Criteria for Managing Audiometric Data in Occupational Hearing Conservation

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ABSTRACT

Hearing conservation programmes usually include hearing testing, although it is not always clear whether the aim of such testing is to identify individuals with a hearing disability, or those who show evidence of having been affected by noise. The requirements for hearing testing in both cases relate to three main considerations: the choice of frequencies at which hearing is assessed; the way in which this threshold data is quantified or otherwise managed; and whether this index is compared to some static limit, or to the individual's own baseline audiogram to assess hearing change. Central to the assessment of hearing for the purpose of identifying individuals at risk for noise-induced hearing loss is a measure that is both sensitive and specific to the effects of noise. A case is made for a choice of frequencies around 4000 Hz, the substitution of hearing loss configuration for the three-frequency average, and an emphasis on hearing change rather than status as a means of interpreting audiometric data for hearing conservation purposes.

OPSOMMING

Gehoor-konserverings-programme sluit gewoonlik gehoortoetsing in, alhoewel dit nie altyd duidelik is of die doel van sulke toetse is om die individue met gehoorafwykings of diegene wat deur lawaai geaffekteer is, te identifiseer nie. In beide gevalle is die vereistes vir gehoorevaluasie verwant aan drie hoofoorwegings: die keuse van frekwensies waarby gehoor getoets word; die wyse waarop die drempelgegewens kwantitatief of andersins verwerk word; en of hierdie indeks vergelyk word met een of ander statiese limiet, of met die individu se eie basislyn-oudiogram om gehoorverandering te ondersoek. Sentraal tot die evaluasie van gehoor, met die oog op identifikasie van risikogevalle vir gehoorverlies wat deur lawaai veroorsaak word, is 'n meting wat beide sensitief en spesifiek is tot die gevolge van lawaai. Daar bestaan oortuigende redes vir die keuse van frekwensies van om en by 4000 Hz, die vervanging van die gemiddelde van drie frekwensies met gehoorkonfigurasie, en die klem op gehoorverandering eerder as gehoorstatus as wyse van interpretasie van oudiometriese data vir die doel van gehoorkonservering.

Most approaches to hearing conservation include the testing of hearing at some point. The aim of this is to monitor employees to identify those who show a deterioration of hearing in spite of the wearing of hearing protection and attempts to reduce noise levels. However, the aspect of hearing deterioration that receives attention appears to suffer from a confusion of purpose that leads to a frustration of the probable intent of the hearing testing in the first place. That is, the prevention of noise-induced hearing loss.

"Deterioration of hearing" may mean two things. One meaning may refer to the development of a hearing status that compromises an individual's ability to make use of his hearing for communicative and other purposes. The other meaning may be any change to hearing that may reasonably be attributed to noise exposure, regardless of what the subsequent effect of such change may be.

CONSERVATION OF AUDITORY COMMUNICATION ABILITY

If the aim of preventing hearing deterioration is to conserve the individual's ability to use audition for communication, then measurement needs to concentrate on those hearing frequencies considered to be most important for the processing of speech information. Speech sounds cover a range of frequencies from at least 100 Hz to 8000 Hz (Fletcher, 1953), while the maximum level of the perceived spectra of summed speech ranges between 500 and 4000 Hz (Pascoe, 1978). Due to the redundancy of information inherent in speech, normal hearing listeners are able to maintain the intelligibility of speech that has been low-pass filtered as low as 1600 Hz (Hirsch, Reynolds & Joseph, 1954), thus probably giving rise to the view that speech information in the frequency range 500 Hz to 2000 Hz is necessary and sufficient for adequate communication. Interestingly the same study also found that eliminating all frequencies below about 1600 Hz also had a similarly minimal effect on speech intelligibility.

However, more recent work carried out with hearing impaired listeners (including noise-induced hearing loss) suggests that for these individuals speech information redundancy is reduced by the hearing loss and other auditory effects such as reduced frequency and temporal resolution (Dreschler & Plomp, 1985), as well as the confounding effects of competing noise (Suter, 1985). These subjects show increased intelligibility in noise with an increased signal bandwidth (Skinner & Miller, 1983), particularly with the inclusion of frequencies above 2000 Hz (Sullivan, Allsman, Nielsen, & Mobley, 1992). Verschuure and van Benthem (1992) found that subjects with steeply sloping audiograms performed better in noise when using hearing aids with high-frequency emphasis. A consistent finding across a number of studies is that the hearing loss at 2000 and 4000 Hz is the best simple predictor of speech reception and speech intelligibility in noise (Abel, Krever, & Alberti, 1990; Smoorenburg, 1990; Verschuure & van Benthem, 1992).

In evaluating hearing thresholds it is also necessary to establish a level beyond which hearing can no longer be considered to be satisfactory (i.e., when an individual is considered to experience some "disability"), and a way to relate the thresholds at different frequencies to that level. The most convenient measure to employ in quantifying hearing loss at several frequencies is some form of simple, or occasionally weighted, average of three or more frequencies. Typically these include some of the octave frequencies from 500 Hz to 4000 Hz, and sometimes 3000 Hz and 6000 Hz (e.g., British Standards Institution, 1976; Ward, 1983). This average is then related to a level beyond which the hearing is considered abnormal and an individual is expected to begin experiencing difficulty with his hearing. This level (the "low fence") is usually 25 dB or 30 dB (e.g., British Standards Institution, 1976; United States Department of Labor, 1983).

Examination of the SABS 083-1983 Code of Practice (1983) which specifies recommended procedures for hearing conservation in South Africa suggests that the approach to hearing measurement in this standard has much in common with the aim of conserving hearing for communication purposes outlined above. It employs the average of the three frequencies 500, 1000, and 2000 Hz as a measure of threshold, and defines an impairment as occurring when this average exceeds 25 dB. Further, the manner of specifying risk is in terms of the probability of the above impairment occurring as a consequence of exposure to a given level of noise, taking into account the age of the individual. Rather than permit an assessment of the risk posed to an individual, the procedure for assessing risk seems intended to assess whether an individual with an impairment (as defined) can reasonably be assumed to have acquired that impairment as a consequence of his noise exposure. In other words, can the "blame" for the loss be attributed to the noise rather than something else (typically age)?

In evaluating this approach an additional point is worth mentioning. This is the similarity between hearing conservation as outlined above and the current approach to compensation for noise-induced hearing loss in South Africa, with respect to the use made of hearing measurement. The formula for the calculation of disability specifies impairment in terms of a threshold (the average of 500, 1000, and 2000 Hz) worse than 25 dB. (Office of the Workmen's Compensation Commissioner, 1988 and 1992). In examining the approach to compensation it is clear that its aim is to ensure that the impairment is sufficiently disabling to warrant compensation. The point to be made is that the specification of impairment is intended to reflect disability, and is primarily concerned with hearing status (rather than change), which is similar to the approach outlined above in respect of SABS 083. It is interesting to contemplate the extent to which considerations of compensation might have influenced the approach to hearing conservation. Ward (1983) and Noble (1988) have commented on the arbitrary nature of the assumptions underlying formulae for compensation, and it would be unfortunate were these to have influenced procedures for conservation.

IDENTIFICATION OF THE EFFECTS OF NOISE ON HEARING

The alternative approach to monitoring hearing deterioration is to do so for the purpose of identifying individuals who are being affected by their noise exposure. This is regardless of whether or not the loss has any disabling effect on the individual's ability to use his hearing for communication and other purposes. The aim in this approach is to devise a measure that is both sensitive (generates a minimum of false negatives), and specific (generates a minimum of false positives) to the effects of noise. This raises the question of what is known about the effects of noise exposure on hearing.

Robinson (1987) provided a useful synthesis of the data from studies on noise-induced hearing loss available at that time. Robinson's treatment of the data was extensive and what follows is a summary of the most obvious trends. Plots at different frequencies of hearing threshold level against the level of noise exposure for different durations of exposure showed that within ten years of exposure to noise levels greater than 85 dB(A) most studies showed evidence of some degree of threshold elevation (to >10 dB HL) at 4000 Hz in 50% of their subjects. At 2000 Hz this was the case for 25% of subjects, while at 1000 Hz there was minimal threshold elevation even at the 25th percentile. Additionally the effect of noise level was greatest at short exposure durations for 4000 Hz (5 to 10 years), only becoming marked (but resulting in less affected threshold levels) at increasingly longer durations for 2000 Hz and 1000 Hz (at approximately 20 and 30-40 years respectively). Growth curves of hearing loss at 4000 Hz as a function of exposure duration at levels of 90 dB(A) and greater showed a rapid growth in the first ten years of exposure, levelling off thereafter. Similar curves at 2000 Hz and 1000 Hz showed a constant growth of hearing loss with exposure duration at progressively lower rates respectively. This was true of both a screened otologically normal population and an unscreened typical population. Rate of hearing loss at 4000 Hz on first entry to noise varied between 1 and 9 dB/year for exposure to noise levels of 85 to 100 dB(A), depending on actual level of exposure and individual variation. Finally, in a study of the effect of age on hearing loss by Robinson and Sutton (1979), the results showed that a noticable effect at 4000 Hz only became discernable after age 30 to 35 years.

Apart from confirming the generally accepted fact that 4000 Hz is the hearing frequency most susceptible to damage by noise, the results of Robinson's work suggest that the degree of hearing loss is greatest at this frequency, it shows the greatest change at increasing noise levels and it shows this change over the shortest duration - i.e., most of the deterioration in hearing at 4000 Hz occurs within the first ten years of exposure, and this deterioration can initially occur at a rate of up to 9 dB/year. Taken in conjunction with Robinson and Sutton's findings that the effect of age on hearing at 4000 Hz is minimal before the age of 35 years, it is reasonable to suggest that change to hearing at this frequency can be attributed to noise alone in the first ten years of exposure to noise of persons under 35. Monitoring of change to hearing at this frequency should therefore provide a sensitive indicator of susceptibility to noise.

The next consideration is the way in which this measure should be utilised. Given that noise can also affect other frequencies in the region of 4000 Hz, for example 6000Hz and 3000Hz, an average of thresholds at several frequencies can be obtained. This is the case for example in the Occupational Safety and Health Administration (OSHA) hearing conservation amendment (United States Department of Labor, 1983) where the average threshold at 2000, 3000, and 4000 Hz is used to assess susceptibility. (The frequencies used in the OSHA amendment are interesting, given the discussion on compensation versus conservation above. It is not clear whether the choice of frequencies is intended to reflect the effects of noise, or their effect on disability. A discussion of the amendment by Suter (1984) suggested that considerations other than hearing conservation played a role in the choice finally decided upon). Alternatively, a shift in threshold at any one of several frequencies can be used. The Australian Standard AS 1269-1989 (Standards Association of Australia, 1989) for example prescribes testing at 3000, 4000, and 6000Hz as a minimum, and a threshold shift at any one of these frequencies as requiring further action.

If it is a noise effect that is to be detected (rather than the presence of some form of disability) then it is important that a change to hearing at these frequencies be reacted to rather than the hearing reaching a certain pre-defined status. This is regardless of whether the change has resulted in thresholds which are still considered normal, or whether the thresholds before exposure lay outside the normal range to begin with. The amount of deterioration of hearing considered significant is 10 dB or greater in the OSHA amendment (United States Department of Labor, 1983) and 15 dB or greater in the Australian Standard (Standards Association of Australia, 1989). At present the SABS 083 Standard has no definition for "deterioration of hearing", even were either a three-frequency average or threshold shift at one of the specified test frequencies to be utilised for this purpose.

AUDIOMETRIC CONFIGURATION

It is important to note that the studies incorporated in Robinson's (1987) work examine the effects of noise on hearing thresholds in terms of measures of central tendency for certain populations. While this provides some information on how a noise-induced hearing loss might develop in an individual case, this data essentially obscures any individual variability that might occur. Similarly, utilisation of threshold shift at isolated frequencies or in terms of an average at several frequencies may reduce the specificity of the measure by permitting hearing loss of other etiology to be misclassified as being noise-induced.

Examination of the audiometric data of individuals who have been exposed to noise suggests that the hearing thresholds of these individuals are poorer at 4000 Hz and the frequencies in the vicinity of 4000 Hz than at other frequencies. This conclusion is also indirectly supported by the data in Robinson's (1987) work. Importantly though the thresholds at 8000 Hz, and 2000 Hz and below, are noticably better than those at 4000 and 6000 Hz. An important feature of utilising thresholds at the frequencies around 4000 Hz as a measure of noise effect may be their level in relation to the thresholds at 2000 and 8000Hz. That is, the depth of the "notch" in the audiogram at 4000 Hz. Thus it may be useful to consider audiometric configuration rather than averaged or isolated frequencies when developing a more specific measure of the effect of noise on hearing.

As part of an earlier study (Delaney, 1993) the author compared the audiometric data of just over 600 noise-exposed subjects from 6 different factories described in terms of three-frequency averages and in terms of audiometric configuration. Three averages were obtained: 500, 1000 and 2000 Hz; 1000, 2000, and the worst of 4000 or 6000 Hz; and 2000, worst of 4000 or 6000, and 8000 Hz. These averages were then grouped as falling below 26 dB, between 26 dB and 55 dB (inclusive), and above 55 dB. The audiometric configuration of each ear was categorised in terms of the depth of the "notch" as showing no noise-induced hearing loss (NIHL); a possible NIHL (a depth of at least 5 dB on one side and 10 dB on the other); and a probable NIHL (a difference of at least 20 dB between 2000 and 4/6000 Hz and 15 dB between 4/6000 and 8000 Hz, or 15 dB between 2000 and 4/6000 Hz and 25 dB between 4/6000 and 8000 Hz). One of the aims was to assess the extent to which the numbers of individuals identified as having been affected by noise might differ when measured using the two different approaches. A summary of the results of this analysis for all six of the factories combined is presented in Fig 1. From these results it can be seen that the number of ears showing an average hearing loss greater than 25 dB (using any of the

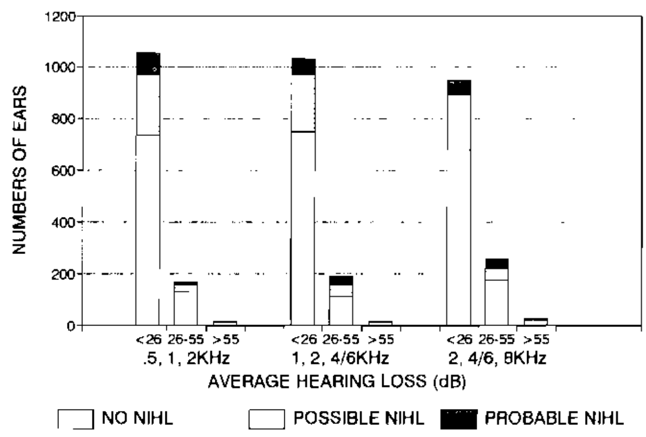

Figure 1. Noise-induced hearing loss (NIHL) component and severity of three-frequency-average hearing loss (<26 dB, 26-55 dB, and > 55 dB), for three different three-frequency-averages.

three averages) is less than the number identified as having a possible or probable noise-induced component to their hearing configuration. Additionally, not all individuals with a three-frequency-average hearing loss show a noise-induced component to their hearing configuration, while a large number of subjects with normal three-frequency-average hearing do. The former finding may suggest that audiometric configuration may be a more specific measure of the effect of noise, while the latter may indicate that it is more sensitive.

Clearly these conclusions rest on the validity of the hearing configuration criteria used to identify a noise effect. The criteria were arrived at by examining the types of hearing configurations identified by experienced audiologists as showing possible or probable noise-induced hearing loss. However, these criteria may as easily be submitted to debate as any other criteria already employed in hearing conservation. Additionally a re-examination in terms of individual audiometric configuration of the raw data from some of the studies already conducted might also provide some guidelines.

CONCLUSION

This discussion attempted to show that an alternative approach to the management of hearing measurement data might provide a more sensitive and specific measure of the effect of noise on hearing, thus permitting the detection of individuals being affected by noise such that conservation measures can be implemented as rapidly as possible. It was also suggested that some of the confusion that exists concerning whether considerations of disability should enter into the identification of individuals susceptible to noise, and whether considerations of compensation should be allowed to influence conservation criteria, should be avoided. Choice of frequencies for assessing the effects of noise, criteria for assessing the significance of hearing change, and whether or not hearing configuration is a better means for managing audiometric data is a matter for debate. However, a careful re-examination of the philosophy and purpose behind hearing measurement in the conservation of hearing may permit the development of a practice that better serves the aim of preventing noise-induced hearing loss.

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