INDUSTRIAL NOISE—AN ANALYSIS OF THE PROBLEM

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THIS paper is the result of the deliberations of a sub-committee set up by the Council of the British Association of Otolaryngologists to consider the problems arising as the result of noise in industry.

Noise as it occurs in industry is giving rise to some concern, not so much for its nuisance value but because of its effects on the hearing. With increased mechanical power the intensity of the traumatic agents is rising and is making a greater impact on the ear. In the foreseeable future the question of compensation for any hearing loss sustained during the period of employment is bound to come up for consideration.

The accompanying paper analyses some of the current views on the noise hazard, how it can be controlled and evaluated, and discusses some of the possible legal implications involved.

The problem has been studied under the following headings:

A. *Hearing Conservation Programme.* (Details of such a scheme.)
This is to include pre-employment assessment of auditory function:
(*a*) Clinical.
(*b*) Audiometric.
(i) Type of Audiometer
(ii) Personnel
(iii) Condition of testing

B. *Reduction of noise.* (Under this head noise measurement to be considered.)
(*a*) At source.
(*b*) Protection of the individual. This is to cover means or methods of protection and if possible their respective merits.

C. *Assessment and Evaluation of any Hearing Loss Sustained.*
On what basis is the loss to be assessed?
(*a*) Biological damage, without obvious disability of which the individual is aware: i.e. threshold shift from original pre-employment assessment.
(*b*) Earning capacity on labour market.

(*c*) Social adequacy: i.e. ability to converse and enjoy the amenities of life—radio, T.V., theatre.

(*d*) Should assessment of any impairment or disability be evaluated on the performance of both ears, irrespective of the individual loss, or is each ear to be considered separately?

The effects of noise on the living human may be divided into two categories:

(1) Effects upon the auditory mechanism.

(2) Effects upon behaviour.

Increased expenditure of mechanical energy and of power constitutes one of the main hazards in industry today. Acoustic trauma, the result of exposure to noise of high intensity, is perhaps the most frequent threat to ears in industry today. The exact incidence amongst industrial workers is unknown. Industrial medicine has not undertaken any comprehensive survey to supply us with the information. Although hearing impairment resulting from a noisy occupation (boiler-making, riveting) is nothing new, it is only recently that serious thought has been given to the relation of hearing loss to noise exposure and to the fact that noise-induced deafness involves changes in the inner ear. We think it is no overstatement to say that most persons who have worked unprotected for two to three years in noise levels exceeding 100 db. will have suffered some measurable impairment in hearing. At the same time we must bear in mind that interpretation of a hearing loss which can be strictly related to exposure to noise requires experience in this problem. It baffles even an expert otologist since so many other factors complicate the diagnosis. To mention only advancing years, past ear infection, infectious diseases in childhood days, past head injuries, progressive nerve deafness, otosclerosis, highlights the difficulties to be faced.

Although curves have been described to show the amount of hearing loss that can on the average be expected with advancing years, it is doubtful whether they represent the true state of affairs. The population on which the observations were made was not selected to eliminate either the people who have been exposed to noise or those with some past otological history of dysfunction. Despite what has been said, in the absence of any history of predisposing factors except exposure to noise, such progressive or permanent deafness found on examination must be conceded to this cause, viz. noise. There are hearing losses which have similar and relatively constant characteristics. In the early stages the loss is localized in the little-used high frequencies and consequently stimulates neither the interest of the worker himself nor that of the management. The possibility of increased efficiency and comfort, and even production, to say nothing of the question of compensation for any hearing loss sustained, has not received the attention it merits. The attitude has been one of leaving

the problem alone since investigating the hazards of noise would simply emphasize and invite attention to a condition which has not been properly defined.

Briefly, the effects of noise upon behaviour, including work output, absenteeism, general health and the ability to carry out various tasks, have been the subject of study in the laboratory and in the field. The general conclusion could be summarized thus:

(*a*) the framework in which annoying noises must be viewed is a psychological rather than an acoustical one,

(*b*) intermittent and steady noise appear to differ in their effects.

The many field studies reported in the area of reduction of annoying noises (when speech communication is not involved) do not reveal definite gains in worker output, accuracy and other factors when proper controls are applied.

Before discussing preventative or precautionary measures it is as well to consider the legal aspect of the problem. Occupational deafness is a new concept which will have to be fitted in to the whole pattern of workmen's compensation sooner or later. At present only deafness resulting from an injury is compensated under the Act. The problem will be a complex one because it involves economics, politics, insurance, law, medicine, psychology, biology. Because a demand for financial compensation is a possibility when hearing loss has been sustained on account of work in harmful industrial noise levels, certain important questions must be considered.

(*a*) What noise levels in industry are injurious?

(*b*) What is the proper method of determining the employee's hearing loss resulting from his occupation as distinguished from other causes?

(*c*) What hearing losses are disabling and what criteria should be used (economic, social or physiological) in defining disability?

(*d*) How will we deal with the problem of accrued liability?

An accident under workmen's compensation is a definite event arising out of and in course of employment. An occupational disease, on the other hand, is a condition which develops over a long period of time, and in loss of hearing cases ætiology is often obscure.

Compensation based on a wage-loss principle is devised to replace income lost by reason of injuries connected with work. Departure from such a principle and introducing awards for non-economic, physiological or social loss may well lead one to ask where is the stopping-point and who is going to bear the cost. It may be popular and politically expedient to make industry pay if it makes a man deaf but where is the trend thus initiated ultimately going to lead us? Logically, even if it involves repetition, compensation should only be admissible if there has been termination of employment or loss of pay. Recently the New York State Legislature has passed a new law to provide workmen's compensation benefits to employees for occupational loss of hearing. In essence, this law freezes into

the statutory law the six-month period of waiting before an award can be granted, provides certain optional machinery for the apportioning of loss between successive employers and leaves the formation of up-to-date technical standard for evaluating compensable hearing loss to future administrative determination by the Workmen's Compensation Board. The questions left for such administrative determination include:

(*a*) frequencies to be used in measuring industrial loss,

(*b*) the point below which there is no hearing disability and the point above which the inability to hear shall be deemed total,

(*c*) the use of monaural or binaural methods of computing the percentage loss of hearing,

(*d*) proper deduction for presbyacusis and other non-industrial causes of hearing impairment,

(*e*) the number of examinations needed to evaluate industrial hearing loss and the fairest method of determining the loss from the results of successive examinations.

I think enough has been said to emphasize the importance of prevention in reducing the many difficulties encountered.

(A) Hearing Conservation Programme

The conservation of hearing is but a facet in a medical programme for industry. The primary objective of any conservation of hearing programme must be the preservation of the ability to hear; and its secondary one, that of protection against workmen's unjustified compensation claims. It is imperative that the medical aspects of such a programme should be under the direct supervision of a qualified medical person, who by training and interest is well acquainted with the technical aspects of the problem. The first requirement in such a project is pre-employment testing and examination. The cornerstone of any future assessment, whether for compensation purposes or continuation in a noisy occupation, is the otologist's evaluation of the extent and cause of any hearing loss, if present. This would constitute a more acceptable proof of loss if it should be needed at a later date. A complete physical examination with a full medical and military history is necessary before any audiometric tests are undertaken. Although the whispered voice, spoken voice, watch-tick, may be used to evaluate hearing ability, likewise tuning-forks, the only test of sufficient accuracy is the pure-tone audiometer. It is the basic instrument on which any industrial conservation hearing programme is founded. Provision of masking noise is essential, but attachments for bone conduction are not necessary. Only properly calibrated instruments which conform to the British Standard Institution specification as regards performance and threshold should be used. In order, however, to ensure accurate measure-

ment of hearing, pure-tone audiometry should be performed in a quiet room. Assuming that no frequencies below 500 cps. will be measured and good-fitting binaural earphones will be worn, then the suggested allowable background noise levels in db. re 0·0002 dynes/cm.^{2} per octave band cycles per second is as follows:

300–600 cps. 40 db.	2400–4800 cps. 57 db.
600–1200 cps. 40 db.	4800–9600 cps. 67 db.
1200–2400 cps. 50 db.	

If no satisfactory room can be constructed some form of prefabricated insulated booth could be used.

Testing rooms should be arranged so that the otologist or trained technician performing the test is either in the same room as the subject or immediately outside the room.

In order to eliminate the factor of any temporary threshold shift no audiometric examination should be made unless a period of at least 16 hours and preferably 36 to 48 hours has elapsed since the last exposure to any form of injurious noise.

A pre-employment examination is therefore the starting point. It will ensure that the employer knows at least the amount of hearing loss, should it occur 5 to 10 years later, for which he is likely to be held responsible.

As an otologist cannot be expected to carry out routine audiometric measurements a properly trained person is necessary—one whose training has been under expert professional supervision. Tests performed by improperly-trained or untrained persons will be of doubtful accuracy and of little value in either hearing conservation or medico-legal matters. If a trained technician is employed he should only be responsible for the accurate measurements of auditory thresholds. It is not his place to interpret, diagnose or advise on the results of audiometric testing or findings.

The pre-employment or pre-exposure audiogram will serve as a record of the normal or pre-exposure hearing status with which all subsequent audiograms may be compared. Any person who is subsequently exposed to noise levels capable of causing hearing impairment should be given a periodic audiometric check. The question of how often check examinations should be made is not easy to answer. Where the noise is excessive, say above 120 db., very frequent examinations are desirable. Likewise if a person is thought to be highly susceptible. Perhaps a six-monthly examination would meet most requirements. A point to be remembered is that exposure to high noise levels gives rise to a temporary loss as well as a permanent one. Audiograms taken immediately after exposure to noise may demonstrate hearing losses which are only temporary, but when compared with the pre-exposure audiogram exhibit changes at the higher frequencies. It is therefore desirable, as has already been stated, to allow if possible a lapse of 24 to 48 hours before testing. Once pre-exposure and

periodical audiometric evaluations have been performed, hearing conservation becomes a real thing by protecting those individuals who demonstrate progressive noise-induced hearing losses or those who show undue susceptibility to noise. For record purposes, one on which losses are recorded numerically instead of being plotted on a graph provides an easy way and permits many tests to be recorded on the same form. Any relevant medical, otological, occupational or military history should be recorded on the same form. Finally, all these documents should be regarded as confidential and maintained and controlled by the Medical Departments in charge.

(B) Noise Reduction

We can now consider some of the means to reduce the hazard of noise. The ideal way to control it is to prevent its generation. When this is impracticable the use of acoustical materials and noise barriers offers possibilities. One can also control noise by removing either the source or the exposed worker to another location; and finally, where any of these means are not possible, individual protection becomes necessary.

Any protective ear device places a barrier between the noise source and the hearing mechanism. Whether worn over the ear or inserted in the meatus it reduces the amount of noise energy transmitted to the inner ear. It is important, however, when considering the amount of attenuation offered by any protective device, to remember that sound energy can reach the inner ear by acoustic leaks through and around the protective device, through vibration of the device and by bone conduction which may short-circuit the device. The different pathways, of course, vary in significance depending on the intensity and frequency of the noise and *amount* of leakage around the ear protection device. If the airborne path of noise which enters the external ear is completely blocked, the noise attenuation afforded to the inner ear is limited to about 50 db. *below* the environment level. The attenuation limit is due to the conduction of environmental noises by the skull to the inner ear. Bone conduction varies with frequency.

Before considering any type of ear protection we must discuss what are the damage risk criteria, because unless noise is attenuated to those levels protection of any form does not fulfil its requirements. Various levels of noise have been proposed as maximum safe levels below which individuals may work for extended periods of time without danger of resultant permanent damage to hearing and above which there may be risk of permanent loss of varying degree. It is not possible to specify potentially damaging noise levels in terms of single, overall sound-level meter readings. Kryter has presented an estimate of a maximum safe intensity level. This estimate is based on the critical-band concept, which he describes as follows:

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"If an extremely wide band of masking noise is taken at the minimum intensity required to mask a pure tone located at the middle of the frequency range, the band of noise can be symmetrically reduced in width towards the tone, lowering the masking effectiveness until the critical-band width is reached. It is usually assumed that the energy in the narrowed band now equals the energy in the pure tone."

The assumption is then made that the critical band concept also applies to the deafening effect of noise. On the basis of studies of published data on industrial hearing loss and laboratory evidence, Kryter estimated that 86 db. re 0·0002 dynes/cm.^{2} for any band of frequencies of less than critical band width was safe over an extended period of time. This estimate has received widespread recognition and has been converted into octave band levels by Beranck.

Many studies have shown that it is not possible to set up meaningful and useful criteria which work for 100 per cent. of a given population. An Exploratory Committee (Z24-X-2) of the American Standards Association has expressed the view that one of the weaknesses of some of these studies comes from the fact that most of the results are expressed as average values. This same Committee investigated the feasibility of establishing standards of undesirable and injurious noise levels and surveyed all available data. It concluded that sufficient validation of this data was not available to warrant the drawing up of such standards at the present time.

The Sub-Committee on Noise in Industry of the American Academy of Otolaryngology and Ophthalmology also suggested that insufficient knowledge is at hand to warrant the setting up of damage risk criteria but has proposed instead a "hearing conservation level".

It has been stated that if the sound energy of a noise is distributed more or less evenly throughout the eight octave bands and if a person is exposed to this noise regularly for many hours a day, five days a week for many years, then if the noise level in either the 300–600 cycle band or the 600–1200 cycle band is 85 db. the instigation of noise-exposure control and tests of hearing is advisable. The more the octave band levels exceed 85 db. the more necessary is the need for hearing conservation. We must not overlook that individuals differ in the effects of noise upon their hearing. Some persons may have more "tender", others "harder "ears than normal. No clear-cut method has been evolved for selecting these persons. When we now consider means of protection we shall not deal with the engineering control of noise but essentially with personal protection.

Protection

The first stage in any noise control problem is to secure adequate quantitative and qualitative information on the extent and magnitude of the problem. This, as has been said, necessitates measuring the noise

spectrum and securing complete information on the environment in which the noise exists. The amount of noise control required, by whatever means, for each of the frequency bands is that attenuation sufficient to reduce the noise to a level within the selected criteria. Unless this is achieved some risk must be accepted.

Surveys of industrial environments show that hazardous noises may be classified broadly into (*a*) Moderate to high level noise, usually encountered in ordinary manufacturing conditions and which are approximately around 100 db. and (*b*) extremely noisy levels associated with jet engines, which are often in excess of 130 db.

Any ear protection must not only aim at adequate attentuation of sound. It must fit comfortably, be non-irritating to the skin over long periods of time, be sanitary and, if possible, be visible in use to permit easy checking by any supervisor.

Ear protectors in general use today fall into two groups viz. the plug or insert type and the ear muff type.

The insert type vary in design and composition. They are made of such materials as rubber, plastic, wax-impregnated cotton-wool. The rubber and plastic types have been more popular because of size and economy. The main objection however is the difficulty of getting a proper fit. External auditory meati vary in size and shape. Optimum protection is only obtained if inserts are fitted properly and remain correctly seated in the meatus. Any leakage, however slight, will lower the attenuation properties. Various sizes of these plugs are available to overcome some of these difficulties.

Comfort is of paramount importance and therefore the soft plastic plug is preferable to a hard one. At this point it must be emphasized that the attentuation provided by cotton-wool is very low and provides poor ear protection.

The muff type encloses the external ear and provides an acoustic seal to the head surrounding the auricle of the ear. A critical requirement of an effective ear muff is that there must be a tight seal between it and the wearer's head. Ideally, each muff should be individually shaped but a practical size for a cup seems to be just large enough to enclose the auricle. The attenuation provided varies widely due to differences in size, shape, seal material, shell mass and type of suspension. An adequate and uniform pressure is required to obtain optimum results. If the applied pressure of the suspension is high and the muff materials are carefully chosen, a relatively good attenuation throughout the audible spectrum can be obtained. Low frequency attenuation is always more difficult to obtain but it is proportional to the applied pressure and the amount of discomfort the wearer can tolerate.

Certain objections have been raised that where communications by speech or warning signals are necessary, ear protection interferes with

them. A study by Kryter has shown that in steady static background noise levels up to 85 db., speech intelligibility is highest when no protectors are worn. In background noises above 85 db. speech intelligibility is gained if ear protectors are worn.

However, to obtain effective ear protection it is necessary to educate both management and employee in the noise problem before attempting to describe any benefit likely to be derived through using ear protection devices. Managements must realize that excessive noise produces hearing loss and unless noise levels cannot be otherwise reduced, then ear protection offers one possible solution to the problem.

Employees likewise must appreciate the nature of the problem in its proper perspective. They should, for example, be told that partial losses of hearing are likely from exposure to noise and that in the initial stages those losses are not readily apparent. As stated, the use of cotton-wool or makeshift ear-plugs should be discouraged. A good ear protector is a safeguard for all but the most extreme noise exposure. It should also be stressed that ear protection will not deprive him of necessary hearing for speech or warning signals. If success in any attempt to protect hearing is the aim of all concerned then supervision becomes necessary. General guidance, distribution and fitting should be the responsibility of the industrial medical officer but supervision must rest with the plant foremen. Only if he, the men and the management have appreciated the value of ear protection devices can any scheme operate effectively.

(C) Assessment and Evaluation of Hearing Loss

The last portion of this paper will be devoted to a discussion of some important medico-legal acoustical considerations which enter into the question of what constitutes a proper formula for determining the worker's percentage loss of hearing causally related to his occupation. As no data are available in this country many of the views expressed are based on what is in operation at present in the States of New York and Wisconsin (U.S.A.).

N. S. Symons in discussing the legal aspects of hearing loss problems in October 1956, in Chicago stated that any formula adopted should be predicated on sound scientific principles because until we know the true degree of the worker's occupational hearing loss and when it can be regarded as permanent, it is difficult to determine the fair compensable value of the impairment. This is particularly so if we accept the departure from the wage loss theory. Expressed in another way he states that there enters into the cost of these claims, if they are paid on a schedule basis, not only the weekly rate of compensation fixed by statute but also the percentage of hearing loss which when applied to the schedule fixes the number of weeks compensation which the claimant will receive. Further-

more, he states that as no single magic number yet exists which constitutes the dividing line between hazardous and non-hazardous exposure, many feel that claims should be barred unless there has been an exposure to a noise level of at least 100 db. The reason for this is that many noise levels above 100 db. do not necessarily cause hearing loss and concomitantly many levels below 100 db. are not specific to industry. Industry should not be asked to pay for hearing losses in cases involving questionable exposure. A six-month waiting period is advocated because it involves the medical principle of recovery from acoustical fatique and defers awards until after a reasonable period of separation from the job. This helps to solve the problem of accrued liability. Minor hearing losses should be excluded from compensation coverage because they neither cause social inconvenience nor are they outside the limits of normal variability.

Glorig in 1953 pointed out that hearing losses may range up to 25 db. before the patient has difficulty in hearing and then more recently House told the Industrial Accident Boards and Commissioners that in general people do not have difficulty in hearing speech unless there is more than 20 db. loss at 500, 1000 and 2000 cps.—the speech frequencies.

In 1955, in a joint statement by the Council on Physical Medicine and Rehabilitation of the A.M.A., and the Committee on Conservation of Hearing of the American Academy of Ophthalmology and Otolaryngology it was stated that in audiometry it is generally accepted that a hearing loss of 15 db. for pure tone may be within the limits of normal variability. Glorig again stated that 15 db. marks the upper limit of normal hearing: expressed differently, normal hearing constitutes an area extending between 1 ± 5 db. on either side of zero.

Audiometry is merely the recording of a subjective response to an objective signal and this response may vary on different occasions and for many different reasons. There is thus no scientific or equitable justification for compensating these minor losses which are normal and non-disabling.

The State of Wisconsin has produced a medical formula which rules out all claims where the average decibel loss at the three frequencies 500, 1000 and 2000 cps. is below 17. However, to offset this low fence their formula treats all cases where the average decibel loss at the specific frequencies is 80 or over 100 per cent. compensable loss.

The old A.M.A. formula used the frequencies of 500, 1000, 2000 and 4000 but gave the losses at these frequencies different values. The current New York formula uses the fixed frequencies of 250, 500, 1000, 2000 and 4000, but divides the average loss at these frequencies by ·8. However, most bodies and jurisdictions, including the U.S. Veterans Federation, the State of Wisconsin and the National Research Council use or recommend the use of the three frequencies of 500, 1000 and 2000.

The reason for using only the three frequencies is that conversation is heard primarily in the three speech frequencies of 500, 1000 and 2000

cycles. (Our experience is that restriction to these three is not without its short-coming. A marked loss at 3000 and 4000 cps. may not adversely affect hearing but it is very likely to influence discrimination of speech, especially in a background of noise.)

The literature on the subject indicates that as soon as the necessary test material has been validated, hearing tests for disability will be by speech testing rather than by the use of Pure Tone. It has been suggested that while it is possible that losses above 2000 cps. may have some effect on speech discrimination the probability is that these would be minor compared to the overall effect resulting from and including the 4000 cps. frequency.

In any medical formula to be used the loss of hearing due to age must be considered. The New York formula permits a deduction of 5 per cent. points for claimants of over 50 and 10 per cent. for those over 60. The Wisconsin formula provides that beginning at the age of 50 $\frac{1}{2}$ per cent. should be deducted and an additional $\frac{1}{2}$ per cent. for each year thereafter. This would amount to $2\frac{1}{2}$ per cent. at 54, 5 per cent. at 59, $7\frac{1}{2}$ per cent. at 64 and 10 per cent. at 69.

Since the common denominator in all rating tables is the decibel loss at the various frequencies the deduction under the different formulae should be translated into decibel losses in order to obtain a true comparison.

If we assume that a given number of decibels of hearing loss is due to presbyacusis there would be less confusion if the number of decibels was deducted from the losses shown by the audiometric examination and the compensation benefits computed on the residual loss after such deduction.

Should some allowance be made for the better hearing in one of two ears when computing the percentage loss of hearing? The original A.M.A. formula recognized this principle by computing the binaural percentage loss as the average of those losses for the better and poorer ear taken separately and weighted in the ratio of 7 to 1. Wisconsin now uses a ratio of 5 to 1 based on the schedule of 160 weeks for total deafness in both ears and 32 weeks for total deafness in one ear.

In many instances there is a difference in the hearing acuity in the ears in a sufficiently large number of cases which would perhaps justify the use of a binaural formula.

A further safeguard adopted by the State of Wisconsin is that when two or more differing audiometric results are obtained within a short period of time the test showing the best or maximum ability to hear shall be used. This appears to be a fairly reasonable rule in view of the many uncertain and intangible factors which enter into audiometric testing.

In the final analysis the question of what constitutes a fair award is a matter of judgment to be agreed upon between labour and industry, or, if this proves impossible, by some form of legislation. The judgment can be intelligently exercised only if we know what hearing losses are disabling

and how much of the loss is caused by work and/or by other unrelated factors, such as ageing. The otologist has a vital role to play in all these deliberations. The development of a proper formula is essential because until we know how much hearing loss a man has due to his work it is impossible to determine how much he should be paid.

To summarize the main points under consideration:

(*a*) Reduction of the noise at source or in working surroundings.

(*b*) Protection of the individual by ear wardens or ear muffs.

(*c*) Indoctrination of management and employee about the noise hazard and how to avoid it.

(*d*) Pre-employment check of ears and auditory acuity with periodical assessments.

(*e*) Determination of an acceptable presbyacusis curve.

(*f*) Agreement on the figure of noise intensity above which the noise hazard is present.

(*g*) Assessment of hearing loss for compensation purpose and by what means.

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