70/38

BRITISH ACOUSTICAL SOCIETY

OCCUPATIONAL HEARING LOSS

23-25 March 1970

ON THE EQUAL-ENERGY HYPOTHESIS RELATIVE TO DAMAGE-RISK CRITERIA IN THE CHINCHILLA

by

W. Dixon Ward and D.A. Nelson

With the steady accumulation of data relating hearing loss to years of 8-hr exposures to continuous industrial noises (e.g., Baughn, 1966; Robinson, 1968; Passchier-Vermeer, 1968), the specification of damage-risk criteria (DRC) for such exposures becomes based on increasingly firm ground. It seems clear from these surveys that common industrial noises below 80 dBA (80 dB on the A-weighted scale of the sound-level meter) are quite innocuous, but that an increase in risk occurs, both in terms of the number of persons affected and the degree of hearing loss produced, as 80 dBA is exceeded. Whether one takes as the basic DRC a level of 80, 85, 90, or 95 dBA, therefore, demands only an arbitrary decision as to just how much loss in how many people is considered tolerable. In the United States, for example, the most recent DRC is one of 90 dBA for continuous 8-hr exposure (the Walsh-Healey Act); this DRC will presumably result in some slight losses in the average worker after 20 years of exposure, but will produce compensable damage in only a few ears.

The problem of how to treat shorter and intermittent exposures is still plaguing us, however. Clearly, if the workers must be in the noise only half the workday, a slightly higher level can be tolerated. It also seems reasonable to expect that if this 4 hr of noise exposure were broken down into, say, 8 30-min exposures with 30-min rest periods between, an even higher level could be permitted. It is known that the temporary effects of noise conform to these expectations; the temporary threshold shift (TTS) produced by an intermittent exposure is less than that produced by the same total exposure in a single chunk (Ward, 1963). Furthermore, the generation of a given TTS requires less and less time, the higher the level. In fact, an entire set of DRC for continuous and interrupted noise exposures, the so-called CHABA DRC, was based on such relations—the underlying assumption was that all noise exposures that produce the same TTS_2 (the TTS measured 2 min after the end of the workday) are equally dangerous in regard to permanent threshold shift, or PTS (Kryter, Ward, Miller and Eldredge, 1966).

Unfortunately, the CHABA DRC, essentially involving separate criteria for each octave band of noise, are very complicated. The trading relation between intensity and time for constant TTS simply is curvilinear, and there is nothing we can do about it. The equivalent of an 8-hr continuous exposure to 1200-2400-Hz noise at 85 dB SPL, for example, is a 4-hr exposure at 87 dB, a 10-min exposure at 105 dB, and a 5-min exposure at 112 dB. In other words, the trading relation in TTS for this octave band of noise varies continuously from 2 to 7 dB per doubling time. And if the noise is on only in short (ca. 1 min) bursts just half the time, an 8-hr exposure at 96 dB will produce the same TTS_2 as 8 hr of 85 dB steady noise (or 4 hr of 87 dB, etc.)

Because of this complexity, the CHABA curves are not widely accepted, and there is a movement afoot to return to the equal-energy hypothesis. This hypothesis, which served as the basis for assessing intermittent noises in one of the first DRC formally established in the USA (AFR 160-3, 1956), simply considers the total tolerable energy to be constant, regardless of level, duration, or temporal pattern separately, so that the trading relation is always 3 dB per doubling time. As in the CHABA DRC, an 8-hr exposure to 1200-2400-Hz noise at 85 dB SPL was considered in AFR 160-3 to be acceptable, but also 4 hr at 88 dB, 2 hr at 91, etc., down to 5 min at 105 dB (compared to the CHABA DRC's 112 dB). Whether the 2 hr at 91 dB came in bursts or in one blast was ignored--only the total energy mattered.

The basis for adopting the EEH (equal-energy hypothesis) was a series of guinea-pig studies by Eldredge and Covell (1958). They found that to a first approximation the same amount of cochlear damage, as indicated by changes in the cochlear microphonic, was produced by a 500-Hz tone for 1 min at 140 dB SPL or exposures equivalent to it in energy, down to 118 dB for 160 min of exposure. The histological picture, it may be noted, was not nearly so clear; all the exposures they used, including some with somewhat less total energy, produced sizable areas of hair-cell destruction, so that the EEH could neither be confirmed or denied.

There is also no applicable data on hearing loss in man, because exposures in industry other than steady ones are generally so variable from person to person that it is difficult to get an adequate sample from which to draw conclusions. Indeed, non-steady exposures are usually carefully eliminated from the data. But even in animals, strangely enough, there is very little that has been reported, since Eldredge and Covell's early experiments, that bears on the validity of the EEH, especially in terms of actual hearing losses as measured with behavioural techniques. One important exception is Miller's (1963) study on cats, in which the PTS produced by 2 hr of white noise at 115 dB SPL was three times as great when the exposure was continuous as when it was broken up into 16 7.5-min bursts with an hour of recovery between successive bursts.

In short, the truth or falsity of the proposition that equal amounts of acoustic energy (in a particular frequency region) will produce equal amounts of PTS is still undecided. I dare say that if one-tenth of the time and energy that has been squandered in standards committees arguing the point had instead been devoted to relevant experiments, we would have at least some idea of whether the EEH is reasonably accurate in some respects or only represents wishful thinking on the part of those who admire its one undeniably desirable aspect: its simplicity.

PROCEDURE

A series of exposures of monauralized chinchillas to a special broad-band noise especially tailored to give equal TTS at all frequencies from 1 to 8 kHz had shown that a 2-hr exposure to 114 dB SPL just barely produced a significant PTS (after 1 week of recovery, the average remaining shift at 1, 2, 4 and 8 kHz had dropped to 10 dB) and that 123 dB for 2 hr produced average PTSs of 60 dB, which was somewhat more than we desired in our study of individual differences in susceptibility--some of the ears showed organs of Corti nearly devoid of hair cells everywhere except at the very apex (Ward and Nelson, unpublished data).

It was therefore decided to run a small test of the EEH simultaneously with attempts to determine an optimum exposure for producing an average of 30 dB of PTS (this would, we estimated, give us a large range of individual PTSs without obliterating half the organ of Corti). Accordingly, 4 groups, of 4 chinchillas each, were exposed to the following noises, respectively: 114 dB for 4 hr, 117 dB to 2 hr, 120 dB for 1 hr, and 123 dB for 0.5 hr. In energy, these were all twice as high as the 114-dB 2-hr exposure that just produced PTS. The animals were exposed in a special pillory-type restrainer that held the head in a relatively fixed position immediately in front of an Altec Voice of the Theater speaker. Behavioural thresholds were obtained, using the method of conditioned avoidance, before and for three months after the noise exposure. The pre-exposure thresholds were used in assigning animals to groups, so that each group had the same average pre-exposure threshold.

RESULTS

My expectation, frankly, was that 114 dB for 4 hr would be only slightly more dangerous than 114 dB for 2 hr, and that 0.5 hr at 123 dB would produce nearly as much PTS as 2 hr at 123 dB, thus giving a good continuum of damage. I have difficulty, in retrospect, in explaining why I expected this result; I guess I had finally succumbed to the blandishments of the "critical intensity" proponents, who insistently aver that there is a certain level—in this case somewhere between 114 and 123 dB—which must be exceeded before one gets permanent damage, and that the duration of exposure is of only secondary importance.

At any rate, the results did not confirm the critical-intensity notion, since moderately severe losses were produced by all 4 exposures. Instead, the equal-energy hypothesis is supported by these 15 chinchillas (one died 3 weeks after exposure). Although there was a trend in the direction that the critical-intensity notion might predict, the spread of values of PTS was so great that a very large difference would be required to become significant at even the 10% level.

Figure 1 makes the point clearly. In this figure are plotted the average PTSs (over 0.5, 1, 2, 4 & 8 kHz) for each animal in the four groups. While the mean PTS in the lowest-intensity (longest duration) group is 35 dB, and that for the highest-intensity is 47 dB, the difference is due mainly to one animal in the 114-dB 4-hr group, whose injury threshold apparently was just barely exceeded and so who showed almost complete recovery.

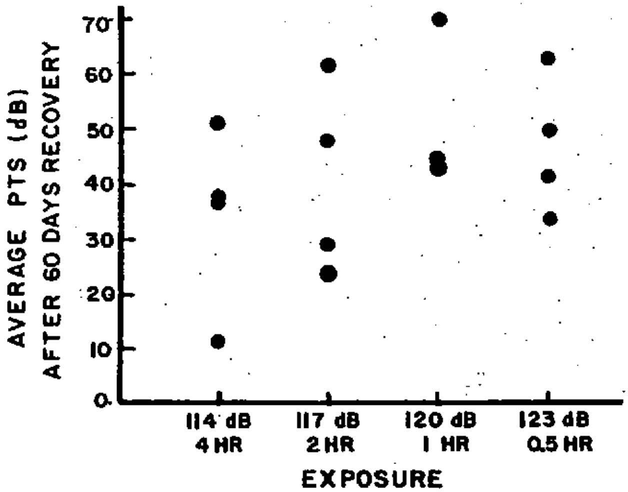

Fig. 1. Average PTS for each animal at 0.5, 1, 2, 4 and 8 kHz (ordinate) 60 days after single exposure to noise whose SPL and duration are given on the abscissa.

DISCUSSION

These results tend to confirm the equivalence of time and intensity reported by Eldredge and Covell for single uninterrupted exposures, using behavioural threshold changes rather than histological damage as the indicator. Thus it appears that the use of a constant product of intensity and time ("immission") as the limit for a single daily continuous exposure is supported.

It does not follow, however, that we may extrapolate from this to a general acceptance of the equal-energy hypothesis. Miller's results clearly indicate that interruption of the daily exposure by frequent noise-free periods not only reduces the TTS but also the PTS produced.

Above all, we are not yet justified in adding up all the daily exposures in such a fashion that 10 years of exposure, 8 hr/day, 5 days/wk to a noise at 80 dB SPL is judged equivalent in hazard to a single 8-hr exposure to 114 dB, as the most extreme use of the EEH would indicate. In our original group of chinchillas, for example, daily 2-hr exposures to the 114-dB noise for a week produced no greater TTS_2 or slower recovery on Friday than on Monday, whereas the EEH would predict that Tuesday's exposure should be enough to produce the same PTS as in the 114-dB 4-hr group in Fig. 1. That is to say, recovery processes that are allowed to proceed for at least 16 hr must have some effect on the ability of the auditory mechanism to withstand the next day's noisy onslaught.

The outcome does seem to imply the existence, not of a critical intensity, but of a critical single immission, in chinchillas. An exposure to this particular noise is nearly safe when the level is 114 dB and the duration is 2 hr, but produces nearly 40 dB of PTS when either the intensity or the duration is doubled. It is interesting to note that a very similar discontinuity can be seen in Miller's cat data--the mean PTS produced by 115-dB noise jumped from 10 dB following 30-min exposures to 35 dB after 2-hr exposures.

In summary, it seems clear that the equal-energy rule is applicable in determining equivalent single daily exposures to noise. However, the need for further research on how damage cumulates from exposure to exposure is even clearer. Over some ranges of parameters, the 3 dB per doubling time may be correct. In others perhaps the 5 dB per doubling time used in the 1969 Walsh-Healey Act may be more appropriate; that particular relation is also only a guesstimate compromise of a political, not a scientific, nature.

ACKNOWLEDGMENT

This research was supported in full by grants from the Public Health Service, U. S. Department of Health, Education, and Welfare. We extend our thanks to our patient chinchilla-testers: Barbara Evans, Jan Forfang, and Lonnie Sutherland.

BIBLIOGRAPHY

Air Force Regulation No. 160-3, Dept. of Air Force, Washington, D.C. (October 29, 1956).

Baughn, W. L. Internat. Audiology 5, 331-338 (1966).

Eldredge, D. H. & W.P. Covell. Laryngoscope 68, 465-486 (1958).

Kryter, K. D., W.D. Ward, J.D. Miller and D. H. Eldredge. J. Acoust Soc. Am. 39, 451-464 (1966).

Miller, J. D., C.S. Watson and W. P. Covell. Acta Oto-Laryngol. Suppl. 176, 1963.

Passchier-Vermeer, W. "Hearing loss". Report 35, April 1968, Inst. v. Gezondheidstechniek TNO, Delft, Netherlands.

Robinson, D. W. "The relationships between hearing loss and noise exposure", NPL AERO Report Ac 32, July 1968.

Ward, W. D. "Auditory fatigue and masking". In Modern Developments in Audiology, J. Jerger, Ed. New York: Academic (1963).