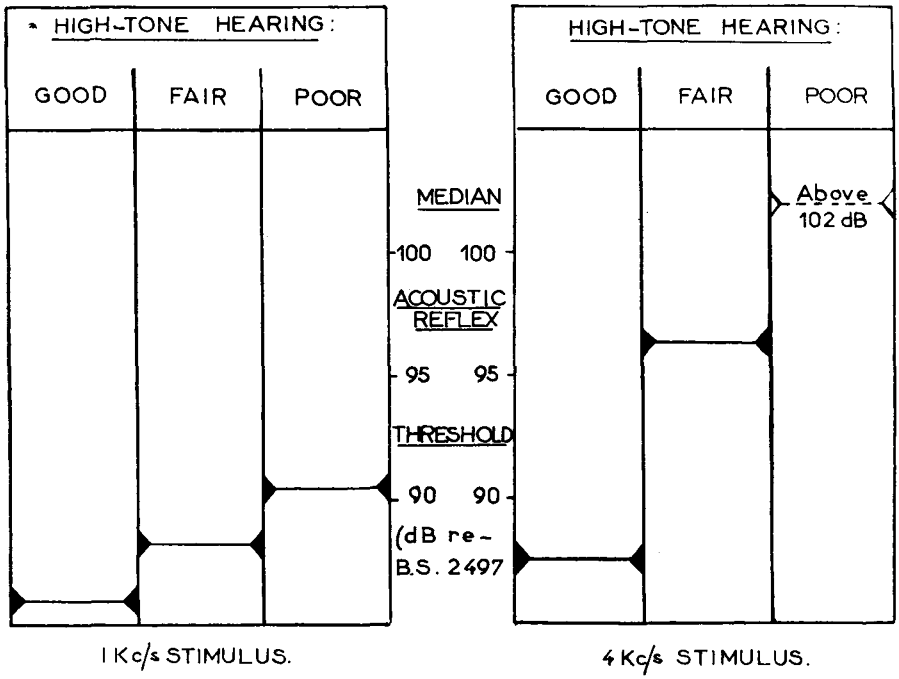

FIG. 5.
Relationship between acoustic reflex threshold and noise-induced hearing loss.

a relatively high acoustic reflex threshold and the acquisition of persistent high-tone hearing losses. Further, as small-arms noise was the sole noise exposure of the majority and the main noise exposure of most of the remainder, the state of a man's high-tone hearing can be taken as an indication of the degree of his susceptibility to gunfire noise-induced hearing loss. Thus a relationship between acoustic reflex function and noise susceptibility may be inferred.

The rise time and duration of rifle shots are much too short to allow the acoustic reflex to exert any protective effect against the noise of the particular shot which evokes the reflex contraction. One may conclude therefore that the less susceptible men, with better intra-tympanic muscle function—as indicated by reflex threshold measurements, gain their relative noise resistance either (i) by using these muscles in an anticipatory manner, or (ii) by the muscles having a prolonged contraction time course

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and thereby maintaining some protective effect against the next shot, or (iii) by a combination of both mechanisms.

The second study involved measurements, in two subjects, of T.T.S. resulting from identical weekly exposures to the noise of 20 rounds of S.L.R. fire at close range. Fig. 6 illustrates the results in the most noise-sensitive of the four ears exposed.

On the first five occasions there was a regular rate of firing and use of a warning system before each shot. The T.T.S. steadily diminished. When the shots were fired at random intervals, without warning but at the same average rate, occasions 6 and 7, the T.T.S. increased. When warnings and a regular rate of fire were used once more, occasion 8, minimal T.T.S. occurred again, even though a noise-free interval of 8 months had intervened.

The principal cause of the above is believed to be the attenuation of sound afforded by contraction of the intra-tympanic muscles in anticipation of each shot. Where warnings were used this was most effective, though some degree of tonic contraction may have occurred also, as appeared to be the case during the unwarned occasions. This hypothesis was further supported by the subjective observations of the subjects themselves; a sensation of tension in the ear before each shot, and to a lesser extent between each shot, became increasingly noticeable as the experiment advanced.

Another factor in the diminution of measured T.T.S. appeared to be an increase in the recovery rate. On occasion 1 there was no recovery between 7·5 and 70 minutes after noise exposure. On occasion 2, from a similar degree of T.T.S. at 7·5 minutes, there was partial recovery over the same period. On occasion 3 there was complete recovery in 70 minutes. An increasing recovery rate could explain the smaller T.T.S. measurements occurring on subsequent occasions, but this can hardly account for the recurrence of T.T.S. when no warnings were given.

It therefore seems that the activity of the acoustic reflex is a significant factor in defining a man's susceptibility to a noise-induced hearing loss, even with such intermittent and short duration noises as from small-arms. It may also provide the physiological basis of the decrease in temporary noise-induced symptoms and in the unpleasantness of a noise, which is often remarked on by those regularly exposed to it. It might even be that use of ear protection during the early stages of repeated noise exposure would provide the necessary protection whilst physiological resistance to the noise was being acquired. There was indeed a trend in this direction in the results of the audiometric survey of Royal Marines recruits; men who protected their ears in the first occasions of noise exposure and thereafter failed to use their ear plugs tended to suffer less damage to their hearing than those who were protected on the later occasions only. Unfortunately though, there were so many exceptions

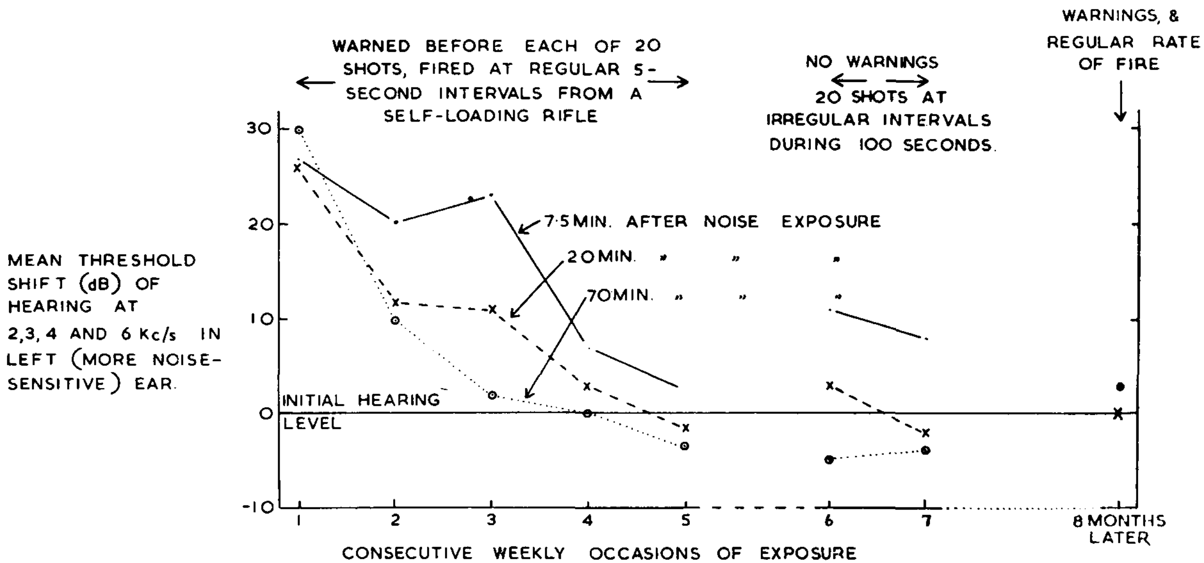

Fig. 6.

Reduction of temporary threshold shift by "habituation".

Notes: (1) Only one of the four ears exposed developed a T.T.S. sufficiently large to give a clear demonstration of the "habituation" effect. The T.T.S. measurements depicted *in Fig. 6 refer to this one ear only.*

(2) The subject's hearing level was checked before each exposure and was found to be unaltered at any of the occasions shown.

to this trend that no reliance can be put on it as an alternative to regular use of ear protection.

Hearing Conservation

The first step in dealing with any situation believed to be noise-hazardous is to measure the sound pressure level in octave bands and compare the results with a recognized damage risk criterion (D.R.C.). As an example, Fig. 7 shows the results of noise measurements (Coles, 1964) in a new diesel-engined tug of the Admiralty's Port Auxiliary Service, together with the D.R.C. recently proposed by Burns (1965).

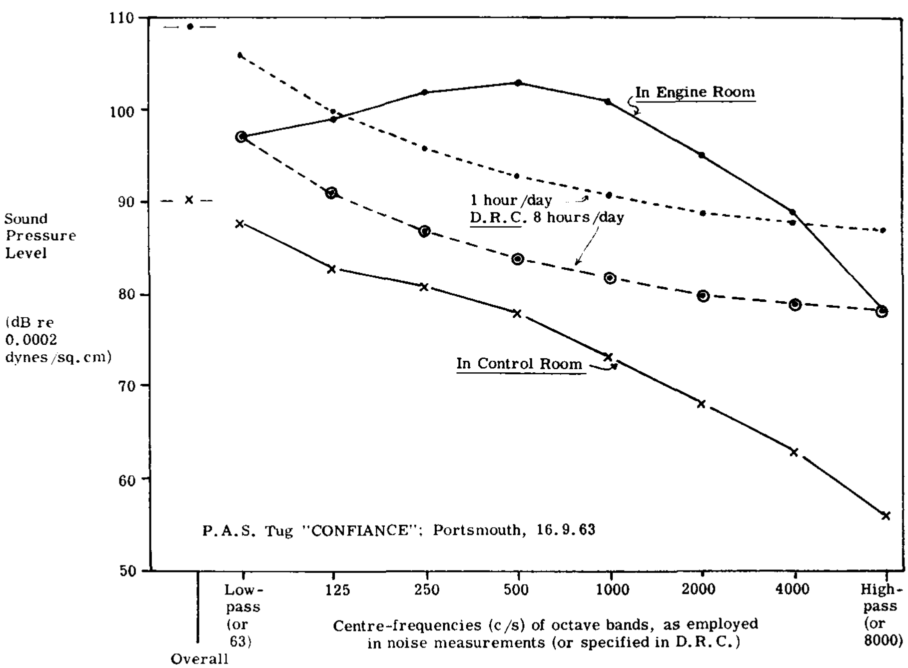

FIG. 7.
Noise level measurement in diesel-engined tug, compared with damage risk criterion (Burns, 1965).

The figure clearly shows that the noise in the engine-room of *Confiance* was in excess of the safe limit for unprotected daily exposures of 8 hours' duration. Three other factors reduced the actual hazard to hearing, however. They were reduction in duration of exposure, use of a sound-treated control room and provision of ear protection.

Burns makes provision for modification of his D.R.C. where shorter durations of exposure are to be employed, as follows: For exposures of 8 hours per day, add 0 decibels to D.R.C. levels. For exposures of 4 hours per day, add 3 decibels to D.R.C. levels. For exposures of 2 hours per day, add 6 decibels to D.R.C. levels. For exposures of 1 hour per day, add 9 decibels to D.R.C. levels. For exposures of 30 minutes per day, add 13 decibels to D.R.C. levels. For exposures of 15 minutes per day, add 19 decibels to D.R.C. levels. For exposures of 7 minutes or less per day, add 25 decibels to D.R.C. levels. Similar allowances for shorter exposures are quoted in most other recently-published D.R.C.

The dotted line, situated 9 decibels above the basic D.R.C. in Fig. 7, illustrates the modification necessary to allow for the average total duration of each engineer's duty in the engine room.

In this vessel, as in many other modern diesel-engined ships, a sound-treated control room is provided from which the engine-room staff may keep watch and at the same time control their engines. The effectiveness of such a provision is shown by the lowest line in Fig. 7 and, for most individuals, auditory hazard is non-existent in the control room—even for prolonged exposures.

Finally, to make the preventive measures complete, "Eargard" muffs are provided for the engineers when they enter the engine room to make their periodic inspections and adjustments of the engines. In Fig. 8 are

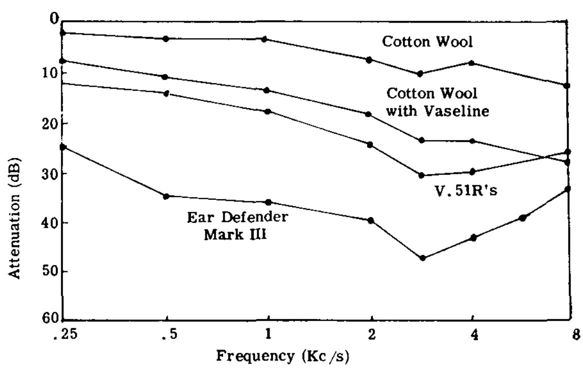

FIG. 8.
Attenuation of fluid-seal ear muffs ("Eargards" or "Ear Defenders Mark 3") compared with other devices (after Hinchcliffe, 1955).

shown the attenuation characteristics of these muffs, together with comparable data referring to V51R ear plugs, to a mixture of cotton-wool and petroleum jelly (a reasonable alternative to V51R plugs) and to dry cotton-wool, which is virtually useless. As can be judged from the figure, the effect of wearing muffs in the engine room would be to reduce the level reaching the ear to lower than that in the control room.

The greatest problem with ear protection is that of persuading men to wear the muffs or plugs provided. The Armed Services sometimes have an advantage here in that use of ear protection can be made a disciplinary matter; more often though its use is merely recommended. In these cases, which are comparable with the usual situation in industry, it is essential to give instruction and explanation at all levels—doctor, management and worker—and to encourage the use of ear protection by example. Quite apart from present disabilities, which often pass unnoticed, attention must be drawn to the future. The relationship between presbyacusis and noise-induced hearing loss is not yet completely elucidated, but a useful approximation is to assume for the present that they are additive (Glorig and Davis, 1961). This being the case, the men must be warned that a "sub-clinical" noise-induced hearing loss acquired in youth will eventually lead to a more noticeable disability than would have been the case with presbyacusis alone.

Acknowledgments

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