OCCUPATIONAL NOISE EXPOSURE AND EFFECTS ON HEARING

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W. Passchier-Vermeer

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EXECUTIVE SUMMARY

This report has been written by order of the Commission of the European Communities, Directorate General of Employment, Social affairs and Education. It is intended to represent the state of the art concerning occupational noise exposure and its effects on workers exposed. In that respect it emphasizes aspects related to the Council Directive 86/188/EEC of 12 May 1986 on the protection of workers from the risks related to exposure to noise at work and to the prominent international standard ISO 1999 "Acoustics-Determination of occupational noise exposure and estimation of noise-induced hearing impairment" issued in 1990.

ISO 1999 specifies a model to calculate hearing threshold levels of populations exposed to noise during working hours. Several questions related to the model have been analyzed in this report. They concern the following three aspects.

1. To estimate hearing threshold levels of populations exposed to occupational noise, the age-related hearing threshold levels of reference populations not exposed to occupational noise have to be known. Since different criteria can be applied to the selection of such a population, ISO 1999 allows for two possibilities by two different data bases:
   a) a non-noise exposed otologically selected population (data base A; see ISO 7029);
   b) any other population selected by the user of ISO 1999 as being appropriate. In two annexes of ISO 1999, two examples of such data bases are given one example being database ISO B.
      Unfortunately, both examples are irrelevant with respect to the hearing of non-noise exposed otologically unselected populations. Therefore, in addition to data base A for otologically selected populations, data are needed for otologically unselected populations.

   In this report it has been shown that at least for smaller sized populations data base ISO A may serve as a data base for otologically unselected populations with the 0,90-fractile values unchanged and with median values increased by 2 dB and 0,10-fractile values increased by 6 dB. Data base ISO B and the data base published by Robinson (1988) both overestimate age-related hearing threshold levels of otologically unselected populations not exposed to occupational noise. Possible explanations of the discrepancy may be the inclusion of subjects with occupational noise exposure in the reference populations from which the ISO B and the Robinson data base have been derived, or differences in the scale on which the audiometric investigations have been carried out, since both data base ISO B and Robinson's data base are based upon mass surveys. At the same time, both data bases are based on surveys carried out 10 to 30 years ago.

2. The experimental data on which ISO 1999 is based, have been collected some 25 years ago. At that time, there did not yet exist international standards on noise measurements and audiometry. It therefore seems relevant to verify the relations between hearing impairment and noise exposure given in ISO 1999 with results of more recent research in which modern equipment and standardized procedures have been applied. In the report an analysis of results of recent epidemiological surveys has been summarized showing that there is, on the average, a very good agreement between observed median hearing threshold levels of occupational noise-exposed populations and those calculated by using the model given in ISO 1999. On the average, $HTL_{0,10}$-values are to a small extent underestimated by the relations given in ISO 1999. However, the analysis of the epidemiological surveys showed a variation in median hearing threshold levels of occupational noise-exposed populations which is about twice as large as could be expected from statistical considerations. Although this extra variability may be partly explained by changes in noise exposure levels in the past, it may also be possible that as yet unknown intervening variables play a role in the development of noise-induced hearing loss. In that respect, it seems unlikely that the impulsiveness of occupational noise is a relevant factor.

3. In ISO 1999, the relations between hearing impairment and noise exposure are base primarily on data collected with essentially broad-band steady non-

tonal noise. According to ISO 1999 the application of the model given represents the best available extrapolation to tonal or impulsive/impact noise. This has been questioned at large, since there is substantial evidence from animal experiments and from experiments using temporary threshold shift as indicator, that effects of impulse/impact noise on hearing are more adverse than those of steady-state noise. However, an analysis of the results of epidemiological surveys could not show any extra damaging effect on hearing due to exposure to impulse/impact noise in comparison with exposure to steady-state and fluctuating noise.

The Council Directive 86/188/ECC specifies that where the daily personal exposure of a worker to noise is likely to exceed 85 dB(A) or the maximum value of the unweighted instantaneous sound pressure is likely to be greater than 200 Pa (140 dB relative to 20μPa), appropriate measures shall be taken. In that respect, the Directive puts equal weight to the noise exposure level during a working day and to the instantaneous sound pressure. It is also indicated in the Directive that if the maximum value of the A-weighted sound pressure level, measured with a conventional sound level meter (type 1 according to IEC 651) using time characteristic I (according to IEC 651) does not exceed 130 dB(AI), the maximum value of the unweighted instantaneous sound pressure can be assumed not to exceed 200 Pa. However, care has to be taken in interpreting maximum dB(AI)-readings of conventional sound level meters in terms of true unweighted instantaneous peak sound pressure levels. The difference between both measures, assumed to be 10 dB according to the Council Directive, may exceed 20 dB in exceptional industrial situations with maximum L_{AI}-values of 130 dB(A) or more.

1. INTRODUCTION

The second edition of ISO 1999 "Acoustics - Determination of occupational noise exposure and estimation of noise-induced hearing impairment" has been issued in 1990. This ISO-standard was preceded by ISO/DP 1999/1 (circulated in 1980), by ISO/DIS 1999/1 (circulated in 1982) and by ISO/DIS 1999/2 (circulated in 1986). Although some important changes have been made in the texts of the successive documents, the relations given between noise-induced hearing impairment and noise exposure remained essentially unchanged. In that respect, the report issued in 1982 by the Commission of the European Communities "Correlation between hearing impairment risk and exposure to noise", which has been based on ISO/DP 1999/1 (1980) is still relevant with respect to the present ISO 1999.

ISO 1999 specifies a model to calculate hearing threshold levels of populations exposed to noise during working hours. In that respect, it is a leading document in the field of hearing conservation. E.g., the Council Directive 86/188/EEC of 12 May 1986 specifies that noise experienced at work shall be assessed by the daily personal noise exposure of a worker ($L_{EP,d}$). This term is essentially the same as the noise exposure level normalized to a nominal 8 h working day ($L_{EX,8h}$), as specified in ISO 1999. However, notwithstanding the prominent character of ISO 1999, the document still raises questions and leads to deliberations on the following aspects:

- the data used in preparing ISO 1999 come from reports by Passchier-Vermeer (1968), based on an analysis of even earlier studies, Baughn (1973), and Burns and Robinson (1970). The experimental data on which ISO 1999 is based, have been collected some 25 years ago. At that time, there did not yet exist international standards on noise measurements and audiometry. It therefore seems relevant to verify the relations between hearing impairment and noise exposure given in ISO 1999 with results of more recent research in which modern equipment and standardized procedures have been applied.
- the relations between hearing impairment and noise exposure are based primarily on data collected with essentially broad-band steady non-tonal noise. According to ISO 1999 the application of the model given represents the best available extrapolation to tonal or impulsive/impact noise. This has been questioned at large, as stipulated by e.g. Henderson and Hamernik in their extensive paper on "Impulse noise: critical review (1986)". It therefore seems necessary to verify the model in ISO 1999 for impulsive/impact noise.

- to calculate hearing threshold levels of populations exposed to occupational noise, the age-related hearing threshold levels of reference populations not exposed to occupational noise have to be known. Since different criteria can be applied to the selection of this population, ISO 1999 allows for two possibilities by two different data bases:
  a) a non-noise exposed otologically selected population (data base A; see ISO 7029);
  b) any other population selected by the user of ISO 1999 as being appropriate. In two annexes + wo, examples of such data bases are given. One example (data base B) gives data adapted from the results of a particular mass survey carried out in the USA. As a note to the relevant annex of ISO 1999 states: some subjects in the population tested have to be assumed to have had unreported occupational or other noise exposure. Therefore, this data base B seems inappropriate to serve as a reference for non-noise exposed populations. The other example of a reference data base has been constructed only to relate data in the first edition of ISO 1999 (issued in 1975) to those in the second edition and is not based on observations of hearing threshold levels of any real population. Therefore, data on age-related hearing threshold levels of otologically unselected reference populations, not exposed to occupational noise, are missing in ISO 1999. Due to the lack of this information, it is in principle impossible to apply the model given in ISO 1999 to otologically unselected populations. Therefore, in addition to data base A for otologically selected populations, data are needed for otologically unselected populations.
- according to ISO 1999, the use of the document for instantaneous sound pressures exceeding 200 Pa (140 dB relative to 20 μPa) should be recognized as extrapolation. The Council Directive 86/188/EEC of May 1986 specifies that if the unweighted instantaneous sound pressure is likely to be greater than 200 Pa appropriate measures shall be taken. However, the measurement of the true instantaneous peak level is complicated requiring specialized equipment (real time analysers) to analyse the pressure wave form. According to Price (1988) it is difficult to obtain accurate or consistent measures of the instantaneous unweighted peak pressure by using conventional sound level meters.

In the following paragraphs, these aspects will be considered in more detail, taking into account results of recent research.

For information, in chapter 6 terms and symbols used in this report have been specified.

2. DATA BASES FOR OTOLOGICALLY UNSELECTED POPULATIONS, NOT EXPOSED TO NOISE DURING WORKING HOURS

2.1 Introduction

To estimate the effects of noise on the hearing of populations exposed to it during working hours, it is advantageous to be able to use the hearing threshold level data of all workers, without having to carry out thorough medical otological examinations to select those workers without any otological abnormalities. It is therefore interesting to know whether differences do exist in hearing threshold levels of a total population of workers - or subpopulation of workers selected according to age, exposure time and exposure level - and of a subgroup of that total population or subpopulation, which has been otologically selected. In the following paragraph it is shown that these differences do exist. Therefore, in paragraph 2.3 these differences for occupational noise exposed populations have been taken into account with respect to data bases for otologically unselected populations, not exposed to noise during working hours.

2.2 Differences between hearing threshold levels of otologically unselected populations and those of otologically selected (sub)population

Three recent surveys considered the differences between hearing threshold levels of otologically unselected populations and those of otologically selected (sub)populations (Irion, 1983; Taylor, 1984; Passchier-Vermeer, 1987, see also Rövekamp, 1987). In all three surveys thorough medical otological examinations were carried out and extensive questionnaires on aspects of hearing and noise exposure had to be answered by the workers.

The survey by Irion concerns 1129 occupational noise-exposed workers. The number of workers with otological abnormalities, not due to occupational noise exposure, those having used ototoxic drugs and/or having had ototoxic infective diseases, those with hearing impairment from manipulations during World War II is in total 285, which is 25% of the total population considered.

The survey by Passchier-Vermeer concerns 2076 workers. The percentage of workers with otological abnormalities, not due to occupational noise exposure, and those having used ototoxic drugs or had ototoxic infective diseases or serious head injuries is 27% of the total population considered.

The survey by Taylor concerns hearing threshold levels of 1230 persons, of which 370 subjects not exposed to occupational noise, 244 press operators and 616 hammer operators. Persons with otological pathology are 15% of the total population.

In the next table the differences, averaged over the three surveys, between the hearing threshold levels of the otologically unselected populations and those of the otologically selected subpopulations are given for the fractiles 0,90, 0,50 and 0,10.

Table 1 Differences between hearing threshold levels of otologically unselected populations and otologically selected (sub)populations. (Otological selection resulted in 15-25% rejections.) Differences for the fractiles 0,90, 0,50 and 0,10.

Frequency (in hertz)	Differences in hearing threshold levels (in dB) for fractile 0,90	fractile 0,50	fractile 0,10
500	0	2	6
1000	0	2	7
2000	0	2	6
3000	0	2	4
4000	1	2	5
6000	0	2	6
average	0	2	6

The table shows that differences are independent of frequency. Therefore an average value over the frequencies considered is also given in the table.

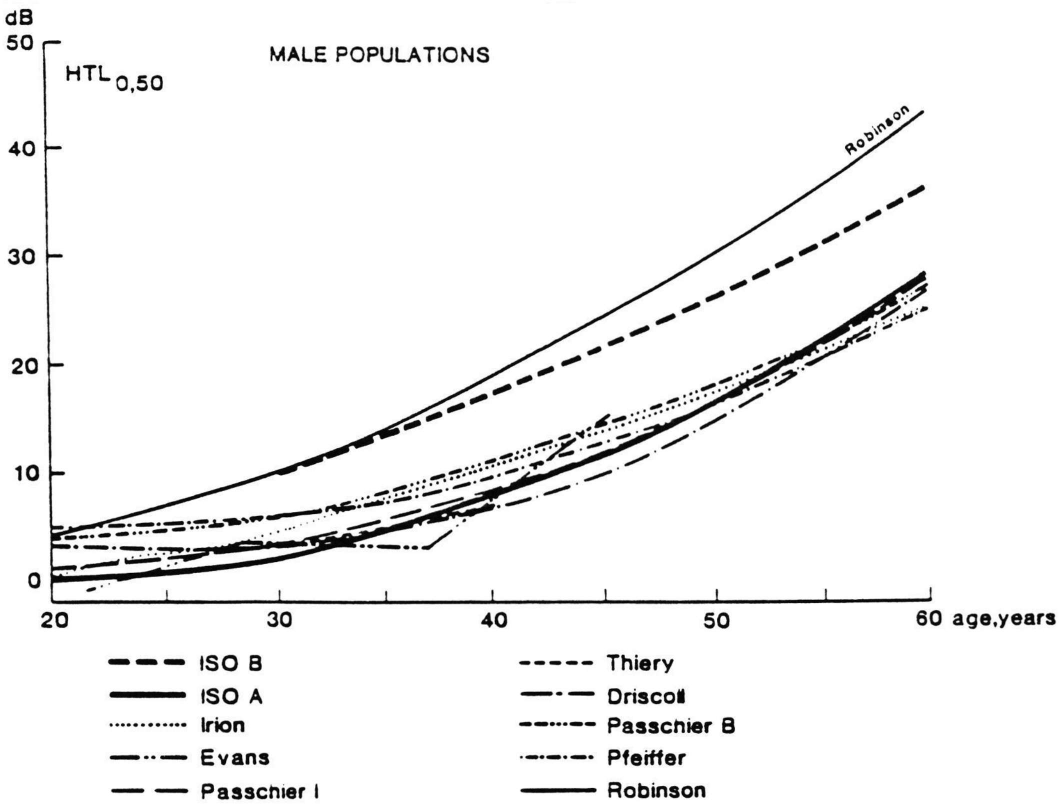
The analysis shows that there is no difference in the $HTL_{0,90}$-values of otologically unselected populations and those of the otologically selected subpopulations. Otological selection results in differences of 2 dB between median values and in differences of 6 dB between $HTL_{0,10}$-values. The otological selection resulted in 15 to 25% rejections from the original otologically unselected populations to construct the otological selected subpopulations. Since the analysis is based mainly on a comparison of hearing threshold levels of noise-exposed populations, the question remains whether the differences mentioned are also applicable to populations, not exposed to noise during working hours. The next paragraph deals with that question.

2.3 Hearing threshold levels for otologically unselected populations, not exposed to noise during working hours.

Recently, seven data bases for male populations have been published (Irion, (1983), German population; Evans (1982), population from Hong Kong; Pfeiffer (1985), German population; Thiery (1988), French population; Driscoll (1984), black USA population, Passchier B (1984) and Passchier I (1987), Netherlands populations). They all, except one, are surveys on populations of 300 to 500 persons. In all surveys careful selection has been made to exclude test persons with noise exposure during working hours.

In figure 1 the median hearing threshold levels at 4000 Hz are given as a function of age for the male populations of the seven investigations, together with ISO data base A, ISO data base B and a data base recently given by Robinson (1988). The data base given by Robinson has been derived from an analysis of eight publications: Glorig (1965), Glorig (1957), Martin (1975), Roberts (1975), Roberts (1970), Royster (1979), Sutherland (1978) and Yaffe (1961). Six out of the eight publications are of the mass-survey type, covering in total more than 80 000 ears. The Robinson data base also concerns otologically unselected populations.

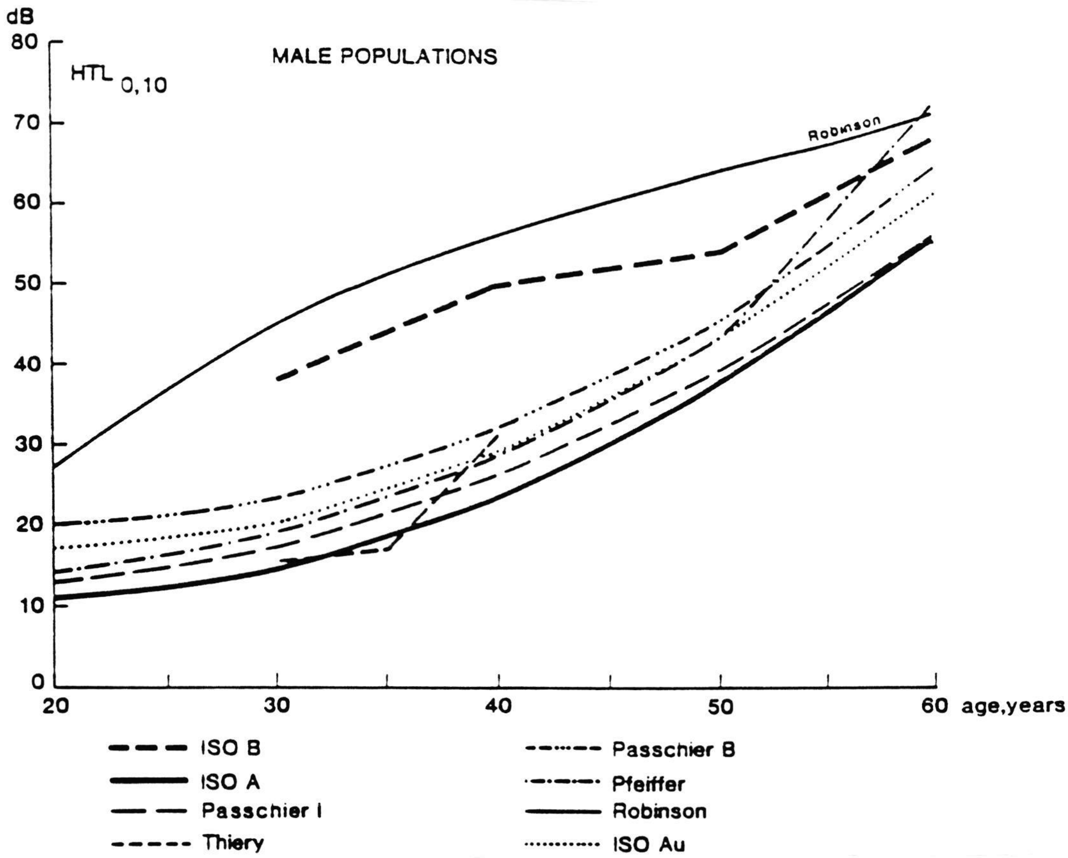
Figure 1 Median hearing threshold levels at 4000 Hz as a function of age. Male populations.



The figure shows that the median hearing threshold levels of the otologically unselected populations from the seven studies mentioned correspond reasonably with those of data base ISO A. At the same time there would have been a good correspondence if data base ISO A would have been increased by 2 dB, as being the difference between median hearing threshold levels of otologically unselected and selected populations.

The next figure gives the hearing threshold levels ($HTL_{0,10}$) at 4000 Hz for 0,10 of the population. The curves in the figure all refer to otologically unselected 11populations, with exceptions of the curve representing the data given by Thiery. To compare the curves with a hypothetical curve representing an otologically unselected data base ISO A, 6 dB has been added to data base ISO A (for the 6 dB, see table 1). This curve is indicated by ISO Au (u: unselected). From the figure it is obvious that the various curves are in agreement with data base ISO Au and that, especially at the middle ages, a large discrepancy exists between these various curves, data base ISO B and the data base given by Robinson.

Figure 2 Hearing threshold levels, just exceeded by 0,10 of the population, at 4000 Hz, as a function of age. Male populations.



As the figure shows, the Robinson data base has hearing threshold levels even well above data base ISO B, especially for fraction 0,10. The discrepancy between the data base presented by Robinson and the other data bases may be due to inclusion in the Robinson data of subjects with occupational noise exposure, since his paper does not touch upon that question. In an earlier report (Robinson, 1978), Robinson states that "the distinction between the unscreened (U) and public participation (P) groups is not only a matter of scale (though this is a characteristic of most of the examples), but the likelihood that other factors may be implicated, such as different environmental test conditions and the preparation and motivation of the subjects. The reliability of the data is unlikely to be in direct proportion to the numbers tested". Moreover, the relations given by Robinson are based on surveys carried out 10 to 30 years ago. Especially the results of the oldest surveys may not be representative for the relations of hearing with age, of populations of nowadays. In the next chapter reference will be made again to the Robinson data base.

All in all it seems justified to conclude that the hearing threshold levels at 4000 Hz of otologically unselected male populations as a function of age correspond to data base ISO A, to which the adjustments mentioned have been applied. For other frequencies (500, 1000, 2000, 3000 and 6000 Hz) this has been verified with two data bases (Passchier-Vermeer, 1988). If appropriate, this result should be limited to smaller sized surveys. At the same time, it should be stipulated that a careful selection has been carried out to exclude persons exposed to noise in present and past jobs.

3. HEARING THRESHOLD LEVELS OF POPULATIONS EXPOSED TO OCCUPATIONAL NOISE

3.1 Introduction

Recently, four extensive surveys have been published on the effects of noise during working hours on the hearing of people (Hohmann, 1984, 1988; Pfeiffer 1985, 1988; Passchier-Vermeer, 1989, 1990; Robinson, 1987). The epidemiological surveys by Hohmann and Pfeiffer deal with the effect of impulse/impact noise on hearing, the other two surveys give an analysis of surveys which deal with all types of noise exposures, i.e. to steady, intermittent, fluctuating and impulse/impact noise. Details and results of the surveys are given in the next paragraphs. First, the relations between noise exposure and hearing are considered for all types of noise exposures, then the results are focussed on exposure to impulse/impact noise. At last the variations in hearing threshold levels between populations are considered.

3.2 Hearing threshold levels of occupational-noise exposed populations

In Passchier-Vermeer (1989, 1990) the data out of 13 recent publications (Evans (1982), Pfeiffer (1985), Thiery (1989), Taylor (1984), Abel (1984), Chung (1985), Prosser (1988), Stanzo (1983), Passchier (1987, 1988), Irion (1983), Waudby (1984), Sataloff (1984)) have been analysed. The data concern hearing threshold levels and noise exposure levels of 56 populations and subpopulations. It has been verified whether the model on the relation between noise exposure and hearing as given in ISO 1999 is appropriate. To that end, age-related hearing threshold levels of reference otologically unselected populations, not exposed to noise during working hours have been taken from data base TSO A, with the modifications given in table 1 of this report.

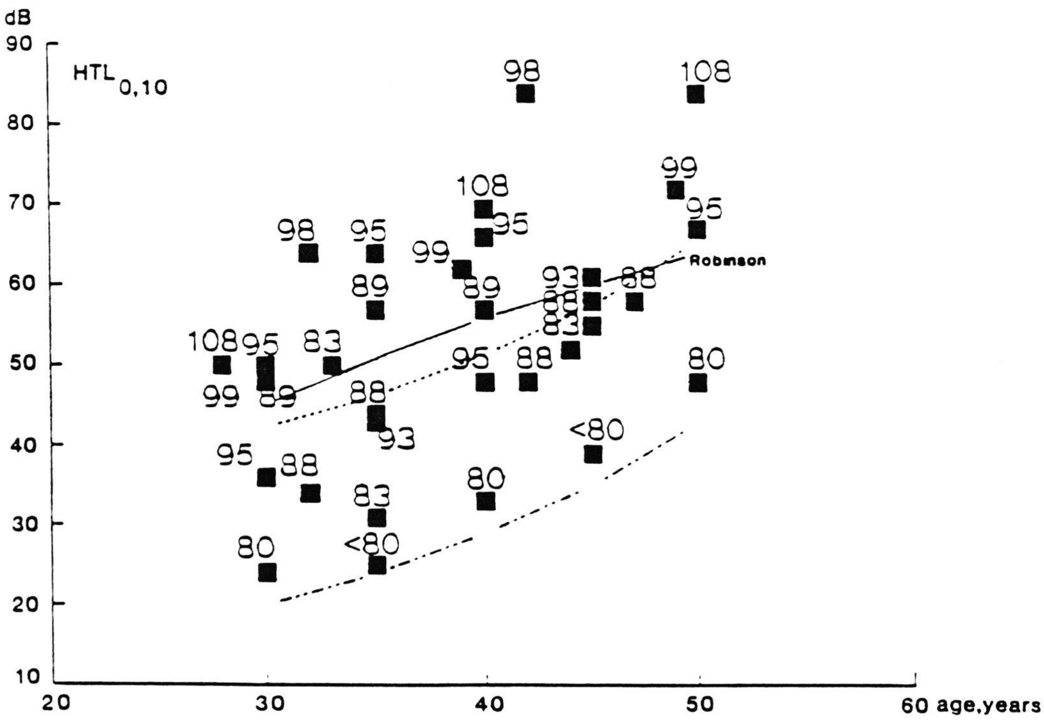
In ISO 1999 relations between median hearing threshold levels and noise exposure are given, noise exposure being expressed in the noise exposure level normalized to a nominal 8 h working day $L_{EX,8h}$. On the average, there is a very good agreement between the observed median hearing threshold levels and those calculated from $L_{EX,8h}$ by using the relations given in ISO 1999. This holds for the whole noise exposure level range considered, i.e. $L_{EX,8h}$ ranging from 80 to 100 dB (A). Only the relations at 4000 Hz have been verified, since at this frequency noise-induced permanent threshold shift is maximal over the whole audio frequency range.

Also, the relations between $HTL_{0,10}$ and noise exposure have been verified. On the average, the observed $HTL_{0,10}$-values are somewhat higher than those predicted by ISO 1999. The discrepancy between observed and calculated values corresponds to a difference of 2 dB(A) in the observed noise exposure levels and those estimated from $HTL_{0,10}$ using the relations given in ISO 1999. This holds for the whole noise exposure level range considered and for the test frequency 4000 Hz.

In a report published by Robinson (Robinson, 1987) on the relations between noise-induced hearing loss and noise exposure, a new analysis is made of older experimental data. He develops a model on the relationship of noise-induced hearing loss and noise exposure, in which the age-related hearing threshold levels play a critical role. There appears to be a large discrepancy between the hearing threshold levels according to ISO 1999 and those according to Robinson's new data for otologically selected and otologically unselected populations.

In figure 3, the observed $HTL_{0,10}$-values of the otologically unselected populations considered in Passchier-Vermeer (1989, 1990) have been plotted as a function of the mean ages of these populations, with their noise exposure level for a nominal 8 h working day as parameter. At the same time, the relation between $HTL_{0,10}$ and age according to ISO 1999 for an $L_{EX,8h}$-value of 95 dB(A) is given. Also, curves for otologically unselected populations, not exposed to noise during working hours, according to Robinson and according to data base ISO A, with the adaption for the otological unselected populations, are plotted in the figure.

Figure 3 $HTL_{0,10}$-values at 4000 Hz of otologically unselected populations as a function of the mean age of the populations, with $L_{EX,8h}$ as parameter. The relation between $HTL_{0,10}$ and age for $L_{EX,8h}$ equal to 95 dB(A), according to ISO 1999, and the relations between $ATL_{0,10}$, for unselected populations not exposed to noise during working hours, and age according to Robinson and to ISO Au are also given.



■ observed $HTL_{0,10}$-value with $L_{EX,8h}$ as parameter

············ $HTL_{0,10}$ according to ISO 1999 for $L_{EX,8h}$ = 95 dB(A)

———— $ATL_{0,10}$ according to Robinson

—··—··— $ATL_{0,10}$ according to data base ISO Au

Figure 3 shows that the values given by Robinson for $ATL_{0,10}$ (i.e. for populations not exposed to noise during working hours!) exceed those given by ISO 1999 for a noise exposure level for a nominal 8 h working day as high as 95 dB(A). It is also obvious that many observed $HTL_{0,10}$-values are much less than given by the Robinson curve. Therefore, this curve must be in error, at least for the populations given in figure 3.

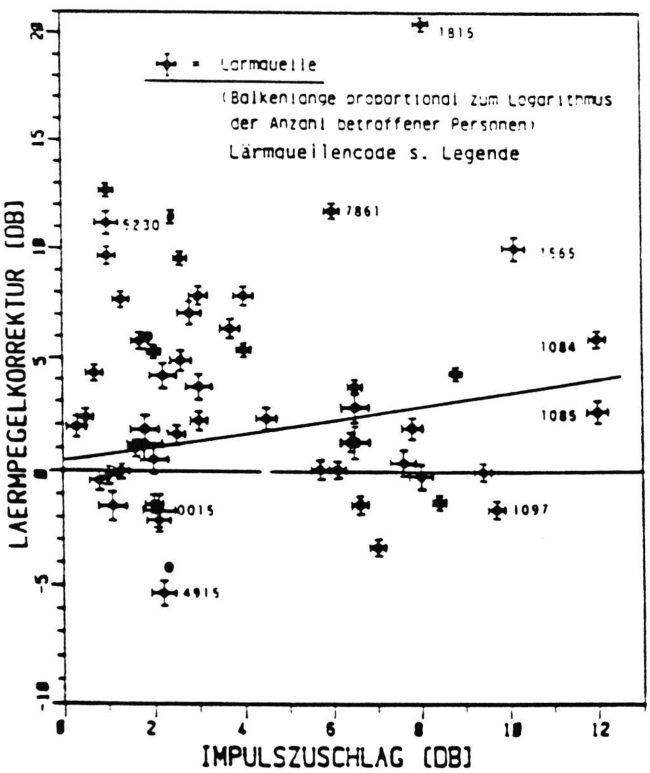
3.3 Effects of impulse/impact noise on hearing

There is substantial evidence that hearing is affected differently by impulse/ impact noise than by steady-state noise (Henderson, 1986). The question is, however, whether this can be shown in epidemiological studies on the permanent effects of noise on hearing threshold levels of populations exposed to noise during working hours.

Three epidemiological studies deal with the permanent effects on hearing of exposure to impulse/impact noise (Hohmann, 1984, 1988; Pfeiffer, 1985, 1988; Passchier-Vermeer, 1989, 1990).

Hohmann carried out a very extensive survey, in which much emphasis has been laid on the noise measurements. The audiometric data concerned more then 250 000 workers. Hohmann relates his audiometric test results to a reference, constructed within this whole audiometric data base. After dividing all workers into 2662 subgroups according to sex, age, noise exposure level and exposure time, reference hearing threshold levels are determined as a function of the variables mentioned. After regrouping, noise exposure levels are determined from the hearing threshold levels of the (sub)populations and compared with the actual measured noise exposure level. The difference is called "Lärmpegelkorrektur". Hohmann gives the "Lärmpegelkorrektur" as a function of the "Impulszuschlag" (the difference between the integrated level of the noise, measured with the sound level meter using time constant I and the noise exposure level, presenting a measure of the impulsiveness of the noise situation at the working places). In figure 4, the appropriate figure from the publication by Hohmann has been reproduced.
The figure shows hardly any relation between both variables. The straight line, giving the most probable fit between Impulszuschlag and Lärmpegelkorrektur has an angle which is not statistically different from 0°. Hohmann concludes that it is correct to assess impulse/impact noise with peak levels below 145 dB(A) by means of the noise exposure level over a nominal 8 hour working day. For impulses/impacts with peak levels over 145 dB(A) a special assessment based on the sound exposure level (L_{Ax}) and the number of impulses/impacts per working day is proposed.

Figure 4 The relation between "Lärmpegelkorrektur" and "Impulszuschlag" according to Hohmann (1984).



0015	Abbaunammer	1815	Schmiedhammer
1084/85	Stanzmascninen	4915	Offset-Rot.-Druckm.
1097	Schagscheren	5230	Webšaal
1565	Giesserei: Auspacken	7861	Flaschenannanme

Among the 56 (sub)populations considered in the analysis by Passchier-Vermeer (1989), thirteen of these (sub)populations have been exposed to typical impulse/impact noise during working hours. The hearing threshold levels of these 13 groups have been analysed with respect to a possible extra damaging effect due to the impulses/impacts. It was concluded that there could not be shown any systematic differences between the hearing threshold levels of the (sub)populations exposed to impulse/impact noise and those of the other (sub)populations exposed to steady state and slowly fluctuating noise.

From a large scale epidemiological investigation on the hearing of workers in the construction industry Pfeiffer concludes that also for impulse noise exposure the model given in ISO 1999.2 (and therefore in ISO 1999) can be applied, without any further impulse/impact correction. His conclusion, however, is based on a comparison of the hearing threshold levels of bricklayers, carpenters, concreters and pipefitters with those of printers and varnishers, assuming the population of painters and varnishers to be an appropriate reference data base. However, in a Netherlands survey (Passchier-Vermeer, 1988) on the hearing of people in the building industry it was shown on the basis of the hearing threshold levels of about 400 painters, that differences do exist between the hearing threshold levels of painters and those of a reference data base. These differences turned out to be on the average 6 dB between median values at 4000 Hz and 9 dB between $HTL_{0,10}$-values at that frequency. At the same time, there turned out to be an excellent agreement between the hearing threshold levels of the painters in the German and Netherlands survey. Unfortunately, Pfeiffer did not compile his own data base, based on hearing threshold levels of persons selected for absence of noise exposure during working hours in present and past jobs.

Therefore, the survey by Pfeiffer does not allow a definite conclusion for the effects of exposure to impulse/impact noise in relation to those effects due to steady-state noise.

3.4 Differences of hearing threshold levels compared between (sub)populations exposed to noise during working hours

In paragraph 3.2 it is shown that the model given in ISO 1999 is in general applicable to estimate the hearing threshold levels of occupational noise exposed populations. Taking into account the age, sex, exposure duration and the noise exposure level $L_{EX,8h}$ of a real or hypothetical population, it is possible from ISO 1999 to calculate the median hearing threshold levels of that population, as well as the statistical distribution of their hearing threshold levels. However, the epidemiological surveys as given by Hohmann (1984, 1988) and as analysed by Passchier-Vermeer (1989, 1990) show considerable differences in the hearing threshold levels observed in populations with comparable values of the parameters mentioned. For the results of the survey by Hohmann, this is demonstrated in figure 4. The figure shows "Lärmpegelkorrekturen" of -5 dB(A) up to +20 dB(A). This indicates differences in hearing threshold levels of comparable populations corresponding to differences in damage-equivalent noise exposure levels of 25 dB(A).

Figure 3 shows the variation in $HTL_{0,10}$-values of the (sub)populations used in the analysis by Passchier-Vermeer (1989, 1990). In Passchier-Vermeer (1989) it is concluded that the observed variation in median hearing threshold levels is about twice as large as could be expected from statistical considerations taking into account possible variations associated with the spread in hearing threshold levels within populations. It is explained (Passchier-Vermeer, 1989) that this extra variability in the median hearing threshold levels of occupational noise-exposed populations may be partly due to (unobserved) changes in noise exposure levels occurred before the start of the surveys and not accounted for in the establishment of the actual noise exposure level. However, it may also be possible that unknown intervening variables have caused the extra variability in median hearing threshold levels. From the surveys by Hohmann and Passchier-Vermeer it seems unlikely that the impulsiveness of the noise at the workplace is a relevant factor in causing this extra variability.

4. MEASUREMENT OF INSTANTANEOUS PEAK SOUND PRESSURE LEVELS

The Council Directive 86/188/ECC specifies that where the daily personal exposure of a worker to noise is likely to exceed 85 dB(A) or the maximum value of the unweighted instantaneous sound pressure is likely to be greater than 200 Pa (140 dB relative to 20 μPa), appropriate measures shall be taken. In that respect, the Directive puts equal weight to the noise exposure level during a working day and to the instantaneous sound pressure. The measurement of the true instantaneous sound pressure (level) is in principle a complicated technique requiring special equipment. Since it is unlikely that this equipment is in general available in the field of hearing conservation, annex I of the Directive states that where an (integrating-averaging) sound level meter is used, which complies at least with the specifications of type 1 according to IEC 651 and IEC 804, the measuring method is generally acceptable and is well suited for reference purposes. It is also indicated in the document, that if the maximum value of the A-weighted sound pressure level, measured with a sound level meter using the time characteristic I (according to IEC 651) does not exceed 130 dB(AI), the maximum value of the unweighted instantaneous sound pressure can be assumed not to exceed 200 Pa.

Two critical remarks seem appropriate in this respect. A study by Price (1988) shows that type 1 sound level meters measure the unweighted peak sound pressure level of impulsive signals on the average within 2 dB of the unweighted true peak level. This average was determined using 8 different sound level meters. However, differences between maximum and minimum readings varied from 4 to 5 dB (using drop forges and blanking presses as noise sources) to 10 dB (using a cap gun in anechoic conditions). Therefore, for impulse/impacts in industrial situations, it seems appropriate to conclude that errors up to 5 dB may occur between single peak sound pressure level measurements.

Van den Berg (Berg, 1980) carried out an extensive survey on the characteristics of impulse/impact noise in industry. Using specialised equipment and using a conventional sound level meter conforming to the specifications of a type 1 instrument given in IEC 651, the differences have been obtained between the A-weighted peak sound pressure levels and the maximum reading (L_{AI}) of the sound level meter using A-weighting frequency characteristics and time constant I. On the average L_{AI} increases linearly with $L_{A,peak}$ according to

$$L_{AI} = -3,9 + 0,93\ L_{A,peak}$$

For an L_{AI}-value of 130 dB(A), $L_{A,peak}$ is equal to 144 dB(A). On the average, $L_{A,peak}$ is 1 to 2 dB below L_{peak}, therefore on average L_{AI} of 130 dB(A) corresponds with L_{peak} of 145 dB for industrial impulses/impacts. However, this only holds for average values. In individual cases, deviations of 5 dB from the average value have been observed. Therefore, in some industrial situations, a maximum L_{AI}-value of 130 dB(A) may correspond to a true instantaneous sound pressure level of 150 dB.

5. CONCLUSION

In the report it has been shown that at least for smaller sized populations data base ISO A may serve as a data base for otologically unselected populations with the 0,90-fractile values unchanged and with median values increased by 2 dB and 0,10-fractile values increased by 6 dB. Data base ISO B and the data base published by Robinson(1988) both overestimate age-related hearing threshold levels of otologically unselected populations not exposed to occupational noise. Possible explanations of the discrepancy may be the inclusion of subjects with occupational noise exposure in the reference populations from which the ISO B and the Robinson data base have been derived, or differences in the scale on which the audiometric investigations have been carried out, since both data base ISO B and Robinson's data base are based upon mass surveys. At the same time, both data bases are based on surveys carried out 10 to 30 years ago.

The analysis of results of recent epidemiological surveys shows that there is, on the average, a very good agreement between observed median hearing threshold levels of occupational noise-exposed populations and those calculated by using the model given in ISO 1999. On the average, $HTL_{0,10}$-values are to a small extent underestimated by the relations given in ISO 1999.

Although there is substantial evidence from animal experiments and from experiments using temporary threshold shift as indicator, that effects of impulse/impact noise on hearing are more adverse than those of steady-state noise, an analysis of the results of epidemiological surveys could not show any extra damaging effect on hearing due to exposure to impulse/impact noise in comparison with exposure to steady-state and fluctuating noise.

An analysis of the epidemiological surveys showed a variation in median hearing threshold levels of occupational noise-exposed populations which is about twice as large as could be expected from statistical considerations. Although this extra variability may be partly explained by changes in noise exposure levels in the past, it may also be possible that as yet unknown intervening variables play a role in the development of noise-induced hearing loss. In that respect, it seems unlikely that the impulsiveness of occupational noise is a relevant factor.

Care has to be taken in interpreting maximum readings of conventional sound level meters (of type 1 according to IEC 651) using A-weighting and time constant I in terms of true unweighted instantaneous peak sound pressure levels. The difference between both measures, assumed to be 10 dB according to the Council Directive, does exceed 20 dB in exceptional industrial situations, in which maximum L_{AI}-values of 130 dB(A) occur.

6. TERMS AND DEFINITIONS

- Equivalent continuous A-weighted sound pressure level, $L_{Aeq,T}$. The level, in decibels, given by the equation

$$L_{Aeq,T} = 10 \lg \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{PA^2(t)}{Po^2} dt$$

where t_2-t_1 is the period T over which the average is taken starting at t_1 and ending at t_2;
P_a is the weighted sound pressure, in pascals and p_o the reference sound pressure equal to 20 μPa.

- Noise exposure level normalised to a nominal 8 h working day, $L_{EX,8h}$: the level, in decibels, given by the equation

$$L_{EX,8h} = L_{Aeq,Te} + 10 \lg Te/T_o$$

where Te is the effective duration of the working day;
To is the reference duration (=8h)

Note: In the Council Directive 86/188/ECC for individual assessment of the daily personal noise exposure of a worker, $L_{EP,d}$ is defined in the same way as $L_{EX,8h}$ with Te the daily duration of a workers personal exposure to noise.

- Hearing threshold level, HTL,H: The permanent threshold of hearing of a person, as defined in ISO 389, in decibels.

- Hearing threshold level, HTL_x, H_x: The value, in decibels, determined from the statistical distribution of hearing threshold levels of a population, above which fraction x of those hearing threshold levels are located.

Note: $HTL_{0,50}$ is often called the median hearing threshold level of a population.

- Hearing threshold level associated with age, ATL, A: The hearing threshold level, in decibels, observed solely in association with age without any influence of noise exposure.

- Hearing threshold level associated with age, ATL_x, A_x: The value, in decibels, above which a fraction x of the hearing threshold levels of a population not exposed to noise during working hours, are located.

- Noise-induced permanent threshold shift, NIPTS, N: The permanent shift, actual or potential, in decibels of the hearing threshold level estimated to be caused solely by exposure to noise, in the absence of other causes.

- Noise-induced permanent threshold shift, N_x: The value, in decibels, above which a fraction x of the N-values of a noise-exposed population are located.

Note: According to ISO 1999 the following formula is applicable:

$$H_x = N_x + A_x - \frac{N_x A_x}{120}$$

- Instantaneous peak sound pressure level, L_{peak}: The level, in decibels, of the maximal peak sound pressure, occurring during noise events, usually of short duration, measured without any frequency-weighting.

- Instantaneous peak sound level, $L_{A,peak}$: The level, in decibels, of the maximal peak sound pressure, determined by using frequency-weighting A (see ISO 651).

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