70/23

BRITISH ACOUSTICAL SOCIETY

OCCUPATIONAL HEARING LOSS
23-25 March 1970

HEARING LOSS AND RISK PREDICTION FOR STEADY NOISE EXPOSURE

by

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The relationships between noise and the irreversible changes in hearing acuity (NIPTS) that result, in long-term situations of repeated daily exposure, have been the subject of many field studies, and one undisputed finding is a considerable variation of susceptibility between persons. This has wide implications for the objectives and conduct of investigations. Thus, interest may centre on the individual, as in the practice of serial audiometry or in the context of compensation, or it may be the more general one, considered here, of ensuring a safe working environment in advance of actual damage. In the latter case, audiometry may be confined to persons working in places of high risk.

Criteria appearing in the literature have sought to specify a maximum safe noise level but since this concept is a rather loose one it is not surprising that there have been variations in form and in substance, for implicit in a criterion is a set of value judgements superimposed on the causal relationships. A methodical formulation would recognise 5 independent aspects, each entailing certain socio-political implications, namely:

a) a species of disability, e.g. failure to understand speech
b) a degree of that disability, e.g. a mild impairment
c) a percentage of persons accepted as remaining at risk
d) a base-line population, e.g. random sample or pathology-free
e) a duration of future exposure, e.g. a working life-time.

Hitherto, global judgements on these matters have been built into the criteria, demanding the implicit faith of the user, and it is not difficult to understand how differences may have arisen. It should be emphasised that to acquire the experimental data needed to take a detached view of the separate aspects, and on some so far unmentioned such as the role of intermittency in noise, is far from easy. However, though much remains to be done before rigorous formulations are possible, there has recently been a great expansion of experimental data bearing upon c) and d), so that a more solid basis now exists for distinguishing matters of fact from those of judgement.

Scope of recent British data

The work of Burns and the writer now permits a prediction of the percentage of persons in an otherwise unimpaired population, whose hearing level due to NIPTS will exceed a stated amount, under a wide range of acoustic conditions. Since this work does not, in itself, touch upon questions a) and b), we shall assume the AAOO speech impairment basis for purposes of illustration. Specifically this means that the impairment can be discussed in terms of a purely audiometric quantity $H'_{.512}$, the average of the hearing levels at 0.5, 1 and 2 kHz.

The concept of risk can now be given concrete definition, namely that percentage of a population whose hearing level, as a result of a given influence, exceeds the specified value, minus that percentage whose hearing level would have exceeded it in the absence of that influence, other factors remaining the same. Thus we may speak of risk due to age, to pathology, to noise, to any pair of these influences, or to the combined effect of all. The underlying principle is that successive components of threshold shift are additive; for this there is some experimental evidence though it may be violated in some circumstances. It is important to note that the resulting risk values are far from proportional to the components, and care is needed in their arithmetical handling. However, the concept has undoubted utility through the directness of its meaning to the non-specialist. Moreover, by admitting risk (strictly, percentage exceedence) as an independent variable along with noise level and exposure duration, freedom is conferred on those who wish to draw up codes suited to their individual needs and embodying their own judgements.

The new experimental data apply under the following conditions:

a) noise level steady and continuous, 8 hours per day, 5 days per week, in the range up to 120 dB(A)
b) exposure duration between 1 month and 50 years
c) population free from aural pathology and from other non-noise impairments of hearing, but subject to normal ageing
d) entry into noisy occupation at any specified age
e) by a conservative extension, regular exposures of less than 40 hours per week, or previous known noise exposure, can be accommodated
f) spectrum of noise immaterial within ± 5 dB/octave slope limits.

The distribution of hearing levels is then given by the formula:

$$H'(p) = 27.5 \left\{ 1 + \tanh \frac{E_A - \lambda(f) + u(p)}{15} \right\} + u(p) + F(N) \quad \text{where}$$

$F(N) = 0$ for $N \leqslant 20$ and $F(N) = C(f).(N - 20)^2$ for $N > 20$,
N being the age in years and $C(f)$ as given below.
$u(p) = 6\sqrt{2}.\ \mathrm{erf}^{-1}\ [(p/50) - 1]$,
p being the centile of population for which $H' \geqslant H'(p)$.
$E_A = L_A + 10.\log(T/T_o)$ is the noise immission level, NIL,
L_A being the noise level in dB(A), T the duration of exposure in calendar years, and T_o the unit of time (1 year).
$\lambda(f)$ depends on audiometric frequency as given below.

Frequency (kHz)	0.5	1	2	3	4	6
$C \times 10^4$	40	43	60	80	120	140
λ (dB)	130.0	126.5	120.0	114.5	112.5	115.5

Numerical illustrations of risk values

Results will be illustrated for the 40-year span commencing with entry into noisy occupation at age 20. For a given value of $H'_{.512}$, the percentage exceedence p may be found from the formula. Proceeding similarly for the final and initial conditions, the associated risk is obtained from the difference of the two exceedences. The formula is based on a pathology-free population, this condition having been secured by means of anamnestic and otological examinations. The argument for this basis is the same as that accepted for reference standards of hearing threshold, namely that otological normality is the natural point of departure for determining impairments. Incidence studies, such as that of Baughn, have used unselected populations, and the risk values derived are not unnaturally greater than given by the formula. To illustrate the influence of extraneous impairment, an arbitrary incidence of 'pathology' can be incorporated into the formula. Specifically, to the non-noise-exposed pathology-free population with H' equal to 0 and standard deviation (SD) 6 dB at each frequency at age 20, is imparted a pathological overlay with mean value 10 and Gaussian distribution of SD 8. Convolution of the distributions thus assigns to the pathology group a mean of 10 and a SD of 10 dB. It is further assumed that the overlay grows to mean 12.5 with SD 9 by age 60. The rationale of this choice is that it closely reflects Baughn's group of 6835 workers.

The effect of age from 20 to 60 years is 7.5 dB at the mean of 0.5, 1 and 2 kHz, and the presbycutic overlay has, again somewhat arbitrarily, been assumed to grow, with Gaussian distribution, to SD 3.5 at age 60. Finally, the effect of noise has been calculated for 103, 108 and 113 NIL, from the formula. The cumulative distributions of the 8 groups defined by the following permutations were then plotted: age 20 or 60; normal or 'pathological'; noise-exposed or otherwise. From the intersections of the distributions with lines drawn at a series of hearing levels, referred to as 'fence heights', the various exceedences, and thence the risks are obtained. There are 19 combinations of the latter type, of which 9 are of interest. Table 1 lists the exceedences for fence heights from 15 to 35 (ISO), together with the median hearing levels of the 8 hypothetical groups A to H.

Table 1

Key	Influences			Median value of H'	Exceedence (%)				
	Age	Pathology	Noise	.512	15	20	25	30	35
A	-	-	-	0	1	0	0	0	0
B	-	+	-	10	30	15	6	2	0
C	+	-	-	7.5	13	4	1	0	0
D	+	+	-	20	66	50	33	19	9
			103	3	10	4	2	1	0
E	-	-	108	5.5	22	13	7	4	2
			113	9.5	33	21	13	7	4
			103	13	44	30	18	10	5
F	-	+	108	15.5	53	39	27	18	11
			113	19.5	63	50	37	26	18
			103	10.5	32	17	8	3	1
G	+	-	108	13	45	30	18	11	6
			113	17	57	40	27	17	11
			103	23	71	59	43	31	20
H	+	+	108	25.5	73	63	52	40	30
			113	29.5	81	71	60	48	37

- signifies influence absent; + influence present

Table 2 is an abridged table of risks, shown for 108 NIL only, obtained by comparing appropriate rows of Table 1. The first 4 rows of Table 2 represent simple noise risks, the next 4 are paired risks, and the last row shows total risk.

Table 2

Key	Source of risk	Base-line of reckoning	Risk (%) 15	20	25	30	35
E - A	Noise	20, non-path.	21	13	7	4	2
F - B	Noise	20, path.	23	24	21	16	11
G - C	Noise	60, non-path.	32	26	17	11	6
H - D	Noise	60, path.	7	13	19	21	21
G - A	Noise plus age	20, non-path.	44	30	18	11	6
H - B	Noise plus age	20, path.	43	48	46	38	30
F - A	Noise plus path.	20, non-path.	52	39	27	18	11
H - C	Noise plus path.	60, non-path.	60	59	51	40	30
H - A	All three	20, non-path.	72	63	52	40	30

The results may now be summarised. Risks vary with fence height in quite different ways, compare G - C and H - D; in consequence the relative importance of different influences depends on the fence height set. For example, E - A exceeds H - D at '15' but at '25' the reverse applies. Secondly, there is a big difference between the simple risk E - A and the composite risks involving noise. Also the noise risk itself increases in the presence of other influences (compare 1st row with the next three), except for very low fence heights. It should also be noted that the values depend appreciably on the assumptions; a premium is thus placed, in such calculations, on the validity of the scientific data and on close specification of the relevant conditions.

Care is needed in handling component risk values as the following correct and incorrect examples show:

Source of risk	False analysis	Correct analysis
Noise alone	7% (E - A)	7% (E - A)
Age	1% (C - A)	11% (G - E)
Noise plus age	8%	18% (G - A)

Use of the symbolic notation will avoid false results.

It is informative to note the risk values that are predicted by the above scheme on the basis of the AAOO criterion at the 25 dB (ISO) fence height ('just-beginning mild impairment'), for the commonly used noise limit of 90 dB(A). Over 40 years the NIL is then 106 and the relevant risk is G - C (13%) or H - D (15%) depending whether or not unimpaired hearing is taken as base-line, and remains so. In case the pathological overlay is acquired between the ages of 20 and 60, the higher figure of 47% applies (H - C), though 32% risk (D - C) exists in this case even without noise. It seems clear that appreciable risk exists on this basis, although it should be borne in mind that the 25 dB fence implies only incipient difficulty with the understanding of conversational speech.