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Guidelines on the diagnosis of noise-induced hearing loss for medicolegal purposes

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These guidelines aim to assist in the diagnosis of noise-induced hearing loss (NIHL) in medicolegal settings. The task is to distinguish between possibility and probability, the legal criterion being ‘more probable than not’. It is argued that the amount of NIHL needed to qualify for that diagnosis is that which is reliably measurable and identifiable on the audiogram. The three main requirements for the diagnosis of NIHL are defined: R1, high-frequency hearing impairment; R2, potentially hazardous amount of noise exposure; R3, identifiable high-frequency audiometric notch or bulge. Four modifying factors also need consideration: MF1, the clinical picture; MF2, compatibility with age and noise exposure; MF3, Robinson’s criteria for other causation; MF4, complications such as asymmetry, mixed disorder and conductive hearing impairment.

Keywords *noise-induced hearing loss* *diagnosis* *medicolegal*

A probable diagnosis of noise-induced hearing loss (NIHL) is easy where there is a history of unprotected noise exposure of high level and long duration, a typical audiometric notch maximal at 3, 4, or 6 kHz and no evident complicating factor or diagnostic competitor. In many other cases though, the diagnosis is much less certain. In medicolegal work, the diagnosis may also be subject to challenge in correspondence, by instructing solicitors and those for the other party or parties, and under cross-examination in court.

In such cases, NIHL is usually accompanied, and often obscured, by age-associated hearing loss (AAHL) and sometimes by other additional forms of hearing impairment. The diagnostic task then reduces to that of defining the likelihood of the presence of a component of NIHL in the overall hearing impairment.

In defining likelihood, we are helped by the legal requirement in civil proceedings–namely to give an opinion on ‘balance of probabilities’ or whether it is ‘more probable than not’. In practice, keeping that legal criterion in mind can be an enormous help. The expert witness is required only to differentiate between probability and possibility, with the onus of proof of probability on the claimant. Nevertheless, a semi-quantitative opinion on the degree of probability can assist the court, by indicating how close to or distant from the borderline it is considered to be.

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Another major issue is how much noise damage has to be present before it counts. The following statements encompass the range of criteria that might be used for this:

1. The risk of noise-induced destruction of at least some cochlear hair cells.
2. The slightest degree of damage that is likely to cause some minimal but finite degree of loss of hearing ability either now, or later when augmented by ageing effects.
3. The likelihood of causation of some specified degree of reduced hearing ability, below which the effect is regarded as of no importance.
4. The presence of a degree of noise-induced hearing loss that is large enough to be measurable reliably and identifiable on the audiogram.

Our opinion and decision on this matter is as follows. Statement (1) defies demonstration in living human beings and is therefore only of theoretical interest. Statement (2) borders on the concept of ‘de minimis non curat lex’, roughly translated as ‘the law does not concern itself with trifles.' With respect to hearing, this is for the courts to define when and if they wish to do so. For us to attempt a definition would be to invite disagreement and criticism from within the professions of otology and audiology, as well as being an incursion into legal prerogative where it might be seen to be usurping the role of the judiciary. Statement (3) is arbitrary, and medical and scientific opinions already vary widely on this. Statement (4) is the only practicable criterion for the amount of noise damage necessary for the diagnosis of NIHL; that is, a reliably measurable and identifiable degree of damage. This statement is also compatible with the legal requirement where the test is whether or not, on the balance of probabilities, noise has made a material contribution to the claimant's overall hearing impairment. This criterion is therefore the one on which the following diagnostic guidelines are based.

Historical background to these guidelines

The authors are not aware of any previously published quantitative guidelines for the diagnosis of NIHL. Operational criteria for diagnosis of the condition were therefore not included in the material presented in our annual 1-day course on 'Medicolegal aspects of noise-induced hearing loss', until 1998. Our change in policy on this issue arose from requests by participants, in the evaluation questionnaires for the 1997 course, for more information on how to diagnose NIHL. In fact, one of us (R.R.A.C.) had already been using his own rough set of criteria for medicolegal work for about 2 years. These then became the basis for our development of the first draft of these guidelines, which were then presented to the 1998 course.

They were then piloted through about 200 medicolegal cases during 1998, amended in places as a result, and then presented as a second draft set of guidelines to the 1999 course. With some further modifications, mostly of an editorial nature, they have now been finalised.

The guidelines are considered by the authors to be well-founded, practicable and useful. It is hoped that they will assist otologists and audiologists in making diagnoses in those many borderline cases that are troublesome. They may also assist the courts in adjudicating on these issues.

Guidelines on the diagnosis of noise-induced hearing loss

In order to keep the text of these guidelines as concise as possible, notes of explanation or further guidance have been placed in Appendix A and a worked example, comparing audiometric measurements with the most likely pattern and extent of AAHL, is given in Appendix B.

1. AIM

1.1. The aim of these guidelines is to assist expert medical witnesses in considering evidence for the diagnosis of NIHL in a medicolegal setting. They do not relate to hearing loss due to acute acoustic trauma, nor to noises having unusual frequency spectra (see para. 2.2), nor do they quantify how much of any hearing impairment is due to noise.

2. SCOPE

2.1. For the most part, the guidelines refer to uncomplicated cases of NIHL; that is, cases of 'typical' NIHL together with presumed 'normal' AAHL.

2.2. In the present context, 'typical' NIHL refers to the form of hearing impairment that gradually accrues in a proportion of those who have repeated exposures to hazardous levels of one or more of the common types of broad-band sound. Sounds not fitting this description include those predominantly of tonal nature or of low-frequency or very high-frequency spectrum. Examples of such unusual spectra would be where the sound level is > 10 dB greater in the 0.25, 0.5 or 8 kHz octave band than in each of the 1, 2 and 4 kHz octave bands.

2.3. 'Normal' AAHL here implies consistency with the range of age-associated hearing data in ISO 7029 (1984)[1] for the appropriate age and sex, and also having the most common audiometric configuration of AAHL in which the hearing loss increases progressively with test frequency and with age, the progression having an accelerating character.

3. GENERAL REMARKS

3.1. Inevitably, guidelines are a matter of judgement. They should be interpreted as guides, not rigid rules. Nevertheless, these guidelines have been derived after careful consideration of the data available and keeping in mind the legal criterion that the diagnosis should be likely 'on balance of probabilities' or 'more likely than not'.

3.2. It is not possible from case law or from scientific research to specify the minimum degree of NIHL that may be considered significant in terms of compensatability (see Note 1 in Appendix A). Consequently, guidelines on the minimum amount of noise exposure that might be significant must depend on the smallest hearing loss that can be measured in an individual with a reasonable degree of reliability. At 4 kHz, this is considered to be about 10 dB.

3.3. The guidelines presented here comprise three Requirements R1, R2 (a) or (b), R3(a) or (b) and four Modifying Factors MF1, MF2, MF3, MF4.

3.4. For the diagnosis of NIHL, requirements R1, R2(a) and R3(a) should be met; or if appropriate R1, R2(b) and R3(b). The diagnosis may then be strengthened or weakened according to how modifying factors MF1, MF2, MF3 and MF4 apply to the individual.

Diagnostic requirements

4. REQUIREMENT R1: 'HIGH-FREQUENCY IMPAIRMENT'

4.1 R1 comprises audiometric evidence of a high-frequency sensorineural hearing impairment. For the present purposes, 'high-frequency' is defined relative to the threshold levels at middle frequencies. It is when a single measurement of hearing threshold level (HTL) at 3, 4 or 6 kHz, after any due correction for earphone type (see Note 2), is at least 10 dB greater than the HTL at 1 kHz or 2 kHz. If an average of two or more measurements in that ear can be used, the 10 dB guideline figure may be slightly reduced (see Note 3).

5. REQUIREMENT R2(a): 'NOISE EXPOSURE'

5.1. If R2(a) is met, at least 50% of individuals exposed to this known or estimated amount of noise would be likely to suffer a measurable degree of hearing loss. This noise estimate includes allowance for proper use of hearing protection (see Note 4) or for any in-built protection from a conductive hearing loss believed to have been present in the relevant noise-exposure years (see Note 5).

5.2. From an assessment of the various sets of epidemiological data and predictive formulae available (see Note 6), the lower limit of noise exposure meeting this requirement is considered to be an equivalent daily 8-h continuous noise exposure ($L_{EP,d}$) of not less that 85 dB(A) (see Notes 7 and 8) for a sufficient number of years to lead to a cumulative exposure of at least 100 dB(A) NIL, the so-termed Noise Immission Level.[2–4]

5.3. The medical examiner may not be able to make an estimate of the total noise exposure, even in terms of whether it meets R2(a) or (b). If a diagnosis of NIHL would be made if these noise exposure requirements were met, then it is recommended that in absence of a noise exposure estimate a conditional diagnosis be made.

6. REQUIREMENT R2(b): 'NOISE EXPOSURE'

6.1. Substantial amounts of NIHL can be caused in a minority of persons exposed to < 100 dB(A) NIL; that is, in those who are more than averagely susceptible. To allow for such cases, a less stringent noise exposure requirement is applicable provided the audiometric evidence of noise damage is stronger. The lower level of total noise exposure for such cases is reduced to 90 dB(A) NIL (see Notes 7 and 8), although the lower limit on $L_{EP,d}$ remains at 85 dB(A). Where the estimated total exposure is in the range 90–99 dB(A) NIL, thereby meeting noise exposure guideline R2(b) but not R2(a), the audiometric guideline R3(b) must be met instead of R3(a).

7. REQUIREMENT R3(a): 'AUDIOMETRIC CONFIGURATION'

7.1. Evidence of probable presence of NIHL is considered to be present if there is a downward notch in the audiogram in the 3–6 kHz range that is large enough to be identifiable with a reasonable degree of confidence; see para. 7.5. An example of such a notch is shown in Fig. 1.

7.2. Evidence for NIHL is also provided on the audiogram by a sufficiently large relative bulge downwards and to the left in the 3–6 kHz range; see para 7.6. In a considerable proportion of NIHL cases, especially after the age of about 50 years, the characteristic high-frequency notch is missing. This is usually due to the additional presence of high-frequency hearing impairment of other causation, either pre-existing or developing concurrently or subsequently, such as associated with ageing. Typically that has the effect of converting a noise-induced audiometric notch into a bulge, an example of which is shown in Fig. 2 and also in Fig. 3 later. In other cases it may reduce the notch to a size (e.g. 5 dB) that is not significant as a notch. Nevertheless, it will add to the size of a potential bulge and should be examined closely to see if it qualifies as a bulge (see para. 7.6 and Note 10).

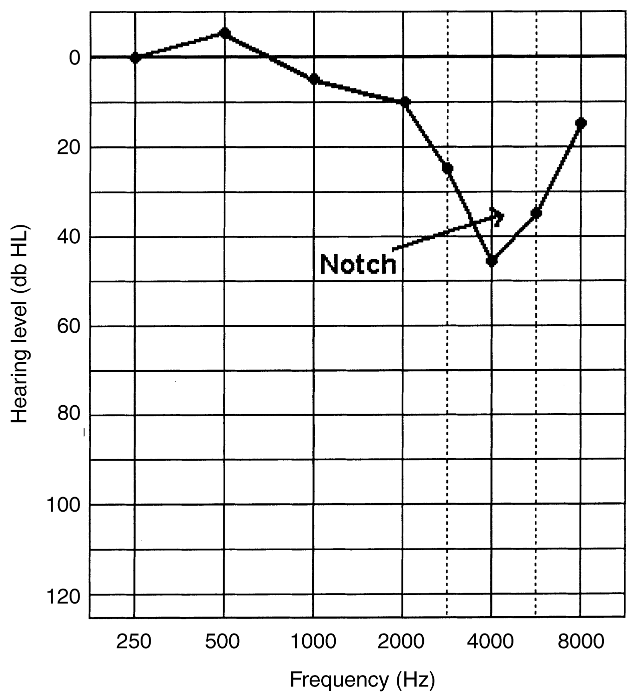

Figure 1. A high-frequency notch in the audiogram, typical of noise-induced hearing loss.

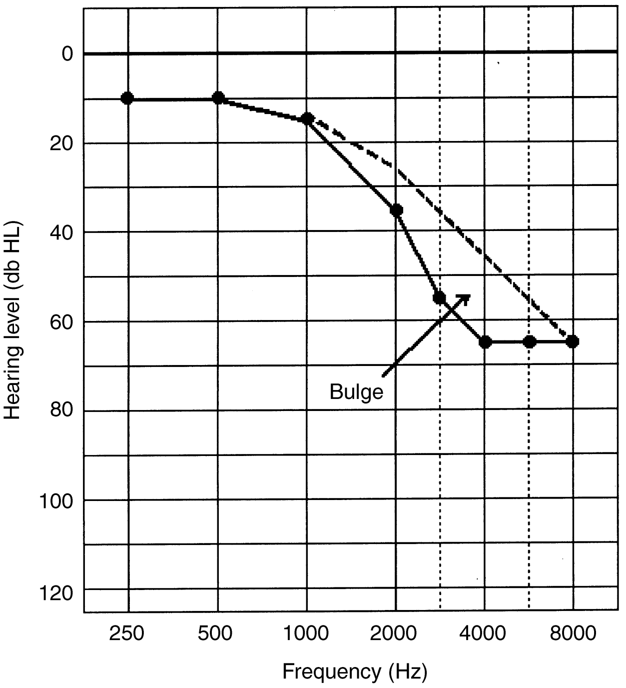

Figure 2. A bulge downwards and to the left in the audiogram, typical of noise-induced hearing loss plus presumed age-associated hearing loss (AAHL). (The dashed line indicates the median AAHL for men aged 70).

7.3. It should, however, be noted that the presence of such a notch or bulge is not pathognomonic of NIHL, as it is sometimes found or can be seen to develop in people with no significant noise exposure. Nevertheless, such a notch or bulge means a high probability of the presence of a substantial amount of NIHL if there has also been sufficient noise exposure and there is no strongly adverse or precluding other factor or diagnosis.

7.4. Likewise, the absence of a notch or bulge of sufficient size to meet R3(a) or (b) does not preclude the presence of some NIHL hidden in hearing impairments having other causation, or of NIHL having an atypical audiometric configuration. But such possibilities would generally be below the balance of probabilities. An exception might be where the size of the notch or bulge only just fails to meet the guideline, but the noise exposure had been particularly high (over 110 dB(A) NIL, for example).

7.5. Definition. A high-frequency *notch* in the air-conduction audiogram (see Note 9) that is sufficiently large to be indicative of the probable presence of NIHL is where the hearing threshold level (HTL) at 3 and/or 4 and/or 6 kHz, after any due correction for earphone type (see Note 2), is at least 10 dB greater than at 1 or 2 kHz and at 6 or 8 kHz. If an average of two or more HTL measurements can be used, the 10 dB figure may be slightly reduced (see Note 3).

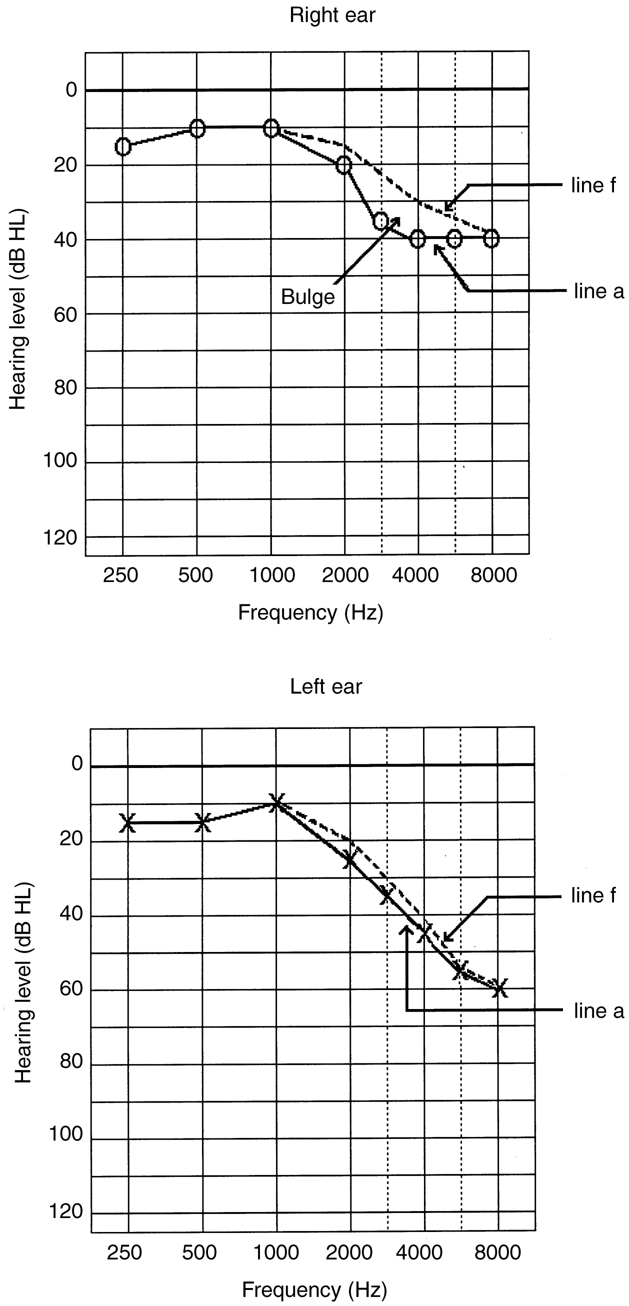

Figure 3. The worked example. (Measured hearing thresholds are shown in line a, and comparison figures of age-associated hearing loss in line f).

7.6. Definition. A high-frequency *bulge* in the air-conduction audiogram (see Note 9) that is sufficiently large to be indicative of the probable presence of NIHL is defined as follows. Such a bulge is present if the HTL at 3 and/or 4 and/or 6 kHz, after any due correction for earphone type (see Note 2), is at least 10 dB greater relative to the comparison values for age-related hearing loss (see Note 10) at corresponding frequencies. If an average of two or more HTL measurements can be used, the 10 dB figure may be slightly reduced (see Note 3). Occasionally the bulge extends to involve 2 kHz, or even 1 kHz.

7.7. Note that the extent of the notch or bulge as defined here for diagnostic purposes does not indicate the full extent of the hearing loss caused by noise damage. For instance, the HTL values at 1 and 8 kHz are most commonly used here as the 'anchor points' for estimating the AAHL comparison values against which the measured HTLs are compared in order to identify a probable noise-induced bulge. But in fact in many cases of noise damage there is probably a component of NIHL in any hearing impairment at 1 and 8 kHz.

8. REQUIREMENT R3(b): 'AUDIOMETRIC CONFIGURATION'

8.1. If the noise exposure requirement in R2(a) is met, then audiometric requirement R3(a) is sufficiently stringent. But if the noise exposure only meets R2(b), and not R2(a), then the corresponding requirement R3(b) has to be met instead of R3(a).

8.2. Requirement R3(b) is similar to R3(a), except that the notch or bulge has to be at least 20 dB to qualify.

Modifying factors

9. MODIFYING FACTOR MF1: 'CLINICAL PICTURE'

9.1. The mode, nature and age of onset and progression of auditory symptoms, especially if prominent temporary post-exposure auditory symptoms are recalled, and the fitting and use of any hearing aid(s) should be compatible with hearing loss resulting from recurrent noise exposure. 'Prominent' here is regarded as recollection of temporary tinnitus and/or dullness of hearing lasting an hour or more. These symptoms are particularly relevant if their duration gradually increased until they were present permanently. Account needs also to be taken of any probable diagnostic competitors or additional diagnoses or noise-protective factors, although any other diagnosis may well be an additional cause of hearing loss rather than an alternative to NIHL. The examiner should indicate the extent to which any such modifying factor supports, modifies or perhaps countermands the diagnosis of NIHL.

10. MODIFYING FACTOR MF2: 'COMPATIBILITY WITH AGE AND NOISE EXPOSURE'

10.1. The hearing impairments measured should be checked for compatibility with the claimant's age, sex and estimated total amount of noise exposure, including military and non-occupational, using the 'NPL Tables' (Robinson and Shipton, 1977)[4] up to the 5th percentile values of susceptibility, or other appropriate source, such as ISO 1999: 1990.[5] By definition, 5% of the population are even more susceptible than that, but the other evidence for the hearing impairment being due to noise and age alone should be strong for more extreme percentiles of susceptibility to be acceptable.

10.2. However, if the amount of hearing impairment is excessive in relation to the age and noise exposure (occupational, military and non-occupational), this does not necessarily negate a diagnosis of NIHL. The extra hearing impairment may well be due to a third causation, additional to NIHL and AAHL.

11. MODIFYING FACTOR MF3: 'ROBINSON'S CRITERIA'

11.1. If the diagnosis of NIHL seems borderline, the audiometric data should be checked for compatibility with Robinson's[6] probability tests to uncover other causation. These comprise a scheme of statistical tests leading to eight criteria, each of which is expressed at two levels of probability based on the 95% and the 98% limits of normal distribution. The criteria relate to the degree of conformity of the measured audiometric configuration with the Burns and Robinson[2] model of NIHL, the degree of left/right asymmetry both in amount of hearing impairment and in audiometric configuration, and the calculated degree of noise susceptibility.

11.2. Where two of these criteria are exceeded, it is probable that there is some alternative or additional diagnosis present, accounting for at least part of the measured hearing impairment. Exceptions occur however, and should be argued on their merits. Where three or more of these criteria are exceeded, an alternative or additional causation becomes highly probable. Note, however, that Robinson's criterion no. 2 for asymmetry, can on its own be very helpful in defining whether measured left/right differences are to be considered acceptable or excessive, or perhaps having some particular explanation such as asymmetrical noise exposure.

11.3. Where a case passes Robinson's criteria, this only means that the data are compatible with a diagnosis of NIHL combined with presumed AAHL, without needing to postulate an additional or alternative diagnosis. They are not criteria for a diagnosis of NIHL.

12. MODIFYING FACTOR MF4: 'COMPLICATED CASES'

12.1. In some cases, there may be considerable left/right differences in the amount of hearing impairment and only one ear complies with the above-stated requirements for a diagnosis of NIHL. In such instances, the user is referred to

Note 11 for recommendations on how the guidelines should be interpreted in asymmetrical cases.

12.2. Various other aural disorders in addition to NIHL and AAHL may be present and be contributing to the hearing impairments measured. In such cases, the guidelines should not be applied rigidly. Where a person is thought to have suffered a material degree of noise-induced threshold shift, but yet does not fully qualify for that diagnosis under these guidelines, the reasons for making an exception to them should be explained in detail.

12.3 Conductive hearing loss. This is likely to affect the assessment of effective noise exposure and/or estimation of the amount of sensorineural hearing loss (see Notes 5 and 9).

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We are grateful to our legal colleague, Cenric Clement-Evans, for his constructive comments at various stages in drafting these guidelines, and for his general encouragement of and collaboration with this work. We are also grateful to Diana Field for preparing the figures, and to Liz Jennings for her editorial assistance.

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Appendix A. Explanatory and further guidance notes

Note 1. Consideration of noise exposure in terms of negligence by the defendant is a separate issue, and should not be confused with diagnosis. Quantification of the amount of NIHL, disability and similar issues are also outside the scope of these guidelines.

Note 2. When Telephonics TDH-39 audiometer earphones have been used, subtract 6 dB from the measured HTL values at 6 kHz. This is to take account of the calibration artefact associated with use of those earphones.[7] (TDH-39 earphones are the most commonly used in the UK: amongst others, they are used in most Amplivox, Bilsom (CA 850), Inter-Acoustics, Kamplex, Madsen and Peters audiometers. On the other hand, Grason-Stadler audiometers use TDH-49 or TDH-50 earphones that are free of this artefact).

Note 3. If an average of two, several or many hearing threshold measurements at the relevant frequencies in a particular ear can validly be used, the 'at least 10 dB or greater' guideline may be reduced slightly, by up to about 3 dB. In borderline cases, an average of all the audiograms available and acceptable for averaging should be used in assessing the evidence for or against the presence of a high-frequency hearing impairment, notch or bulge. To this end, if when testing the hearing of a case that seems borderline in any of these respects, it will usually help to carry out one or more re-tests at the defining frequencies with repositioning of the earphones between tests. The results of each re-test should be plotted on the audiogram and/or tabulated in the report.

Note 4. Corrections for reported use of hearing protection. In order to estimate the noise reaching the internal ear, allowances have to be subtracted from the levels of noise at work during the years in which hearing protection was understood to have been properly used. Such allowances should only be made where it is believed that the hearing protection had been used virtually all the time (in those years or for a stated proportion of them) that the individual was exposed to hazardous levels of noise.

If the particular protector used can be identified, its attenuation characteristics may be obtainable either from published data (e.g. Martin[8]) or from information provided by its manufacturer. Account has then to be taken of the evidence that hearing protectors are less effective as worn in industry than as measured in the laboratory,[9] their real-world attenuation being about 16 dB less for earplugs and 8 dB less for earmuffs.

Where the actual protector used cannot be identified with certainty, or its attenuation characteristics are not known, recourse may be necessary to the figures in Table 1. This gives values for the mean real-world attenuation of A-weighted noise levels likely to be achieved for various classes of hearing protector.

Table 1. Realistic sound attenuation data for hearing protectors

Class of hearing protector	Real-world attenuation (dB)
Music headphones	0
Cotton wool (dry or waxed)	5
Soft plastic earplugs	10
Canal caps (suprameatal plugs on headband)	10
Personalised earmoulds	10
Glass down earplugs (e.g. Bilsom range)	15
Plastic foam earplugs (e.g. EAR range)	15
Earmuffs	20

Note 5. The presence of a conductive hearing loss may require corrections to be made to the external noise levels in order to estimate the effective levels likely to reach the internal ear (see para. 5.1.). Subtractions from the air-conduction thresholds may also be needed in order to estimate the sensorineural hearing impairment (see Note 10). Due to measurement variability and distortions, air-bone gaps may seem to differ widely (and unrealistically) between frequencies, and may also be markedly small at 2 kHz. Therefore, the best estimate of the conductive component is the air-bone gap averaged over 0.5, 1, 2 and 3 or 4 kHz, providing: (1) that in any bone-conduction tests at 4 kHz the ipsilateral ear is occluded sufficiently to prevent hearing of air-conducted sound radiated from the bone-conduction transducer; and (2) that the bone-conduction thresholds at 2 kHz are excluded from the average if the apparent air-bone gap at 2 kHz is smaller that at all the other frequencies. If the average air-bone gap is $<$ 10 dB, corrections for conductive hearing loss should not be made.

Note 6. Various formulae[2,4,5,10,11] predict, from the estimated noise exposure and subject's age and sex, the extent of hearing impairment to be expected in various percentiles of susceptibility.

At face value these formulae predict that even the most extremely noise-resistant percentiles would suffer some degree of NIHL. They also suggest that noise exposures of low level (e.g. low 80 s in decibels) and duration (e.g. only a few years) would cause small but finite degrees of NIHL in some of those so exposed.

However, their original data sources were limited to cross-sectional studies, and the evidence for such effects is weak, being extrapolations from effects measured mostly in people with around average degrees of susceptibility and large amounts of noise exposure. The earlier work also exaggerated the apparent effect of small noise exposures. Moreover, epidemiological studies involving low level and/or short-duration and/or intermittent exposures (e.g. in forestry workers, marine engine room personnel, miners, underground railway workers, navy divers, aircraft handlers, and exposure of young persons to amplified music) seem to indicate an occurrence of less than the expected degree of hearing loss and in smaller proportions of those exposed.

These scientific considerations have to be judged also in relation to the legal criterion of 'balance of probabilities', and to what can be regarded as a reasonably reliable single measurement in an individual ear. At 4 kHz this is considered to be about 10 dB (see para. 3.2.). According to International Standard 1999 (1990),[5] noise exposure at 90 dB(A) for 10 years, which equates to a NIL value of 100 dB(A), causes a median NIHL of 11 dB at 4 kHz (and, incidentally about 3.5 dB in the 1, 2 and 3 kHz average). Hence, our use of the 100 dB(A) NIL value in R2(a).

Note 7. $L_{EP,d}$ noise levels below 85 dB(A) in fact cause very little NIHL. With low noise levels, the noise immission calculations tend to over-estimate the potential auditory hazard. For example, a virtually safe noise level of 80 dB(A), if heard for 20 years, would yield an apparently unsafe NIL of 93 dB(A). Therefore, it is recommended that $L_{EP,d}$ levels below 85 dB(A) should not be taken into account in estimating the total noise exposure.

Note 8. Noise exposure estimates are often rounded to the nearest whole decibel. Noise level values of 84.5–84.9 dB(A) and NIL values of 99.5–99.9 dB(A) or 89.5–89.9 dB(A) should therefore be regarded as being 85 dB(A), 100 dB(A) or 90 dB(A), respectively.

Note 9. Bone-conduction measurements are very variable and prone to calibration artifacts and distortions, such as the Carhart effect which occurs in most forms of conductive hearing loss. They should not therefore be used for judging the shape of audiograms for diagnostic purposes, although they are of course useful for identification and quantification of a conductive hearing loss. The possibility of a noise-induced notch or bulge should therefore be judged only from the shape of the air-conduction audiogram.

Note 10. Derivation of comparison values of age-associated hearing loss (AAHL). In order to obtain comparison values of AAHL in an individual ear the following procedures are recommended. See also the worked example shown in Table 4, lines a–g.

First, correct the measured hearing threshold level (HTL) values for any conductive hearing loss of $\geq$ 10 dB (see Note 5) and, if appropriate, for the use of TDH-39 earphones (see Note 2). Then, look at the corrected HTL values (line a) at the audiometric frequencies just above and below those most usually affected by noise. At the high frequency end of the range this is usually 8 kHz. Occasionally though, e.g. where there is a precipitous fall-off above 6 kHz, that frequency is a better indicator of the upper end of the probable AAHL pattern affecting the rest of the frequency range. The HTL at 8 kHz is therefore usually taken as the 'upper anchor point' for estimating the likely extent of AAHL in an individual ear.

Towards the lower end of the frequency range, 1 kHz is usually the best frequency to use as the 'lower anchor point'. Audiometry is fairly precise at that frequency. It is also relatively free from ambient and physiological noise masking effects and other factors which so often seem to cause 10–20 dB impairments at 0.25 and 0.5 kHz. Occasionally 0.5 or 2 kHz will be more appropriate, for example when the HTL there is more than 5 dB better than at 1 kHz.

Statistical data on AAHL are then consulted. Those shown in Tables 2 and 3 are recommended. For the plaintiff's sex and approximate age (up to 10 years above or below the actual age) the AAHL data that correspond best to the values at the two 'anchor points'(line b) are then selected (line c).

Next, calculate (line d) the misfit values. These are the differences between the statistical values (line c) and the measured HTLs at the two 'anchor points' (line b). Then (line e), interpolate misfit values for the intermediate frequencies. Go on to add these misfit values (lines d and e) to the statistical values (line c) to derive the adjusted AAHL values (line f). The adjusted AAHL values (line f) are the ones to compare with the corrected HTLs (line a) to estimate to what extent a NIHL-like bulge may be present (line g).

Note 11. Asymmetrical hearing impairment. Robinson,[6] in the second criterion of his scheme for identifying other causation in cases of NIHL, indicates the 'normal' limits of asymmetry in uncomplicated cases of NIHL.

In some cases of asymmetrical sensorineural hearing impairment there may be an apparent explanation. Examples include: asymmetrical noise exposure, the asymmetrical protective effect of unilateral or greater conductive hearing loss on one side or of a unilaterally poorly fitting hearing protector, asymmetrical AAHL or other asymmetrical components of the hearing impairment.

In yet other cases, there is no apparent explanation for the presence of a significant NIHL-like notch or bulge on one side only. These cases are compatible with the presence of NIHL but with varying degrees of probability. For instance if one ear meets R3(a) or R3(b), and the other ear also shows a notch or bulge but it is smal-

Table 2. Typical age-associated hearing loss (AAHL) data for men*

		Predicted hearing threshold levels (dB) at the following ages in years												
Frequency (Hz)	Percentile	20	25	30	35	40	45	50	55	60	65	70	*75*	*80*
250	75	2	2	2	3	3	4	4	5	6	7	8	*9*	*11*
	50	8	8	8	8	9	10	11	12	13	14	16	*17*	*19*
	25	14	14	15	15	16	17	18	20	21	23	25	*27*	*29*
500	75	1	1	1	1	2	2	3	4	5	6	8	*9*	*11*
	50	5	5	6	6	7	8	9	10	11	13	14	*16*	*18*
	25	11	11	11	12	13	14	15	17	19	21	23	*25*	*28*
1000	75	−2	−2	−1	−1	0	0	1	2	4	5	6	*8*	*10*
	50	2	2	3	3	4	5	6	7	9	11	13	*15*	*17*
	25	7	7	7	8	9	11	12	14	16	18	21	*24*	*27*
2000	75	−1	−1	0	0	1	3	4	6	8	11	13	*16*	*19*
	50	4	4	5	6	7	9	11	13	16	19	22	*26*	*30*
	25	9	10	11	12	14	16	19	22	25	30	34	*39*	*44*
3000	75	−1	−1	0	1	3	5	7	10	14	17	21	*26*	*31*
	50	4	5	6	7	9	12	15	19	23	28	34	*40*	*46*
	25	11	11	13	15	17	21	25	30	36	42	49	*57*	*65*
4000	75	0	1	2	4	6	9	13	17	21	27	33	*40*	*47*
	50	6	7	8	11	14	18	22	28	34	41	49	*58*	*68*
	25	14	14	16	19	24	29	35	42	50	59	70	*81*	*93*
6000	75	0	1	2	4	7	10	14	19	24	30	37	*45*	*53*
	50	7	8	10	12	16	20	25	32	39	47	56	*65*	*76*
	25	16	17	19	22	27	33	39	48	57	67	79	*92*	*105*
8000	75	0	1	2	5	8	12	17	23	29	37	45	*54*	*64*
	50	8	9	11	14	18	24	30	38	46	56	67	*79*	*92*
	25	17	18	21	25	31	38	46	56	67	80	94	*110*	*120*

*Modified from International Standard ISO 7029 (1984)[1] which gives estimates for threshold shifts as a function of age in highly screened populations and is known as Database A. The above table is modified from the standard by utilising a baseline for 18-year-olds that differs from the zero value in the standard. The baseline is from the bottom line of Table 6 in Lutman and Davis (1994)[12] after subtraction of 6 dB at 6 kHz to allow for the artificial increase in hearing threshold levels in that study attributable to the use of TDH-39 earphones. Specifically, the baseline values are 7.5, 5.0, 2.0, 3.5, 4.0, 6.0, 7.0 and 7.5 dB, respectively, at 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz. Figures in italics are derived from extrapolation beyond the age limit of 70 years used in the standard. Values > 120 dB have been truncated at 120 dB. See also Note 12.

Table 3. Typical age-associated hearing loss (AAHL) data for women*

		Predicted hearing threshold levels (dB) at the following ages in years												
Frequency (Hz)	Percentile	20	25	30	35	40	45	50	55	60	65	70	*75*	*80*
250	75	2	3	3	3	4	4	5	6	6	7	9	*10*	*11*
	50	8	8	8	8	9	10	11	12	13	14	16	*17*	*19*
	25	14	14	14	15	16	17	18	19	21	23	24	*27*	*29*
500	75	1	1	1	1	2	2	3	4	5	6	8	*9*	*11*
	50	5	5	6	6	7	8	9	10	11	13	14	*16*	*18*
	25	11	11	11	12	13	14	15	17	19	21	23	*25*	*28*
1000	75	−2	−2	−1	−1	0	0	1	2	4	5	6	*8*	*10*
	50	2	2	3	3	4	5	6	7	9	11	13	*15*	*17*
	25	7	7	7	8	9	11	12	14	16	18	21	*24*	*27*
2000	75	−1	−1	0	0	1	2	4	5	7	9	11	*14*	*17*
	50	4	4	4	5	6	8	10	12	14	17	20	23	27
	25	9	9	10	11	13	15	17	20	23	26	30	*34*	*39*
3000	75	−1	−1	0	1	2	3	5	7	9	12	15	*18*	*21*
	50	4	4	5	6	8	9	12	14	17	21	24	*28*	*33*
	25	10	11	11	13	15	17	20	23	27	32	36	*42*	*48*
4000	75	0	1	1	2	4	5	7	10	12	15	19	*23*	*27*
	50	6	6	7	9	10	13	15	18	22	26	30	*35*	*41*
	25	13	14	15	16	19	22	25	29	34	39	45	*51*	*58*
6000	75	1	1	2	3	5	7	10	13	17	21	25	*30*	*36*
	50	7	8	9	10	13	16	19	23	28	34	39	*46*	*53*
	25	15	16	17	20	23	26	31	36	43	50	57	*66*	*75*
8000	75	0	1	2	3	6	8	12	16	20	25	31	*37*	*44*
	50	8	8	10	12	15	18	23	28	34	41	48	*56*	*65*
	25	17	18	20	23	26	31	37	44	51	60	70	*80*	*92*

*Modified from International Standard ISO 7029 (1984)[1] which gives estimates for threshold shifts as a function of age in highly screened populations and is known as Database A. The above table is modified from the standard by utilising a baseline for 18-year-olds that differs from the zero value in the standard. The baseline is from the bottom line of Table 6 in Lutman and Davis (1994)[12] after subtraction of 6 dB at 6 kHz to allow for the artificial increase in hearing threshold levels in that study attributable to the use of TDH-39 earphones. Specifically, the baseline values are 7.5, 5.0, 2.0, 3.5, 4.0, 6.0, 7.0 and 7.5 dB, respectively, at 0.25, 0.5, 1, 2, 3, 4, 6 and 8 kHz. Figures in italics are derived from extrapolation beyond the age limit of 70 years used in the standard. Values > 120 dB have been truncated at 120 dB. See also Note 12.

ler than the 10 dB or 20 dB required, then the probability of NIHL is still high. If one ear is markedly better at high frequencies and shows a significant notch or bulge, but the worse ear shows little or no trace of such, then there is still a more-likely than-not probability of NIHL: the greater hearing impairment in the worse ear may be due to some unidentified cause additional to NIHL and ordinary AAHL, that additional disorder having hidden or obliterated the noised-induced notch or bulge. In other cases there is not much difference between the two ears at high frequencies but, without apparent explanation, only one ear shows a significant notch or bulge and the other shows little or no trace of one: such cases should be regarded as very borderline and be decided on the strength of other evidence (e.g. severity of noise exposure or of temporary postexposure symptoms). Finally, if only the worse ear at high frequencies shows a significant notch or bulge, and there is little or no trace of NIHL in the better ear, then there is only a possibility of NIHL, not a probability.

Note 12. ISO 7029[1] includes a baseline term to represent the median hearing threshold level (HTL) of 18-year-olds, although the standard suggests that for practical purposes this may be assumed to be zero. Since the publication of the standard, it has become evident that values greater than zero are appropriate for representative populations screened to exclude otological disorder and noise exposure. The formulation within ISO 7029 entails that the distribution of HTLs is not fixed, but varies according to the median value. Hence, incorporation of a nonzero baseline also increases the spread of the distribution. A revision of ISO 7029 is being prepared and is currently at a final draft stage. The revised version will remove the dependence of the spread on the baseline value. Hence, the values in Tables 2 and 3 have been calculated without this dependence, to conform to the forthcoming version of the standard.

Appendix B. Worked example of application of requirement R3(a)

Take a hypothetical claimant, aged 57. He had a total of 23 years of unprotected exposure to high levels of noise in the steel industry, which would easily meet qualifying requirement R2(a), making R3(a) the relevant guideline for looking at his audiogram. His hearing was measured with an audiometer employing TDH-39 earphones. There was no conductive hearing loss.

The calculations to see whether or not there is a high-frequency audiometric bulge that meets the NIHL diagnostic guidelines are set out in Table 4 for each ear separately.

DIAGNOSTIC CONCLUSIONS

In the table for the right ear, the better-hearing ear, in line g there is a significant bulge of +13 dB at 3 kHz and of +10 dB at 4 kHz. But there is only a small, nonsignificant trace of a bulge in the worse-hearing ear of only +5 to +3 dB from 2 to 4 kHz in line g. The pattern of asymmetry (see Note 11) is such that the probable diagnosis is of NIHL and AAHL in both ears, together with an additional hearing loss of uncertain causation on the left which has obscured most of the noise damage on that side.

The measured thresholds corrected at 6 kHz (lines a in Table 4) and the adjusted AAHL values (lines f) are illustrated in Fig. 3.

Table 4. Worked example: calculations for the identification of possible presence of noise-induced hearing loss

		Hearing threshold levels (dB) at the audiometric frequencies (kHz)							
	Line	0.25	0.5	1	2	3	4	6	8
Right ear	a HTL measured* and corrected	15	10	10	20	35	40	39†	40
	b HTL at selected 'anchor points'			10					40
	c Selected AAHL statistics‡			8	13	20	28	32	38
	d Misfit values at 'anchor points' (line b minus line c)			+2					+2
	e Interpolated misfit values				+2	+2	+2	+2	
	f Adjusted AAHL values (line c plus lines d and e)			10	15	22	30	34	40
	g Audiometric bulge (line a minus line f)			0	+5	+13	+10	+5	0
Left ear	a HTL measured* and corrected	15	15	10	25	35	45	54†	60
	b HTL at selected 'anchor points'			10					60
	c Selected AAHL statistics§			13	21	30	40	51	54
	d Misfit values at 'anchor points' (line b minus line c)			−3					+6
	e Interpolated misfit values				−1	+1	+2	+4	
	f Adjusted AAHL values (line c plus lines d and e)			10	20	31	42	55	60
	g Audiometric bulge (line a minus line f)			0	+5	+4	+3	−1	0

*Corrected for any conductive hearing loss of ≥ 10 dB (see Note 5).
†Corrected by 6 dB for TDH-39 earphone calibration artefact (see Note 2).
‡ From Table 2, age 55, median values.
§ From Table 2, age 55, 75th percentile values.

