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Hearing loss due to steady-state noise

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Introduction

This paper is concerned with the formulation of a criterion for the limit of safe noise and a part of the work necessary to establish this limit for the simple case of steady-state noise with continuous exposure during five 8 h working days per week. The investigation is part of the work for a working group of the Research Committee on Occupational Health, T.N.O., Netherlands.

Criterion for safe noise

The working group considers noise safe if it does not result in a threshold shift which affects the speech intelligibility of workers during their leisure time. This time includes both the free time after their work and their retirement period. The limit of safe noise, based on this criterion, is more relevant to the daily situation of workers than is a limit based on noise induced permanent threshold shift (n.i.p.t.s.), which persists over a period of months following noise exposure without indication of progressive recovery.

To establish this limit it is necessary to find a relation between the noise and the hearing levels of workers after their daily exposure to this noise. We started, therefore, an examination of the literature to determine this relation. As, however, most of the published data are not directly suitable for this purpose, we had to split up our investigation into two complementary questions:

(1) What is the relation between noise and the hearing levels of the workers before the daily exposure to the noise?

(2) What is the relation between the hearing levels before and after the exposure to the noise?

This paper is restricted to the first question, and so presents our findings about the relation between noise and the hearing levels before the daily exposure to noise. We will not show all the details here, but only give the results. Work is in progress to resolve the second question.

Hearing loss

Only the hearing losses at 2000 and 4000 Hz will be considered; 2000 Hz is about the upper limit of the frequency range that is important to understand speech, whereas at about 4000 Hz the hearing losses are at a maximum. Hearing loss is here to be understood as the difference between the hearing level before the daily exposure to noise and the normal threshold of hearing for young people.

Data from several authors (A.S.A. 1954; Rosenwinkel & Stewart 1957; Nixon & Glorig 1961; Burns, Hincliffe & Littler 1964) were used to investigate the increase of the hearing loss as a function of exposure time. The data deal with seven groups of workers; each group worked in a surrounding with a different noise level. The groups consisted of workers of all ages, who worked from only a few months up to 40 years in unchanged steady-state noise. This enabled us to divide the groups into subgroups according to exposure time; thus we have subgroups composed of workers who are exposed to noise from, for example, 0 to 5 years, from 5 to 10 years, etc. In the literature we found information about the median hearing losses of the subgroups. The median hearing loss is defined as the hearing loss that is not exceeded by 50 % of the measured hearing losses in the subgroup. If we diminish the median hearing loss by the median hearing loss of people not working in noise and having the same average age we find the median hearing loss caused by noise (H^{50}).

If we plot H^{50} at 4000 Hz as a function of the average exposure time of the subgroups it turns out that H^{50} increases as a function of exposure time up to about 10 years; after 10 years H^{50} remains constant with exposure time. By analysing statistically the ordinate values at exposure times of 10 years and more it turned out that the constancy of the median hearing loss caused by noise is significant at the 5 % level for six of the seven groups. For one group the median hearing loss caused by noise decreases after 15 years of exposure. The fact that the median hearing loss caused by noise remains constant after an exposure time of 10 years, is in accordance with the findings of Glorig based on three of these groups. We can say that H^{50} for an exposure time of at least 10 years is a characteristic value for the hearing loss at 4000 Hz. H^{50} for an exposure time of at least 10 years is indicated as H^{50} (10 years). We get a quite different picture if we plot H^{50} at 2000 Hz as a function of exposure time. At this frequency H^{50} is an ever-increasing function of exposure time; moreover, we can represent it by a straight line. The gradient of this line can now serve as a characteristic of the hearing loss at 2000 Hz. The gradient is indicated as Δ^{50}.

Noise

In order to relate noise with the characteristic values of the hearing losses, we must also find a suitable measure for the noise. Measures are, for example, the sound level of the noise in dB(A), and a so-called noise rating number (Kosten & van Os 1962) for the octave bands with mid-frequencies 500, 1000 and 2000 Hz. The dB(A) value takes into account all the sound-pressure levels in the frequency range from 10 to 20000 Hz, although the low and high frequencies are attenuated in a standardized way. The noise-rating (n.r.) number of a noise can be determined by comparing the octave band spectrum of the noise with a family of 'noise-rating curves', some of which are shown in figure 1. The number of a curve is equal to the level at 1000 Hz. The n.r. number of a noise is equal to the number of the n.r. curve that just touches the octave band spectrum. For conservation of hearing in industry only the sound pressure levels of a noise in the octave bands with mid-frequencies 500, 1000 and 2000 Hz are considered, since only noise in these octave bands damage the hearing in the frequency range that is important to understand speech. So for the octave band spectrum in figure 1 the n.r. number for 500 to 2000 Hz is equal to 96.

The limit of safe steady-state broad band noise, that is proposed in a draft Recommendation by the International Organization for Standardization, corresponds to n.r. 85. This limit is based on n.i.p.t.s. at 500, 1000 and 2000 Hz.

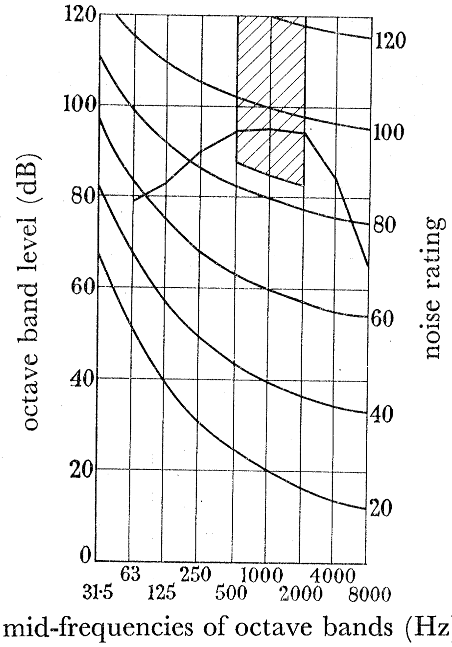

Figure 1. Noise-rating curves, according to Kosten & van Os (1962). The hatched area represents unsafe noise according to a draft I.S.O. recommendation.

Relation between noise and hearing loss

Figures 2 and 3 show H^{50} (10 years) at 4000 Hz as a function of the n.r. number for 500 to 2000 Hz and of the sound level in dB(A), respectively, whereas figures 4 and 5 show Δ^{50} at 2000 Hz as a function of the n.r. number for 500 to 2000 Hz and of the sound level in dB(A) respectively. The curves are based on the data of 15 groups (A.S.A. 1954; Rosenwinckel & Stewart 1957; Nixon & Glorig 1961; Burns *et al.* 1964; Kylin 1960; van Laar 1966); seven of these groups were already mentioned; the workers of the eight other groups have individual exposure times from 10 to 20 years. From the median hearing loss at 4000 Hz, H^{50} (10 years) was calculated and from the median hearing loss at 2000 Hz and the mean exposure time Δ^{50} was calculated.

Except for one group the octave band spectra were all more or less flat. In the exceptional spectrum the sound-pressure level of the octave band with mid-frequency 8000 Hz is very high in comparison with the other octave band sound-pressure levels.

Figure 2 shows the median hearing loss caused by noise at 4000 Hz after an exposure time for at least 10 years as a function of the n.r. number for 500 to 2000 Hz. H^{50} (10 years) is an increasing function of the n.r. number; from 5 dB at n.r. 75 up to 50 dB at n.r. 98. The spread of the measured values around the smooth drawn curve is small, not more than 3 dB, except for the group with n.r. 93, where the deviation is 5 dB.

Figure 3 shows again the characteristic value of the hearing loss at 4000 Hz, but now as a function of the dB(A) value. The spread of the points around the curve is negligibly larger than the spread of the points in figure 2. Therefore the characteristic value of the hearing loss at 4000 Hz can be estimated with the same accuracy from the dB(A) value as from the n.r. number. The numerical difference between the n.r. number and the dB(A) value is about 4; this means that a noise level of 89 dB (A) causes the same median hearing loss at 4000 Hz as noise with n.r. 85.

In figure 4 the increase per year of the median hearing loss caused by noise at 2000 Hz is presented as a function of the n.r. number for 500 to 2000 Hz. Δ^{50} at n.r. 80 or below turns out to be zero. As there will be no hearing loss caused by noise after zero years of exposure we can say that for noise with n.r. 80 or smaller n.r. values, the median hearing loss at 2000 Hz caused by noise is zero. At n.r. 98, however, the gradient is about 1·4 dB/year, which corresponds to a hearing loss of 28 dB caused by an exposure to noise for 20 years.

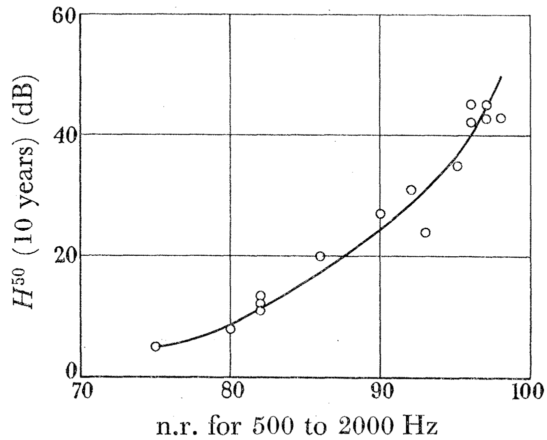

FIGURE 2. Median hearing loss at 4000 Hz caused by exposure to steady-state noise for at least 10 years as a function of the n.r. for 500 to 2000 Hz.

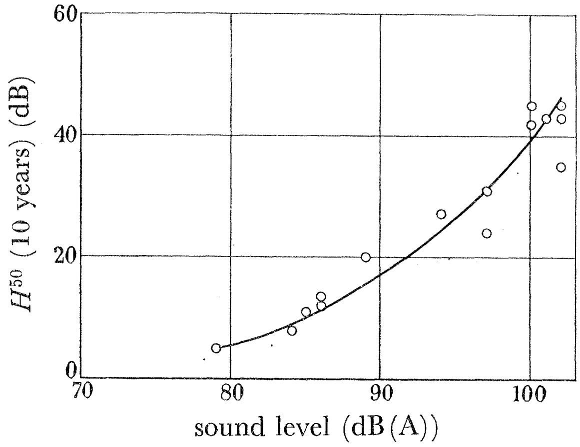

FIGURE 3. Median hearing loss at 4000 Hz caused by exposure to steady-state noise for at least 10 years, as a function of the sound level.

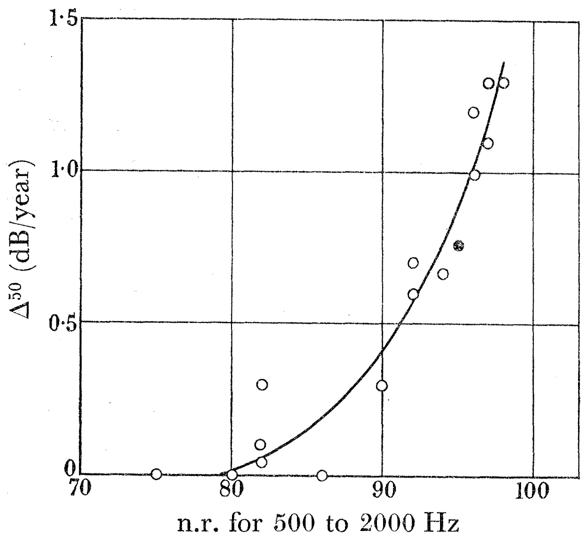

FIGURE 4. Increase in median hearing loss at 2000 Hz caused by exposure to steady-state noise, as a function of the n.r. for 500 to 2000 Hz. The point ● represents the noise spectrum with a relatively high sound-pressure level in the octave band with mid-frequency 8000 Hz.

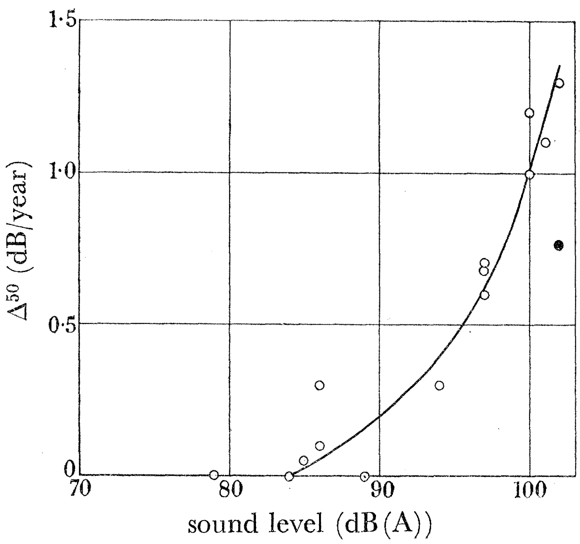

FIGURE 5. Increase in median hearing loss at 2000 Hz caused by exposure to steady-state noise, as a function of the sound level. The point ● represents the noise spectrum with a relatively high sound-pressure level in the octave band with mid-frequency 8000 Hz.

Although the n.r. number for 500 to 2000 Hz takes into account the sound pressure levels in the three octave bands with mid-frequencies 500, 1000 and 2000 Hz only, the spread of the points around the smooth-drawn curve is small. Apparently the sound-pressure levels in the other octave bands do not affect the median hearing loss at 2000 Hz. This is demonstrated for the octave band with mid-frequency 8000 Hz with the black point at n.r. 95 in figure 4. This value comes from the group with the octave band spectrum with the large sound-pressure level in the octave band with mid-frequency 8000 Hz. If this sound-pressure level had originated any hearing loss at 2000 Hz, the point should lie above the curve, because all the other points which determine the curve have sound-pressure levels that are rather low in this octave band. However, the point fits the curve quite well.

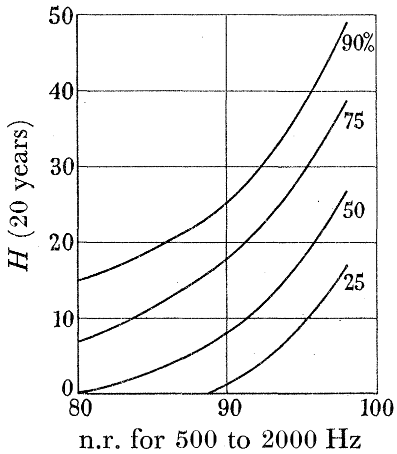

FIGURE 6. Hearing loss at 2000 Hz caused by exposure to steady-state noise for 20 years as a function of the n.r. for 500 to 2000 Hz.

From figure 4 we see that the n.r. number is an accurate measure of noise in estimating hearing losses at 2000 Hz.

Figure 5 presents the characteristic gradient at 2000 Hz as a function of the sound level in dB (A). When we exclude the black point, the spread of the points around the smooth drawn curve is rather small again. The deviation of the black point from the curve, however, is about 0·8 dB/year. This deviation is due to the large sound-pressure level in the octave band with mid-frequency 8000 Hz. This point demonstrates that sound levels in dB (A) do not give definite information about the hearing losses caused by noise at 2000 Hz. It is necessary therefore to make an octave-band analysis of the noise, so as to determine the n.r. number.

Figures 2 to 5 present the relation between noise and the resulting median hearing loss; from the curves we can determine the value of the hearing loss which will not be exceeded by 50 % of the workers operating in a given noise environment. If we want to establish the limit of safe noise, however, we require information about the upper limit of the hearing losses of a much greater percentage of workers that are exposed to noise. We therefore calculated from the available data the 75 and 90 percentile curves of the hearing losses caused by noise. Because only the hearing losses at the speech frequencies have to be considered with respect to the determination of the limit of safe noise, only values for 2000 Hz will be discussed.

If we plot for one group the 90, 75, 50 and 25 % values respectively of the hearing losses caused by noise as a function of exposure time, we get four parallel lines. The distances between the lines are dependent on the noise level and increase with increasing n.r. number for 500 to 2000 Hz. As each of the lines has the same gradient, we cannot use this value to distinguish between the different lines. We therefore take the values of the hearing losses caused by noise at an exposure time for 20 years. In figure 6 these four hearing-loss values are shown as functions of the n.r. number for 500 to 2000 Hz. The distances between the curves in the figure for a certain n.r. number are the same as the distances between the parallel hearing loss versus exposure time lines for that n.r. number. At n.r. 85 the 90 % curve has a value of 19 dB. This means that 10 % of workers have a hearing threshold that is at least 19 dB above the median hearing level that belongs to their age.

From the curves in figure 6 the hearing losses at other exposure times can be calculated. For example: At n.r. 85 the distance between the 90 % and the 50 % median curve is 16 dB, whereas the median hearing loss after an exposure for 20 years is equal to 3 dB. Thus at an exposure time of 40 years, the 90 % value is $\frac{40}{20} \times 3 + 16 = 22$ dB.

Conclusion

The hearing losses in figure 6 are measured before the daily exposure. We are ultimately interested in the hearing losses after the daily exposure to noise. The next point in the programme of the working group will be the determination of the relation between the hearing losses before and after the daily exposure to noise. If this is done and if we assume the level at which hearing loss begins to affect speech intelligibility, we can establish the limit of safe steady-state noise that is in accordance with our criterion.

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