G.P. Review Article

Hearing Impairment Caused by Occupational Noise*

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SUMMARY

Occupational noise-induced hearing impairment is an insidiously developing injury which only becomes apparent when it affects the hearing of conversational speech. As no remedy is possible, prevention is the only answer.

In view of the impending legislation in South Africa a review of the literature is presented. This is confined to the auditory effects of potentially hazardous occupational noise in industry. Two principal properties of sound—intensity and frequency—are briefly discussed. In the study of exposure to noise important factors are: (a) over-all noise level, (b) exposure duration in a working day, and (c) exposure duration over a working lifetime. The data derived from studies of hearing loss and of temporary threshold shift make it possible to predict the risk-percentage (incidence) and to some extent the amount of hearing loss resulting from exposure to a certain noise environment in the exposed population of workers. This enables appropriate authorities to set acceptable limits as criteria. If these are exceeded hearing conservation programmes, aimed at reducing the hazard, are indicated. Some features of these are mentioned and the value of audiometry is pointed out, especially for attempts to establish high susceptibility to suffer hearing loss in individuals.

An outline of regulations regarding hearing impairment compensation in other countries is given.

A few remarks are made on the role of the medical practitioner in industrial hearing conservation programmes.

S. Afr. Med. J., **45**, 935 (1971).

For general practitioners engaged in part-time work in industry it must be difficult to find time to read the extensive literature on the subject of hearing damage caused by occupational noise. In view of the impending legislation in this field, a review article could be of value to them. As it is impossible to cover the whole field, I have selected a few aspects of medical and practical interest.

A medical definition of occupational noise might be: 'Any sound a person is exposed to in his daily work, as an inherent component of his working environment, that may cause a disturbance of his physio-psychological equilibrium'. It is generally known that a variety of noise (unwanted, undesirable and excessive sound) may cause such disturbance. This may be reversible—after cessation or even with continuation of exposure—or it may be irreversible. The effects may at first not be apparent to the exposed worker at all. Comparatively little work has been done on the non-auditory effects of noise such as annoyance effect, effect on efficiency, effect on blood pressure, pulse rate, respiration and muscle tension. One practical aspect of the so-called non-auditory effects is the disturbance of communication by speech in a field of noise. In view of the purpose of this article the discussion will be restricted to auditory effects and to industry as the environment responsible for them.

Loss of hearing as a result of exposure to excessive occupational noise (leaving aside damage by explosions and other impact noises of high intensity) is an insidious process. It only becomes clearly apparent to the victim at the stage where his social relationships are hampered by a diminished capacity to hear conversational speech. Such hearing impairment usually occurs after many years of exposure—at a stage of a man's life where he is probably most dependent on social relationships—around retirement age. Hearing impairment is used here in the sense of reduced capacity to hear conversational speech and will be defined more precisely later on. As it is due to damage sustained by the elements responsible for the transduction process in hearing—the hair cells in the cochlea—there is no remedy for this sensori-neural type of deafness.

Prevention is the only answer to this occupational injury problem.[1]

MEDICAL ACOUSTICS

Before discussing excessive occupational noise and its effect on hearing, it may be worth while to refresh the memory with a few remarks on what could be called medical acoustics. To avoid duplication the interested reader is referred to an article by W. van der Sandt[2] recently published in the *Journal*. In his article, sound, the effect of noise, the evaluation of noise exposure, hearing tests, the indications for a hearing conservation programme and the outline of such a programme are discussed. (Some statements will be made below in a categorical manner, simply referring to the original literature to avoid lengthy elaborations.)

Sound has two principal properties: intensity and frequency.

Sound Intensity and Sound Pressure

Crucial for the understanding of the terminology used in the literature on noise is the concept of the decibel (dB). Medical practitioners, except for ENT surgeons and re-

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search workers, do not normally use logarithmic scales in their everyday life. Now the decibel is the unit used to express a physical relation, i.e. of the ratio between the acoustic power, intensity or resulting pressure of a sound and a standard reference on a logarithmical scale. Intensity is the amount of acoustic power flowing through a unit area and can be expressed in absolute terms as Watts/m^2 or, using a reference of 10^{-12} W/m^2, in decibels, thus: $(10 \log \frac{\text{Intensity measured}}{\text{Intensity reference}})$ dB.

As power and intensity are difficult to measure, instruments are designed to measure the resulting pressure, i.e. the variation of barometric pressure at a certain point, below and above the ambient pressure in the air, when a sound wave traverses this particular point. Sound pressure is proportional to the square root of the sound power or of the sound intensity. The reference pressure is 0·0002 microbar (or 20×10^{-6}N/m^2). This is the pressure resulting from the sound-intensity reference of 10^{-12}W/m^2, which can just be heard by a normal ear if at a frequency of 1 000 cycles per second (Hertz). The sound-pressure level $Lp = 10 \log (\frac{p1}{p0})^2$ or $2 \times 10 \log \frac{p1}{p0}$ where p1 is the measured pressure in microbar and p0 the reference pressure of 0·0002 microbar. When $p1 = p0$ the sound-pressure level $= 20 \log 1 = 0$ dB.

The human ear not only has a phenomenal sensitivity, being able to discern a pressure of 0 dB (only 0·0002 microbar), but also a fantastic tolerance in that it can withstand a pressure of 1 million times as strong before it registers pain at 120 dB. The ear, as the microphone, reacts to pressure changes, but it does not respond in a linear fashion.

The decibel proved to be most useful as a unit of comparison both for sound-pressure measurements and for perception evaluation. Audiometers and sound-level meters record pressure and are read in decibels.

Due to the fact that we are dealing with a logarithmic scale the combining of sound-pressure levels is not a simple matter of adding figures. Working out the resulting pressure of a number of sound sources in decibels requires the use of mathematical formulae or, more conveniently, of tables and charts. Two examples may illustrate this:

1. A certain sound source causes a pressure level of 70 dB at a particular point. When another equivalent source, which alone would cause the same pressure level at that point, is added, the pressure will only increase by $\sqrt{2}$, where the sound power was doubled. Expressed in decibels this is represented by 70 dB + (10 log 2) dB = 70 dB + 3 dB = 73 dB and not 140 dB. Doubling the sound power gives an addition of 3 dB, halving the sound power results in a sound pressure level of 3 dB less.
2. If one industrial noise source causes a sound-pressure level (SPL) of 90 dB at a certain point, and another of 80 dB is added, the total pressure at that point will be 90·5 dB and not 170 dB. Silencing the 80 dB source again will reduce the sound-pressure level from 90·5 to 90 dB. However, silencing the 90 dB source would reduce the sound-pressure level to 80 dB (i.e. 10 dB less).

In general it can be stated that a difference of 20 dB in resulting pressure between 2 sound-producing sources means that the source with the highest reading represents a pressure in absolute terms (microbar) 10 times as high as the other one. A sound source of 60 dB produces a sound pressure 1 000 times as high as that of the threshold reference of 0 dB. There are a number of methods to work out the resultant pressure levels of a number of sources combined. In practice, however, the sound-level meter makes it possible to measure the over-all average sound level at a certain point in dB A (see below).

Frequency of Sound Waves

The ear discerns the frequency of the sound waves it is exposed to by the perception of *pitch,* a subjective evaluation. Even so, some people, who are said to have an absolute musical hearing sense, can name the note on e.g. the piano of a certain pure sound of a particular frequency. Whereas the intensity, or rather the pressure of a sound is translated by the ear as *loudness,* dependent on the number of nerve cell endings which are stimulated at the same time (von Bekesy), the *pitch* is determined by the location of the stimulated nerve cells in the cochlea, dependent on the frequency of the sound waves (Helmholtz). The highest tone on a piano is about 4 000 Hz. This is the frequency for which the ear is most sensitive, i.e. at this frequency a sound with even less energy than that of the reference standard can be heard. Conversely the ear shows damage by sound earlier in this range than in any other (Fig. 1). For frequencies another logarithmical scale

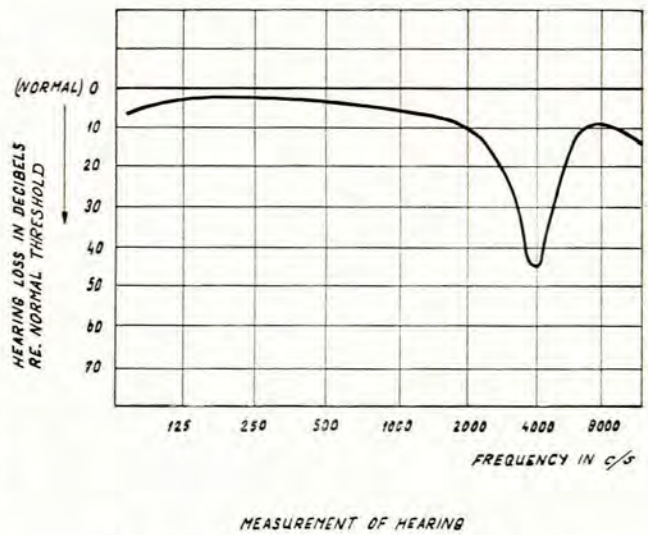

Fig. 1. Audiogram showing a 4 000 Hz dip.

is in use, that of octaves. Each doubling of frequency is represented by one octave, just as each doubling of sound power is represented by 3 dB.

Although speech ranges in frequency from 125 to 6 000 Hz, it is generally agreed that for excellent sentence intelligibility frequencies below 300 Hz and above 2 000 Hz need not be heard. (Fig. 2).[3] This is the basis for deter-

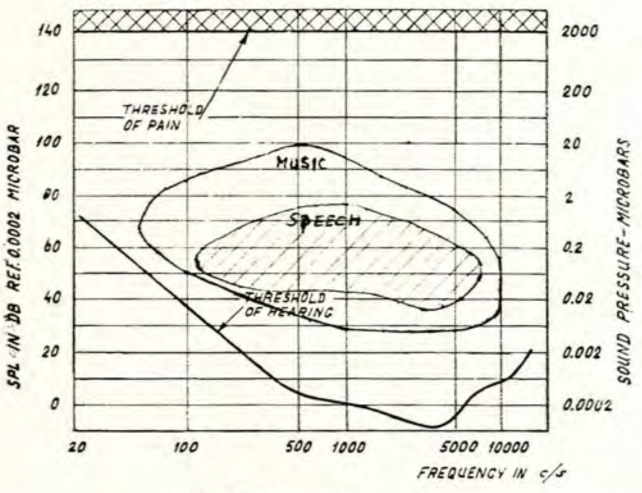

Fig. 2. The auditory area.

mining hearing impairment for speech by measuring the hearing thresholds at the mid-frequencies 500, 1 000 and 2 000 Hz. The American Academy of Ophthalmology and Otolaryngology (AAOO) recommends the following definition and rules for evaluating the amount of hearing impairment:

'Significant hearing impairment exists when the average of the audiometric measurements made at the three mid-frequencies 500, 1 000 and 2 000 Hz is higher than 26 dB according to the ISO standard 1964 (American Standard of 1969), or 15 dB or more according to the ASA standard of 1951. For every decibel that the estimated hearing level for speech exceeds this level, allow 1·5% in impairment of hearing up to the maximum of 100%.'[4]

The maximum is reached at 93 dB (82 dB by the American Standard of 1951).

The American National Standards Institute (ANSI) specification for audiometers which uses zero reference levels as recommended by the ISO (1969) shows a wide range of normal hearing. It extends from the very best hearing threshold (about −10 dB) to 26 dB where significant hearing impairment is deemed to begin. On the old calibrating standard (ASA 1951) this would read respectively as 0 dB (normal) to 15 dB (significant impairment).

It should be noted that the change of standards is based on a difference in calibration of the audiometer. It does not signify a difference in evaluation of the percentage of impairment, which remains related to the amount of hearing loss for speech, i.e. the reduction of man's ability to hear sounds of a certain physical intensity.

The SABS[5] requires the use of audiometers complying with IEC publication 178 and calibrated in accordance with ISO recommendation R.389 and defines as hearing impairment a threshold shift of hearing of more than 25 dB for the average of the audiometric measurements at 500, 1 000 and 2 000 Hz made under prescribed conditions.

In audiometry the threshold of hearing for pure tones at a number of frequencies, measured in decibels, is plotted against these frequencies relative to the 'normal hearing threshold' and depicted as 'hearing loss'. In industrial programmes the recommended test frequencies for audiometry are 500, 1 000, 2 000, 3 000, 4 000 and 6 000 Hz (AAOO).[4] Sometimes the 8 000 Hz frequency is added.

In the analysis of an industrial noise with an octave band analyser the sound pressure is tested at a number of mid-frequencies using electronic filters and plotted on a decibel scale. The sound analyser (ISO recommendation 140 (1960)) or octave band analyser uses the mid-frequencies 63 to 8 000 Hz. In Figs. 3 and 4, taken from

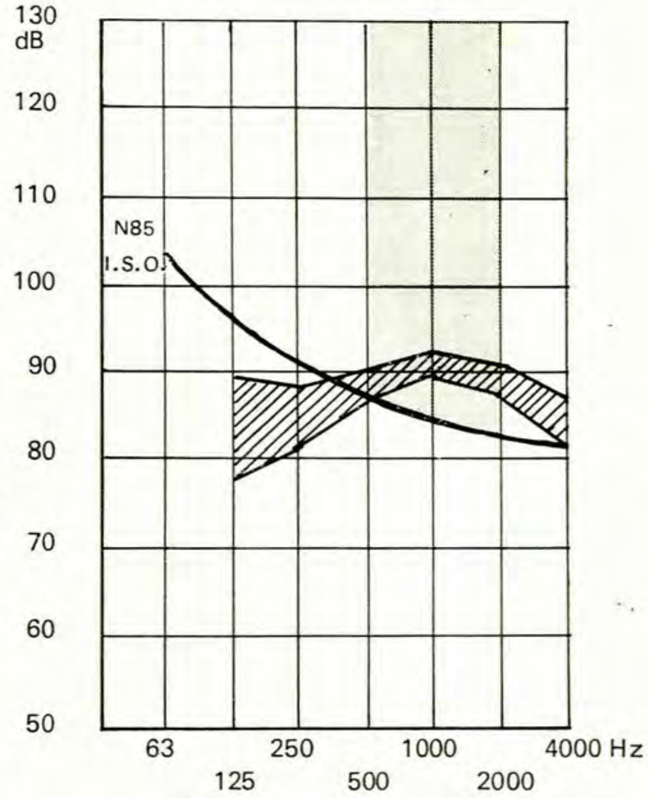

Fig. 3. Noise spectrum hulzentrekkerij.

an atlas of noise spectra and departmental composite audiograms in industry in the Netherlands,[6] an example is given of a noise spectrum (Fig. 3) in one department of a factory and the resulting hearing loss found in workers' audiograms in a composite form, after exposure of 3 years and of 3 - 15 years in that department (Fig. 4). These, incidentally, show that the worst hearing loss for the median group occurs between about 2 000 Hz and 6 000 Hz, the highest loss being in the 4 000 Hz range. This is not always so clearly demonstrated. Glorig *et al.*[7] consider the hearing loss found in an audiogram at 2 000 Hz as the most meaningful indication of actual hearing impairment development.

A remarkable fact shown by investigations is, that an excessive sound of a certain frequency will exert its damaging influence on hearing at a frequency range about ½ - 1½ octave higher, as reflected in the audiogram. If this is so, the most dangerous frequencies for excessive noise to cause hearing impairment would be those in the range of 250 Hz to 2 000 Hz.

EXPOSURE TO NOISE

The severity of noise exposure depends on:

1. Over-all noise level, measured as sound level in dBA (and frequency composition).
2. Duration and distribution of exposure during a typical workday.
3. Total exposure time during a work-life.

Severity in this context refers to the probability that the noise exposure will produce hearing loss. It is common knowledge that hearing becomes worse with advancing age (presbycusis). The data of the Research Centre of the Committee on Conservation of Hearing USA (Table IV)[4] shows that 40% of the population who have not had habitual exposure to noise above 80 dBA nevertheless surpass the threshold of significant hearing impairment by the age of 65 years. Part of the hearing loss with age may be attributable to living in a developed society with its concomitant daily noise (socio-acusis) as opposed to purely physiological ageing. In Table I the term 'percentage due to noise' is used to express the increased risk of developing a significant impairment of hearing due to noise exposure. The values were found by subtracting the percentage attributable to other causes from the total percentage actually observed in sample populations with known or estimated habitual noise exposure.[4]

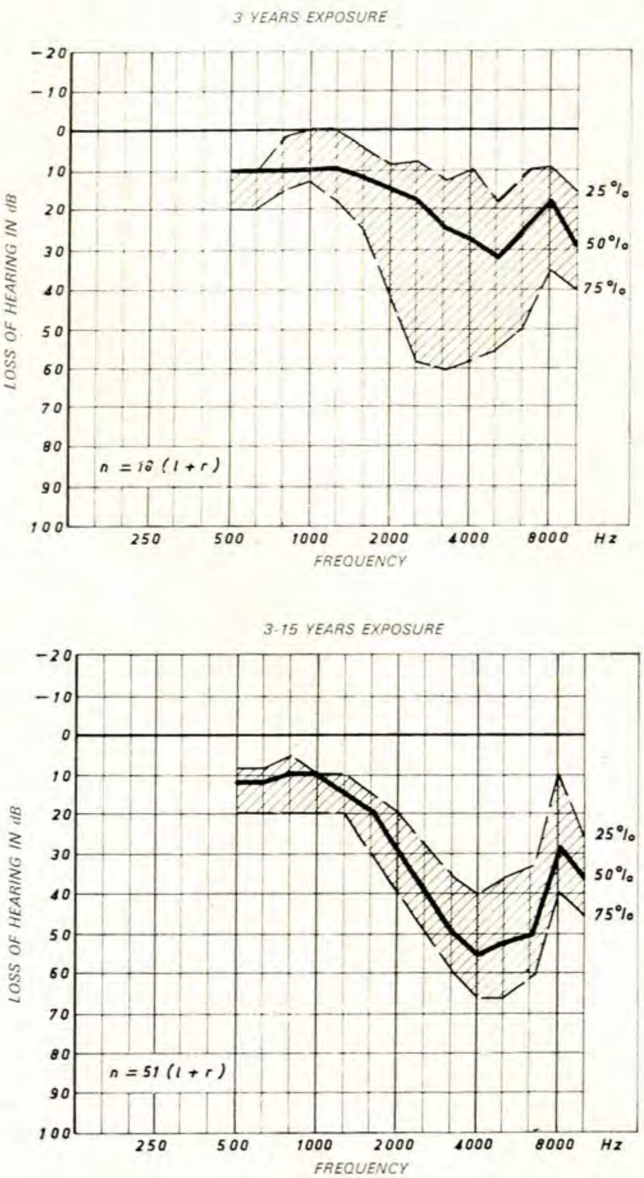

Fig. 4. Two composite audiograms.

Over-all Noise Level

For screening and practical purposes the measurement of over-all noise level is a valuable simplification and a special instrument for this is available. This is the sound-level meter (SLM) as mentioned in the IEC recommendation 123 (1961).[5] The sound level A is the over-all sound-pressure level expressed in dBA of a steady noise, measured on the A scale of this meter. The filter used for this scale attenuates or excludes both high and low frequencies which may be physically present but to which the ear is relatively or completely insensitive. The 'weighting' the filter gives to the different parts of the spectrum corresponds closely to the tendency of each part to produce loss of hearing in the range of frequencies important for hearing of speech. Examples of sound pressure level in everyday life[1] are: 85 dB in a passenger bus; 75 dBA in average traffic on a street corner; and 65 dBA in normal speech.

Although in itself the use of this meter is simple, it is necessary to observe a number of rules to obtain meaningful data, avoiding the pitfalls. For that reason only trained people should be entrusted with its use. Over-all average sound level is regarded as an appropriate measurement to assess the hearing damage potential of a particular industrial noise situation, considering the duration of exposure and distribution in time as a second important factor.[4,8-10] This applies to a steady noise in which the sound levels of the frequencies represented do not differ more than 5 dB per octave in both directions.[9] A sound level meter which would record the sound level during the full 8 hours of a working day would be ideal (noise-time integrator). In practice, measuring sound levels in dBA during representative short periods and correlating these with available data regarding the risks attached to exposure to certain levels during certain periods is acceptable. The assumption that no hearing loss is to be expected when the over-all sound level a worker is exposed to remains below 80 dBA for 8 hours a day during a full working life of 45 years is well founded on observations and measurements.[4]

TABLE I. PERCENTAGE RISK OF DEVELOPING A HEARING RISK

Exposure Level in dBA		20	25	30	35	40	45	50	55	60	65	
Age		20	25	30	35	40	45	50	55	60	65	Years
Exposure (age = 20)		0	5	10	15	20	25	30	35	40	45	
80	Total	0·7	1·0	1·3	2·0	3·1	4·9	7·7	13·5	24·0	40·0	Percentages of Exposed Population
	Due to noise			No increase in risk at this level of exposure								
85	Total	0·7	2·0	3·9	6·0	8·1	11·0	14·2	21·5	32·0	46·5	
	Due to noise	0·0	1·0	2·6	4·0	5·0	6·1	6·5	8·0	8·0	6·5	
90	Total	0·7	4·0	7·9	12·0	15·0	18·3	23·3	31·0	42·0	54·5	
	Due to noise	0·0	3·0	6·6	10·0	11·9	13·4	15·6	17·5	18·0	14·5	
95	Total	0·7	6·7	13·6	20·2	24·5	29·0	34·4	41·8	52·0	64·0	
	Due to noise	0·0	5·7	12·3	18·2	21·4	24·1	26·7	28·3	28·0	24·0	
100	Total	0·7	10·0	22·0	32·0	39·0	43·0	48·5	55·0	64·0	75·0	
	Due to noise	0·0	9·0	20·7	30·0	35·9	38·1	40·8	41·5	40·0	35·0	
105	Total	0·7	14·2	33·0	46·0	53·0	59·0	65·5	71·0	78·0	84·5	
	Due to noise	0·0	13·2	31·7	44·0	49·9	54·1	57·8	57·5	54·0	44·5	
110	Total	0·7	20·0	47·5	63·0	71·5	78·0	81·5	85·0	88·0	91·5	
	Due to noise	0·0	19·0	46·2	61·0	68·4	73·1	73·8	71·5	64·0	51·5	
115	Total	0·7	27·0	62·5	81·0	87·0	91·0	92·0	93·0	94·0	95·0	
	Due to noise	0·0	26·0	61·2	79·0	83·9	86·1	84·3	89·5	70·0	55·0	

Whenever the over-all sound level exceeds this or any other criterion incorporating exposure time, set by an appropriate authority, an unacceptable hearing damage hazard is deemed to exist. In that case the more refined method of noise spectrum analysis may be indicated to make it possible to arrive at recommendations to improve the situation. This would be the start of a hearing conservation programme. The history of the developing of criteria to institute such a hearing conservation programme is a fascinating one,[4,7,8,11,12] but will only be discussed briefly.

Exposure Duration in Hours per Day

In industry it will be rare for a certain individual or group to be exposed to the same steady noise for 40 hours a week during a full work-life of 45 years. A number of studies have been made to find a way to calculate from the actually measured durations of exposure per day and intensities of exposure, the equivalent sound level A or 'L_{eq}', which carries the same risk of impairment of hearing as the actual exposure. This L_{eq} is expressed as a single number in dB. The simplification used in the calculation is based on the theory that is regarded as approximately correct, viz. 'The risk of injury depends on the total sound energy of the noise exposure regardless of how the energy is distributed in time'.[4] Thus for every halving of the exposure duration double the energy (i.e. an increase of 3 dBA) is permissible without increasing the risk (ISO Draft recommendation TC43/SCI (1969)). This is still under discussion but is regarded as to be on the conservative side as it does not take into account the partial recovery which takes place during intervals of lower noise levels. In the USA (Walsh Healy Act) 5 dB is proposed as an acceptable increase instead of 3 dB for each halving of exposure time.[4]

The calculation of equivalent sound level (L_{eq}) makes use of the 'trading relation' that has been established between intensity (dBA) and exposure time. Laboratory studies of temporary threshold shift (TTS) have contributed greatly to determining this trading relation. The SABS publication 083(1970)[5] states that, whenever the equivalent noise level (measured and evaluated in accordance with procedures mentioned explicitly) exceeds 85 dBA, hearing conservation methods are required (noise rating for hearing conservation). It defines equivalent noise level (L_{eq}) as that level of a steady noise that is reputed to cause an average stated amount of hearing impairment in a stated percentage of a group of individuals who are exposed to it over a period of 40 hours a week. The term 'average stated amount of hearing impairment' appears to refer to 'hearing impairment' defined in the same publication as mentioned earlier. A table showing the risk due to noise exposure in percentage of individuals (incidence) is presented for exposure level as (L_{eq}) plotted against years of exposure. This table closely resembles my Table I, derived from the AAOO Guide[4] and the Callier Hearing and Speech Center, Dallas, Texas (A. Glorig, 1971). Although not explicitly stated, it could be inferred from this SABS publication[5] that the risk shown for the column L_{eq} = 85 dBA (with a maximum of 10% of the exposed group developing (significant) hearing impairment due to noise after 40 years' exposure) is regarded as acceptable.

A method of calculating the L_{eq} is given: a number of SLM readings in dBA, regarded as representative for the exposure level, and corrected for impulse noise, are taken. The equivalent noise level is then calculated by a formula converting these readings to an exposure duration of 40 hours per week and serves as the decisive criterion for hearing conservation (noise rating for hearing conservation) if it exceeds 85 dBA.

The SABS publication[5] does not enumerate allowable increases of sound levels when the actual exposure time per day is reduced. It does prescribe, however, that reduction of exposure time is indicated when audiometric tests show a deterioration of hearing that maximum protection of hearing has failed to stop (prevent).

The AAOO Guide[4] describes a two-step method, using pre-calculated tables, to assess the equivalent continuous sound level L_{eq} from the measured durations and intensities (in dBA). This L_{eq}, carrying the same risk of hearing impairment as the actual exposure, is in principle similar to that defined in the SABS code when the criterion of 86 dBA is applied. The booklet also provides guidelines in regard of the relationship between allowable exposure levels and durations for a number of criteria. For instance Table III, page 20, gives the following figures for equal risk noise exposures for a criterion of 86 dBA noise level, i.e. hearing conservation noise rating of 86 dBA for 8 hours a day:

Corresponding durations in hours per day	8	6	4	3	2	1½	1	½	¼
Exposure levels in dBA	86	88	91	92	94	97	99	104	109

From these figures the conclusion may be drawn that it is permissible to allow workers to be exposed to, for example, 92dBA for a duration of 3 hours in a working day provided that for the remaining 5 hours they are not exposed to any sound level above the chosen criterion 86 dBA per day. To reduce the exposure time to 3 hours per day would be one of the many possible, if not always practical, steps which can be taken in a hearing conservation programme.

If during a number of periods per day the sound level dBA exceeds the criterion level (here 86 dBA) the combined effect is judged as follows: the number of hours per day of actual exposure (A1, A2, . . . An) to each sound level is compared with the total permissible time in hours for each sound level (T1, T2, . . . Tn) as if it were the only exposure above the criterion level. The series of fractions (A1 ÷ T, A2 ÷ T2, . . . An Tn) is then summed. If this sum exceeds unity, the risk from the combined exposure is greater than that of 8 hours to the criterion level and so is not permissible.[4]

Exposure Duration in Years

Burns and Robinson[9] report in a monograph their findings and considerations after investigations extended over 5 years. Among other objectives they sought to establish a quantitative relationship between industrial steady noise exposure and resultant impairment of hearing and an estimation of the degree of risk inherent in prolonged exposure to a certain noise environment. They developed the concept of Noise Immission Level (NIL) expressed in dB as a frequency-weighted measure of the total sound energy impinging on the ear throughout a duration of full-time exposure in units of months' exposure (noise level in dBA plus 10 times the logarithm of a duration).

Although they have not acquired valid data to judge the effect of part-time exposure, they confirm the equal energy effect concept in this sense that low level/long time exposure results in the same hearing impairment as high level/short time exposure (full-time). They present interesting findings regarding the possibility of predicting the amount of hearing loss and the risk (incidence) of developing hearing impairment after many years of exposure. These are mainly based on retrospective studies:

Example 1. Algebraically and by using nomograms it can be predicted for a selected percentile (e.g. 10%) that, after full-time exposure for 25 years to a noise level of 96 dBA, a hearing loss of 36 dB in the 2 000 Hz frequency range will result. This is corrected for presbycusis.

Example 2. It is also possible by using the same nomograms to work out the percentage of population (incidence) expected to develop a significant hearing impairment (more than 25 dB for the frequencies 500, 1 000, 2 000 Hz combined). Fig. 5 gives an example of the 'risk' curves for 90 dBA and 95 dBA as a function of exposure time in years.[9] From this the conclusion may be drawn that after full-time exposure to 90 dBA during about 19 years, 2% of the workers are expected to develop significant hearing impairment, whereas after 25 years about 10% would be so affected, 90% not reaching this critical level before 25 years of exposure. Normal presbycusis but no other additional cause for hearing loss is incorporated in this graph.

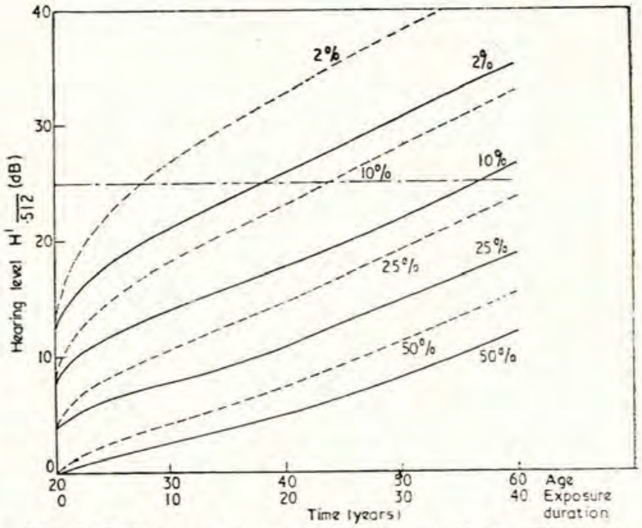

Fig. 5. Risk curve for noise and age combined. The ordinate is the average hearing level at 0·5, 1 and 2 kHz. The AAOO 'beginning mild impairment' fence at 25 dB (ISO) is shown. Each pair of curves signifies the level of the occupational noise: 90 dB(A), continuous line; 95 dB(A), interrupted line.

In general it could be confirmed, that the longer the exposure lasts, the greater the hearing loss will be. There is, however, no linear relation. Depending somewhat on the sound level there is a rapid increase during the first years, gradually (according to other authors more abruptly after 10 to 12 years) levelling off to become more or less parallel to the normal presbycusis curve (Fig. 6).

In the same way the percentage risk of developing a significant hearing impairment increases with the number of years of full-time exposure. This again depends on the sound level. The higher this is, the higher the risk and the higher the increase in risk with time. For a sound level of 90 dBA the increase is fairly gradual although more rapid during the first 10 years. For higher sound levels the increase of risk (incidence) is greater, again levelling off after about 15 years (Table I).

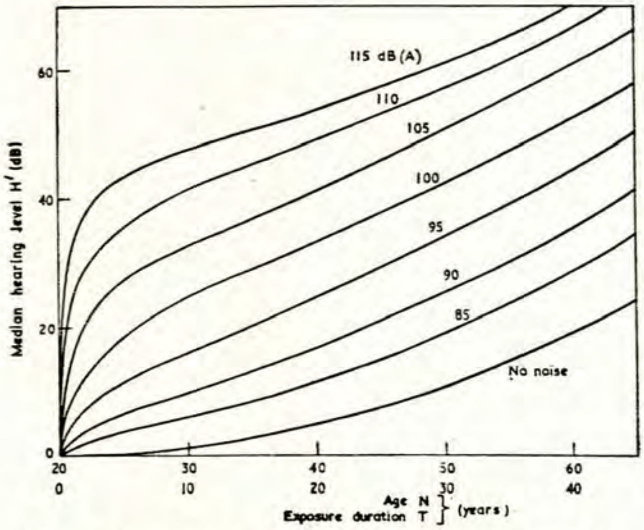

Fig. 6. Comparison of noise-induced hearing loss with effect of aging.

DAMAGE RISK CRITERIA FOR HEARING CONSERVATION

In the articles referred to[7,11] Glorig discusses clearly and at length the basic considerations for establishing damage risk criteria. The rationale of defining a damage risk criterion is the desirability of setting a limit for noise to be acceptable, incorporating all the factors which are known to be of importance for the development of noise-induced hearing loss. Fortunately there is general agreement on the objective of setting such a limit, i.e. to prevent or minimize the danger that significant hearing impairment will result in the exposed population from exposure to occupational noise in industry. In other words the objective is to *preserve the hearing ability for speech* as this is the most important part of the function of hearing in man. Thus, a damage risk criterion serves as a hearing conservation criterion. It would be impractical to set a standard which would protect each and every individual, as this would be so low as to bring some industries to a complete standstill.

Laevens[12] reviews the many criteria proposed by a number of authors and concludes that an over-all sound level of 85 dBA appears to be an acceptable limit. The use of the ISO N 85 noise rating curve is based on the expectation that, with full-time exposure to a sound level of 87 dB at 500 Hz, 85 dB at 1 000 Hz and 82 dB at 2 000 Hz, no significant hearing loss for conversational speech will result in most people.

For South Africa a hearing conservation criterion is the one mentioned in the SABS publication 083-1970,[5] which sets a limit of 85 dBA for the equivalent noise level as a noise rating for hearing conservation, above which non-acceptable, hearing impairment is likely to occur. In all this, the sound-pressure level, frequency (by weighted measurement), duration of exposure, etc. are taken into account.

Implicit in setting a hearing conservation criterion is the acceptance of a certain risk that some more susceptible individuals may nevertheless suffer hearing loss in time. Special provisions will have to be made for these. All available data are of a statistical nature and cannot be applied to individuals as such.

Burns and Robinson[9] suggest that the limit should not be set higher than 90 dB for full-time exposure which is likely to persist for many years, judging that the ultimate risk is then acceptable. They state that no unprotected ear should ever be exposed to a sound pressure level of 135 dB or more.

The AA00 Guide[4] mentions that 90 dB as equivalent sound level A has been the most frequent choice, but usually with the recognition that personal protection and also careful monitoring of hearing for tell-tale losses of sensitivity beginning at 4 000 Hz should be employed. Audiometry is of great value in this respect. No reliable predictive test is available as yet to establish high susceptibility for developing hearing impairment in an individual. The earlier mentioned so-called 'dip' at a frequency of 4 000 Hz in the audiogram is one warning sign. Another is the finding of a temporary threshold shift (measured 2 minutes after the day's exposure) of more than 12 dB at a frequency of 2 000 Hz under certain conditions.

Temporary and Permanent Threshold Shifts

One approach to establish whether and how much hearing loss resulted from exposure to excessive noise has been the study of personnel employed in industry for long periods. Examples, both of exposure (level and time) and of the resulting hearing loss are shown in Figs. 3 and 4 and also in Fig. 7, reproduced from the AIHA manual.[13]

Another approach, developed by Glorig and others over many years, is the study of noise-induced temporary threshold shift (TTS) and its relation to permanent threshold shift (PTS), which is the same as hearing loss. With some reservations their theoretical assumptions appeared to correlate quite well with their findings. A full discussion would cover many pages. Only a few selected statements, pertinent to the subject under review, will therefore be made.[7,9,11,13]

1. A TTS always precedes the development of PTS.

2. Individual variations exist, but in one individual the TTS after the same exposure will approximately be the same after each day and is remarkably constant.

3. The distribution of susceptibility of individuals can be expressed in a Gauss curve.

4. The easily fatigued ear (more likely to show a TTS) will be the one most easily damaged permanently.

5. The major portion of TTS develops during the first 2 hours of exposure, the main recovery during the same period after it.

6. TTS (and also PTS) appears first in the higher frequency range of about 4 000 Hz, gradually spreading out from that range.

7. PTS increases gradually with each exposure as a growing residual shift.

8. PTS is never greater in amount (in dB) than the TTS, measured 2 minutes after exposure, in one individual.

9. The progression of PTS is most marked during the first few years up to 12 years of exposure, after which it gradually levels off to more or less parallel with the normal presbycusis curve.

10. In a person who has already developed a certain hearing loss, the superimposed TTS after equivalent exposure will be less than in a similar individual with a normal resting threshold.

11. A specific noise exposure (level and time combination) will, depending somewhat on the resting threshold level, result in a specific TTS and PTS. The TTS accrueing from an exposure of 8 hours daily and measured 2 minutes after this (in young persons with unimpaired hearing) is approximately equal in dB to the PTS (hearing loss) after about 10 years' habitual exposure to the same noise. Some modification for different frequencies is applicable here.

12. TTS and PTS studies with exposure at the levels of the ISO N 85 curve did not show resultant significant hearing impairment.

One of the conclusions drawn from the studies of TTS (mainly using the 4 000 Hz frequency range) was that it is possible to predict hearing loss for a group of individuals after say 10 years' exposure to certain noise levels, based on the relation between TTS and PTS. The results appear to be confirmed by other retrospective studies.

Another is the assumption[7] that there will be no significant hearing loss after 10 years, if the TTS at the end of an exposure period per day less than 5 hours does not exceed 12 dB at 2 000 Hz. This forms the basis of the second warning sign in audiometry.

Thirdly the study of TTS has shown some promise of offering a solution to the problem of finding the highly susceptible individual before it is too late. Burns and Robinson[9] confirm from findings in their own work that higher susceptibility to develop TTS tends to be associated with higher susceptibility to suffer noise-induced permanent hearing loss. They regard the measurement of TTS, 6 minutes after exposure (more practical than the 2 minutes stipulated by others) as useful for identifying a number of individuals as belonging to the more highly susceptible group. They make the reservation that it does not necessarily follow that all the highly susceptible subjects are screened out. The inherent variability of audiometry at present is regarded as the stumbling block to obtaining further precision. The best stimulus for this kind of in-

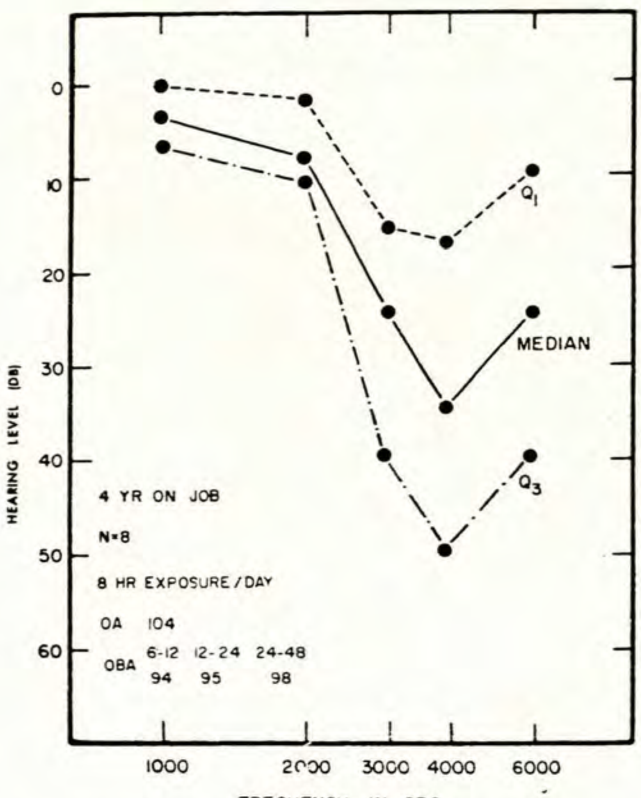

Fig. 7(a). Noise-induced permanent threshold shift after 4 years on the job.

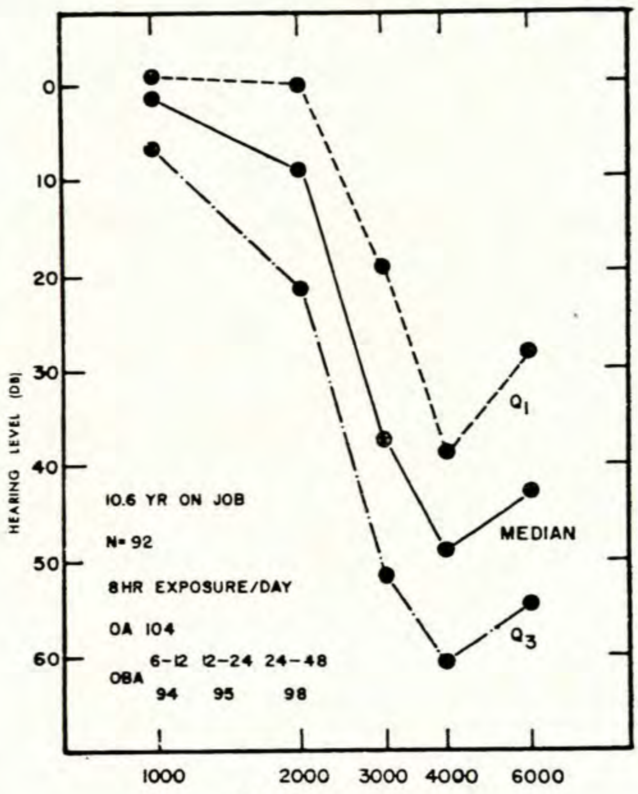

Fig. 7(b). Noise-induced permanent threshold shift after 10 years on the job.

vestigation appears to be the day's exposure rather than some other artificial laboratory stimulus.

The Role of Audiometry

It appears warranted to state that audiometry, aimed at establishing a pre-employment resting threshold level, measuring TTS under prescribed conditions and serial follow-up with fixed intervals, is important in industrial hearing programmes. The audiogram can supply warning signs, data for further research (e.g. departmental composite audiograms) and it can assist in establishing or refuting disability in compensation claims. Burns and Robinson[9] advocate at least 3 audiograms for each examination, taking the mean average for each frequency as the minimum on which reliance can be placed for pre-employment and follow-up audiograms. The role of specialized methods such as screening audiograms (with a few selected frequencies only) and speech audiograms[14] is under extensive study.

HEARING CONSERVATION PROGRAMMES

The medical objective of hearing conservation in industry may reasonably be confined to preservation of the ability to hear conversational speech. Some warning signs of a subjective nature that the noise to which a worker is exposed is excessive are: 'head noises' or 'ringing' in the ears after exposure or persistent 'muffled' hearing for a few hours after work. Interference of communication by speech is another. When shouting is required at a distance of 15 cm, the over-all noise level will probably exceed 90 dB. A rough test for screening a suspect site is given[5] as follows:

Present to a listener at 33 cm distance, excluding the possibility of lip-reading, a series of unconnected words at raised voice level. If more than 50% mistakes are made, further analysis is indicated. Obviously in this situation there is appreciable interference with speech-communication.

Whenever and wherever it is established that occupational noise exceeds the set criterion, a hearing conservation programme should be instituted. The first step, as mentioned before, is sound-level measurement and further analysis if indicated.

The engineering objective in hearing conservation may be described as the aim to attenuate the noise effect by reducing the noise (taking note of frequency) to a level acceptable within the criterion. Evaluation of the magnitude of the prevalent noise, measured against the selected limit, gives the amount of reduction which is necessary. For example, if there is a sound level of 110 dBA an attenuation of 25 dB would be sufficient.

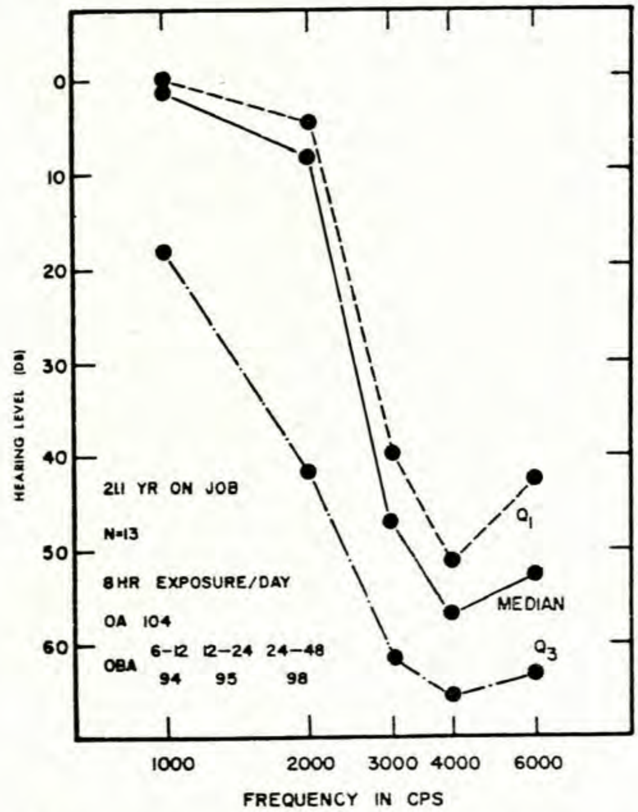

Fig. 7(c). Noise-induced permanent threshold shift after 21 years on the job.

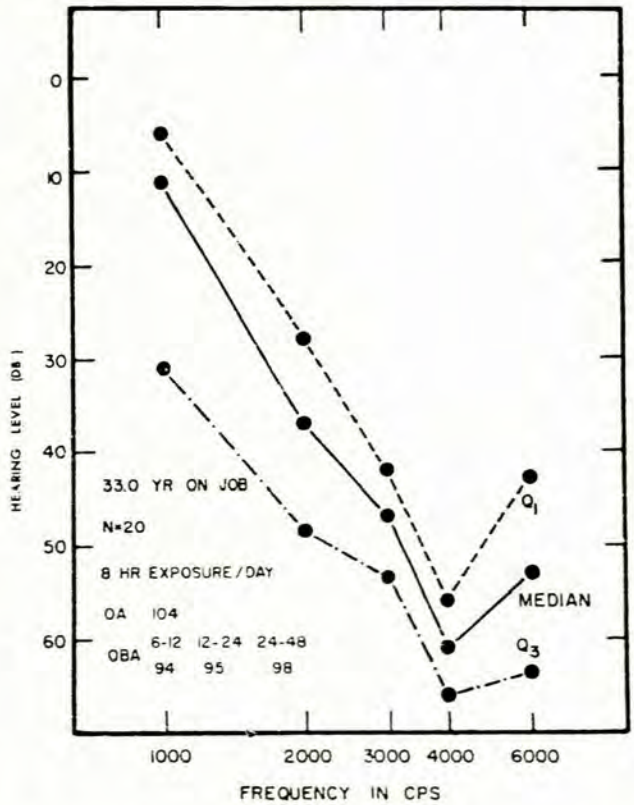

Fig. 7(d). Noise-induced permanent threshold shift after 33 years on the job.

In general, measures to control noise (the second step) may be aimed at the source, the path of conduction and the receiver:[15-17]

1. Reducing the sound at its source by modification or special design of engines and gears, mounting machinery on insulating bases, using mufflers on exhausts, etc. is the most effective approach. Attention should be given to the most intensive source as explained earlier. Economical and engineering considerations may thwart this.
2. Examples of aiming at the path are enclosing the source (or the operator) in sound-insulating compartments and erecting sound barriers.
3. Aimed at the receiver are personal protection methods such as wearing ear-muffs, reducing exposure times[16] or increasing the distance between source and operator. Theoretically in a free space without reverberation doubling the distance from a point sound source reduces the sound pressure by 6 dB. In practice doubling the distance will only result in a reduction much less than 6 dB.

The first 2 are engineering problems. Only when these fail to bring the noise to an acceptable level, should personal protection be resorted to. If ear-muffs are to be worn, danger zones should be clearly demarcated, just as is usual for other hazards.[17] Constant supervision after suitable instruction and education of the workers to induce motivation is essential. This then would be the third step with audiometry as an important aid. In theory again, by completely blocking the airborne path with ear protectors a maximum attenuation of about 50 dB could be obtained, as bone-conduction may come into play then. Leakage through badly fitting muffs or plugs will diminish the effect. However, the average attenuation of well-designed ear-muffs with a tight seal, measured by the loudness balance method[18] is only about 25 dB for the frequencies 1 000 - 4 000 Hz. Contrary to what is generally assumed, ear muffs do not unduly interfere with communication by sound signals or even speech. Plugs have the disadvantage that supervision is far more difficult.

When the decision to institute a hearing conservation programme has been made, adequate analysis, planning and execution of the necessary steps by engineers precede any action industrial doctors will have to take. Of course their interest and advice may be of tremendous value even before they themselves become actively involved in the programme. This is when personal protection methods, audiometry and supervision prove necessary.

HEARING IMPAIRMENT AND COMPENSATION

The concern of medical men will be conservation rather than compensation. Nevertheless, it is of interest to note the views and discussions held in other countries on the subject of compensation.[3,4,8,19] The WHO Chronicle[3] remarks: 'The potential cost of noise-induced hearing loss probably exceeds that of any other occupational disease when assessed in terms of compensation (and increased accident rates).'

Impairment is a medical condition which affects one's personal efficiency in the activities of daily life, assessed by scientific evaluation of function.[19]

Disability is a concept relating to decreased ability to perform one's daily work (often explicitly related to earning capacity). It is a medico-legal concept in compensation considerations.[19]

The AMA Committee on medical rating of physical disablement mentions 35% as the percentage of total disability for 100% binaural hearing impairment.[19]

Monaural impairment is determined by establishing the arithmetic average of hearing thresholds in the audiometric frequencies 500, 1 000 and 2 000 Hz. If 26 dB is regarded as the limit of significant impairment (0%) and 93 dB as 100% impairment, and 1·5% is allowed for each dB loss over 26 dB[4] hearing impairment can be expressed as a percentage.

In calculating binaural impairment the percentage for the better ear is given a weighting factor 5. The average of 5 times the value for the better ear plus 1 time the value for the worse ear is thus converted to percentage of 'total binaural impairment'. For example: (5 times 6 + 1 time 10) ÷ 2 = 20% impairment.

If total loss of hearing in both ears is scheduled as 50% disability (S.A. Workmen's Compensation Act, First Schedule: Injuries) the percentage of hearing loss in this example may be taken to represent 20% of 50% = 10% compensable disability of the whole man. A tool to assess in an objective way the disability, or rather the hearing loss itself, is the summed evoked potential method described by T. G. Heron.[20]

In Austria, Germany, Italy, Japan and Sweden, and to some extent in Switzerland, occupational hearing loss is recognized as a compensable injury.[3] The same applies to a number of States in the USA, some of which regard only total loss in both ears as compensable. In Canada compensation is based on a percentage of the body as a whole (i.e. disablement) of 30% for total loss in both ears.[4] In Italy 60% reduced working capacity is deemed to exist when there is 'complete deafness' in both ears. Unofficial tables are in use there to calculate the percentage for partial deafness.

In the USA compensation may be payable for occupational hearing loss even though there has been no loss of wages, a viewpoint different from that held in Germany and Italy. In both these countries compensation (pension) may be paid to workers who have lost at least 20% of earning capacity due to occupational hearing loss. In the USA again, there is a variety of regulations and provisions. Some States award compensation by statute, others by a decision of the Court.

A number of States there and also some countries in Europe allow a correction for presbycusis, generally a deduction of 0·5 dB for each year above the age of 40 years. The question of liability of the employers, if a worker has had several during his working life, is a difficult problem left undiscussed here. Where compensation is paid by a general fund irrespective of who the employers were, it may be solved by regulation.

As yet there is no generally accepted table for compensation purposes[8] based, for example on the percentage of hearing impairment and resultant disability, which might be calculated by the abovementioned method and related to the wage a worker was earning at the time of examination for considering his claim. Although this may be regarded as desirable, it is not a medical problem and may be left to the appropriate authority in each country.

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