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HEARING AT RISK: IDENTIFICATION OF ENHANCED RISK OF HEARING DAMAGE

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1. INTRODUCTION

A basic problem with noise induced hearing loss (NIHL) is that often the problem is not recognised until significant damage has occurred. Noise control legislation is now in place to force the problem to the attention of industry. Occupational health and safety personnel attempt to force the problem to the attention of individual workers. Yet in practice NIHL still occurs, for three main reasons:

(1) inadequate noise control by the employer;

(2) ineffective use of hearing protection by the employee;

(3) higher then average individual susceptibility to hearing damage.

This paper deals with the third area, individual differences in response to noise. A case is presented for the existence of an identifiable category of 'at-risk' persons, for whom normal hearing protection is inadequate to prevent damage. Methods of identifying the at-risk population are reviewed. A strategy for efficient screening of an industrial workforce to detect the at-risk group is developed. Finally, we describe a new audiometric instrument for carrying out this screening task.

2. CHARACTERISTICS OF AN 'AT-RISK' POPULATION

One striking aspect of NIHL is the variability of the damage. Many papers have reported data covering workers in the same occupation and with the same noise exposure over many years, yet some having little or no damage and others "who suffer a tremendous loss of hearing" (Chung et al,[1]; also Taylor et al,[2]; this topic is reviewed in Henderson et al [3].) In addition to the variation in NIHL itself, similar subject-to-subject variation has been reported in related auditory phenomena such as temporary threshold shift (TTS) (Davis [4]), change in damage susceptibility of an ear ('toughening effect'; Hamernik et al [5]), and in other species (Mensh et al [6]).

The variation in hearing damage proves that, at least for a favoured few, NIHL can be largely avoided. This fact suggests at least the possibility of doing something better for the other end of the range. The question that naturally arises is: if some people can be very resistant to noise damage, why can't the others be more resistant? And if they can't be somehow made more resistant, can they at least be identified beforehand, and given extra protection?

These questions are emotive and vague. A first step in progress in this area is to move to more statistical considerations. The question of what to do about low resistance to noise damage could be examined objectively in terms of the distribution of noise resistance across the population.

Taking as a starting point the existence of a quality which we label noise resistance, which varies from person to person, then the first question is to try to be more specific about the distribution of this quality. Unfortunately noise resistance is more of a notion than a physical attribute. It is not easily defined and measured, like height and weight. The statistical data governing hearing protection legislation comes from many sources. Like all aggregate data, it tends toward a normal distribution.

Given a normal distribution of hearing damage vs noise exposure, and given noise protection laws which protect a certain percentage of the workforce, then the main problem with improving the situation is the problem of 'diminishing returns'. To move a criterion further out on a normal distribution means expending more and more effort (on noise control and hearing protection) in order to include smaller and smaller extra increments of the population within the 'adequately protected region'.

The only possibility for avoiding the problem of diminishing returns lies in the direction of identification of a subgroup of the general population which for some reason has an enhanced risk of hearing damage. Thus the hope for reduction in NIHL reduces to the issue of the identifiability of a category of persons who are of higher than average susceptibility.

3. IDENTIFICATION OF AN 'AT-RISK' POPULATION

There are two general approaches to the identification problem:
- (1) early detection of damage;
- (2) correlates of enhanced risk.

3.1 Early Detection of Damage

The problems with early detection of hearing loss are much like the problems of reducing NIHL by increasing hearing protection: it requires considerable extra effort covering the entire workforce. Given that there was the will to expend the extra effort, there are also methodological problems. Again, there are two general approaches:
- (1) more frequent and more accurate conventional audiometry;
- (2) other measurements of change in hearing beyond the conventional pure-tone audiogram.

3.1.1 Conventional Audiometry. There is a case to be made for more frequent and more accurate conventional audiometry, particularly when (as at present) many workers get NO audiometry. In many countries, including the UK, existing legislation does not require routine audiometric testing as part of an industrial hearing conservation programme. Conventional audiometry could be expected to pick up hearing losses of 30 dB or more. This is a distinct improvement upon waiting for people to notice their own high frequency (4 kHz and above) hearing loss, which often does not happen until the loss is beyond the 50 dB level (Karmy et al [7]). A second beneficial effect of regular audiometric tests is that they have been shown to be a most effective way to convince workers to use their hearing protectors (Karmy & Martin [8]).

Unfortunately, there are limits to the sensitivity of conventional audiometry. It is effective for detecting losses in the range above 30 dB, but this represents considerable damage. Since a sizeable proportion of person entering a workforce will have hearing thresholds below -10 dB HL, audiometry at best picks up losses at about the '40 dB damage' point (for high frequencies). Some improvements in this situation could be made with more frequent testing and more accurate audiometers, but again this would be a situation of 'diminishing returns' of investment vs benefit.

3.1.2 Other Auditory Damage Indications. A second approach to early detection of damage has been to consider measurements other than the pure tone detection threshold (the conventional audiogram). Auditory perception has the general dimensions of time, frequency and amplitude, and only amplitude is involved in standard audiometry.

The temporal dimension as affected by NIHL has been considered by Tyler et al [9], who studied the effect of NIHL on various time-dependent phenomena, including speech intelligibility. Frequency resolution was studied by West & Evans [10], and frequency selectivity by Bergman et al [11]. These studies show potentially useful measurements, and there are many other aspects of hearing which could also be useful, though not so far examined with respect to NIHL - such as reaction time tests (Wright et al, [12]). The problem is that, as yet, there is no auditory measurement which has been clearly shown, for a large industrial population, to be superior to threshold tests for early detection of NIHL.

3.2 Correlates of Enhanced Risk

The limitations of conventional and not-so-conventional audiometry to detect NIHL in the very early stages has led to many investigations of non-auditory correlates of NIHL. There are several factors which may correlate with NIHL:

(1) general, constant: such as eye colour, sex, age, medical condition;
(2) metabolic, constant: specific properties of the metabolic system;
(3) auditory, noise dependent: auditory measurements during or after non-damaging exposures to sound, such as TTS;
(4) non-auditory, noise dependent: non-auditory physiological measurements during or after non-damaging exposures to sound, such as blood pressure and heart rate.

3.2.1 General, constant factors. Retrospective studies of hearing damaged populations have uncovered various factors which, over limited samples, correlated well with NIHL. These have included being male, having blue eyes and having heart trouble. Often more controlled samples weakened or removed these correlations. All such factors were finally discounted by Lawton and Robinson [14]. Chung et al [1] concluded that smoking was significantly related to NIHL. Problems involved in such studies are discussed by Henderson et al [3].

3.2.2 Metabolic, constant factors. Studies of the mechanism of NIHL have led to suggestions of very specific factors involved in susceptibility. Gunther et al [15] found increased NIHL in magnesium-deficient rats and guinea pigs, and in a group of 24 humans. A postulated mechanism for allowing the magnesium deficiency to affect NIHL was reduction of blood flow to the hair cells. Other noise effects involving blood flow are discussed in 3.2.4.

3.2.3 Auditory, noise dependent. There have been many studies of temporary auditory effects of noise, and their potential relation to permanent hearing loss. The most well known is temporary threshold shift (TTS; Kryter [16]). At one time it was believed that TTS after a 2 min exposure predicted permanent hearing loss (PTS) after 10 to 20 years. Later studies showed the many weaknesses of the prediction. Kraak [17] showed that better prediction of eventual damage could be obtained by monitoring the rate of recovery from TTS. This important idea of rates (or temporal integration) rather than absolute changes recurs in non-auditory studies, below. Use of TTS to predict hearing loss is now uncommon in North America because of threat of litigation. Evidently a few minutes of loud noise cannot be used to save a persons hearing for life. However in Germany TTS is elicited using impulses as a test for susceptibility (among soldiers) to gunshot noise damage (Pfander [18]).

Other auditory phenomena which have been studied for their relation to NIHL include asymptotic threshold shift (ATS), tinnitus, the acoustic reflex and the cochlear echo. Lawton and Robinson [14] looked at many factors, and concluded that 'the survival of hearing ... is closely related to good functioning of the cochlea'. They estimated cochlear function from the slope of threshold vs duration for a short 4 kHz tone (auditory integration), and the slope of masked threshold vs masking level. This result does not seem to have found its way into industrial health and safety practice.

Probably the most important auditory measurement which is still viable and testable is the acoustic reflex: the action of the middle ear muscles, particularly the stapedius muscle, to attenuate sound transmission. Abnormality in the acoustic reflex was the most successful predictor of NIHL in the survey by Henderson et al [3]. Fortunately, the acoustic reflex can be elicited with sounds considerably lower in level and duration than required to produce TTS, meaning no problems with safety and litigation.

3.2.4 Non-auditory, noise dependent. We naturally associate sound with hearing. However there are also non-auditory effects of noise (Jansen [13]). These include:

- blood flow constriction (vasoconstriction);
- blood pressure;
- heart rate;
- dilation of the pupil of the eye.

There have not been as many investigations relating these non-auditory effects to NIHL as there have been in the auditory case, but relationships between noise and general medical and physiological effects has at least a 30 year history, dating back to a study by Rosen and Olin [19] linking hearing loss and heart disease.

For at least ten years work has been continuing in Dusseldorf to relate NIHL to non-auditory measurements. A recent summary is by Meyer-Falke et al [20], in which vasoconstriction, diastolic blood pressure and TTS were found to correlate well with hearing loss for a sample of about 500 subjects. It was the time course of the vasoconstriction and blood pressure (before, during and after a 'noise dose') which were distinctive, rather than absolute changes. Going further, they established characteristic normal and non-normal profiles for these measurements. The result is a promising procedure for relating some simple physiological measurement data to clear categorisation into low or high risk of NIHL.

4. A SCREENING PROCEDURE FOR 'HEARING-AT-RISK'

The results summarised in the proceeding section show that there are indicators of elevated risk for NIHL, but that the required tests have not moved from the laboratory into industry. Therefore there is not an abundance of data to support the procedures. This situation is a classic case of a 'bootstrapping' problem: until the tests are more widely performed in industry, there will be no data to motivate such wider use.

On way to promote wider testing is to consilidate the results of previous research into a relatively simple screening procedure, devised from the most promising of the cited studies. Our suggested procedure combines auditory and non-auditory responses to a small noise dose, presented to one ear at a time. The level and duration of the noise dose must be small enough to avoid potential problems of litigation, but high enough to elicit the acoustic reflex. Our suggested stimulus is a broad band noise at 95 dB(A) for 5 minutes.

Before, during and after the presentation of the noise dose, on-line measurements is made of the following:

- acoustic reflex;
- vasoconstriction at the fingertip.

It might also be necessary to measure diastolic blood pressure, if results on the acoustic reflex and vasoconstriction do not adequately pick out the 'at risk' subgroup. If further refinement of the screening procedure is required, the auditory integration and masking measurements of Lawton and Robinson [14] could be performed as a second part of the test.

Important features of the screening test are:

- relatively simple and quick to administer;
- entirely objective;

- with minimum operator supervision;
- with on-line monitoring of the time course of the measurements;
- with automatic storage of results;
- and automatic comparison with models to determine categorisation.

The test is in principle straightforward, but it is apparent that no existing conventional audiometer, or any other single instrument, is capable of carrying out the test, collecting the results, and performing the required analysis. Therefore a new audiometer is required to go with the new procedure. A suitable device has been developed by Alfred Peters plc, specifically for the purposes of this industrial screening task. This device is described in the next section.

5. A 'HEARING-AT-RISK' AUDIOMETER

The required instrument for identifying enhanced NIHL susceptibility differs from a conventional industrial audiometer in the following ways:

- measurement of the acoustic reflex;
- measurement of vasoconstriction;
- comparison of measured data to standard profiles, for categorisation.

However it shares with conventional audiometers the requirement to generate a signal of specified spectrum and level. The procedure shares with 'self-recording' audiometers the function of recording the time course of a measurement.

Some modern audiometers include the ability to combine measurements with computer storage and analysis. Peters have pioneered this approach: our standard industrial audiometer, when connected to a host computer, already does comparison of data sets and decision making (regarding Health and Safety Executive action categories, not risk of NIHL).

If industry had to purchase a separate instrument for hearing-at-risk tests, it would impede the use of the approach. Therefore our design combines the above special functions with the capability of:

- conventional manual audiometry;
- self-recording 'automatic' audiometry.

The basic screening test combines a timed presentation of a controlled noise exposure with:

- an optical system for measuring the rate of blood flow (in the fingertip);
- an impedance measurement using a probe tube in the ear canal.

The instrument is not designed to be a full impedance audiometer, as it will not have a method for changing the ear canal pressure (it could be added as an option). Other physiological measures, such as blood pressure, could also be added. The instrument has an 8-channel analogue signals interface, so extra measuremets require connection of a transducer and appropriate programming.

The unit will automatically (under microprocessor control) carry our all the test timing and recording of results, and has an interface to a control computer for storage and printout of test data, and final analysis.

The specification for the manual audiometer is to full IEC 645-1 type 1, being a twin channel device with a full complement of test and masking signals. This full specification allows for manual (or computer assisted, using Peters software) testing using all standard audiometric procedures. The full type 1 capability also allows extention of the hearing-at-risk screening test to include the 'threshold vs duration' and 'masked threshold vs masker level' tests advocated by Lawton and Robinson [14], if so required.

The final instrument is a 'computer-assisted audiometer', one of a range of Peters products combining audiometry with computer control and support. The system fully automates the screening procedure, replacing what could be a complex and demanding manual procedure with a simple, reliable automatic test.

The procedure and equipment is designed to be supervised by personnel ordinarily found in industrial medicine, such as factory nurses, who should not have to be audiological scientists in order to conduct the test. This consideration is vital to the success of the approach: any such procedure must recognise the constraints of time, money and personnel found in industry if there is to be any chance of wide acceptance, and hence any chance of actually reducing the incidence of NIHL.

6. SUMMARY

A case has been made for the existence of a sub-group of the general population which has enhanced risk for noise induced hearing loss (NIHL). A review of research to uncover identifying characteristics of this sub-group has shown that the acoustic reflex (stapedius muscle action in response to loud sounds) and the vasoconstriction reaction (blood flow reduction in response to sound, as measured by light flow through the fingertip) are strong candidates for a screening proceedure to identify the at-risk group.

The suggested test is given in outline form, requiring a five minute 'noise dose' on each ear, with continuous monitoring of acoustic reflex and vasoconstriction. Signal presentation and impedance measurement uses a probe system similar to that used for conventional impedance audiometery.

Alfred Peters plc have designed an instrument specifically intended carry out the screening procedure quickly and accurately. The instrument combines standard audiometric functions with the additional measurement of the time course of vasoconstriction and acoustic reflex. It operates automatically (under computer control) to carry out the test, and to collect, store and analyse the results.

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