"THE SISI TEST"

The value of the SISI test for a more reliable
NIPHL diagnosis made by the industrial medical officer

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ABSTRACT

As a result of the world-wide continuing industrialization and the subsequent rising number of people suffering from noise-induced permanent hearing loss (NIPHL), industrial medical officers and staff members of audiological centres find themselves increasingly confronted with the problem of injurious noise.
If, therefore, the industrial medical officer could be given the means to make the diagnosis 'NIPHL' with more certainty and at an earlier stage, this would undoubtedly add to better hearing conservation programme results and a better policy as far as referrals to audiological centres are concerned.
In the present dissertation, a description has been given of an investigation into the value of the 'short increment sensitivity index' (SISI) test for the diagnosis 'NIPHL'. The study was carried out among 716 subjects, selected from the employee population of 16 Dutch industrial firms.
In eight chapters, the aim of the study, the method of investigation, the equipment used, and the results are discussed.

Chapter 1. INTRODUCTION

Day after day, whether at home or at work, millions of people all over the world are exposed to a crescendo of noise. According to a report published in 1968 by the American 'Committee on Environmental Quality of the Federal Council for Science and Technology', between 6 and 16 million people in the USA were working under harmful noise conditions. Since the population in the USA numbers over 200 million, this means that 3 to 8 per cent of that population is in danger of falling a victim to a noise-induced permanent hearing loss (NIPHL). If we take these percentages to apply to the European situation as well, it follows that in the Netherlands, for instance, with a total population of approx. 13 million people, 400.000 to 1 million persons would run such a risk. In Britain (number of inhabitants: 56 million), 1.5 to 4.5 million people would be affected. Now the most injurious noise levels are found in the so-called 'manufacturing industries'. In last year's 'Official Handbook of Britain' (H.M.S.O., 1972) the number of workers in this sector of industry is estimated at 8.5 million. With 4.5 million people daily exposed to injurious noise, one out of every two workers in the British manufacturing industries would be a candidate for a noise-induced permanent hearing loss. Calculations for the Netherlands made some years ago already pointed to a similar conclusion. Finally, if we apply these American percentages to the over 250 million people living in the EEC countries, we see that the 7.5-20 million people employed in noise-producing industries will sooner or later have to pay for their choice of occupation in the form of a noise-induced permanent hearing loss.

This noise hindrance, experienced both at work and elsewhere, has certain physiological, psychological and sociological effects, culminating in an increased interference with man's need for rest, relaxation, sleep, and communication, and with his work situation. Moreover, people also tend to produce more and more injurious noise in the course of their recreational activities. In the big cities of the Western world, the waste products of a still rising living standard literally force themselves upon everyone who lives there. At first, discomfort was mainly limited to water, air, and soil pollution, but in the last two decades the percentage of 'noise pollution' in our densely populated urban areas has more than doubled.

Gradually, however, thanks to continuing press, radio, and TV campaigns, and frequent protests voiced by a great number of action groups, the general public is becoming aware of the fact that the above-mentioned types of pollution are caused by its, i.e. the public's, own way of life. By and large our society is becoming more environment-minded and, although reluctantly, is beginning to show signs of willingness to submit to financial sacrifices in order to attack the problem of environmental pollution and to remove the waste products which the polluters have left behind; waste products which often remain in the environment for a considerable time. However, what people do not, or hardly, realize is that industrial progress is unthinkable without noise.

The acoustician is mainly interested in the origin of noise, in the source from which noise energy is released, and transmitted through the immediate surroundings. The expert on noise problems requires information on the composition of the noise, i.e. on component parts such as frequency spectrum and intensity. This information is needed in order to be able to take preventive, technical measures. In this connection, mention should be made of a recently published booklet entitled 'Code of practice for reducing the exposure of employed persons to noise'. According to the introduction, this code 'deals with the engineering aspect of the reduction of noise exposure of employed persons; it does not include advice to machinery manufacturers, which will be covered separately, or on the medical management of noise-exposed personnel, or on the place of audiometry'.

The expert on noise problems can register noise in the form of a series of objective, physical quantities. The psychologist, on the other hand, tries to obtain an insight into man's reaction to noise. He will attempt, therefore, to relate subjective experiences such as noise annoyance to objectively assessed physical quantities. In sociological circles too (sociology being here defined as the study of group behaviour and social organisation) there is a growing preoccupation with the problem of deafness in man, including the problem of noise-induced hearing loss (*Darbyshire, 1970*).

From a medical point of view, the noise-problem has still different aspects, which necessitate a clearly different approach. Thus far, the medical profession has been mostly interested in the question of the social consequences of noise-induced hearing loss for the individual, and in the question of whether this condition will interfere with the most vital function of the hearing organ, i.e. its capacity to receive speech (*Lindeman, 1969, 1971*).

Empirical research has shown that irritation of the hearing organ, in addition tot inducing typical hearing phenomena, also affects other parts of the body, and more especially the nervous system. These non-auditive system responses mainly result from stimulation by the auditive system of nervous systems which are not primarily concerned with hearing as such. The noise in question may then be well under the 'damage risk criterion' level. Noise annoyance may greatly affect man's psyche: apart from disturbing communication, it may also influence the individual's work output, leading to a decrease in output resulting from a decreased capacity to concentrate. Recent research suggests, however, that 'simple tasks can be aided by noise, while more difficult or complex ones are degraded' (*Hockey, 1972*).

Noise may also lead to a diminishing privacy at home. From the literature it is known that noise can cause artificial nightblindness, resulting from the fact that the eye - under conditions of extremely loud noise - is unable to achieve itself to an optimal dark adaptation. Difficulties may also arise with regard to colour vision. At certain noise levels, people tend to mention the complementary colours instead of the actual ones, due to a restriction of the field of vision. In many laboratories, research is being carried out into the extra-auditive effects of noise upon man. The first, hesitant, steps in the study of the influence of noise upon the autonomic nervous system, upon hormonal changes, and upon changes in metabolism usually come from the sector of psychophysiological research (*Kryter, 1970; Welch, 1970; Paparella, 1970*). The study of these extra-auditive influences of noise upon man is still in an initial stage.

However, thanks to the continuous research efforts of a great many investigators, more insight has gradually been obtained into the physiology of the peripheral hearing organ.

From this introduction it may now be clear, that noise not only forms a source of stress to millions of people, but that it also presents an immense problem to the technicians who have to combat it, and to the industrial medical officers and those at audiological centres who find themselves confronted with increasing numbers of people with hearing complaints.

Chapter 2. THE AIM OF THE STUDY

In chapter 1 it has already been mentioned that as a result of the world-wide continuing industrialization and the subsequent increase in injurious noise, the number of people suffering from NIPHL is still rising. Not only factory noise, but also traffic noise and noise produced in the course of leisure-time activities (e.g. by outboard motors, lawn mowers, and amplifying equipment) contribute to these high noise levels.

Adequate noise abatement requires an immense organization, of which the first task should be to locate, by means of sound measurements, those places and situations where the prevailing amount of noise leads to hearing impairment in man. The second step should then be the reduction of this injurious noise to a non-injurious level by means of preventive technical measures. Since noise - defined as unwanted sound - has a discontinuous character, it will often be impossible to obtain sufficient insight into the injurious quality of noise via (short-term) sound measurements, however.

This is why workers who are exposed to high noise levels should be subjected to periodic audiometric screening (identification) tests.

Of all workers entering a firm, a pre-employment audiogram should therefore be made so that possible future reductions in hearing acuity can be traced.

Nowhere in the world is research into the relationship between noise and NIPHL being carried out on anything approaching a nation-wide scale. In some countries, however, tentative beginnings are being made with periodic audiometric tests for employees working in a noisy environment.

In the Netherlands an increasing number of industrial medical officers is gradually beginning to realize the importance of such tests.

There is a growing public awareness that even in the protection of his employees' hearing the employer has certain duties. Thus, he has to take preventive technical measures to bring injurious noise levels down to the (widely accepted) so-called 'damage risk criterion' level, or, if this proves impossible, to supply the employees concerned with hearing-protective devices.

As a result of these developments - hastened, certainly, by the growing fear that in future large sums may have to be paid for the compensation of NIPHL - the number of industrial medical services advocating or performing audiometric tests in increasing. Every hearing disorder need not be the result of exposure to injurious noise.

In the Netherlands, audiometric screening tests are usually conducted by means of a Peekel continuous sweep frequency audiometer which, at a fixed intensity, checks the frequency range between 250 and 8000 Hz.

If a hearing impairment is discovered, a threshold audiogram is made.

Usually, the industrial medical officer (or his assistant) will only be able to make an air-conduction audiogram.
If the subject is found to have a hearing disorder, he will have to be referred for an audiological examination to a well-trained official, working either at the industrial medical service or at a recognized Audiology Centre of a University Hospital. An examination of this type involves the taking of a thorough medical history, special attention being given to the subject's ENT history and to data about former and/or present noise exposure. After that, an air-conduction (A/C) and a bone-conduction (B/C) audiogram are made. If these two audiograms show identical lesions, (i.e. if there is no gap between A/C and B/C) the diagnosis 'sensorineural deafness' is likely to be correct.

According to its definition, NIPHL is a defect located in the cochlea - which makes it important that a proper differentiation between 'cochlear' and 'retrocochlear' can be established.

In order to determine the localization of an impaired auditory mechanism, a series of tests, usually grouped into a 'battery', can be applied.
The auditory pathway can be divided into four sections, each section being the seat of a fundamental process:

1. relay of vibratory energy to the organ of Corti;
2. conversion of this vibratory energy into a nerve impulse;
3. relay and integration of the nerve impulse;
4. neural processes giving rise to cognition and association.

A conductive deafness refers to malfunction of number 1; a sensorineural deafness refers to malfunction in one or all of the remaining three.
In the course of the years, a number of tests has been developed for the differential diagnosis 'cochlear' versus 'retrocochlear', of which the most important are:

1. the alternate binaural loudness balance (ABLB) test;
2. the monaural bi-frequency loudness balance (MBFLB) test;
3. the short increment sensitivity index (SISI) test;
4. the Békésy audiometric test;
5. the threshold tone decay test;
6. the speech discrimination test;
7. the loudness discomfort level (LDL) test.

The aim of the present study is to check whether the data provided by an A/C and a B/C, plus a brief medical history, plus the results of one or more differential diagnosis tests yield enough information to make the diagnosis 'NIPHL' possible.
A starting-point for the study is a statement made some years ago to the effect that 'not one of these tests, be it the loudness balance procedures, the SISI test, Békésy audiometry, or threshold tone decay testing, is infallible in pinpointing the site of lesion underlying the auditory abnormality under study; the probability of correctly identifying the site of lesion underlying a particular sensorineural hearing disorder is greatly enhanced, however, when the full array of test results is analyzed, rather than when one bases the audiological impression on the test finding from any particular special auditory measure' (*Rose, 1971*).
Since noise-induced permanent hearing loss is known to affect both ears, it is virtually impossible to make use of the ABLB test.
With the MBFLB test procedure, the patient makes an equal loudness balance between two test frequencies in an ear having normal hearing at one or more frequencies. Apart from the fact that this test is difficult to perform, the resulting data do not seem to be completely reliable.

The tone decay test is a reliable and frequently used method for the detection of retrocochlear pathology. A possible difficulty may be the divergence of opinion, apparent from the literature, about how the test can best be carried out; a divergence which, consequently, leads to different classifications. The advantage of the test is, however, that it can be performed with any conventional type of adiometer, without additional costs or additional equipment. A further disadvantage is, that for a proper interpretation of the tone decay test a great deal of audiological knowledge is needed. Most industrial medical officers will not possess such detailed knowledge.

In the present study an attempt is made to answer the question whether, in addition to the A/C audiogram, the industrial medical officer could make use of one of the above-mentioned audiological tests in order to be able to make the diagnosis 'NIPHL' with more certainty. This test procedure should:

1. be workable;
2. be suitable for any type of audiometer, without the need for additional equipment;
3. be not too time-consuming.

Finally, the results should be easy to interpret.

As has been said before, some of these audiological tests are unsuitable, since they do not offer a workable procedure, since the results are difficult to interpret, or since they cannot be carried out without additional equipment. Thus, the making of a Békésy audiogram or a speech audiogram for the determination of discrimination loss requires special equipment. The use of the LDL test is a very difficult and subjective affair, which, moreover is 'more variable than other loudness tests and tends to be of little value in patients who are habitually exposed to intense noise' (*Priede et al.*, *1971*).

The only remaining test of the list of seven, the SISI test, can be performed with most common types of audiometers. If not, a special SISI test adaptor is usually sufficient to make the audiometer ready for use. Furthermore, the SISI test is workable, easy to interpret, and not too time-consuming.

The second aim of the present study is, therefore, to gain a better insight into the reliability of the test. As is the case with many audiological examination techniques, there appears to exist a divergence of opinion among various authors in this respect, even to the extent of their voicing more or less contradictory statements.

Chapter 3. THE SISI TEST

Noise-induced permanent hearing loss is a disorder located in the cochlea, whereby part of the hair cells in the organ of Corti are either damaged or completely destroyed. Empirical research has shown, that people who suffer from cochlear pathology are able to perceive slight differences in intensity more readily than people with normal hearing, conductive deafness, mixed deafness, or some retro-cochlear disorder.

The SISI test is an approach to the measurement of the ear's ability to detect small intensity changes at suprathreshold levels. In the SISI test (*Jerger et al., 1959*), a 1 dB increment is superimposed on a continuous carrier (pedestal) tone (of the same frequency) set at 20 dB above the patient's threshold. The listener indicates when he detects a change each time the increment is momentarily introduced.

The following is a brief review of the considerable amount of literature on the subject. Ever since *Jerger* introduced the test 14 years ago, much has been written about its value, the general tendency being, however, that it is an extremely workable audiological test procedure.

Thus, *Blegvad (1966)* states that 'The SISI test is an important development in modern audiology, especially because its basic design tends to eliminate a number of sources of error, and because it aims for a higher degree of objectivity'. The same author further on emphasizes that failures experienced with this test are not to be ascribed to the method of testing as such, but to inadequacy of the equipment in terms of rise and decay times and the amplitude of the increment. 'It should be kept in mind', according to *Blegvad*, ' that even minor changes of increment magnitude will cause substantial changes in SISI score'.

Though many attempts have been made to make the test more reliable in this respect, *Sanders (1969)* reports that '1 dB increments were more consistent than 0.75 dB and 0.5 dB increments in distinguishing cochlear pathology form normal hearing or from other auditory conditions'.

Some other favourable opinions are voiced by authors such as

Martin (1972): 'The SISI test is a widely used and valued procedure for determining the presence of cochlear pathology'; *Jantis et al. (1964)*: 'The SISI test is recommended as a routine audiologic technique in the differential diagnosis of abnormal auditory function'; *Ownes (1965)*: 'On the whole, the test appears highly useful in determining the site of lesion'; *Young et al. (1967)*: 'The SISI test is used widely and is given considerable weight in making a clinical diagnosis of auditory disorders'; *Harford (1967)*: 'By way of interpretation, even though the SISI test is less than perfect in predicting the site of lesion, a consensus of investigations supports the use of the SISI test as a diagnostic tool; it is especially worthwile when used in conjunction with other special auditory tests'; and *Katz (1969)*: 'The SISI test is valuable in assessing the status of the sensory elements of the cochla; with accurate pure-tone thresholds, the simplicity and 'all-or-none' character of the test makes it particularly applicable for retarded persons'.

Not all of the literature supports these high expectations as regards the SISI test, but the majority of the authors are very positive about this method of screening.

The many positive comments on the SISI test have been one of the arguments in favour of its selection for the purpose of the present study, as a possible additional diagnostic tool for the industrial medical officer, a tool to be used for the diagnosis of noise-induced permanent hearing loss.

Chapter 4. SELECTION OF SUBJECTS AND FACTORIES

The sample population for the study of the validity of the SISI test as an additional diagnostic tool in the diagnosis 'noise-induced permanent hearing loss' consisted of a total of 716 subjects. At our request, the participating industrial medical officers had already made a pre-selection among the employee population in order to ensure that the subjects would be as much as possible chosen from these employees known to have acquired a hearing disorder due to a noisy work environment. In order to be able to try out the SISI test for the assessment of hearing losses ranging from nihil to considerable, a small number of subjects without hearing disorders were added as well. People known to suffer from a conductive hearing loss were as much as possible excluded.

The 716 subjects of the study were selected from the employee populations of 16 industrial firms, known (from prior noise measurements and/or prior audiometric testing) to have a noise level of over 85 dB (A). Among these firms, situated all over the Netherlands, were a refinery, a car factory, a factory for the manufacture of ship's propellers, a typewriter factory, an electric light bulb factory, a shipyard, a chocolate factory, a wool and cotton mill, an iron and metal foundry, and an engineering works. The subjects came from five large, six medium-sized, and five small firms.

With the assistance of the industrial medical officers (who were either employed by the firms concerned on a full-time basis or who worked for an industrial medical foundation in charge of the medical supervision of a number of firms), 350 employees were selected from the five large firms (i.e. approx. 70 subjects per firm), 270 from the six medium-sized firms (i.e. approx. 45 subjects per firm), and 96 from the remaining five small firms (i.e. approx. 19 subjects per firm).

Although, owing to the prevailing ambient noise levels, it was not always easy to find a room suitable for audiometric testing, the difficulty was always overcome eventually. The following maximum ambient noise levels for audiometry rooms for physicians have been taken from a publication by *Sataloff (1966)*:

	octave band				
decibles C scale of sound level meter	300-600 45	600-1200 45	1200-2400 50	2400-4800 55	4800- 60

Chapter 5. TYPE OF EQUIPMENT AND METHOD OF AUDIOLOGICAL EXAMINATION

For all the subjects taking part in the study, an air conduction (A/C) audiogram was made. In the case of the A/C audiogram being abnormal, a bone conduction (B/C) audiogram was made as well. The audiometric screening was carried out with a Peekel D7 continuous sweep frequency audiometer (calibrated to ISO-R-389 and equipped with Beyer DT-48-S earphones), with which it is possible to detect, in a very short time, the hearing loss anywhere in the audible frequency range. Because the frequency sweep is continuous from 100 Hz to 10,000 Hz, it is possible to find small hearing loss dips e.g. noise-induced hearing dips. However, this type D7 audiometer can also be used for the more generally accepted method of determining the hearing threshold on a number of fixed frequencies by intensity variation of the test tone. Both methods can be used without any restriction. The rectangular audiogram card is placed over a lucid screen. Behind this screen, a little lamp with a lens indicates in X-Y co-ordinates the frequency of the test tone and its dB level. Because the light spot shines also through the audiogram card, the audiogram can easily be plotted, without the necessity of reading off scales.

By use of a special circuit, the standard reference equivalent threshold sound pressure level has been made a straight line on the audiogram card over the whole frequency range.

The same level is also used for B/C.

The test tone can be adjusted in steps of 5 dB from + 10 dB to - 105 dB.

In Appendix A an example of an audiogram card is given.

The frequency scale has divisions of 1½ cm per octave.

The intensity scale has divisions of 1½ cm per 20 dB.

The frequency scale is continuous and purely logarithmic from 100 Hz to 10,000 Hz.

The standardized (ISO 402) octave frequencies are indicated by thick lines, 125 Hz, 250 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz. The two thin lines between the octave lines are terts intervals.

Also some (outdated) intermediate frequencies, prescribed by IEC standard 177, are indicated by dots on the audiogram card. These frequencies are 750 Hz, 1500 Hz, 3000 Hz and 6000 Hz.

In Appendix A two A/C audiograms (left ear) made for one and the same subject are shown. But whereas for the left diagram on the card the so-called 'octave method' (fixed frequencies) was used, the right diagram is the result of audiometric testing by means of the continuous sweep frequency method (fixed intensity). The enormous advantage of the second method, especially for the early detection of noise-induced hearing loss, is clearly visible. In both cases, the registered hearing loss at 4000 and 8000 Hz is 40 dB, but the octave method has missed the large dip of 70 dB at about 5000 Hz.

Noise-induced hearing loss manifests itself usually between 3000 and 6000 Hz. As the dip grows larger, the maximum will move in the direction of 4000 Hz, but this does not mean that it also starts at that latter frequency.

The hearing loss shown in Appendix A was, as the subject's medical history suggests, probably obtained during the fulfilment of military service, where the employee concerned had to work with heavy mortar shells. The onset of the dip probably began at 5000 Hz, and the dip would not have been detected with a routine octave method screening test, provided that such a test had been carried out.

Another advantage of the continuous sweep frequency method over the fixed frequency method is, that a patient will have less difficulty in perceiving a continuous tone than a single tone. The method has the disadvantage, however, that it is much more complicated than the octave method.

In addition to the making of an A/C and B/C audiogram, the Peekel D7 audiometer can also be used for the performance of the Lüscher DLI test, the SISI test, the ABLB test and the Stenger test (a test for the detection of pseudo-hypocusis). The audiometer has a masking signal of white and pink noise, which is adjustable from 0-100 dB in 11 steps.

Since this type of audiometer, as far as we know, is not used in Britain, it seemed a good idea to describe it in more detail. For the purpose of the study, two identical audiometers (registration numbers 795/796 and 803/804) have been used. Prior to the audiological examinations, both audiometers were calibrated at the factory, after which an NIPG*) senior technician checked them upon their SISI test qualities. The only difference found was, that for the audiometer with registration number 795/796 the time interval between the 1 dB increments was 4,75 seconds instead of the usually accepted 5 seconds, whereas for the second audiometer (803/804) this interval amounted to 5,75 seconds (see Appendix A). On all other prints, the SISI test on both audiometers met the commonly accepted standards.

For each subject an A/C audiogram for both ears was made. The continuous frequency tone was presented at an intensity of 15 dB in the range between 250 and 8000 Hz. The subject's hearing was considered to be normal, if the above-mentioned frequency range at the intensity of 15 dB could indeed be heard. The subject indicated success or failure by opening or closing his uplifted right hand. In case of deviating results, a threshold audiogram for air and bone conduction was made. For the A/C audiogram, masking was only used if the difference in hearing acuity between both ears amounted to over 40 dB. For the B/C audiogram, the non-tested ear was continuously masked as a routine.

After this audiological examination, the subject's medical history was taken, including an ENT history, an occupational history, and data about subjective hearing complaints, head traumata, drug taking, familial deafness, and leisure-time activities (to find out about possible noise-exposure).

The next step was the administration of the SISI-test, according to the procedure described by *Jerger et al. (1959)*: The SISI test employs a 1 dB increment superimposed on a continuous pure-tone of the same frequency, at intervals of 5 seconds. Each increment rises from the steady-state level to a maximum amplitude in 50 milliseconds, remains at maximum amplitude for 200 milliseconds, and then decays to the steady-state level in 50 milliseconds.

For the steady-state tone, a sensation level of 20 dB was used. According to *Jerger* 'a latency of 5 seconds between increments is adequate to preclude a rhythmic clue, yet not too brief for the subject to prepare for the next increment', a statement which was con-

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*) The Netherlands Institute for Preventive Medicine

firmed by us in a pilot study among 10 subjects, the time interval (presented at random) varying between 2 and 7 seconds. A 5-second interval proved to be a workable limit. In the course of this pilot study, the suggestion to carry out systematic so-called 'catch items' after the fifth, tenth, and fifteenth increment of the SISI test procedure in order to guard against false-positive and false-negative responses was followed as well. The 'catch item' should consist of no increment. We came to the conclusion, that the introduction of these 'catch items' had a negative effect upon the reliability of the test procedure as such, so that it was decided not to use them for the actual research project.

A thing that clearly emerged from the pilot study, however, was the importance which should be attached to the subject of instruction. Thus, the pre-examination instruction was begun with an increment two or three times greater than 1 dB. If the subject had mastered the perception of this increment, then he was told to listen to an increment of the same duration, but of a much lower intensity. He had to indicate perception of the 1 dB increments, by saying 'yes' or raising a finger. At first, we made use of a two-channel registration system, which gave the steady-state tone plus the increments as well as the subject's responses on a strip of paper. This resulted in an enormous pile of paper, however, so that this type of registration was abandoned in favour of the procedure of simply counting the subject's responses.

Subjects with cochlear damage, such as Menière's disease and noise-induced hearing loss achieved high (positive) SISI scores (70 to 100 per cent), while those with conductive and retro-cochlear pathology had low (negative) SISI scores (0 to 20 per cent). Scores between 20 and 70 per cent are most commonly observed in presbyacusis. The examination was carried out at two frequencies, i.e. of 1000 and 4000 Hz.

The entire examination, i.e. the making of an A/C audiogram (and sometimes also of a B/C audiogram), plus the medical history, plus the SISI test, plus the otoscopic examination (to check whether there was any impacted cerumen) took about 40 minutes. In the cases where cerumen had to be removed, this was done at least 48 hours prior to the audiological examination to avoid a threshold increase in the audiogram due to irritation of the tympanic membrane.

The examination of the external auditory meatus is also necessary, since it occasionally happens that a piece of cotton wool or glassdown ear protecting material is left, which will show as a 'disorder' on the audiogram.

Chapter 6. RESULTS

In total 716 subjects were examined. Table 1 shows the age distribution of the study population per 10-year groups.

Table 1

Total number of subjects examined

age distribution of study population in 10-year groups							
	<20	20-29	30-39	40-49	50-59	≥60	total
total number of subjects examined	15	154	209	178	123	37	716
percentage	2.1	21.5	29.1	24.9	17.2	5.2	100

Table 2 gives a general review of the SISI scores (both ears) for the total number of subjects.

Table 2

General review of total number of subjects examined

	SISI scores	left ear																					not measured	n
		000	005	010	015	020	025	030	035	040	045	050	055	060	065	070	075	080	085	090	095	100		
right ear	000	41	5	6	–	2	1	3	1	–	–	1	1	–	–	–	–	1	1	1	–	2	6	72
	005	2	2	3	–	1	–	–	1	–	–	–	–	–	–	–	–	1	–	–	1	1	2	14
	010	4	3	6	5	2	2	2	–	–	2	–	–	1	–	–	–	–	–	–	–	2	2	31
	015	1	1	3	–	3	1	–	–	–	–	1	–	–	–	1	–	–	1	–	–	2	1	15
	020	1	–	2	2	–	–	–	1	–	–	–	1	1	–	–	–	–	–	–	1	1	1	11
	025	1	–	–	–	1	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	5
	030	1	–	1	–	–	1	–	1	2	–	–	–	2	1	–	–	–	–	–	1	–	–	10
	035	1	–	–	–	1	–	–	–	–	–	1	–	–	–	1	2	–	–	–	1	–	1	8
	040	1	–	–	–	1	–	3	–	–	2	1	–	–	1	–	–	1	–	1	–	–	–	11
	045	–	–	–	–	–	–	–	–	2	–	–	1	1	–	–	–	–	–	–	–	1	1	6
	050	–	–	1	1	–	–	–	1	–	–	2	–	–	2	–	2	–	–	–	–	3	1	13
	055	–	–	–	1	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	1	2	6
	060	–	–	–	1	–	–	–	–	–	–	1	–	–	–	1	–	1	–	–	–	1	–	5
	065	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	2	–	–	1	–	1	3	9
	070	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1	1	1	–	2	1	–	4	11
	075	1	–	–	–	–	1	–	–	–	–	–	–	–	–	2	1	1	–	–	–	1	1	8
	080	–	–	–	–	–	–	–	–	–	–	–	1	–	–	3	2	2	1	3	2	5	4	23
	085	1	1	–	–	1	–	–	–	–	–	1	1	–	–	1	1	–	1	1	3	2	–	14
	090	1	–	1	–	–	1	–	–	–	–	–	–	1	–	–	–	2	2	2	3	10	3	26
	095	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1	1	1	2	7	1	14
	100	1	–	4	–	–	–	–	–	2	–	2	–	1	–	1	1	4	6	5	8	138	29	202
	not measured	10	2	8	2	2	1	1	4	6	–	2	–	3	–	–	2	9	1	5	8	40	96	202
	n	67	14	35	12	14	9	10	10	12	4	12	7	11	4	12	14	24	14	23	31	219	158	716

On the left ordinate the SISI score results for right ears have been plotted, on the abscissa those for left ears are shown. The SISI scores have been expressed in percentages of the total number of increment presentations. Thus, the 1 dB increment is presented 20 times, which means that each response, in percentages, equals 5 per cent. Table 2 shows that 452 subjects (n=716) had both their ears tested. Among these 452, 23 subjects appeared to have a normal pure-tone audiogram for their left and right ear, whereas the remaining 429 suffered from noise-induced permanent hearing loss. The diagnosis 'NIPHL' has been based on the results of an A/C + B/C pure-tone audiogram in combination with the information obtained via the subject's medical history.

In spite of the fact that a pre-selection had been performed in order to exclude people with a conductive deafness or normal hearing, 96 subjects turned out to have normal hearing or a hearing disorder attributable to a source other than noise. These 96 employees (of whom 50 had a normal hearing) were excluded from the study. Of the 716 employees who originally formed part of the study population, a total of 85 subjects appeared to have a normal hearing after all.

Since the aim of the study was to determine the suitability of the SISI test as a quicker and more reliable way of making the diagnosis 'noise-induced hearing loss', it seemed to be a good idea to perform this test in a number of persons with a normal pure-tone audiogram as well, so that the whole range between 'normal' and 'considerable hearing loss' could be examined.

Of the 85 subjects with normal hearing 23 were selected for a bilateral SISI test; for 1 subject a SISI score for the right ear only was obtained, of 11 subjects only their left ear was tested, and 50 subjects with normal hearing for both ears were excluded from further examination.

For sixty-two subjects a SISI test was made of the right ear only, since they suffered from a conductive deafness of the left ear. For 106 subjects the same applies to the left and right ear respectively.

To sum up:

SISI test binaural	: n = 452	(63,1%)
sensorineural	: n = 429	
normal	: n = 23	

SISI test right ear only: n = 62 (8,6%)
sensorineural : n = 61
normal : n = 1

SISI test left ear only : n = 106 (14,8%)
sensorineural : n = 95
normal : n = 11

No SISI test : n = 96 (13,4%)

The total number of ears examined was (2 x 452) + 62 + 106 = 1.072 ears. Since the total number of ears (for 716 subjects) was 1.432, this means that the results obtained refer to 75% of the ear sample originally available. The emphasis in the discussion of the results will be on the data obtained among those employees whose both ears were subjected to a SISI test (n = 452).

Table 3 shows the age distribution, in 10-year groups, of the 452 subjects for whom a SISI score for both ears was obtained. A comparison with the percentages of table 1 reveals, that the exclusion of 264 subjects does not lead to a large increase in percentage for each age group.

Table 3

Total number of subjects with a SISI score for both ears

age distribution of study population in 10-year groups							
	<20	20-29	30-39	40-49	50-59	≥60	total
total number of subjects examined	9	95	130	101	92	25	452
percentage	2.0	21.0	28.8	22.3	20.4	5.5	100

Over 90% of the subjects examined are between 20 and 60 years of age. This applies both to the entire study population of 716 persons and to the group of 452 among them, for whom a SISI score for right and left ear was made.

Table 4 gives the main data of table 2.

Table 4

Main details of table 2

		left ear <70	left ear ≥70	not examined	total
right ear	<70	156	40	20	216
right ear	≥70	24	232	42	298
right ear	not examined	41	65	96	202
	total	221	337	158	716

Of special importance here are the high SISI scores, since these scores only are an indication of the fact that the pathological conditions found are cochlear in character.

The data-processing usually concerns SISI scores of 70% or more (*Jerger, 1959*), although some researchers (*Jantis, 1964; Owens, 1965*) start with SISI scores of 60% or more, arguing that a score of 12 positive responses (out of the 20 presentations of 1 dB increments) already points towards a cochlear involvement.

Table 4 shows - as was to be expected - that there is a very significant relationship between the results obtained for the right and the left ear ($P \ll 0.001$).

In Appendix B, the results of the pure-tone audiometric testing have been represented as median audiograms with the corresponding percentiles: P_{10} (first decile), P_{25} (first quartile), P_{75} (third quartile), and P_{90} (last decile). P_{50} (second quartile) represents the median value. The Figures, with the relevant Tables, are also given in Appendix B.

Figures 1-6 show the median audiogram for the right ear for the total number of 716 subjects, divided into age groups. Figures 7-12 represent the same for the left ear, whereas in figures 13 and 14 the median audiograms are given for all the right and the left ears, respectively. From these last two figures it becomes apparent, that both ears have identical types of disorders. Sound measurements performed at the firms concerned had already revealed that there was no difference in noise exposure for the right or the left ear; on the strength of this information it was already to be expected, therefore, that the injurious effects of factory noise would be the same for both ears. Figures 15-28 represent the median audiograms for the 452 subjects - classified according to age group - for whom SISI scores for both ears were obtained; figures 15-20 give the results for the right ear, figures 21-26 for the left ear, whereas figures 27 and 28 refer to all the right and all the left ears, respectively. Here too, no difference between the results for the right and the left ear could be found: fig.27 is identical with fig.13, and fig.28 is identical with fig.14. From these figures, the 'general impression' as regards the median audiograms for both groups is very much the same. In other words: the fact that these data only referred to the 452 subjects for whom a SISI score for both ears could be obtained, did not lead to selection.

For the pure-tone audiograms, the hearing losses in dB at 500, 1000, 1600, 2000, 2500, 3150, 4000, 5000, 6300 and 8000 Hz were taken.

The SISI test was carried out at the frequencies of 1000 and 4000 Hz. For the data-processing only the SISI scores obtained at 4000 Hz were used, however, since at an earlier stage of the study it had already become apparent that at 1000 Hz there was hardly any response.

An orientatory pilot-study had previously led to the conclusion that, as regards the SISI test, screening at a larger number of frequencies hardly yields more information, whereas it is more time-consuming and more tiring for the subject concerned, a fact which does not add to the reliability of the outcome. Testing at the frequency of 4000 Hz seemed amply sufficient, the more so, since the highest peak of the hearing dip is usually found around 4000 Hz.

Table 5 deals with the question of whether the age of the subjects has any influence upon their SISI scores.

Table 5

SISI scores, for six age groups, of the subjects
who had both their ears examined

	left ear <20 yrs		
	<70	≥70	n
right ear <70	6	1	7
right ear ≥70	1	1	2
right ear n	7	2	9

	left ear 20-29 yrs		
	<70	≥70	n
right ear <70	51	11	62
right ear ≥70	5	28	33
right ear n	56	39	95

	left ear 30-39 yrs		
	<70	≥70	n
right ear <70	47	13	60
right ear ≥70	10	60	70
right ear n	57	73	130

	left ear 40-49 yrs		
	<70	≥70	n
right ear <70	30	6	36
right ear ≥70	4	61	65
right ear n	34	67	101

	left ear 50-59 yrs		
	<70	≥70	n
right ear <70	19	9	28
right ear ≥70	3	61	64
right ear n	22	70	92

	left ear ≥60 yrs		
	<70	≥70	n
right ear <70	3	0	3
right ear ≥70	1	21	22
right ear n	4	21	25

In this table, the SISI scores for the right and the left ear have been set out against each other. The results clearly show, that the number of people, classified according to age group, with a high SISI score increases with advancing age.

SISI score of ≥70% for both ears

<20 year	1 subject	out of 9	=	approx. 10%
20-29 years	28 subjects	out of 95	=	approx. 30%
30-39 years	60 subjects	out of 130	=	approx. 45%
40-49 years	61 subjects	out of 101	=	approx. 60%
50-59 years	61 subjects	out of 92	=	approx. 65%
≥60 years	21 subjects	out of 25	=	approx. 85%

SISI score of >70% for one ear

<20 year	2	subjects out of	9	=	approx.	20%
20-29 years	39	subjects out of	95	=	approx.	40%
30-39 years	73	subjects out of	130	=	approx.	55%
40-49 years	67	subjects out of	101	=	approx.	65%
50-59 years	70	subjects out of	92	=	approx.	75%
>60 years	21	subjects out of	25	=	approx.	85%

The conclusion seems justified, therefore, that there indeed exists a relationship between age and SISI score.

The results also point to a difference in SISI scores for the right and the left ear. Table 6 shows no difference in this respect for the youngest age group, but the number of people belonging to the older age groups who achieve a SISI score of 70% or more for the left ear but not for the right ear clearly rises with increasing age. For subjects 60 years and over this does no longer apply.

Table 6

Percentage of subjects - divided into six age groups - with a SISI score of 70% or more

age group	right ear	left ear
<20 yrs	22	22
20-29 yrs	35	41
30-39 yrs	54	56
40-49 yrs	64	66
50-59 yrs	70	76
>60 yrs	88	84

Another question studied was the existence of a possible relationship between the pure-tone hearing losses in dB at 4000 Hz and the SISI scores. Tables 7a and 7b give the results for the right and the left ear for four classes of SISI scores.

Table 7a

Relationship between four classes of SISI scores and pure-tone hearing losses (right ear) in dB at 4000 Hz

hearing losses in dB at 4000 Hz	SISI scores				total number of subjects
	000	005/065	070/095	100	
15	45	63	11	7	126
20	6	12	4	3	25
25	4	4	11	9	28
30	1	11	9	7	28
35	2	10	13	12	37
40	2	9	4	16	31
45	2	3	8	10	23
50	2	5	7	13	27
55	1	4	3	23	31
60	-	1	5	26	32
65	1	-	3	18	22
70	-	1	-	13	14
75	-	1	1	7	9
80	-	2	1	4	7
85	-	2	1	3	6
90	-	-	-	-	-
95	-	2	2	2	6
total	66	130	83	173	452

Table 7b

Relationship between four classes of SISI scores and pure-tone hearing losses (left ear) in dB at 4000 Hz

hearing losses in dB at 4000 Hz	SISI scores				total number of subjects
	000	005/006	070/095	100	
15	39	55	6	6	106
20	1	11	5	3	20
25	2	12	4	6	24
30	3	9	21	9	42
35	3	10	10	12	35
40	5	9	9	12	35
45	1	6	11	15	33
50	1	4	6	19	30
55	-	3	7	25	35
60	-	-	1	20	21
65	-	1	3	28	32
70	1	1	-	11	13
75	-	-	1	8	9
80	1	1	3	-	5
85	-	-	3	2	5
90	-	-	-	1	1
95	-	1	3	2	6
total	57	123	93	179	452

There seems to be no clear difference between the findings for the right and the left ear. For the right ear 256 subjects out of the 452 (56%) achieved a SISI score of 70% or more, whereas when the left ear was tested, this number rose to 272 (or 60%). Here too, as was the case when the relationship between SISI scores and age was studied, the number of left ears with a higher SISI score exceeded the number of right ears.

From tables 7a and 7b it furthermore becomes clear, that approx. 28% of the subjects tested achieve a SISI score between 5% and 65%. Some of these results may have to be ascribed to presbyacusis.

The findings for both the right and the left ear indicate, that spprox. 40% of the subjects examined could hear the entire series of 20 1 dB increments presented to them. Tables 7a and 7b form the basis for table 8.

Table 8

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and the corresponding number (and percentage) of subjects, for each category, with a SISI score of 70% or more, for both ears

hearing losses in dB at 4000 Hz	total number of right ears	SISI score right ear		total number of left ears	SISI score left ear	
		n	%		n	%
15	126	18	14.3	106	12	11.3
20	25	7	28.0	20	8	40.0
25	28	20	71.4	24	10	41.7
30	28	16	57.1	42	30	71.4
35	37	25	67.6	35	22	62.9
40	31	20	64.5	35	21	60.0
45	23	18	78.3	33	26	78.8
50	27	20	74.1	30	25	83.3
55	31	26	83.9	35	32	91.4
60	32	31	96.9	21	21	100.0
65	22	21	95.9	32	31	96.9
70	14	13	92.9	13	11	84.6
75	9	8	88.9	9	9	100.0
80	7	5	71.4	5	3	60.0
85	6	4	66.7	5	5	100.0
90	-	-	-	1	1	100.0
95	6	4	66.7	6	5	83.3
total	452	256		452	272	

Table 8 gives the relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz for the right as well as the left ear and the corresponding number (and percentage) of subjects with a SISI score of 70% or more. It appears that, at a hearing loss of 25 dB for the right ear and of 30 dB for the left ear, the percentage of people with a positive SISI score suddenly rises considerably. This percentage approaches almost 100%, and drops again when the hearing loss registered reaches a value of over 70 dB (mainly observed for the right ear).

A (cautious) conclusion could be, that the SISI test functions best in those cases where the hearing loss lies between 30 and 70-75 dB at 4000 Hz.

As has already been said at the beginning of this chapter, the study population consisted of 452 subjects for whom a SISI score for both the right and the left ear could be obtained. In addition, there were 106 subjects with a SISI score for their left ear and 62 subjects with a SISI score for their right ear, so that the total study material included 514 right ears and 558 left ears.

Tables 9a and 9b show the relationship - for the right and the left ear, respectively - between successive categories of pure-tone hearing losses in dB at 4000 Hz and three classes of SISI scores.

Table 9a

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and the corresponding three classes of SISI scores for the total of right ears examined

hearing losses in dB at 4000 Hz	SISI scores						total number of subjects
	≤20%		25-65%		≥70%		
	n	%	n	%	n	%	
15	91	68.9	26	19.7	15	11.4	132
20	14	42.4	9	27.3	10	30.3	33
25	10	31.3	-	-	22	68.8	32
30	5	16.7	7	23.3	18	60.0	30
35	5	8.9	9	20.0	32	71.1	45
40	5	12.8	9	23.1	25	64.1	39
45	4	15.4	2	7.7	20	76.9	26
50	3	9.7	4	12.9	24	77.4	31
55	4	10.5	3	7.9	31	81.6	38
60	-	-	2	5.6	34	94.4	36
65	1	4.2	-	-	23	95.8	24
70	-	-	1	5.9	16	94.1	17
75	-	-	1	11.1	8	88.9	9
80	-	-	2	28.6	5	71.4	7
85	1	14.3	1	14.3	5	71.4	7
90	-	-	-	-	-	-	-
95	-	-	2	25.0	6	75.0	8
total	142		78		294		514

Table 9b

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and the corresponding three classes of SISI scores for the total of left ears examined

hearing losses in dB at 4000 Hz	SISI scores						total number of subjects
	≤20%		25-65%		≥70%		
	n	%	n	%	n	%	
15	84	66.7	27	21.4	15	11.9	126
20	8	29.6	7	25.9	12	44.4	27
25	8	27.6	8	27.6	13	44.8	29
30	10	18.5	9	16.7	35	64.8	54
35	10	20.4	6	12.2	33	67.3	49
40	8	20.0	9	22.5	23	57.5	40
45	3	7.9	6	15.8	29	76.3	38
50	3	8.3	3	8.3	30	83.3	36
55	4	9.2	2	4.7	37	86.0	43
60	-	-	-	-	28	100.0	28
65	-	-	1	2.6	38	97.4	39
70	1	6.3	1	6.3	14	87.5	16
75	-	-	1	9.1	10	90.9	11
80	1	14.3	1	14.3	5	71.4	7
85	-	-	-	-	6	100.0	6
90	-	-	-	-	2	100.0	2
95	1	14.3	1	14.3	5	71.4	7
total	141		82		335		558

Of the 514 right ears examined, 294 (or 57%) achieved a SISI score of 70% or more, as against 335 (60%) out of the 558 left ears. Again, the percentage obtained is slightly higher for the left ear.

Table 10, based upon tables 9a and 9b taken together, gives the results for the total number of ears (1072) examined.

Table 10

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and the corresponding three classes of SISI scores for the total of right and left ears examined

hearing losses in dB at 4000 Hz	SISI scores						total number of subjects
	<20%		25-65%		≥70%		
	n	%	n	%	n	%	
15	175	67.8	53	20.5	30	11,6	258
20	22	36.7	16	26.7	22	36.7	60
25	18	29.5	8	13.1	35	57.4	61
30	15	17.9	16	19.0	53	63.1	84
35	14	14.9	15	16.0	65	69.1	94
40	13	16.5	18	22.8	48	60.8	79
45	7	10.9	8	12.5	49	76.7	64
50	6	9.0	7	10.4	54	80.6	67
55	8	9.9	5	6.2	68	84.0	81
60	-	-	2	3.1	62	96.9	64
65	1	1.6	1	1.6	61	96.8	63
70	1	3.0	2	6.1	30	90.9	33
75	-	-	2	10.0	18	90.0	20
80	1	7.1	3	21.4	10	71.4	14
85	1	7.1	1	7.7	11	84.6	13
90	-	-	-	-	2	100.0	2
95	1	6.7	3	20.0	11	73.3	15
total	283		160		629		1072

Out of the 1072 ears, 629 (or 59%) achieved a SISI score of 70% or more. Here again, the SISI test proved to be most successful for the category of people with hearing losses at 4000 Hz ranging between 30 and 75 dB.

From table 10 it can furthermore be seen, that for 160 ears (15%) a score was reached between 25 and 65%, whereas for 283 ears (26%) the SISI score equalled 20% or less. These percentages (15% and 26%) have mainly to be ascribed to the lower dB losses.

The SISI test functions almost at its optimum for those cases where the pure-tone hearing losses at 4000 Hz lie between 60 and

75 dB. Over 90% of the subjects in that category has a SISI score of 70% or more.

Note: The outcome of 'a hundred per cent' for the SISI score of 70% or more is probably due to the small number of subjects (2) with a hearing loss of 90 dB. (table 10)

A pure-tone hearing loss at 4000 Hz of 30 dB seems to be the 'lower limit' for a positive SISI score, although in some subjects with a lower hearing loss a high SISI score for one or both ears was registered as well.

Table 11

Cross tabulation of three categories of pure-tone hearing losses in dB at 4000 Hz

right ear	left ear <70	left ear ≥70	n
<70	79	1	80
≥70	3	7	10
n	82	8	90

right ear 15 dB
left ear 15 dB

right ear	left ear <70	left ear ≥70	n
<70	6	5	11
≥70	1	1	2
n	7	6	13

right ear 20-30 dB
left ear 15 dB

right ear	left ear <70	left ear ≥70	n
<70	1	2	3
≥70	-	-	-
n	1	2	3

right ear ≥35 dB
left ear 15 dB

right ear	left ear <70	left ear ≥70	n
<70	8	1	9
≥70	4	6	10
n	12	7	19

right ear 15 dB
left ear 20-30 dB

right ear	left ear <70	left ear ≥70	n
<70	16	2	18
≥70	4	15	19
n	20	17	37

right ear 20-30 dB
left ear 20-30 dB

right ear	left ear <70	left ear ≥70	n
<70	7	4	11
≥70	2	17	19
n	9	21	30

right ear ≥35 dB
left ear 20-30 dB

right ear	left ear <70	left ear ≥70	n
<70	7	-	7
≥70	7	3	10
n	14	3	17

right ear 15 dB
left ear ≥35 dB

right ear	left ear <70	left ear ≥70	n
<70	6	2	8
≥70	5	18	23
n	11	20	31

right ear 20-30 dB
left ear ≥35 dB

right ear	left ear <70	left ear ≥70	n
<70	26	7	33
≥70	14	165	179
n	30	172	212

right ear ≥35 dB
left ear ≥35 dB

In table 11 the SISI scores for the right and the left ear have been set out against each other.

In the first column, the hearing losses for the right ear are seen to stay at 15 dB, whereas those for the left ear rise from 15 dB, via 20-30 dB, to 35 dB or more.

The second column shows the hearing losses for the right ear which this time stay at 20-30 dB, whereas those for the left ear again range from 15 dB, via 20-30 dB, to 35 dB or more.

The third column, finally, gives the hearing losses for the right ear which stay at 35 dB or more, whereas those for the left ear rise from 15 dB, via 20-30 dB, to 35 dB or more.

One of the further results shown in this table is that 7 out of the 90 subjects with a bilateral 'hearing loss' of 15 dB (7.8%) succeeded in achieving a SISI score of 70% or more. (It is in fact not quite correct to talk about a 'hearing loss' of 15 dB, since the pure-tone audiometric testing was carried out at 15 dB; therefore, it is not impossible that for some people the threshold was actually lower than 15 dB.)

Of the 212 subjects with a bilateral hearing loss of 35 dB or more, 165 (77.8%) succeeded in achieving a high SISI score for both ears. Twenty-six subjects within this category (12%) were unable to achieve a positive SISI score, however.

Fourteen subjects with a bilateral hearing loss of 35 dB or more managed to achieve a positive score for their right, but not for their left ear; for seven subjects, the reverse was true.

In the category of bilateral hearing losses of 20 dB, 25 dB, or 30 dB, about as many SISI scores over 70% as under 70% were found: 15 out of 37 (40%) and 16 out of 37 (43%), respectively.

There are cases, therefore, of a bilateral hearing loss of 35 dB or more, whereby the subject achieves a positive SISI score for one ear, and a negative SISI score for the other. Cases which, on the strength of audiometric and case history evidence, had been labelled 'NIPHL'.

Why this can be so is not known. A possible explanation may be that for the ear for which a negative SISI score was obtained, a different aetiology nevertheless existed.

Some authors interpret a SISI score only then as 'positive' - i.e. as pointing to cochlear pathology - if the score achieved is

70% or more. Others, however, are of the opinion that a SISI score of 60% or more already forms a clear indication of a cochlear defect.

Tables 12a and 12b show the relationship (for all the right ears and all the left ears, respectively) between successive categories of pure-tone hearing losses in dB at 4000 Hz and three classes of SISI scores.

Table 12a

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and three classes of SISI scores for the total of right ears examined

hearing losses in dB at 4000 Hz	SISI scores ≤20% n	%	25-55% n	%	≥60% n	%	total number of subjects
15	91	68.9	20	15.1	21	15.9	132
20	14	42.4	8	24.2	11	33.3	33
25	10	31.2	-	-	22	68.7	32
30	5	16.6	4	13.3	21	70.0	30
35	4	8.8	6	13.3	35	77.7	45
40	5	12.8	9	23.0	25	64.1	39
45	4	15.3	-	-	22	84.6	26
50	3	9.6	3	9.6	25	80.6	31
55	4	10.5	3	7.8	31	81.5	38
60	-	-	1	2.7	35	97.2	36
65	1	4.1	-	-	23	95.8	24
70	-	-	1	5.8	16	94.1	17
≥75	1	3.2	6	19.3	24	77.4	31
total	142		61		311		514

Table 12b

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and three classes of SISI scores for the total of left ears examined

hearing losses in dB at 4000 Hz	SISI scores						total number of subjects
	≤20%		25-55%		≥60%		
	n	%	n	%	n	%	
15	84	66.6	19	15.0	23	18.2	126
20	8	29.6	7	25.9	12	44.4	27
25	8	27.5	7	24.1	14	48.2	29
30	10	18.5	8	14.8	36	66.7	54
35	10	20.4	5	10.2	34	69.3	49
40	8	20.0	8	20.0	24	60.0	40
45	3	7.8	4	10.5	31	81.5	38
50	3	8.3	2	5.5	31	86.1	36
55	4	9.3	2	4.6	37	86.0	43
60	-	-	-	-	28	100.0	28
65	-	-	-	-	39	100.0	39
70	1	6.2	1	6.2	14	87.5	16
≥75	2	6.0	3	9.0	28	85.0	33
total	141		66		351		558

A comparison between tables 9a and 12a shows that 17 subjects belonging to class 25-65% in table 9a are now to be found in the class of 60% and more of table 12a. Likewise, 16 subjects belonging to the class 25-65% of table 9b are now in the 60% and more class of table 12b. This is a relatively small shift of 294 to 311 subjects (approx. 6%) for the right ear and of 335 to 351 subjects (approx. 5%) for the left ear, so that the conclusion seems justified, that for practical purposes it probably does not matter much whether the limit for a positive SISI test is set at 60% and more or 70% and more.

Table 13, finally, gives the results of tables 12a and 12b taken together.

Table 13

Relationship between successive categories of pure-tone hearing losses in dB at 4000 Hz and three classes of SISI scores for the total of right and left ears examined

hearing losses in dB at 4000 Hz	SISI scores						total number of subjects
	<20%		25-55%		≥60%		
	n	%	n	%	n	%	
15	175	67.8	39	15.1	44	17.0	258
20	22	36.6	15	25.0	23	38.3	60
25	18	29.5	7	11.4	36	59.0	61
30	15	17.8	12	14.2	57	67.8	84
35	14	14.8	11	11.7	69	73.4	94
40	13	16.4	17	21.5	49	62.0	79
45	7	10.9	4	6.2	53	82.8	64
50	6	8.9	5	7.4	56	83.5	67
55	8	9.8	5	6.1	68	83.9	81
60	-	-	1	1.5	63	98.4	64
65	1	1.5	-	-	62	98.4	63
70	1	3.0	2	6.0	30	91.0	33
≥75	3	4.6	9	14.0	52	81.2	64
total	283		127		662		1072

This table shows, that the shift of 629 (i.e. the subjects belonging to the class of 70% and more in the tables 9a and 9b, taken together) to 662 (i.e. the subjects of the class of 60% and more of table 13) is for 60 per cent the result of pure-tone hearing losses of less than 35 dB.

Furthermore, 59 per cent of the subjects with pure-tone hearing losses of 25 dB are shown to achieve a SISI score of 60% and more.

For the category of pure-tone hearing losses between 25 and 40 dB at 4000 Hz, about 65 per cent of the population sample achieves a SISI score of 60% and more. For the category between 45 and 75 dB, this percentage is about 88%.

Chapter 7. COMPERATIVE STUDY

In order to be able to determine whether for the diagnosis 'noise-induced permanent hearing loss' one differential auditory test would be sufficient or whether it would be necessary to carry out two or three additional tests, it was decided to try out two other tests for the detection of cochlear pathology (i.e. Békésy audiometry and the tone decay test) in addition to the SISI test.

Thanks to the co-operation of Prof.G.A. Sedee (Head of the ENT Department of the University Hospital, Utrecht) 12 patients who attended the Otological Policlinic could be selected who were willing to act as subjects. Initially, an A/C an B/C audiogram was made and a SISI test carried out by means of a Peters Clinical Audiometer. For the Békésy audiogram, an Interacoustics Békésy Automatic Audiometer, model BA-3, calibrated to ISO-1964 standards and equipped with FDH-39 earphones was used.

Using the fixed frequency technique at a speed of 5 dB/sec., 2½ pulses/sec., 30 seconds per frequency, automatically six frequencies (500, 1000, 2000, 3000, 4000 and 6000 Hz) were tested in ascending order.

Both the pulsed (blue) and continuous (red) tones were presented, each for a period of three minutes for each ear: in each case, the pulsed tone was presented first.

The Békésy Type II audiogram is characteristic of cochlear pathology, such as NIPHL and Menière's disease. In the Type II audiogram the continuous (C) tone threshold separates from the periodically interrupted (I) tone around 1000 Hz. The separation usually does not exceed 20 dB.

In addition, the amplitude of the continuous trace narrows considerably to 3 to 5 dB,

The fixed frequency Type II tracing reflects a similar relationship in which separation occurs for mid- and high frequency only.

After the C trace stabilizes 5 to 20 dB below I, the two curves travel more or less parallel. The amplitude of the C tracing is reduced in relation to I.

The Békésy Type I audiogram shows an interweaving of I and C thresholds throughout the audiogram. Normally, Type I audiograms typify normal hearing and lesions of the middle ear, but about 47% of all Type I audiograms are obtained from subjects with presumably cochlear pathology and sensorineural loss of unknown aetiology (*Hughes, 1972*). A tone decay test was performed as well.

Abnormal threshold tone decay is a symptom associated with retrocochlear lesions, such as an acoustic neurinoma. This differential auditory measure requires the use of a conventional audiometer only.

The purpose of the test is to determine the difference between the patient's threshold and the intensity level at which the patient can continuously perceive a pure tone for sixty seconds. To this end a continuous pure-tone signal is initially delivered at threshold level and is then increased in 5 dB steps, as needed, to maintain its perception. The length of time that the patient perceives this signal at each intensity level is carefully monitored with a stopwatch.

A tone decay of 30 dB or less is considered to reflect a cochlear lesion. Rapid adaptation in excess of 30 dB is most frequently encountered among patients with eight nerve involvement (*Martin, 1971*).

This tone decay test could be carried out by the above mentioned Interacoustics Békésy Automatic Audiometer, owing to the fact that a special set had been built-in for the purpose.

For the taking of the patient's medical history, special attention was given to otological data, the factor 'noise', and subjective hearing complaints. The 'otologic history' comprised the factors hearing trouble, pain in ears, running ears, ear operation, ear accident, trauma of skull, infectious diseases, toxic drugs, hereditary deafness, previous and present tinnitus, vertigo, and headache caused by noise. The 'noise history' concentrated on questions about previous and present job activities, military training (small arms and artillery), air force training, air base shooting, hunting, and exposure to explosions.

The subjective hearing complaints inventory dealt with questions such as the patients' evaluation of their own hearing, their estimate of their degree of hearing handicap (if thought to be present), the difficulties encountered when talking with someone else in a quiet and in a noisy surrounding, the patients' speech hearing capacity when attending a church service, a meeting, a theater, or a birthday party, and when listening to radio or television.

In Appendix C, the A/C and B/C as well as the Békésy audiograms for these 12 subjects are given.

On the following pages a brief 'profile' is given of each of the 12 patients concerned. The data include some medical history findings, the SISI scores, the results of the tone decay test, and the outcome of the Békésy audiograms.

<u>Patient nr. 25229</u>

age: 43

occupation: machinist
noise source: maintenance work shop
military service: passed; exempted
exposure to explosions: none
hearing-protective devices: none

Békésy audiogram: Type II (not quite certain)
tone decay: normal

SISI	1000	2000	4000 Hz
Right	0	10	50%
Left	0	60	80%

Peters audiogram: mixed deafness

tinnitus: right ear
vertigo: -
cerumen: -
ENT history: -

<u>Patient nr. 9993</u>

age: 37

occupation: milling machine operator; furniture factory
noise source: circular saw
military service: completed (hardly any shooting)
exposure to explosion: none
hearing-pretective devices: none

Békésy audiogram: Type II right ear, Type I left ear
tone decay: normal

SISI	1000	2000	4000 Hz
Right	0	70	100%
Left	0	0	0%

Peters audiogram: sensorineural hearing loss (right ear above 2000 Hz)

tinnitus: right ear
vertigo: -
cerumen: -

Patient nr. 29282

age: 51

occupation: hair removal and preparation of slaughter-cattle

noise source: machinery, meat products factory

military service: completed (much shooting)

exposure to explosions: none

hearing-protective devices: none

Békésy audiogram: Type II left ear, Type I right ear

tone decay: normal

SISI	1000	2000	4000 Hz
Right	0	0	0%
Left	80	100	-%

tinnitus: bilateral

vertigo: +

cerumen: -

ENT history: -

Peters audiogram: sensorineural hearing loss

Patient nr. 29978

age: 55

occupation: pile driver operator

noise source: pile driver

military service: completed (much shooting)

exposure to explosions: none

hearing-protective devices: none

Békésy audiogram: Type II

tone decay: normal

SISI	1000	2000	4000 Hz
Right	0	0	0%
Left	0	0	90%

Peters audiogram: sensorineural hearing loss

right ear above 2000 Hz

air/tone gap

tinnitus: right ear

vertigo: -

cerumen: -

ENT history: -

concussion: + (24 hours unconscious following accident)

Patient nr. 9651

age: 52

occupation: spinner/weaver
noise source: power-loom
military service: rejected
exposure to explosions: none
hearing-protective devices: none

Békésy audiogram: Type II
tone decay: normal

SISI	1000	2000	4000 Hz
Right	0	20	100%
Left	0	70	90%

tinnitus: bilateral ±
vertigo: -
cerumen: -
ENT history: -

Peters audiogram: sensorineural hearing loss

Patient nr. 27293

age: 52

occupation: painter
noise source: scraping off of rust
military service: completed (hardly any shooting)
exposure to explosions: at short distance during World War II
hearing-protective devices: none

Békésy audiogram: Type II
tone decay: normal

SISI	1000	2000	4000 Hz
Right	55	75	100%
Left	0	50	100%

tinnitus: bilateral
vertigo: -
cerumen: -
ENT history: -

Peters audiogram: sensorineural hearing loss

Patient nr. 24087

age: 37

occupation: employee, maintenance work shop
noise source: pneumatic hammers
military service: completed (not much shooting)
exposure to explosions: none
hearing-protective devices: none

Békésy audiogram: Type II	tinnitus: +
tone decay: normal	vertigo: +
SISI 1000 2000 4000 Hz	cerumen: -
Right 0 100 100%	ENT history: suspected Menière's disease
Left 0 100 100%	

Peters audiogram: sensorineural deafness

Patient nr. 25005

age: 52

occupation: glass grinder
noise source: grinding wheel
military service: passed, exempted
exposure to explosions: none
hearing-protective devices: none

Békésy audiogram: Type II right ear, Type I left ear	tinnitus: right ear (shrill, high-pitched tone which equals tone at 80 dB at 3000 Hz)
tone decay: normal	vertigo: ±
SISI 1000 2000 4000 Hz	cerumen: -
Right 70 80 100%	ENT history: -
Left 60 70 75%	

Peters audiogram: sensorineural hearing loss

Patient nr. 70597

age 53

occupation: metal grinder
noise source: grinding wheel
military service: completed (not much shooting)
exposure to explosions: none
hearing-protective devices: none

Békésy audiogram: Type II	tinnitus: -
tone decay: normal	vertigo: -
SISI 1000 2000 4000 Hz	cerumen: -
Right 0 10 75%	ENT history: -
Left 0 60 85%	

Peters audiogram: sensorineural hearing loss

Patient nr. 80320

age: 40	occupation: metal grinder
	noise source: grinding wheel
	military service: completed (not much shooting)
	exposure to explosions: none
	hearing-protective devices: none

Békésy audiogram: Type II — tinnitus: right ear

tone decay: normal — vertigo: +

cerumen: -

ENT history: suspected Menière's disease

SISI	1000	2000	4000 Hz
Right	20	80	100%
Left	0	0	65%

Peters audiogram: sensorineural hearing loss

Patient nr. 82001

age: 53	occupation: tailor in men's clothing factory
	noise source: industrial sewing machines
	military service: rejected
	exposure to explosions: none
	hearing-protective devices: none

Békésy audiogram: Type II — tinnitus: +

tone decay: normal — vertigo: -

cerumen: -

ENT history: -

SISI	1000	2000	4000 Hz
Right	0	0	70%
Left	0	0	90%

Peters audiogram: sensorineural hearing loss

Patient nr. 80856

age: 50	occupation: reinforced brick netting weaver
	noise source: power loom
	military service: completed (not much shooting)
	exposure to explosions: none
	hearing-protective devices: none

Békésy audiogram: Type II	tinnitus: +
tone decay: normal	vertigo: -
SISI 1000 2000 4000 Hz	cerumen: -
Right 0 0 100%	ENT history: -
Left 0 0 100%	

Peters audiogram: sensorineural hearing loss

For 19 out of the 24 ears examined (79%) a SISI score of 60% or more was obtained, i.e. a percentage about identical to the percentage found in the main study (see Chapter 6). An advantage of the SISI test over Békésy audiometry is the time-saving element, that is, if for the diagnosis NIPHL only the frequency of 4000 Hz is applied. SISI testing of both ears, including time for instruction, for one frequency requires no more than 4 minutes, as against 12 minutes at least for Békésy audiometry. Another, previously mentioned, disadvantage of Békésy audiometry is the special, rather expensive equipment needed. The division into Types, moreover, is no easy matter.

The tone decay test is a less suitable screening method for the industrial medical officer, since as a rule he will not possess the audiological knowledge needed.

From the results of this comparative study the conclusion can be drawn, therefore, that the industrial medical officer, who wants to make a reasonably reliable diagnosis of NIPHL, can obtain sufficient information by means of an A/C audiogram plus a SISI test (at 4000 Hz) plus a focussed medical history.

Chapter 8. SUMMARY AND CONCLUSIONS

Summary

In recent years, the number of people exposed to injurious noise levels, and consequently the number of people at risk of obtaining a noise-induced permanent hearing loss (NIPHL) has been steadily rising. As a result, industrial medical officers as well as the medical personnel at the audiological centres are being more and more confronted with patients with hearing complaints. More often than not, the patients who visit an audiological centre will be referred by their industrial medical officer.

From industrial medical circles the question has been raised, therefore, whether the routine audiological test which forms part of the general health screening carried out by the industrial medical officer could be expanded in such a way, that it would be possible for this officer to make the diagnosis NIPHL with some certainty. Now, the only audiological equipment usually available to the industrial medical officer is a screening audiometer for the execution of A/C audiograms. And even if he has more equipment, then his knowledge of this particular subject will often be insufficient to carry out a full-scale audiological test. The aim of the present study, therefore, was to check whether a relatively simple audiological test could be found by means of which the industrial medical officer could make the diagnosis NIPHL.

The choice fell upon the SISI test. Since it had already become apparent from the literature, that there existed some divergence of opinion as to the value of the SISI test, it was decided to try the test out among a fairly large study population.

In Chapter 1 of this dissertation, a brief discussion is given of the number of people who in our Western world run the risk of obtaining a NIPHL. Furthermore, it is emphasized that noise will not only affect the hearing organ, but other organs and organ systems as well.

Chapter 2 gives the aim of the present study as well as the reasons why the SISI test was eventually selected from among the differential audiological tests available.

In Chapter 3, the opinions of believers and disbelievers in

the SISI test have been cited, from which review it becomes clear that the former category outnumbers the latter.

Chapters 4 and 5 mainly deal with the selection of the study population and of the industrial firms. In addition, the method of testing and the type of audiometer used are described in some detail.

The results are presented in chapter 6. The age distribution of the subjects and the relationship between age and SISI score have been set out in 13 tables. Moreover, the relationship between the category of pure-tone hearing losses in dB at 4000 Hz and the corresponding SISI score is discussed. Attention is also paid to the question of what happens, if the 'lower limit' for a positive SISI score is lowered from the generally accepted 70% or more to 60% more.

Chapter 7, finally, gives the results of an additional survey carried out among a sample population of patients attending the Otological Policlinic of the University Hospital Utrecht in order to study the question whether the use of the SISI test in combination with two or three other differential audiological tests would add even more to the reliability of the diagnosis NIPHL.

Conclusions

If the SISI could indeed provide the industrial medical officer with an additional diagnostic tool for making the diagnosis NIPHL with reasonable certainty, this would stimulate:

- a quicker reaction by means of technical preventive and protective measures (in terms of the prescription of hearing-protective devices);
- a better hearing conservation programme;
- a more adequate referral policy, due to the fact that the industrial medical officer would be able to select his referral cases with much greater precision.

From the results of the present study, the conclusion can be drawn that the SISI test can indeed play a valuable part here, provided that:

- the test is carried out efficiently, special attention being given to the instruction of the subjects;
- it is kept in mind, that the SISI test yields the best results with pure-tone hearing losses of over 30 dB at 4000 Hz;

- in cases where only the last fifteen 1 dB increments have been perceived, the number of 1 dB increments is raised to 25, on the ground that for some unknown reason the first five 1 dB increments have not been heard;
- a 'warming-up period' is included, par example during which the subject has to perceive, two or three 5 dB increments prior to the actual test;
- it is borne in mind, that of subjects with a NIPHL a pure-tone hearing loss between 25 and 40 dB at 4000 Hz, an average of 65 per cent will achieve a SISI score of 60% and more;
- the SISI test works best when used for subjects with a NIPHL and a pure-tone hearing losses between 60 and 75 dB at 4000 Hz; of that category, over 90 per cent achieves a positive score.

On the strength of the results obtained, the conclusion seems justified that the industrial medical officer will be able to make a reasonably reliable diagnosis NIPHL, if he bases this diagnosis upon the data of an A/C audiogram plus a SISI test at 4000 Hz plus a focussed medical history. The subject's pure-tone hearing loss should be over 30 dB, however.

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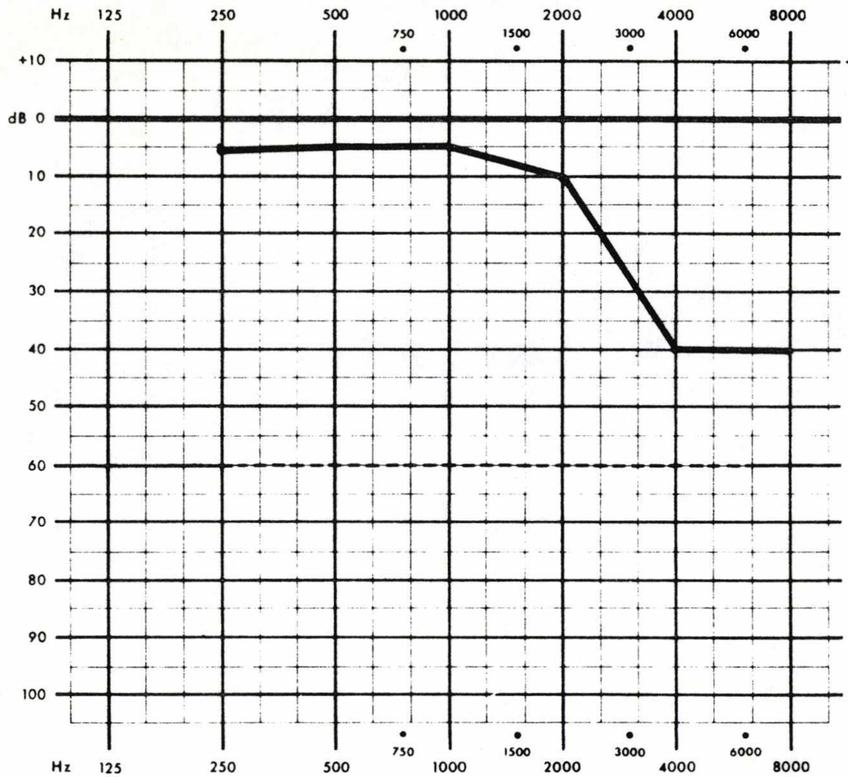
*) TNO = Toegepast Natuurwetenschappelijk Onderzoek = Netherlands Organization for Applied Scientific Research

APPENDIX A

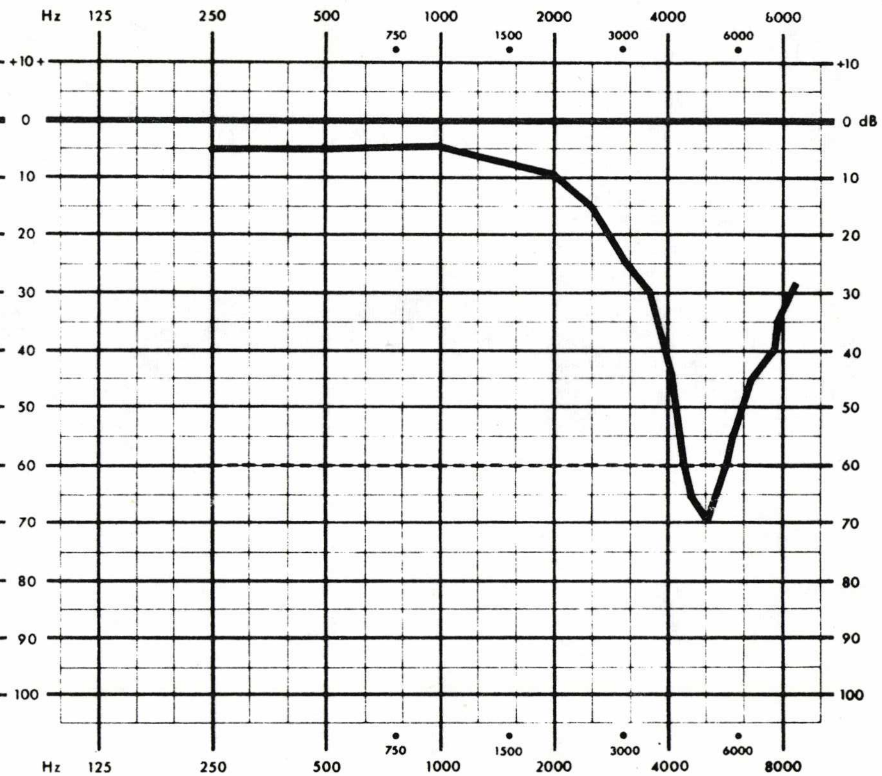
Specification SISI test

Example of continuous frequency
versus octave method audiogram

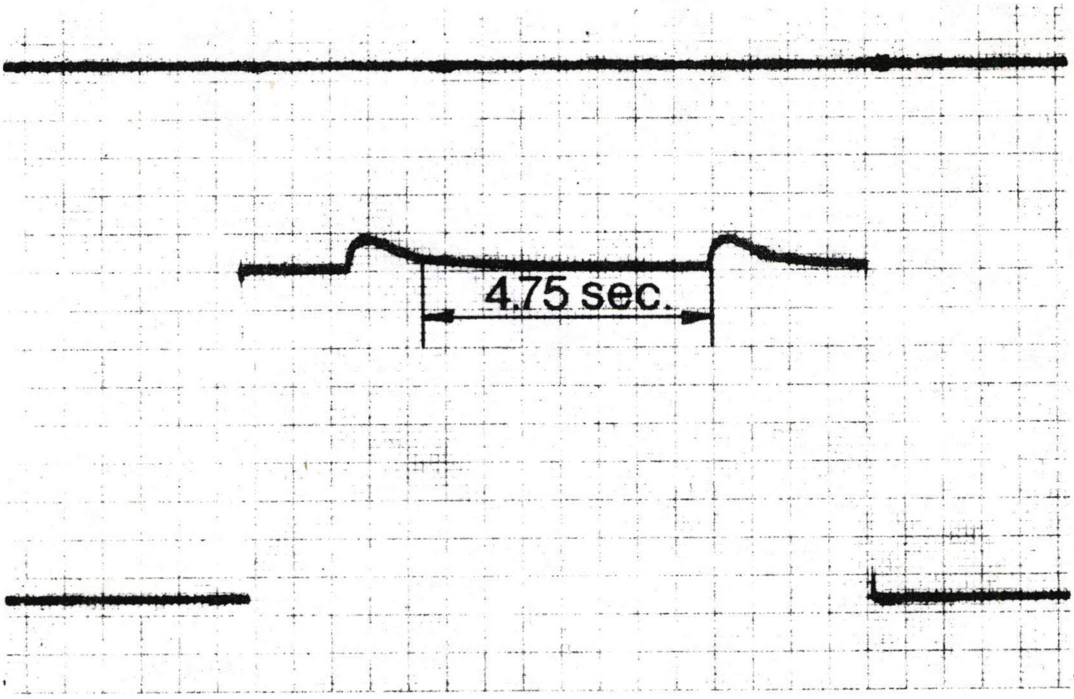
OCTAVE AUDIOGRAM



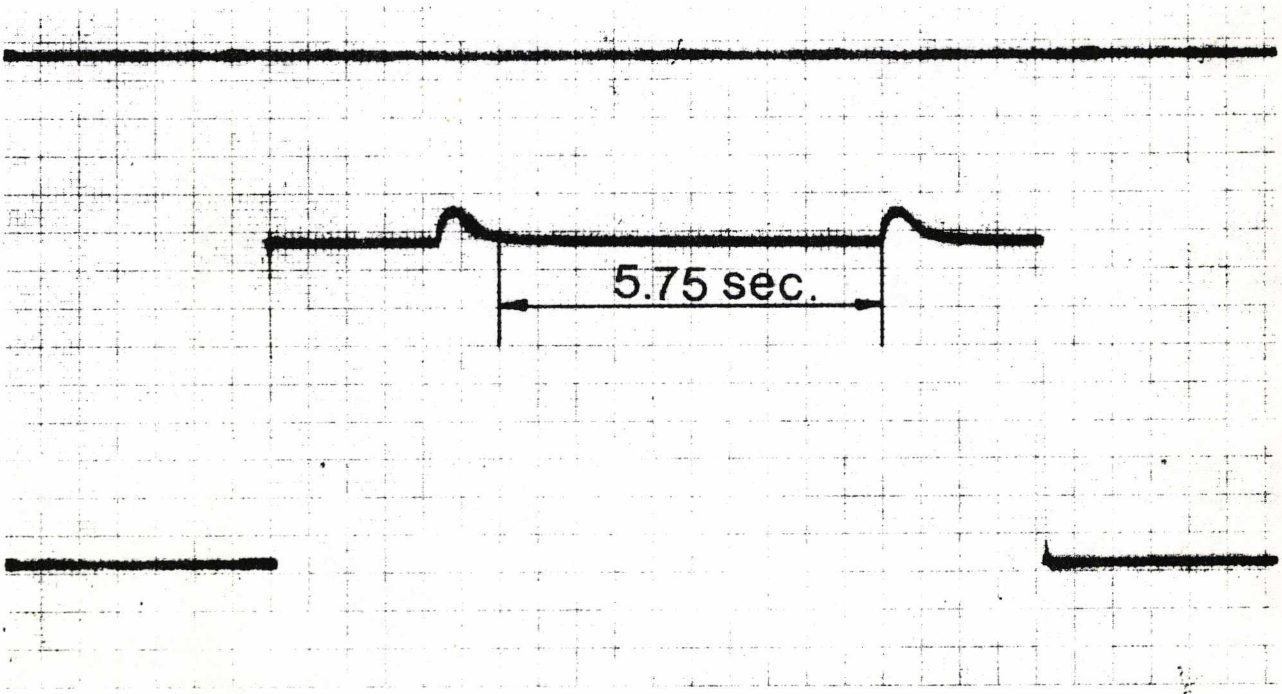
CONTINUOUS FREQUENCY AUDIOGRAM



4000 Hz 80dB 1cm/sec. T795/796



4000 Hz 80dB 1cm/sec. T803/804



APPENDIX B

Median audiograms

Figures and tables

Fig.1. Median audiogram right ear Age group < 20 yr

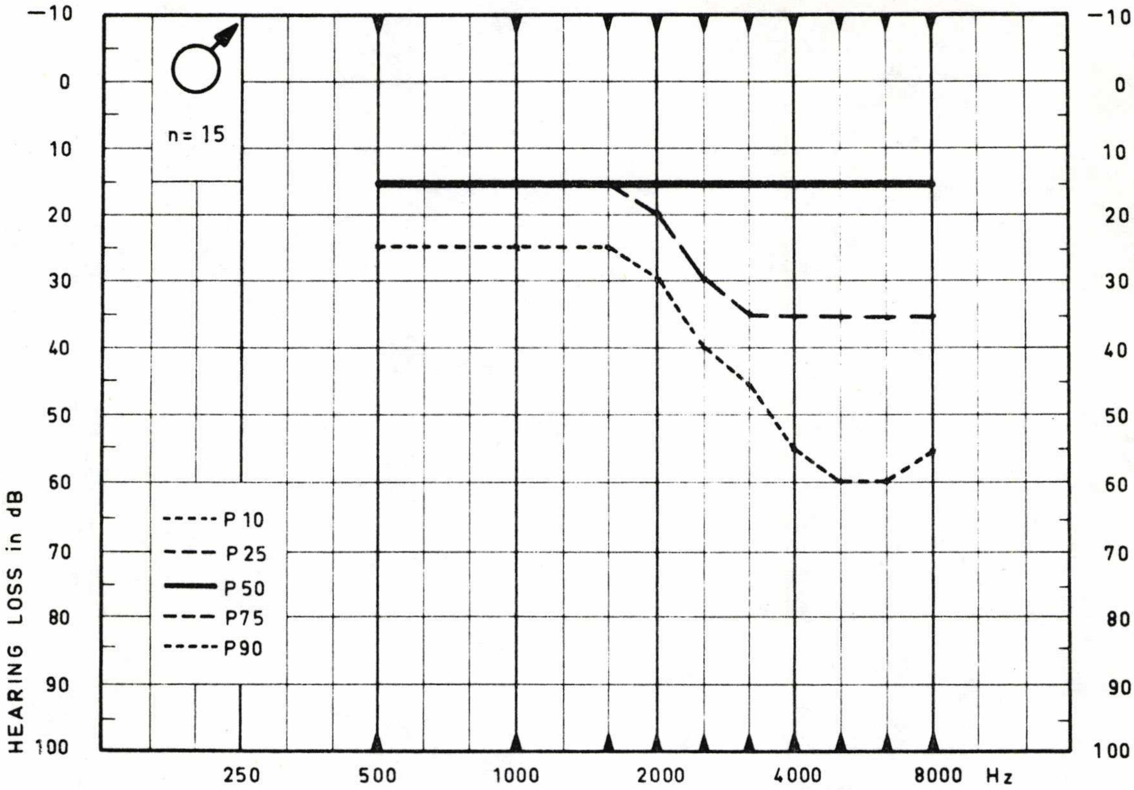


Fig.2. Median audiogram right ear Age group 20-29 yr

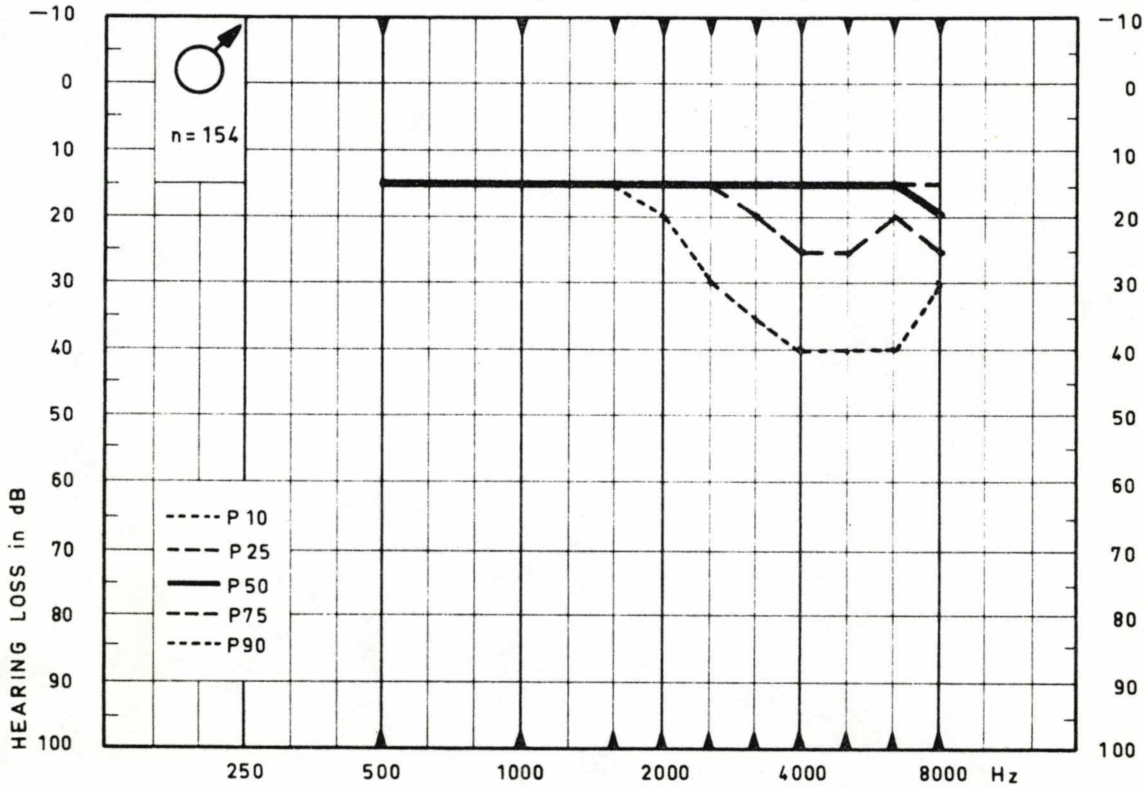


Fig.3. Median audiogram right ear Age group 30-39 yr

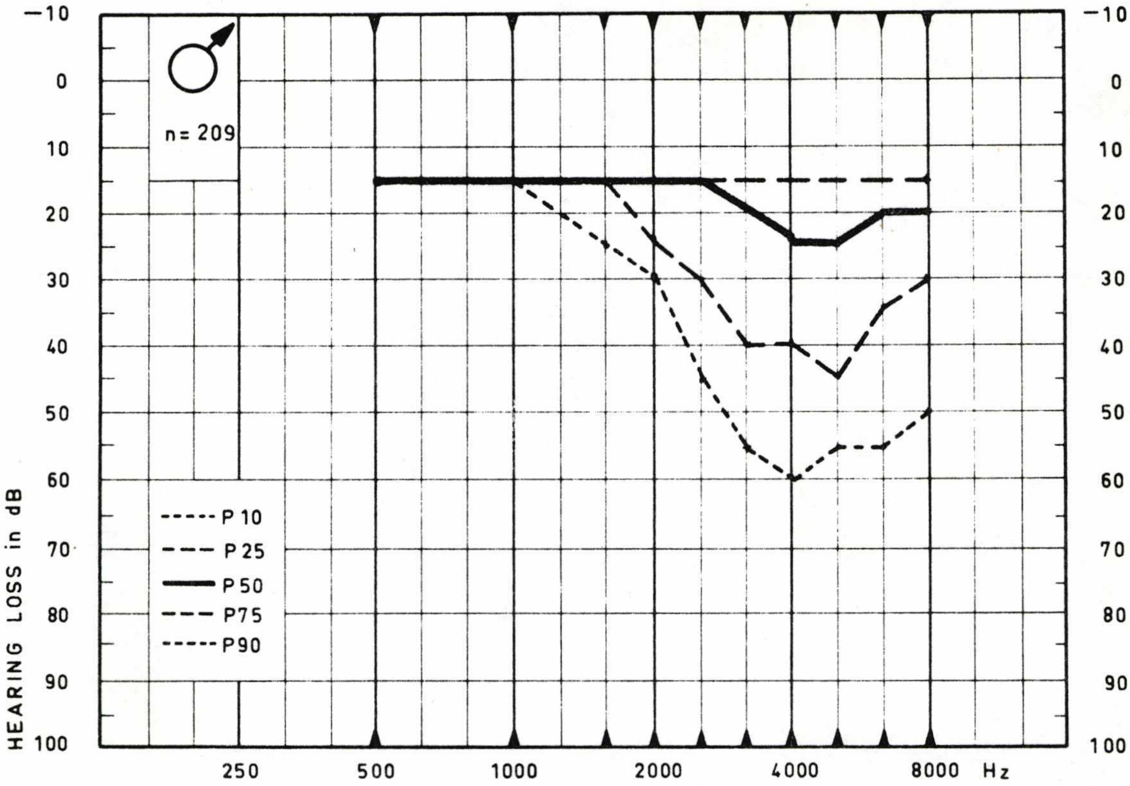


Fig.4. Median audiogram right ear Age group 40-49 yr

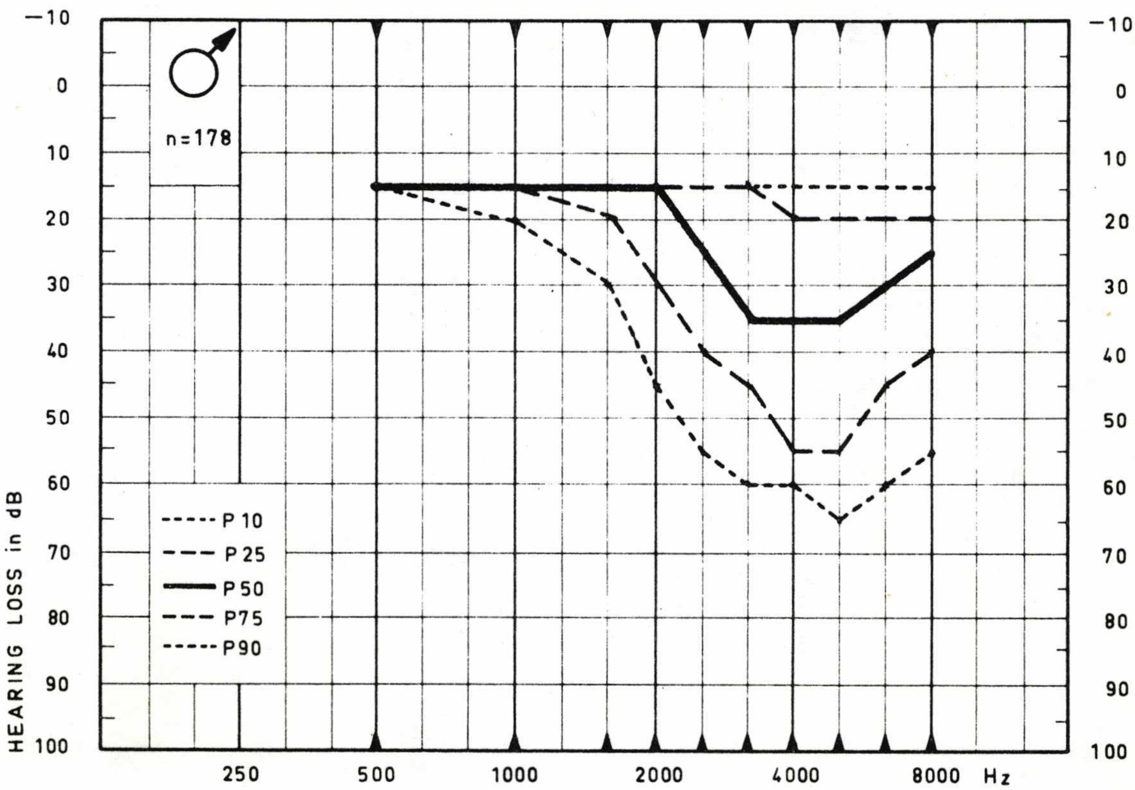


Fig.5. Median audiogram right ear Age group 50-59 yr

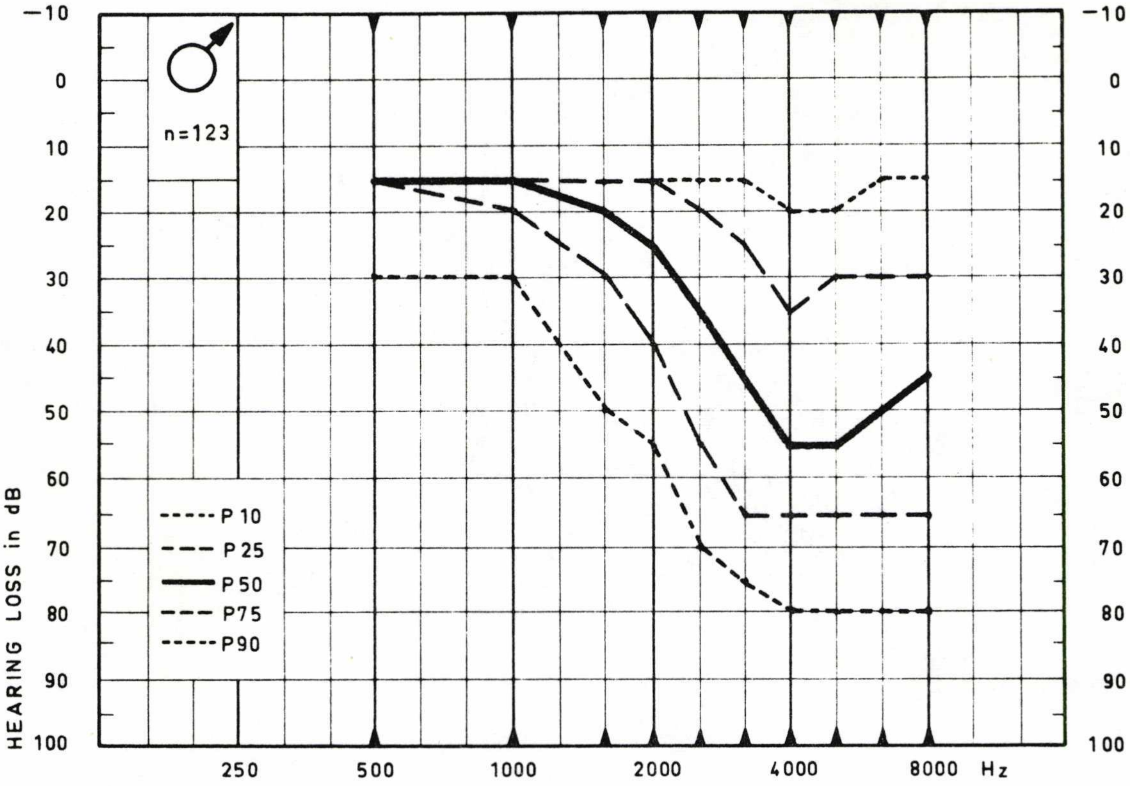


Fig.6. Median audiogram right ear Age group ≥60 yr

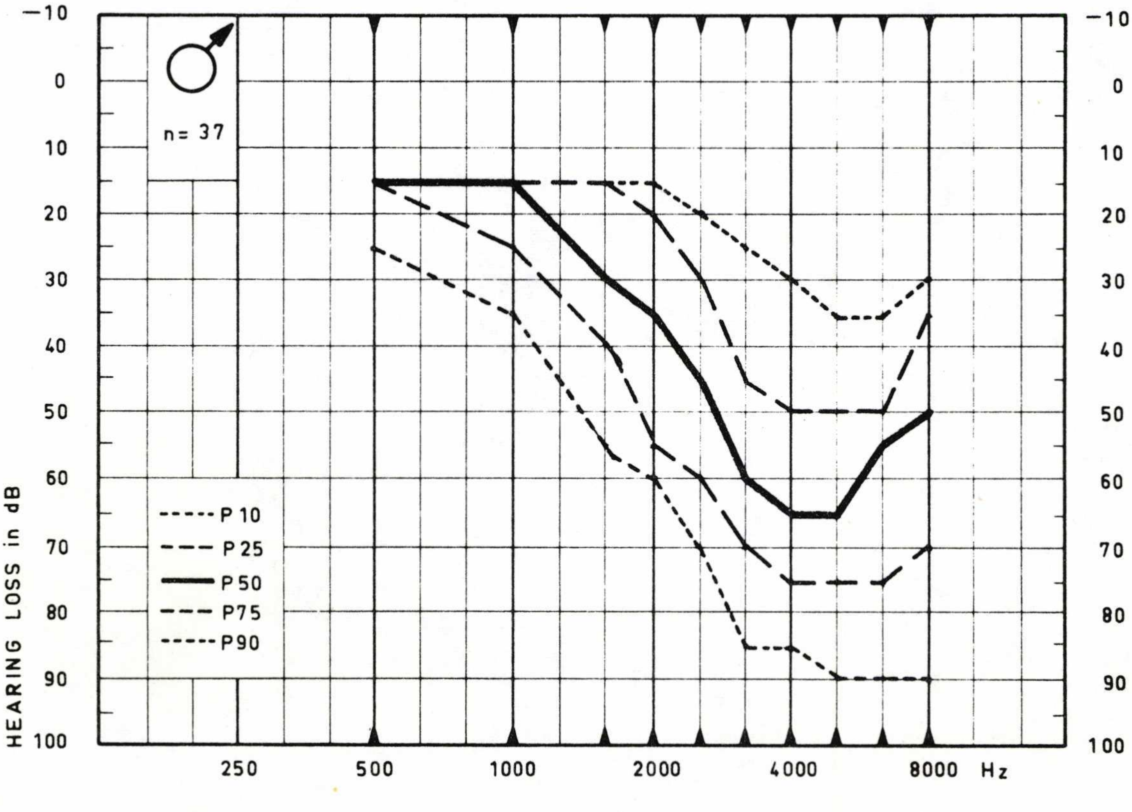


Fig.7. Median audiogram left ear Age group <20 yr

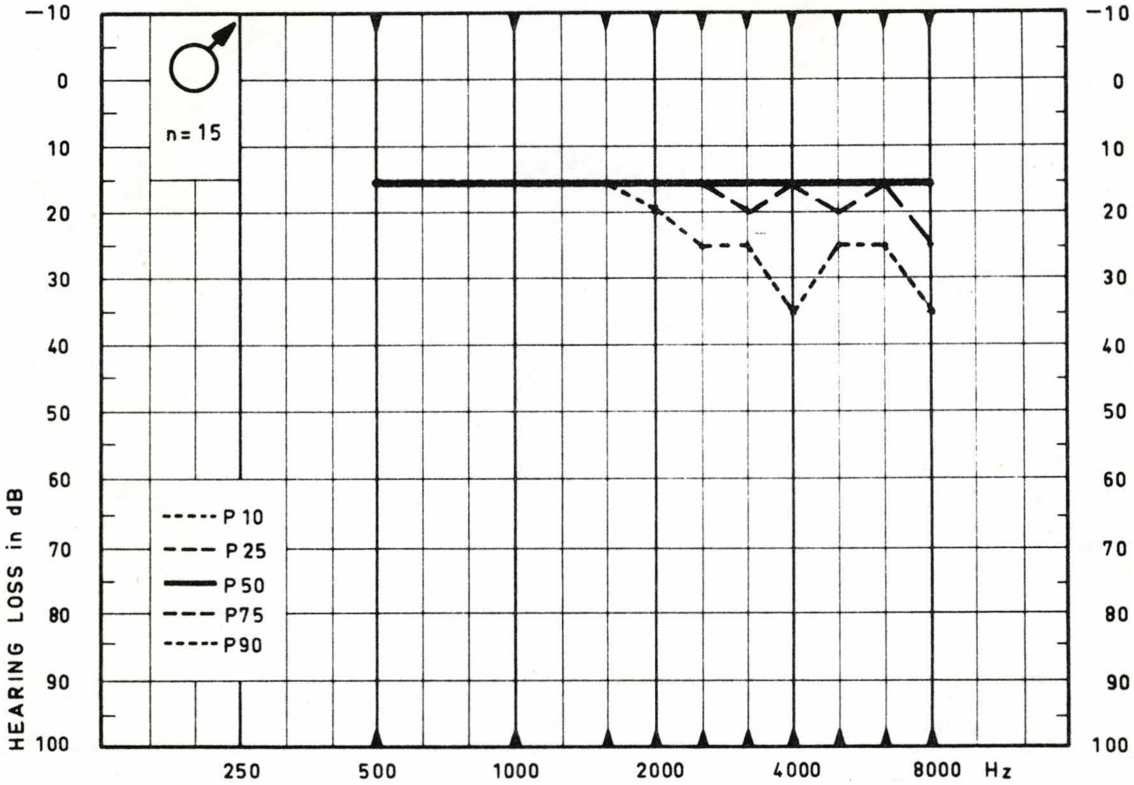


Fig.8. Median audiogram left ear Age group 20-29 yr

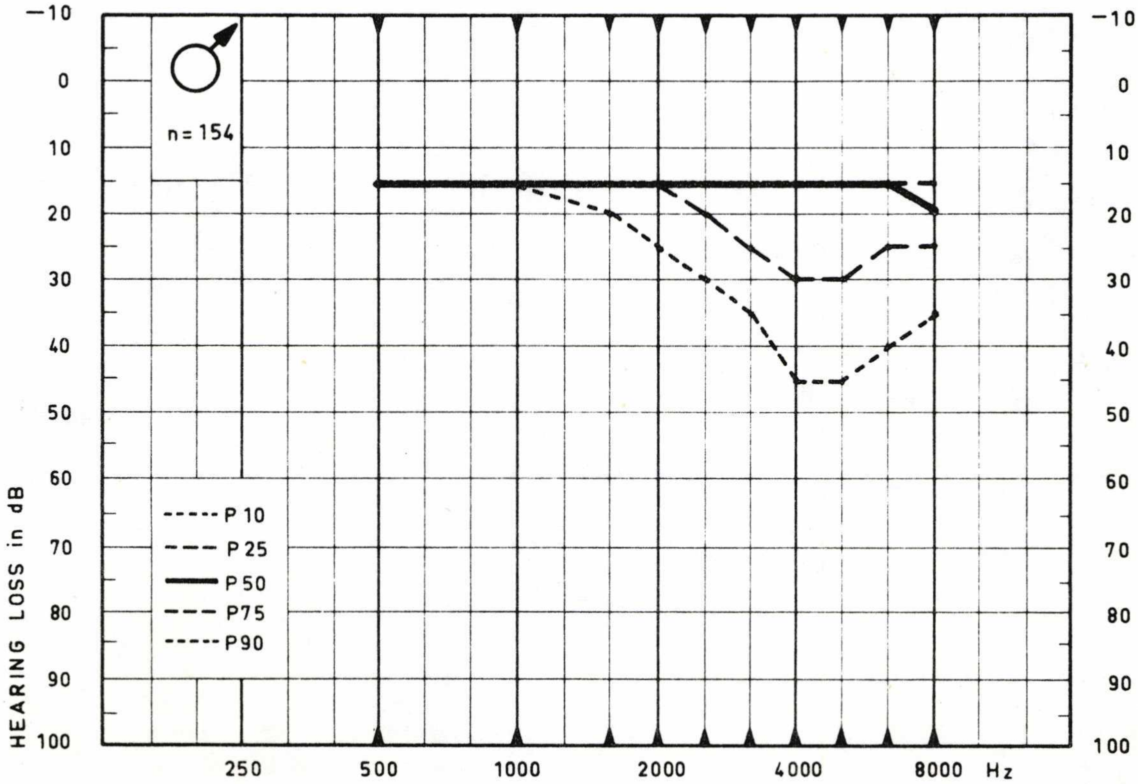


Fig.9. Median audiogram left ear Age group 30-39 yr

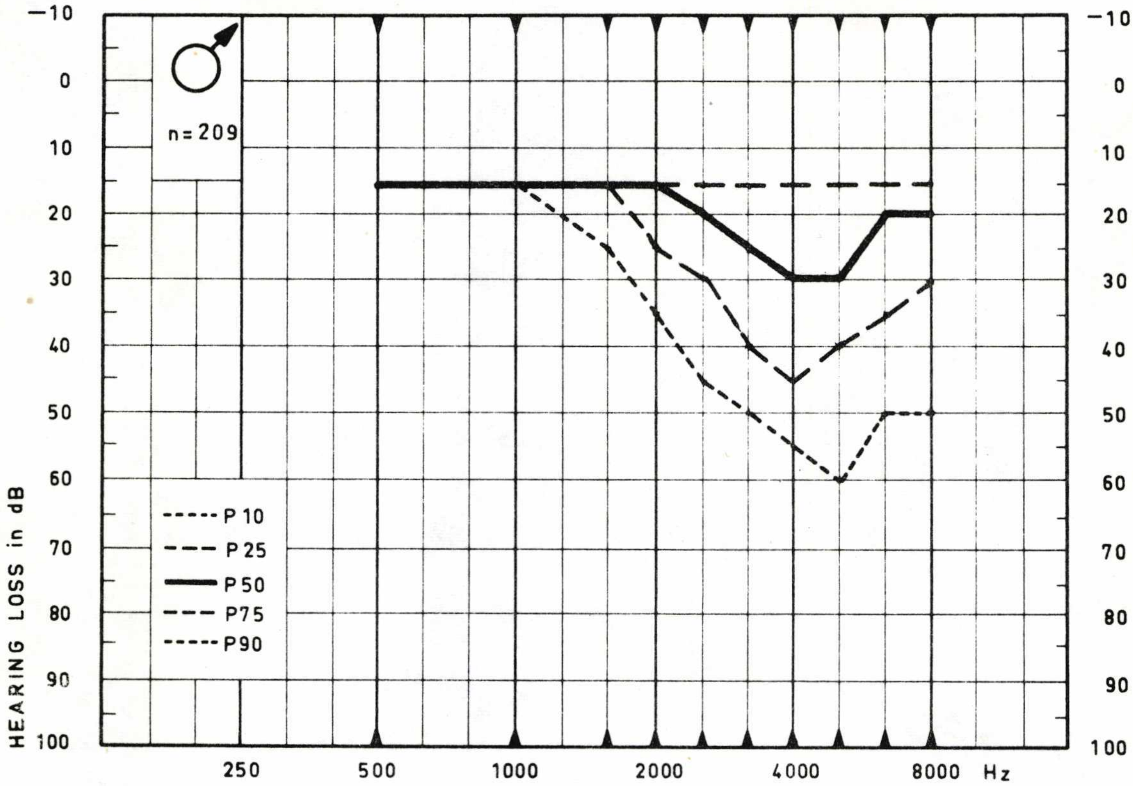


Fig.10. Median audiogram left ear Age group 40-49 yr

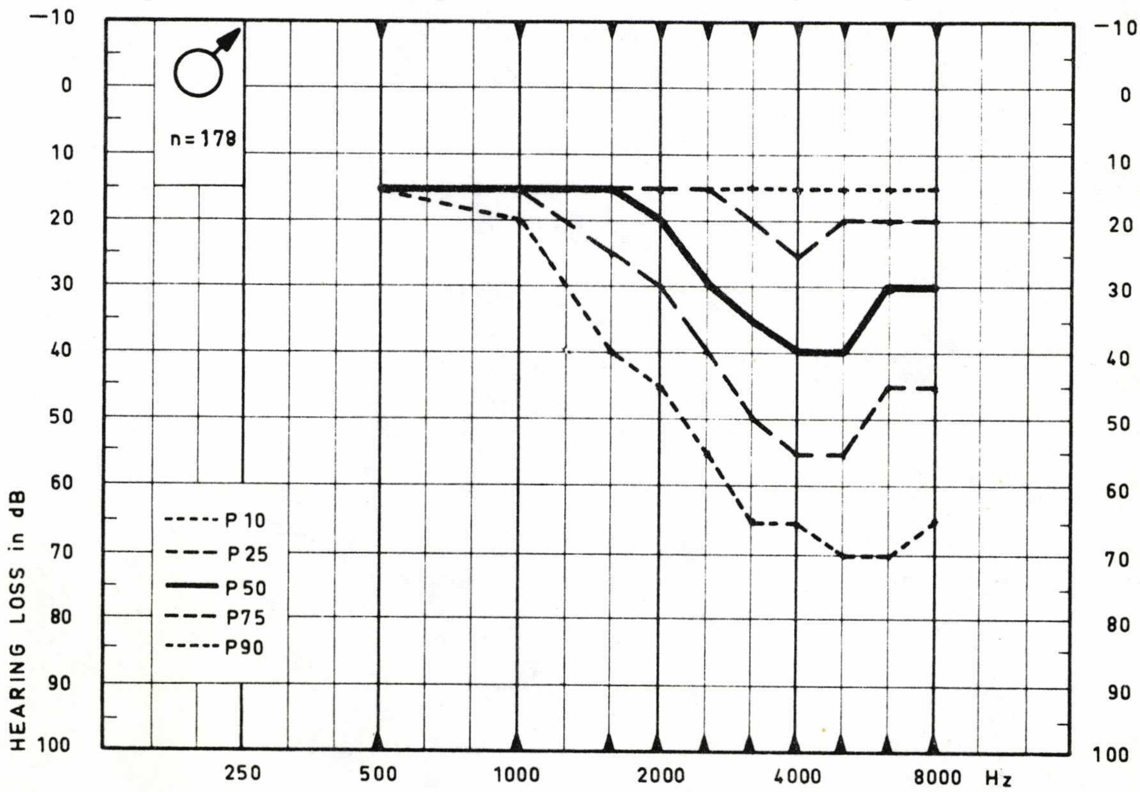


Fig.11. Median audiogram left ear Age group 50-59 yr

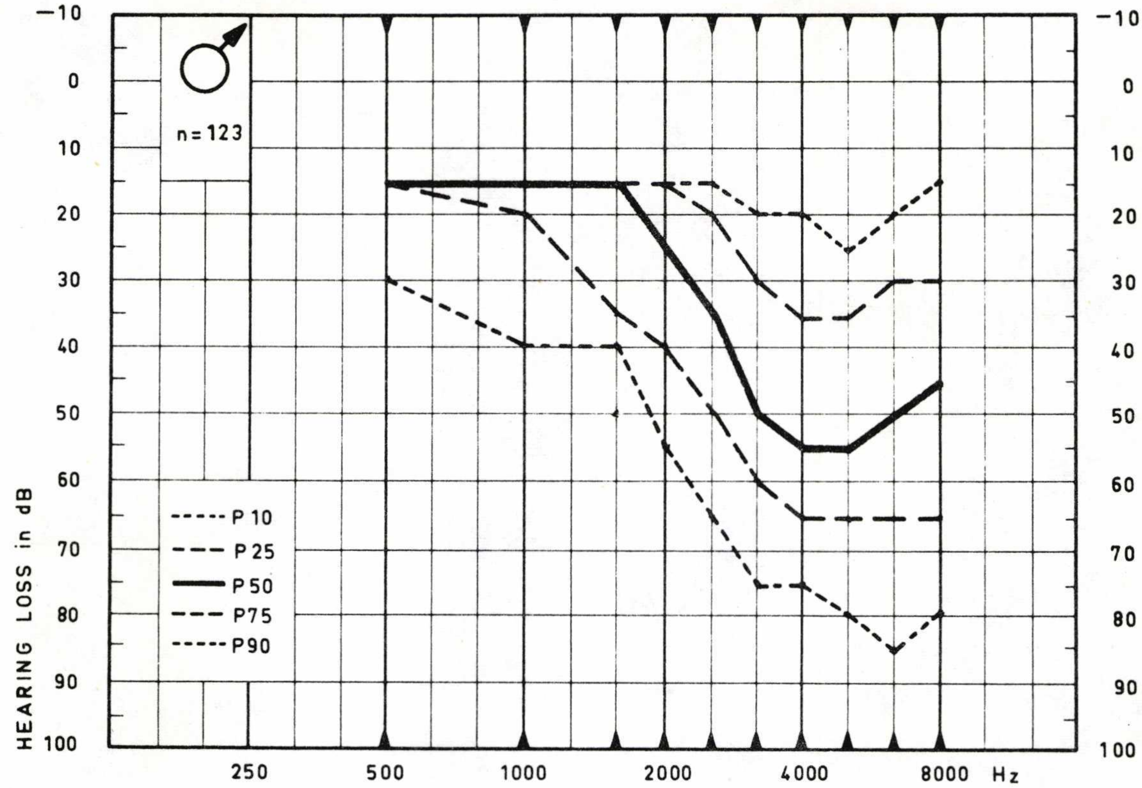


Fig.12. Median audiogram left ear Age group ≥ 60 yr

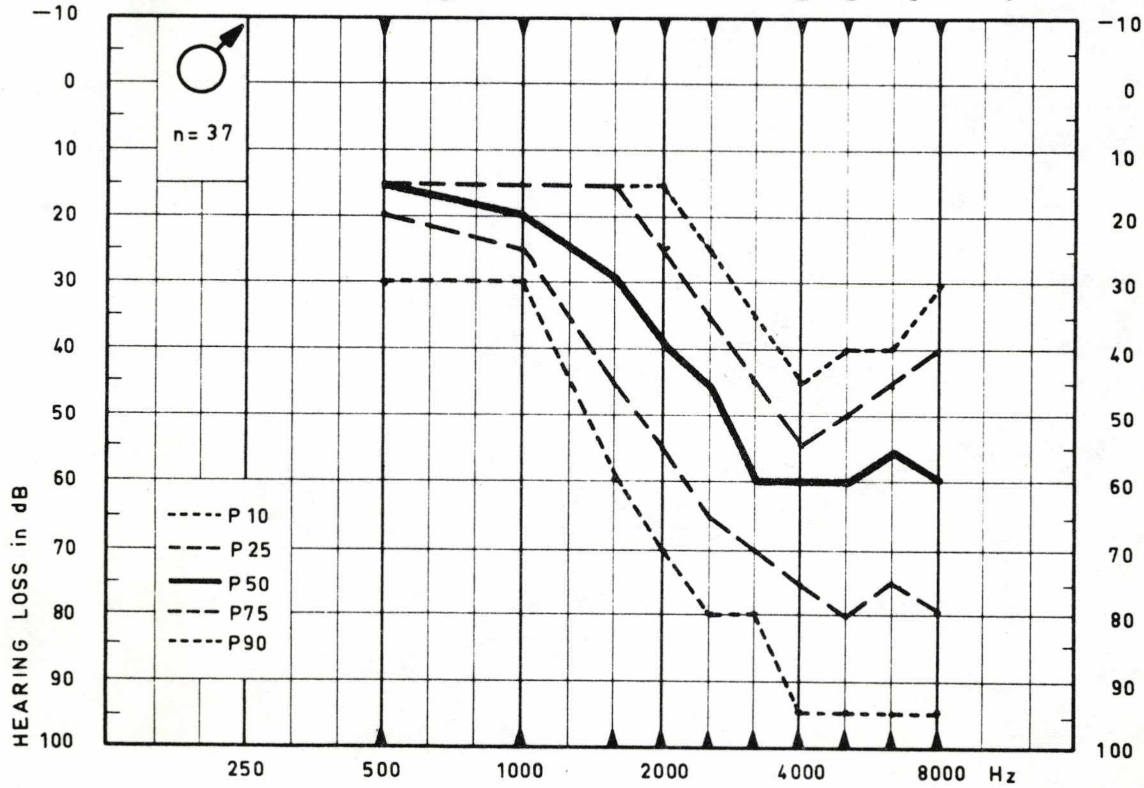


Fig.13. Median audiogram right ear All age groups

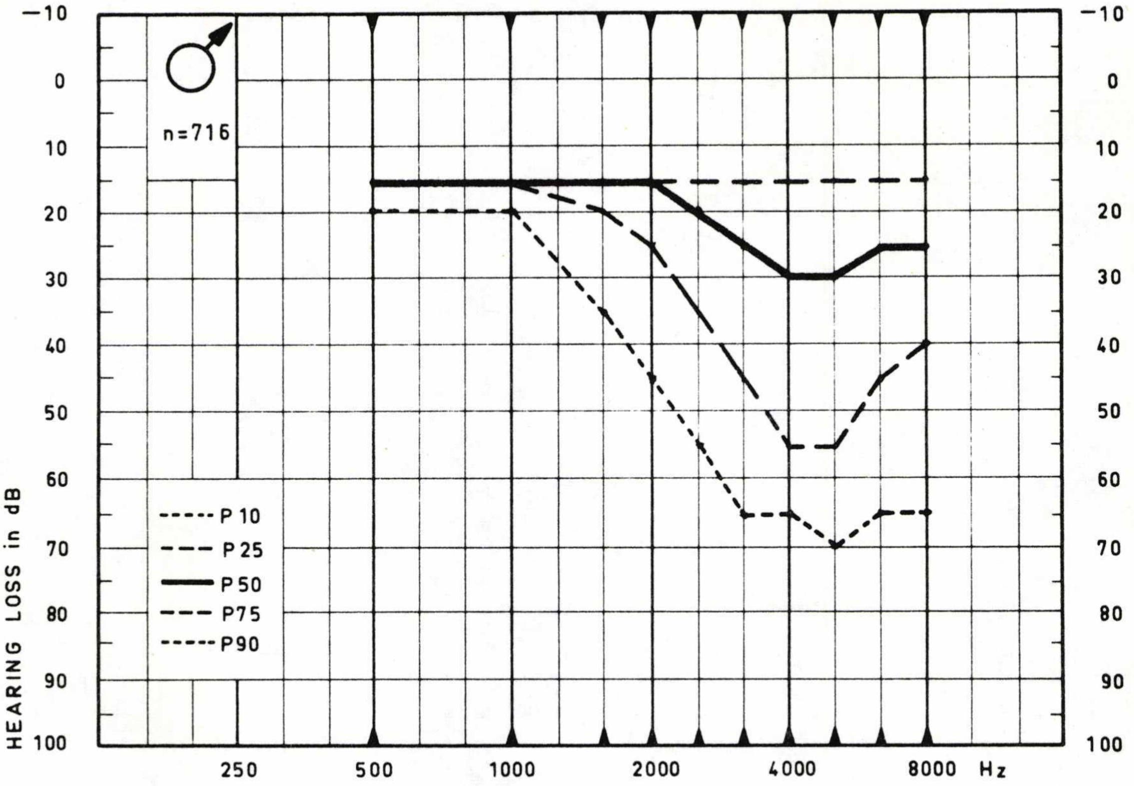


Fig.14. Median audiogram left ear All age groups

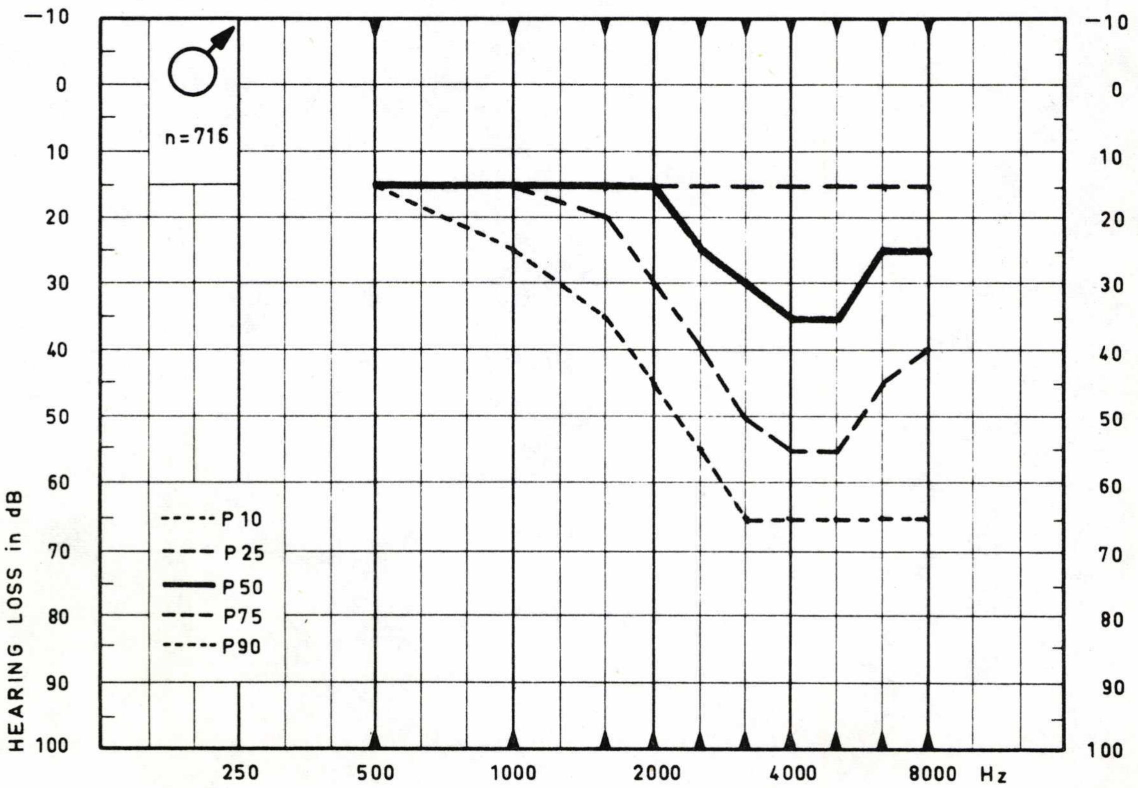


Fig.15. Median audiogram right ear Age group <20 yr

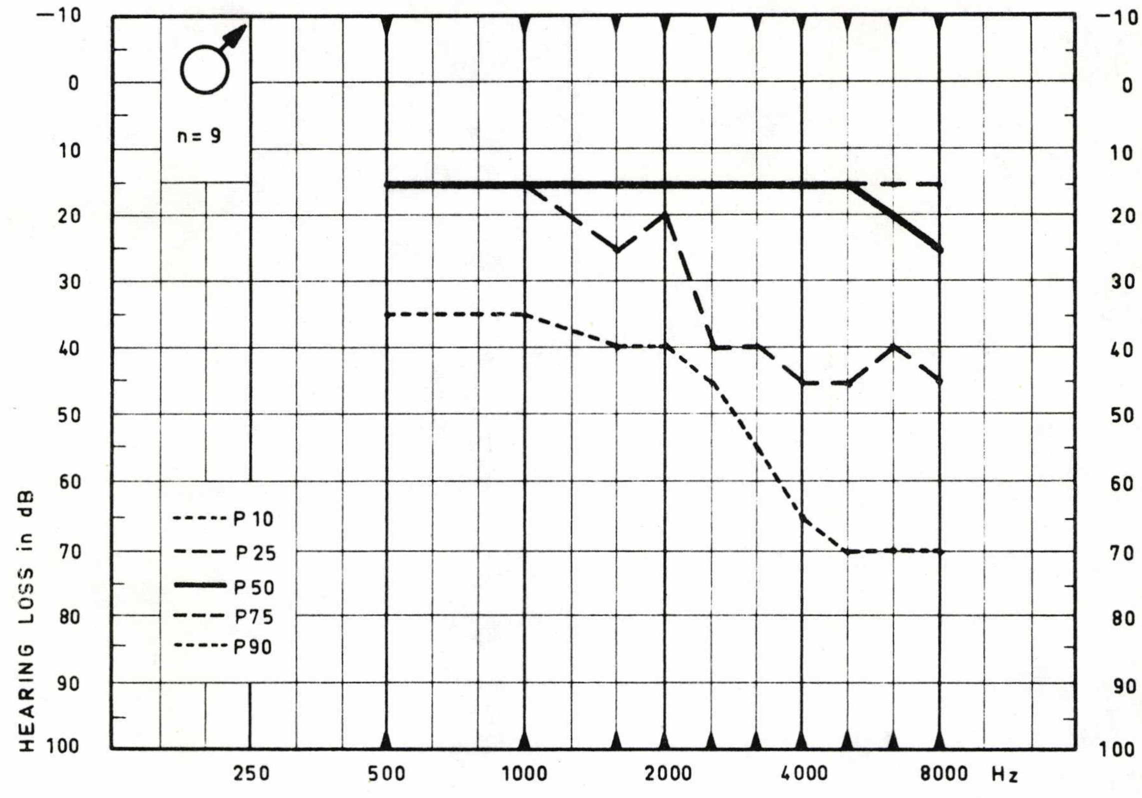


Fig.16. Median audiogram right ear Age group 20-29 yr

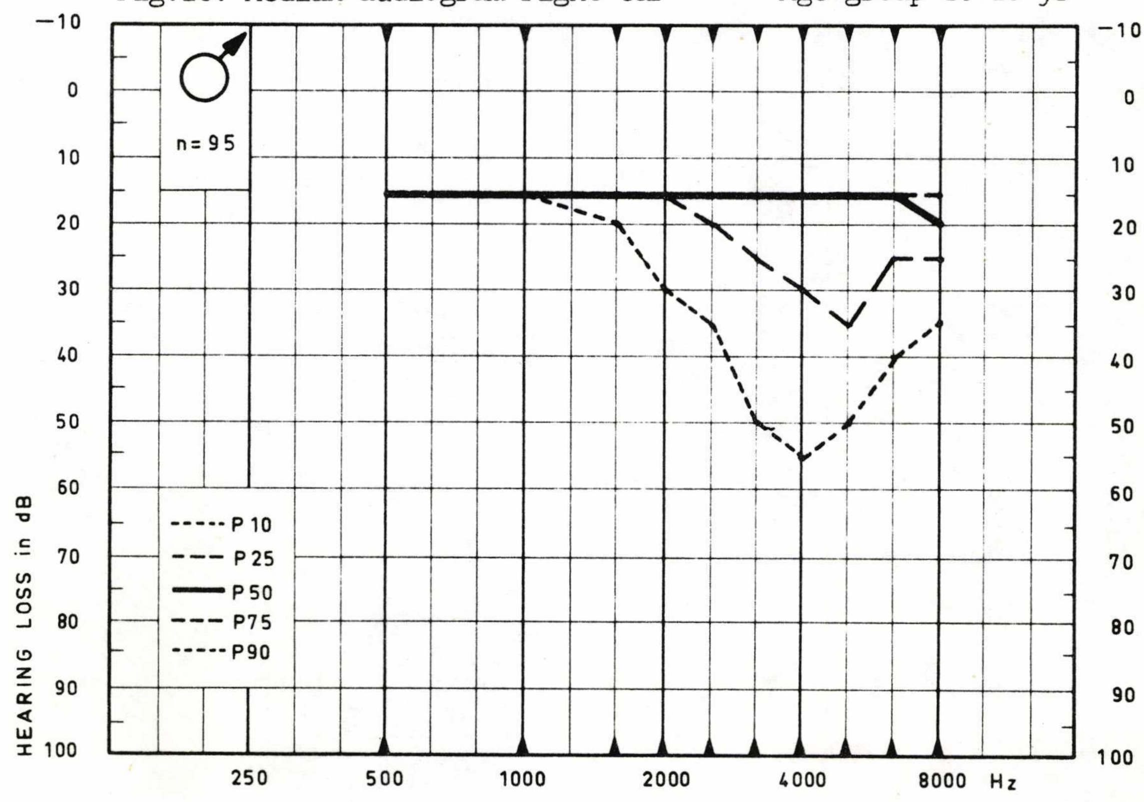


Fig.17. Median audiogram right ear Age group 30-39 yr

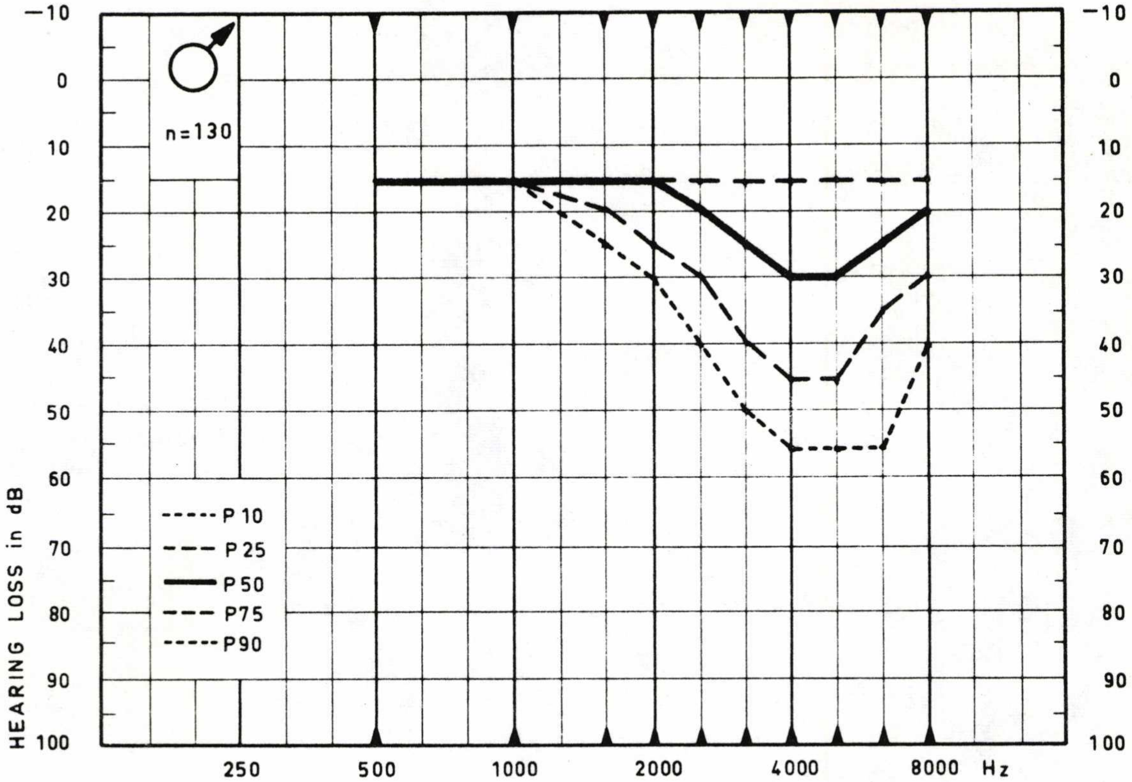


Fig.18. Median audiogram right ear Age group 40-49 yr

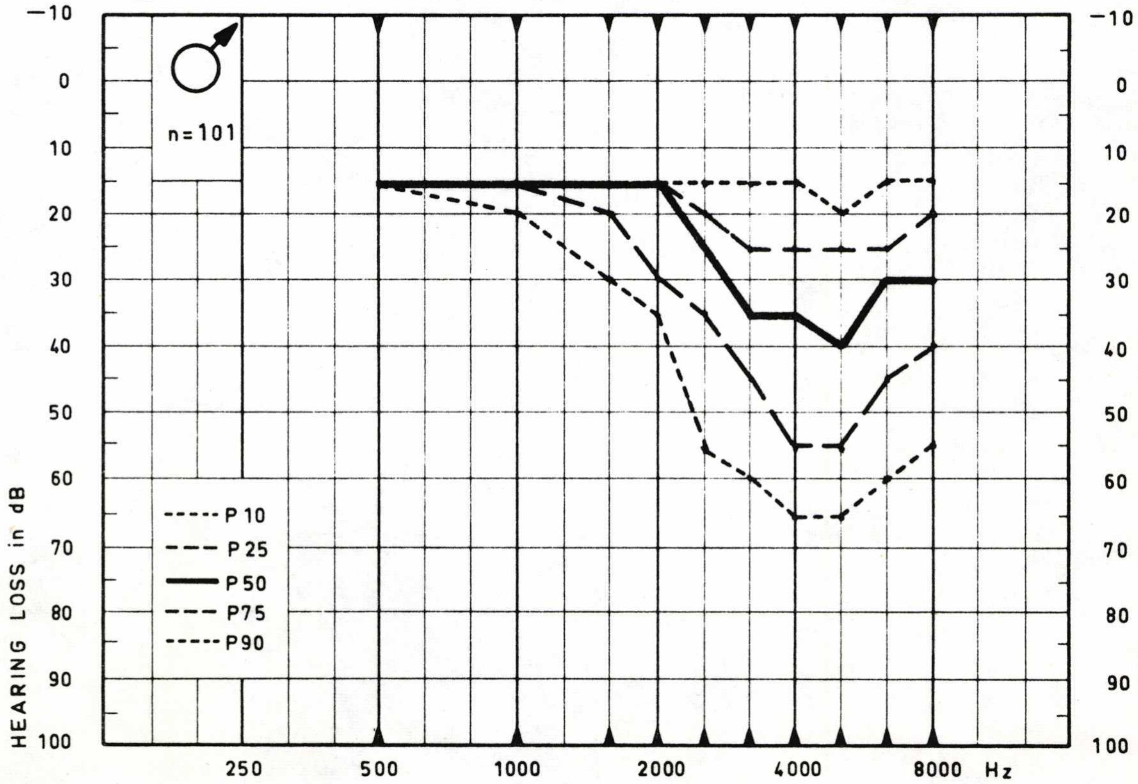


Fig.19. Median audiogram right ear Age group 50-59 yr

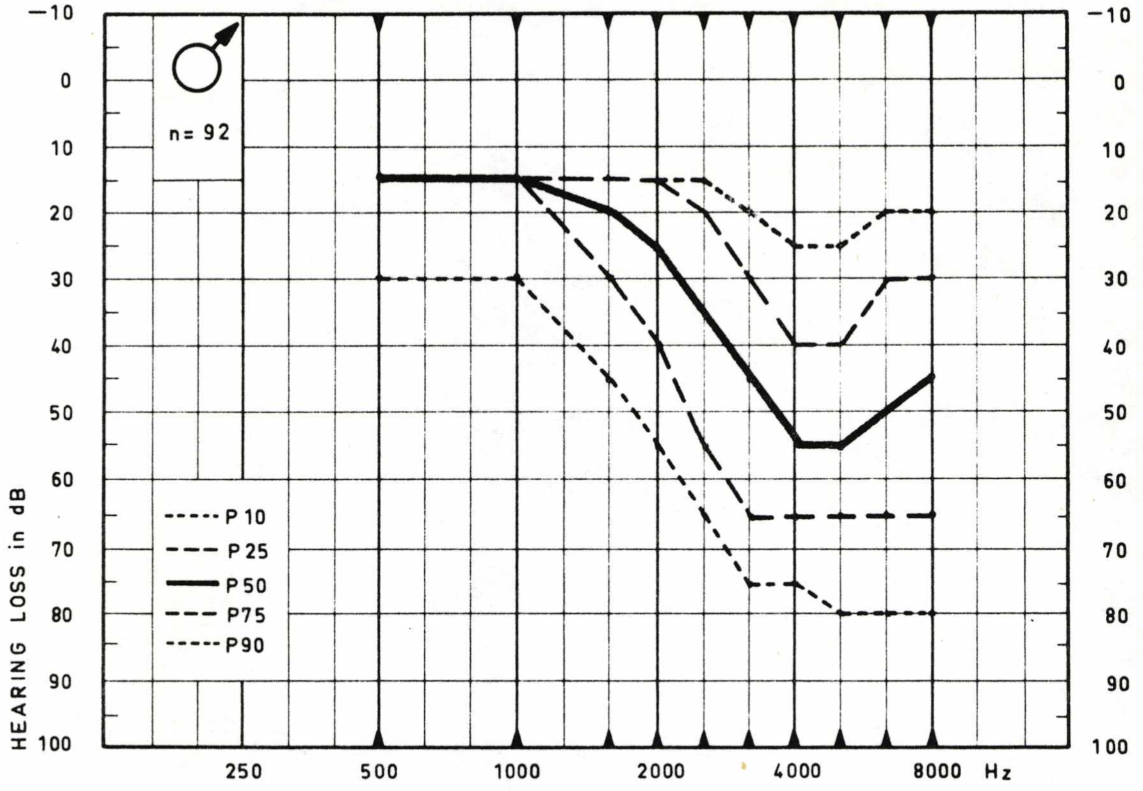


Fig.20. Median audiogram right ear Age group ≥ 60 yr

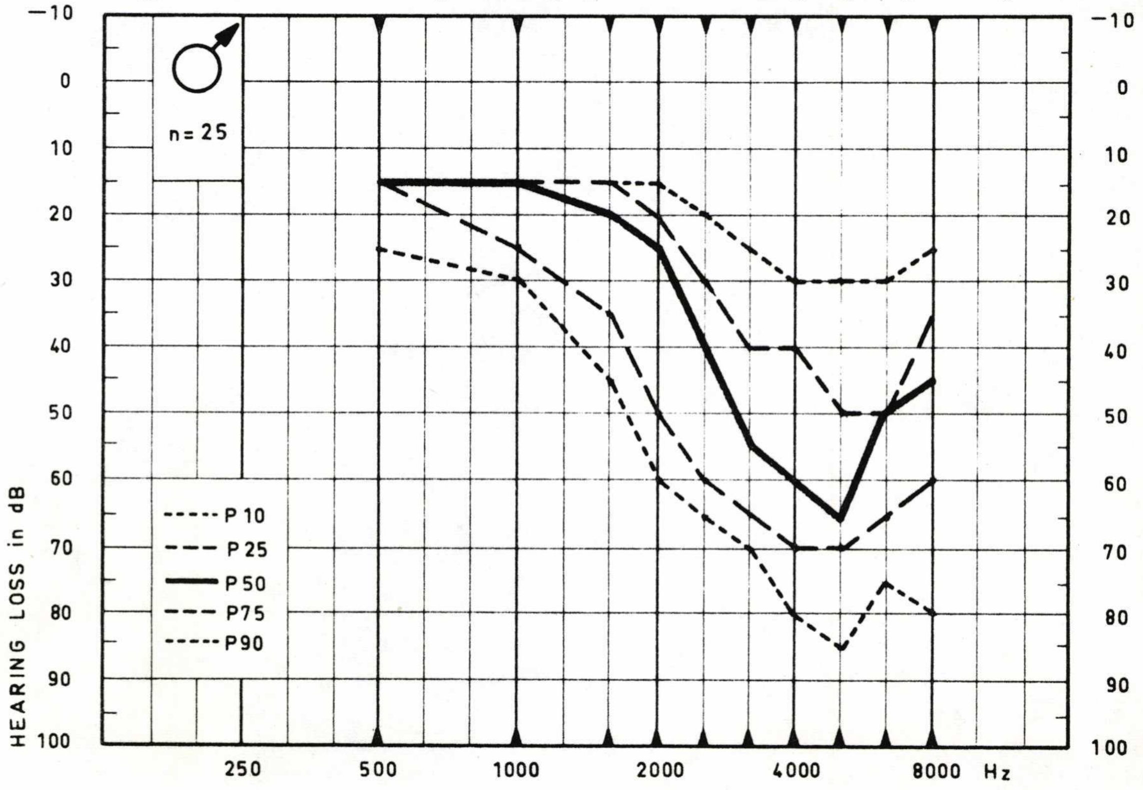


Fig.21. Median audiogram left ear Age group <20 yr

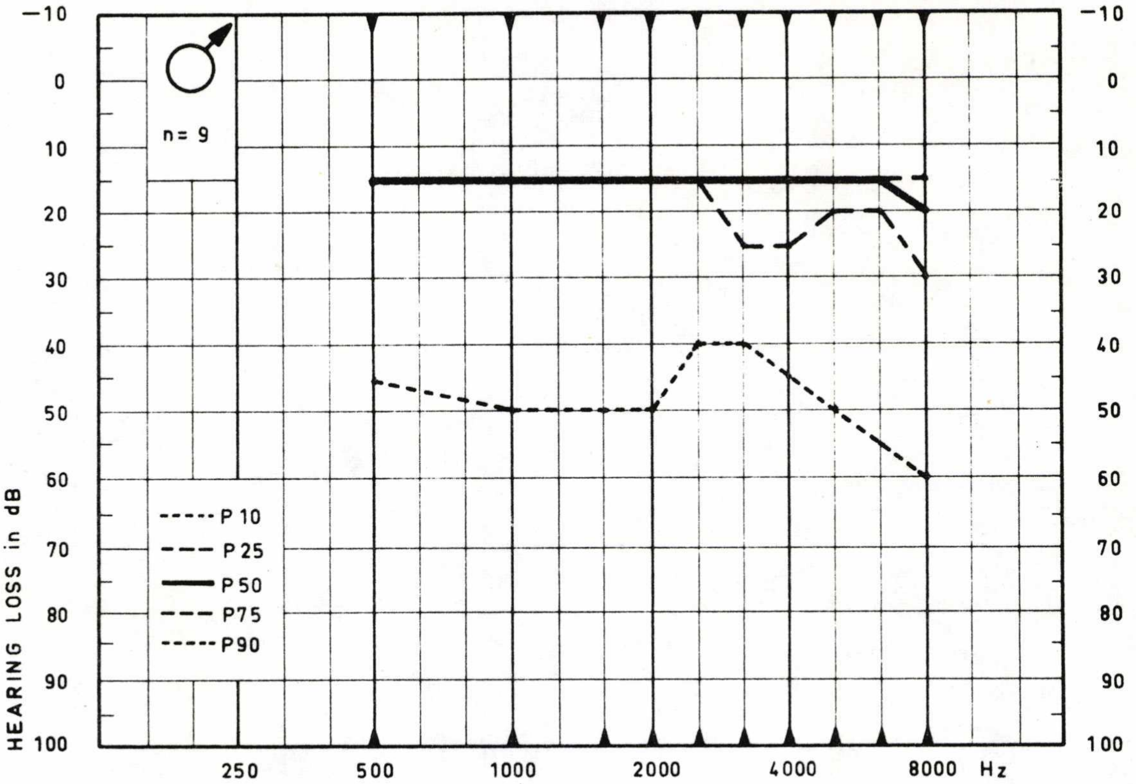


Fig.22. Median audiogram left ear Age group 20-29 yr

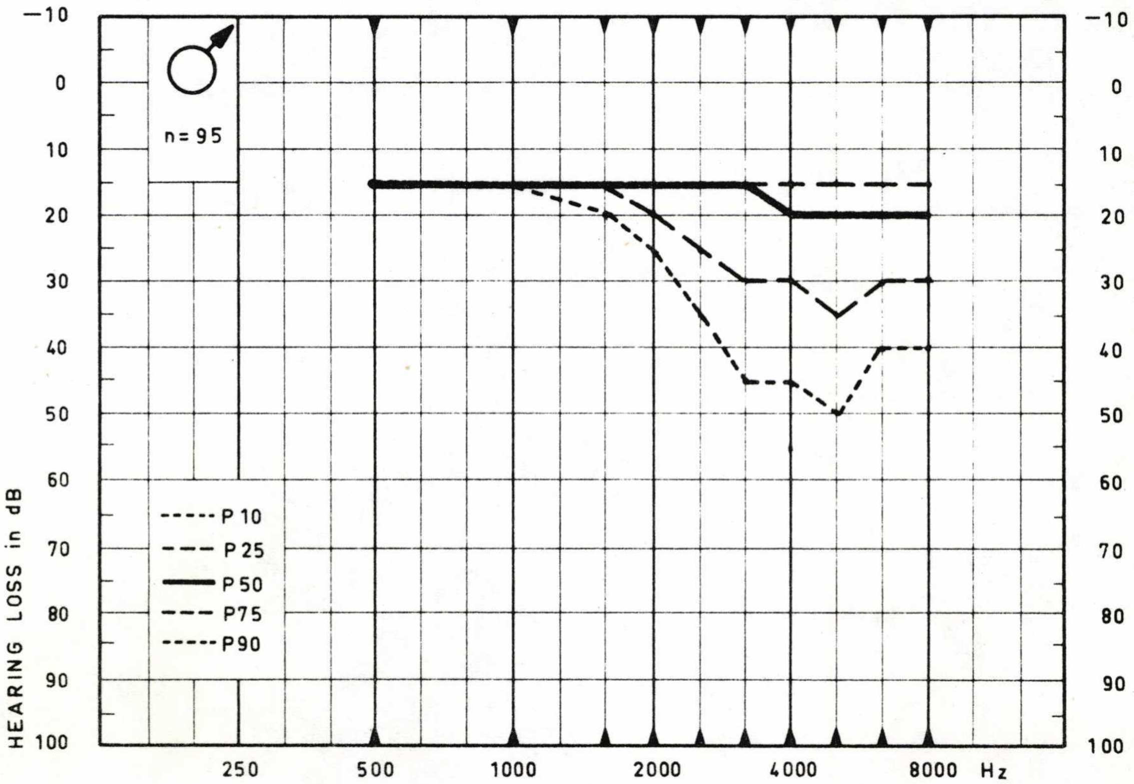


Fig.23. Median audiogram left ear Age group 30-39 yr

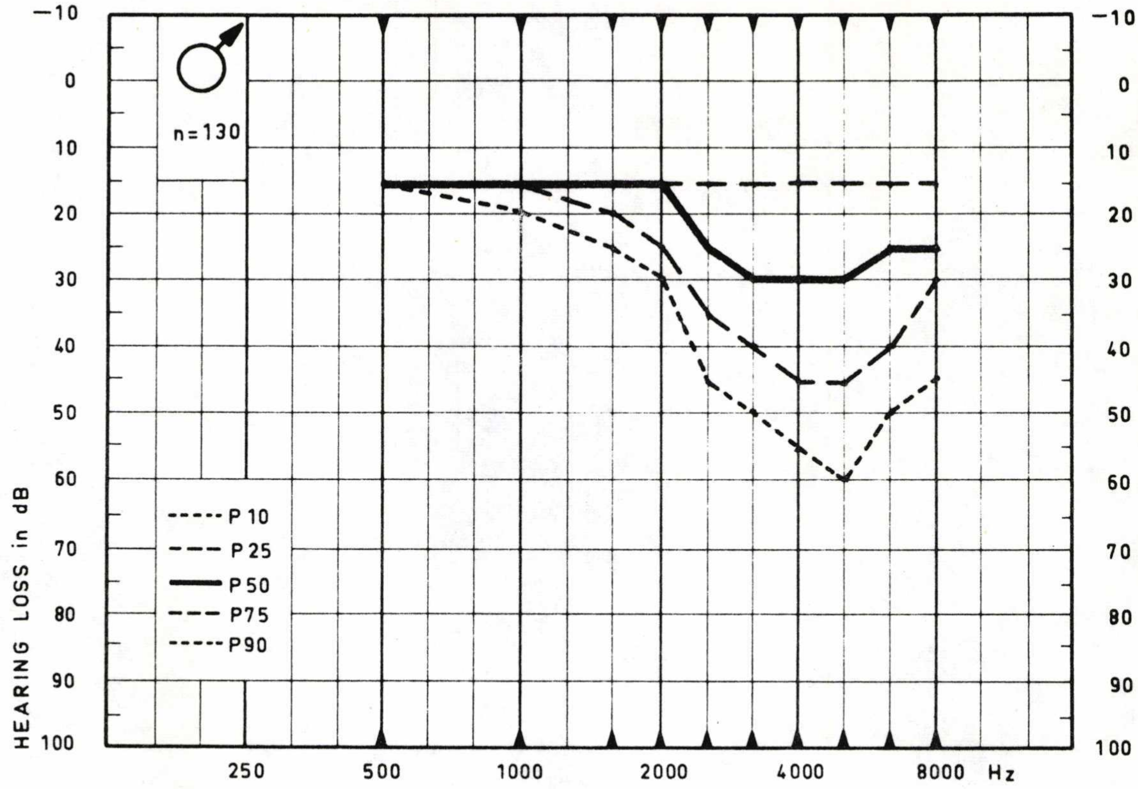


Fig.24. Median audiogram left ear Age group 40-49 yr

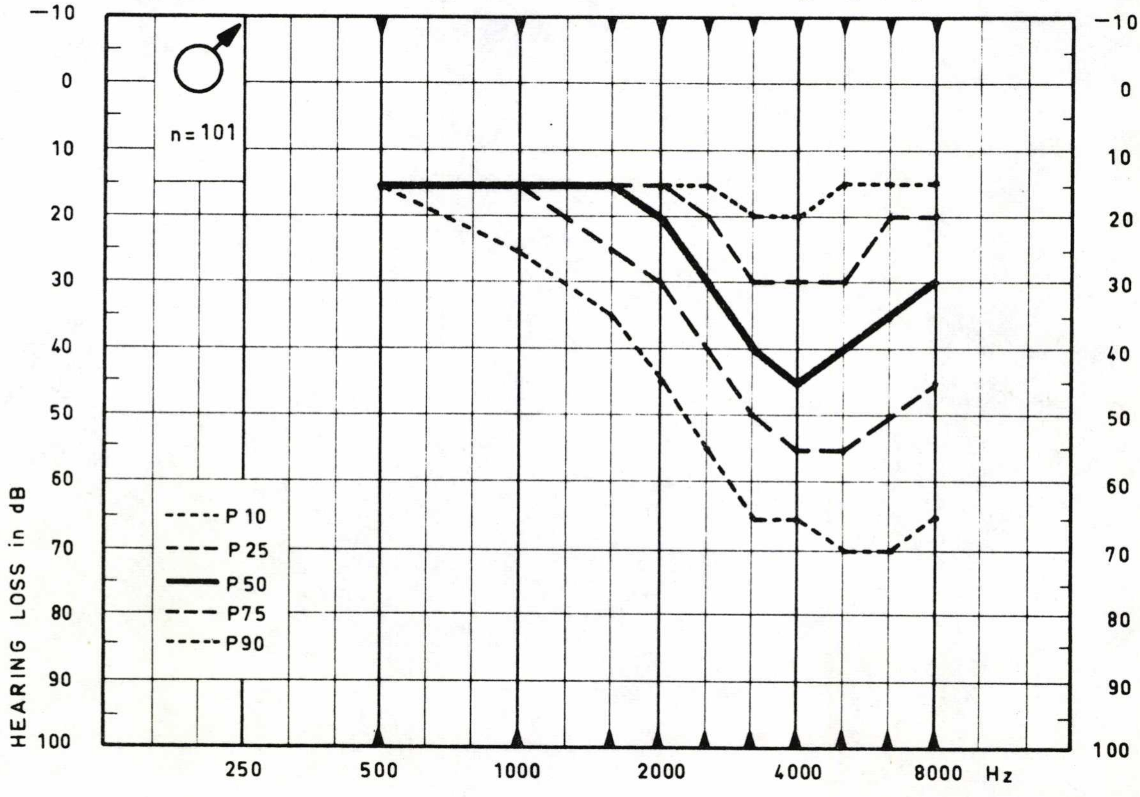


Fig.25. Median audiogram left ear Age group 50-59 yr

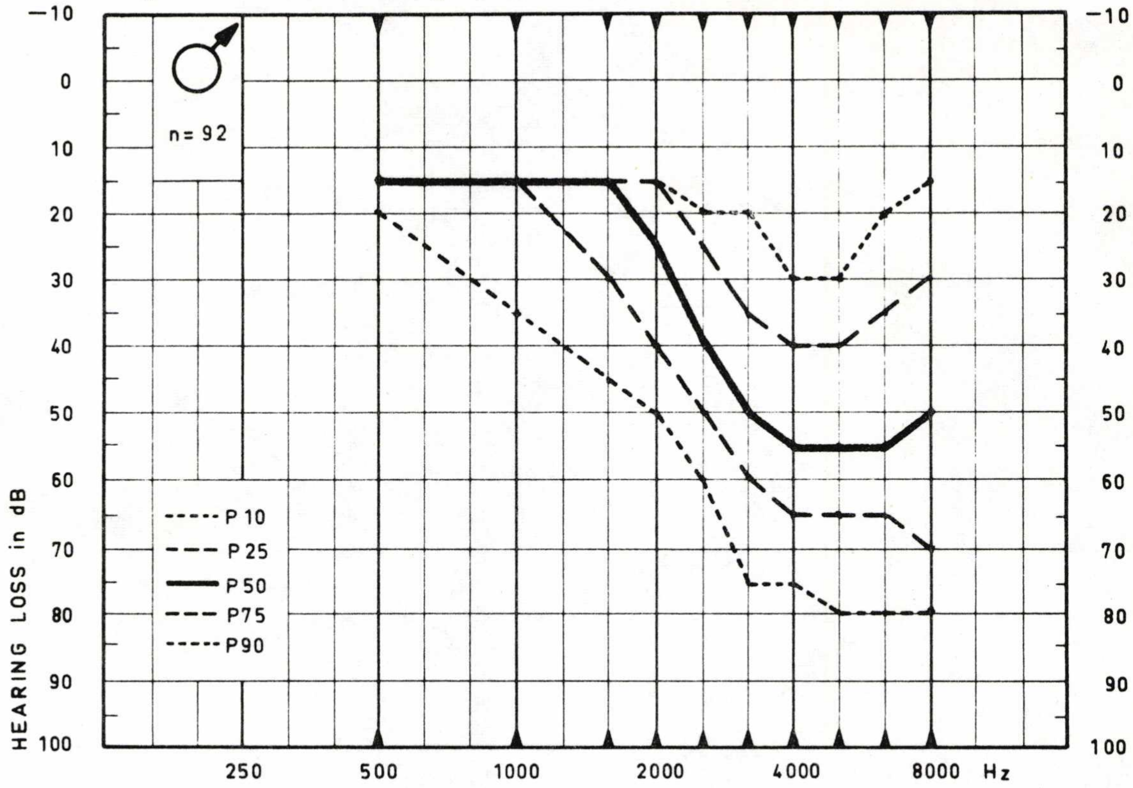


Fig.26. Median audiogram left ear Age group ≥60 yr

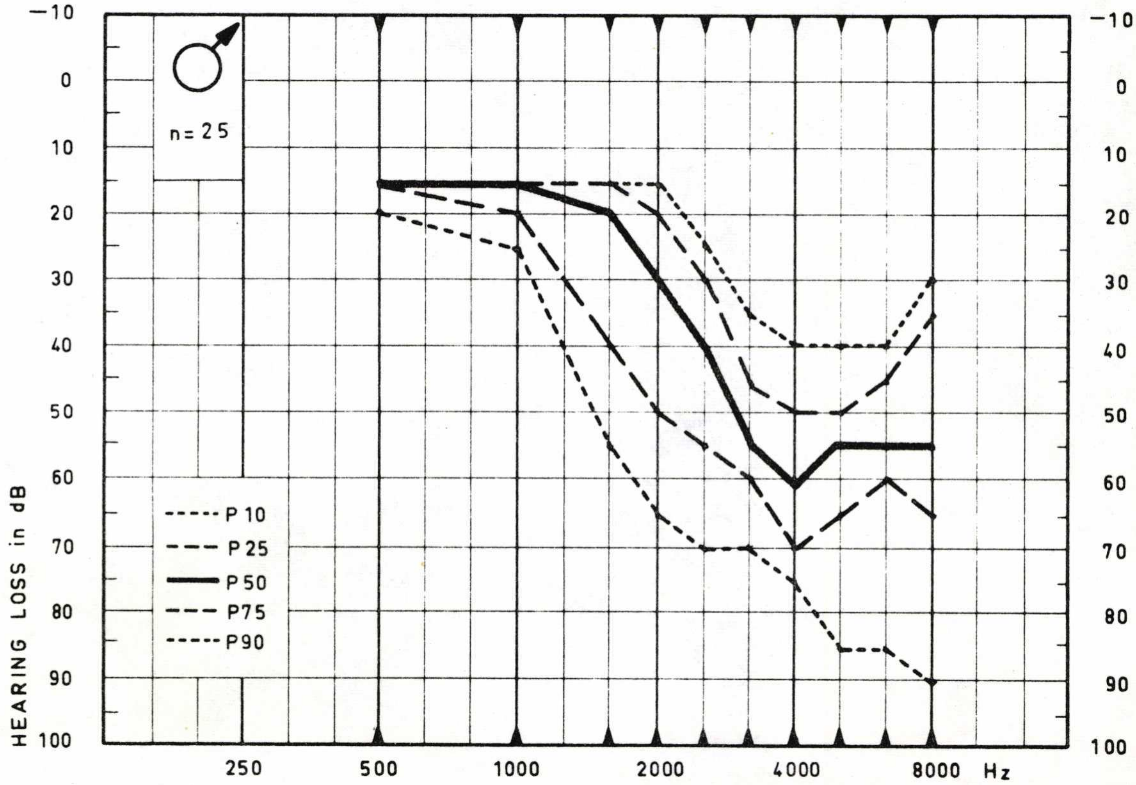


Fig.27. Median audiogram right ear All age groups

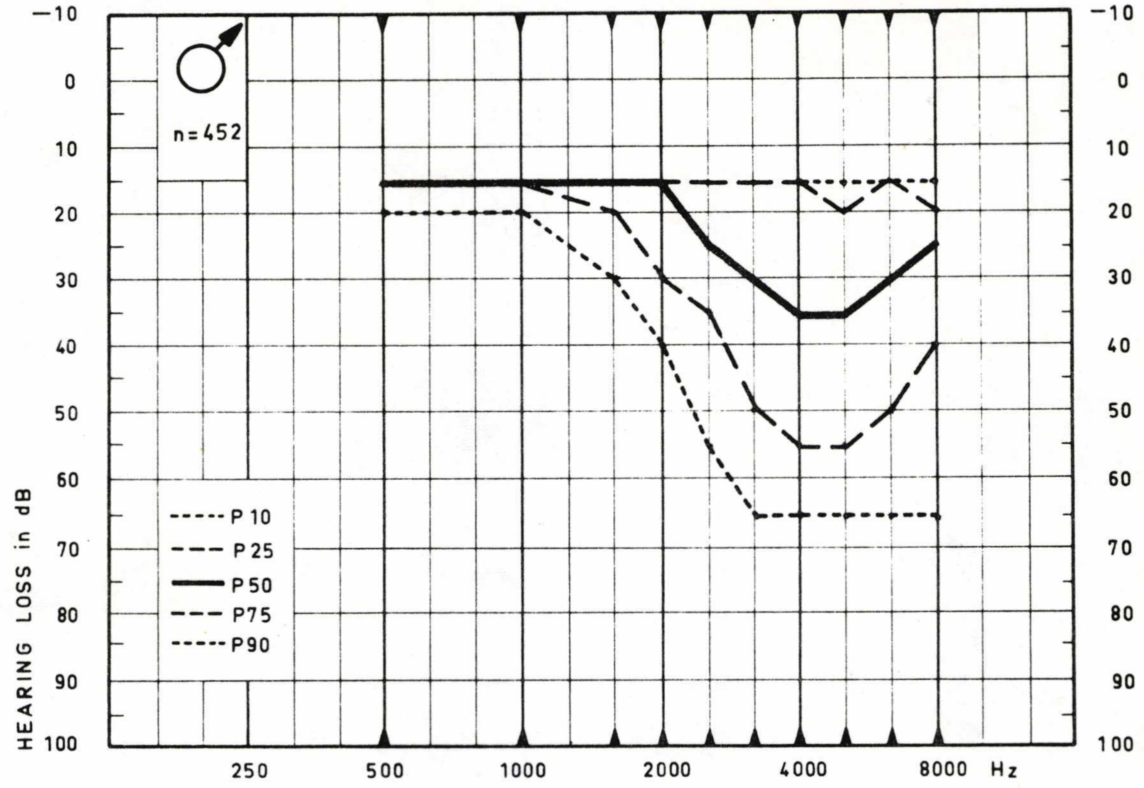
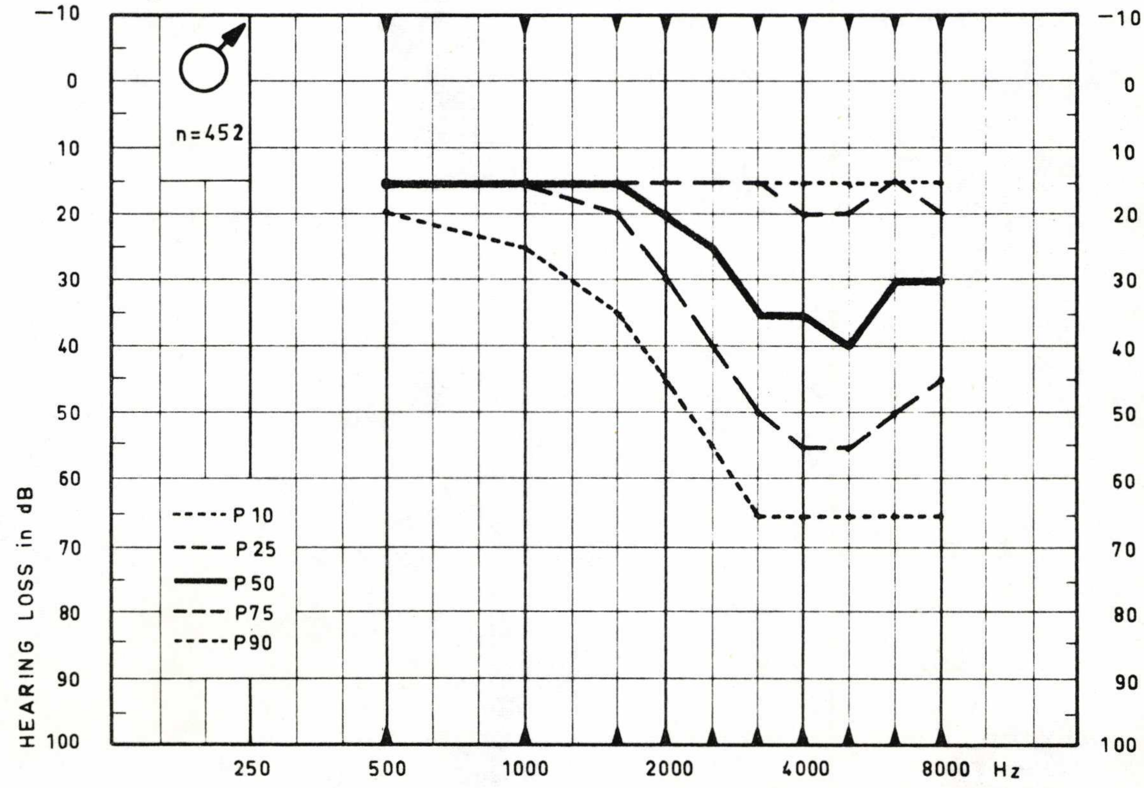


Fig.28. Median audiogram left ear All age groups



	refers to figure 1					refers to figure 2					refers to figure 3					refers to figure 4				
percentiles	right ear <20 yr					right ear 20-29 yr					right ear 30-39 yr					right ear 40-49 yr				
Hz	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	25	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
1000	15	15	15	15	25	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20
1600	15	15	15	15	25	15	15	15	15	15	15	15	15	15	25	15	15	15	20	30
2000	15	15	15	20	30	15	15	15	15	20	15	15	15	25	30	15	15	15	30	45
2500	15	15	15	30	40	15	15	15	15	30	15	15	15	30	45	15	15	25	40	55
3150	15	15	15	35	45	15	15	15	20	35	15	15	20	40	55	15	15	35	45	60
4000	15	15	15	35	55	15	15	15	25	40	15	15	25	40	60	15	20	35	55	60
5000	15	15	15	35	60	15	15	15	25	40	15	15	25	45	55	15	20	35	55	65
6300	15	15	15	35	60	15	15	15	20	40	15	15	20	35	55	15	20	30	45	60
8000	15	15	15	35	55	15	15	20	25	30	15	15	20	30	50	15	20	25	40	55

	refers to figure 5					refers to figure 6					refers to figure 7					refers to figure 8				
percentiles	right ear 50-59 yr					right ear ≥60 yr					left ear <20 yr					left ear 20-29 yr				
Hz	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	30	15	15	15	15	25	15	15	15	15	15	15	15	15	15	15
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6300	15	30	50	65	80	35	50	55	75	90	15	15	15	15	25	15	15	15	25	40
8000	15	30	45	65	80	30	35	50	70	90	15	15	15	25	35	15	15	20	25	35

	refers to figure 9					refers to figure 10					refers to figure 11					refers to figure 12				
percentiles / Hz	left ear 30-39 yr					left ear 40-49 yr					left ear 50-59 yr					left ear ⩾60 yr				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	15	15	15	15	15	15	15	15	15	15	30	15	15	15	20	30
1000	15	15	15	15	15	15	15	15	15	20	15	15	15	20	40	15	15	20	25	30
1600	15	15	15	15	25	15	15	15	25	40	15	15	15	35	40	15	15	30	45	60
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2500	15	15	20	30	45	15	15	30	40	55	15	20	35	50	65	25	35	45	65	80
3150	15	15	25	40	50	15	20	35	50	65	20	30	50	60	75	35	45	60	70	80
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6300	15	15	20	35	50	15	20	30	45	70	20	30	50	65	85	40	45	55	75	95
8000	15	15	20	30	50	15	20	30	45	65	15	30	45	65	80	30	40	60	80	95

	refers to figure 13					refers to figure 14				
percentiles / Hz	right ear all age groups					left ear all age groups				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	20	15	15	15	15	15
1000	15	15	15	15	20	15	15	15	15	25
1600	15	15	15	20	35	15	15	15	20	35
2000	15	15	15	25	45	15	15	15	30	45
2500	15	15	20	35	55	15	15	25	40	55
3150	15	15	25	45	65	15	15	30	50	65
4000	15	15	30	55	65	15	15	35	55	65
5000	15	15	30	55	70	15	15	35	55	65
6300	15	15	25	45	65	15	15	25	45	65
8000	15	15	25	40	65	15	15	25	40	65

percentiles / Hz	refers to figure 15					refers to figure 16					refers to figure 17					refers to figure 18				
	right ear <20 yr					right ear 20-29 yr					right ear 30-39 yr					right ear 40-49 yr				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	35	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
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2500	15	15	15	40	45	15	15	15	20	35	15	15	20	30	40	15	20	25	35	55
3150	15	15	15	40	55	15	15	15	25	50	15	15	25	40	50	15	25	35	45	60
4000	15	15	15	45	65	15	15	15	30	55	15	15	30	45	55	15	25	35	55	65
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6300	15	15	20	40	70	15	15	15	25	40	15	15	25	35	55	15	25	30	45	60
8000	15	15	25	45	70	15	15	20	25	35	15	15	20	30	40	15	20	30	40	55

percentiles / Hz	refers to figure 19					refers to figure 20					refers to figure 21					refers to figure 22				
	right ear 50-59 yr					right ear ≥60 yr					left ear <20 yr					left ear 20-29 yr				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	30	15	15	15	15	25	15	15	15	15	45	15	15	15	15	15
1000	15	15	15	15	30	15	15	15	25	30	15	15	15	15	50	15	15	15	15	15
1600	15	15	20	30	45	15	15	20	35	45	15	15	15	15	50	15	15	15	15	20
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6300	20	30	50	65	80	30	50	50	65	75	15	15	15	20	55	15	15	20	30	40
8000	20	30	45	65	80	25	35	45	60	80	15	15	20	30	60	15	15	20	30	40

refers to figure 23 | refers to figure 24 | refers to figure 25 | refers to figure 26

percentiles / Hz	left ear 30-39 yr					left ear 40-49 yr					left ear 50-59 yr					left ear ⩾60 yr				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	15	15	15	15	15	15	15	15	15	15	20	15	15	15	15	20
1000	15	15	15	15	20	15	15	15	15	25	15	15	15	15	35	15	15	15	20	25
1600	15	15	15	20	25	15	15	15	25	35	15	15	15	30	45	15	15	20	40	55
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3150	15	15	30	40	50	20	30	40	50	65	20	35	50	60	75	35	45	55	60	70
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5000	15	15	30	45	60	15	30	40	55	70	30	40	55	65	80	40	50	55	65	75
6300	15	15	25	40	50	15	20	35	50	70	20	35	55	65	80	40	45	55	60	75
8000	15	15	25	30	45	15	20	30	45	65	15	30	50	70	80	30	35	55	65	80

refers to figure 27 | refers to figure 28

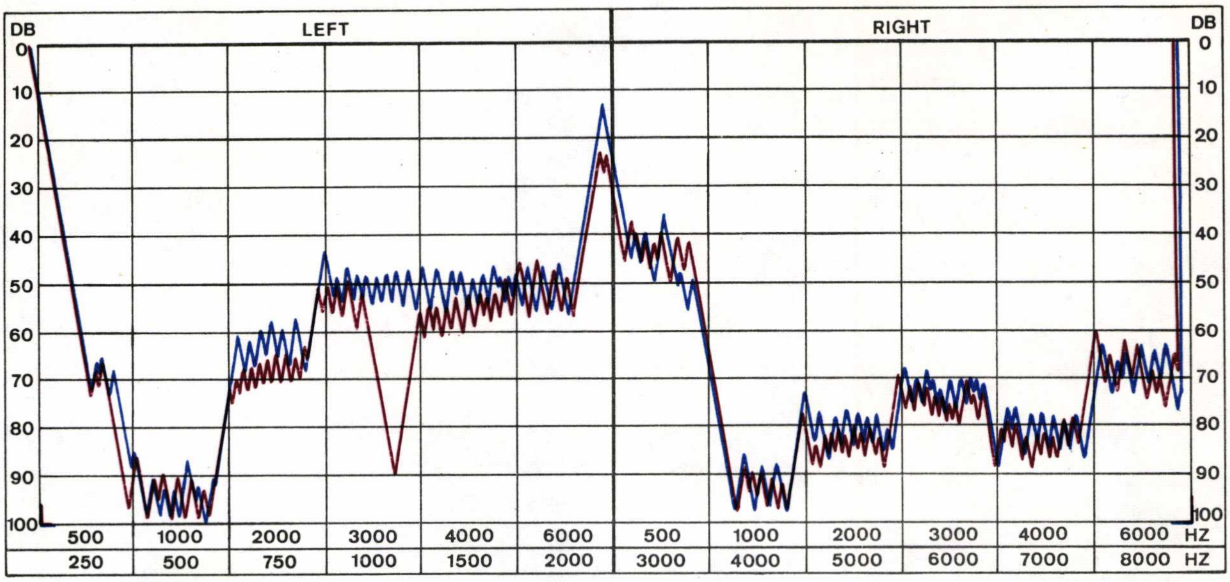
percentiles / Hz	right ear all age groups					left ear all age groups				
	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}	P_{10}	P_{25}	P_{50}	P_{75}	P_{90}
500	15	15	15	15	20	15	15	15	15	20
1000	15	15	15	15	20	15	15	15	15	25
1600	15	15	15	20	30	15	15	15	20	35
2000	15	15	15	30	40	15	15	20	30	45
2500	15	15	25	35	55	15	15	25	40	55
3150	15	15	30	50	65	15	15	35	50	65
4000	15	15	35	55	65	15	20	35	55	65
5000	15	20	35	55	65	15	20	40	55	65
6300	15	15	30	50	65	15	15	30	50	65
8000	15	20	25	40	65	15	20	30	45	65

APPENDIX C

Comparative study

Békésy audiograms
pure-tone audiograms

NUMBER 25229 AGE 43 YEARS

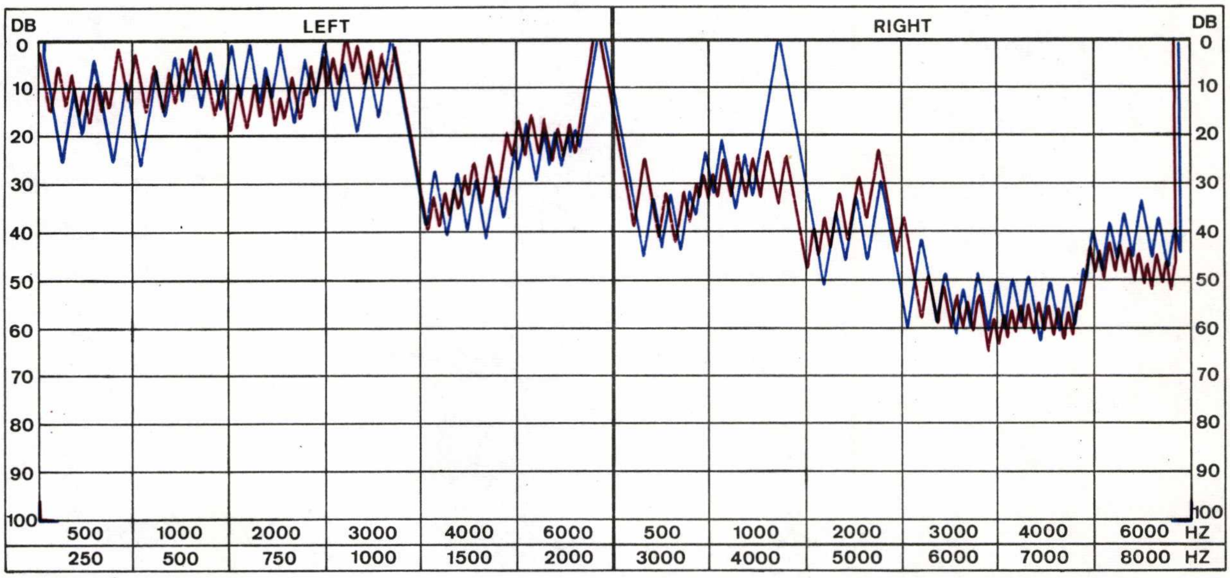


ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

NUMBER 9993 AGE 37 YEARS

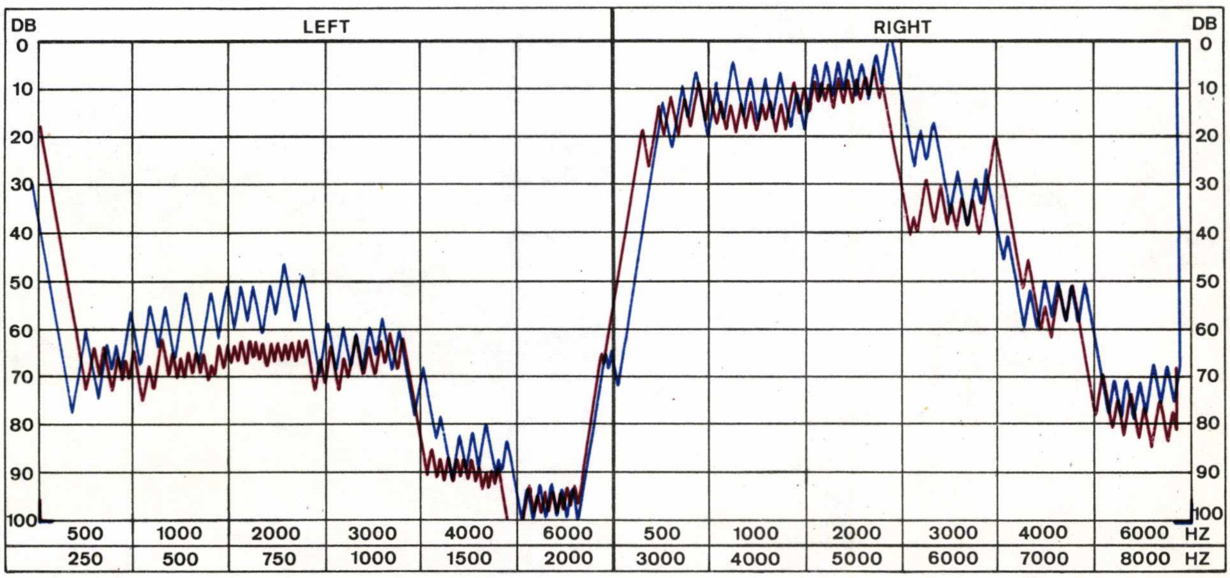


ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

NUMBER 29282 AGE 51 YEARS



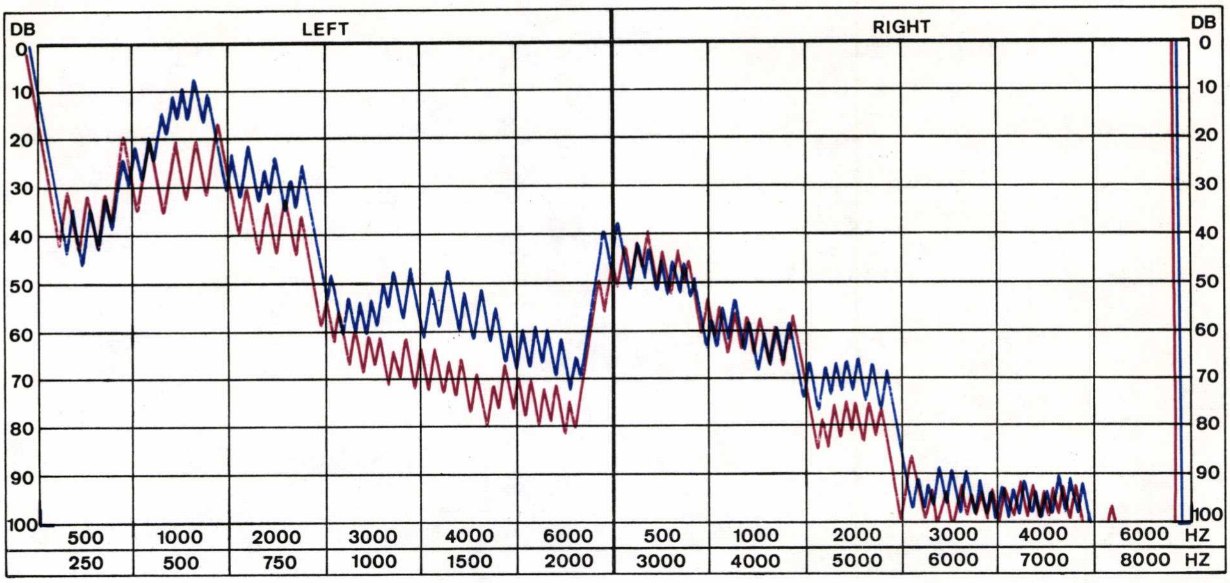
ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

inter acoustics

NUMBER 29978 AGE 55 YEARS



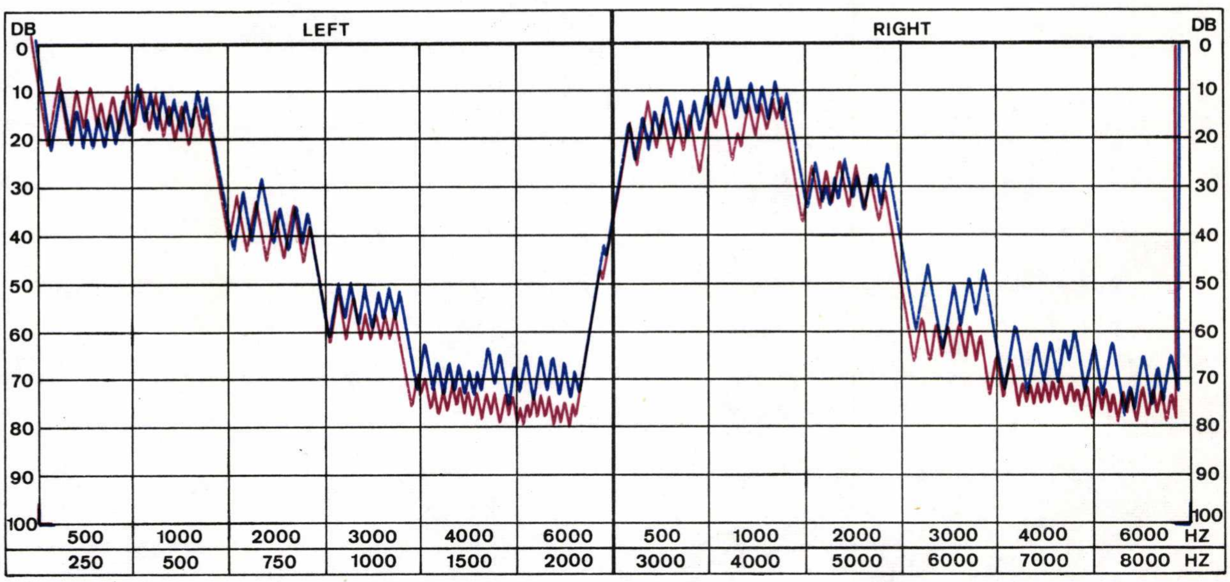
ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

inter acoustics

NUMBER 9651 AGE 52 YEARS



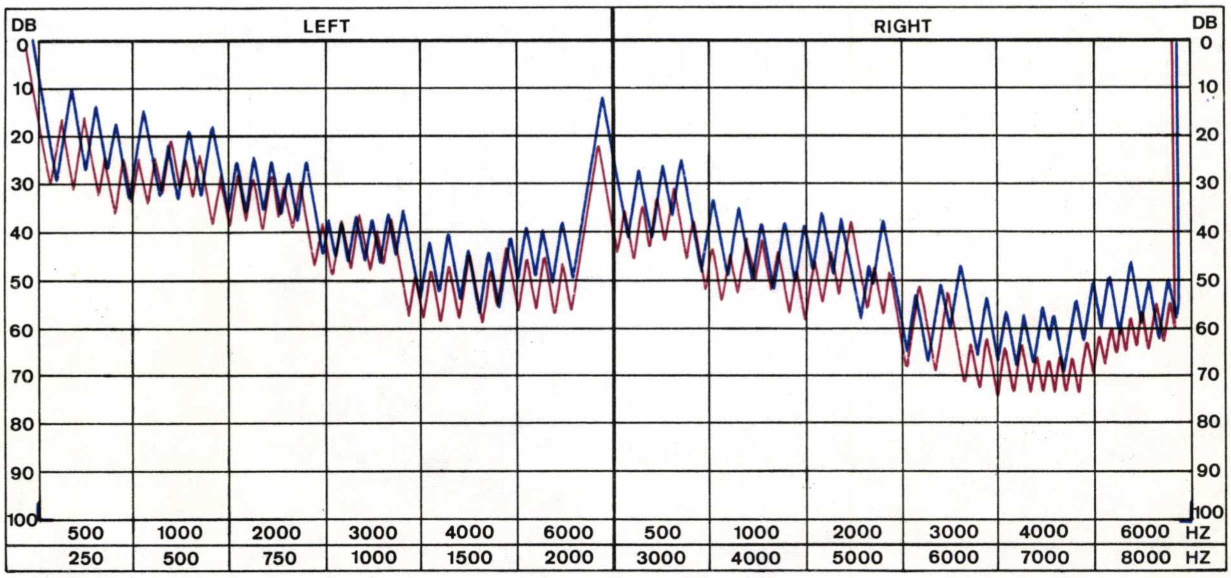
ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

inter acoustics

NUMBER 27293 AGE 52 YEARS

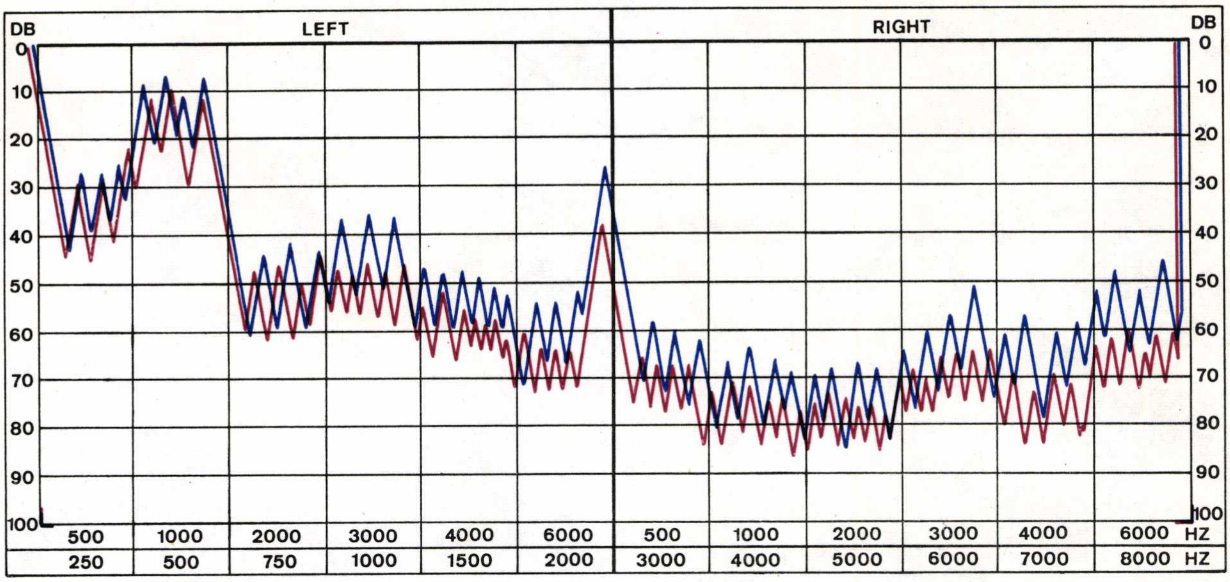


ISO-1964
ANSI-1969

TYPE
AF6

INTERACOUSTICS AS
ASSENS DENMARK

NUMBER 24087 AGE 37 YEARS

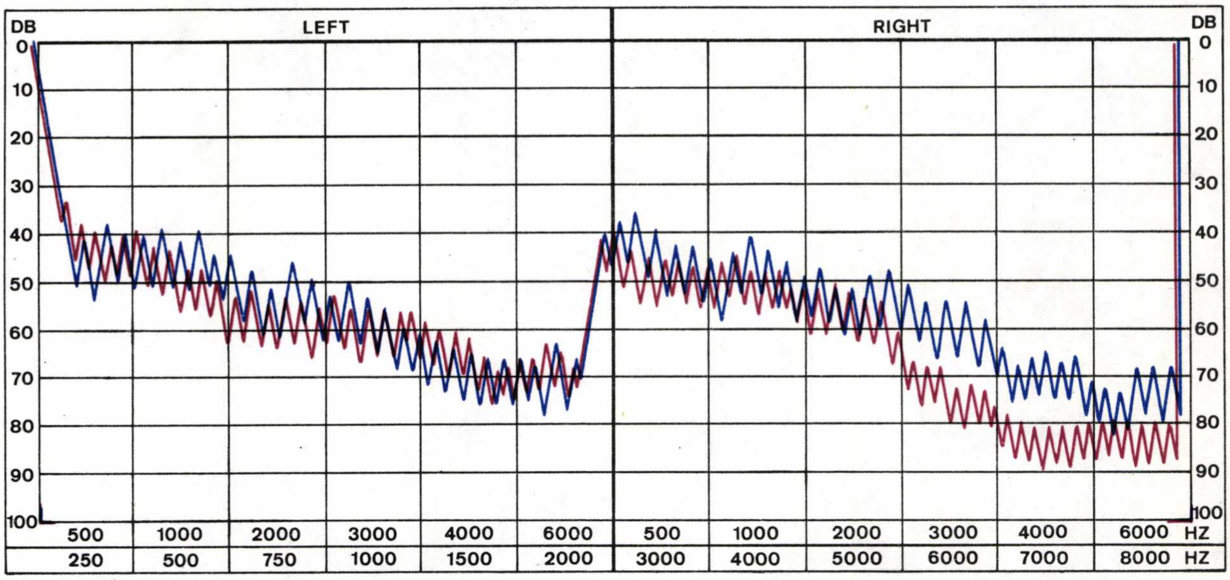


ISO-1964
ANSI-1969

TYPE AF6

INTERACOUSTICS AS
ASSENS DENMARK

NUMBER 25005 AGE 52 YEARS

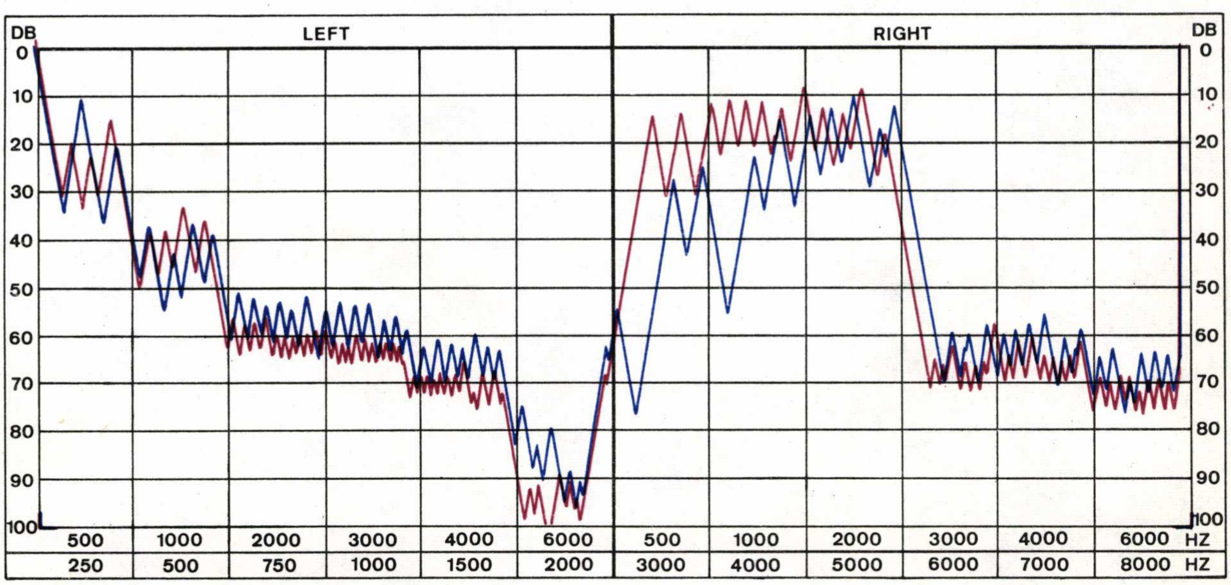


ISO-1964
ANSI-1969

TYPE AF6

INTERACOUSTICS AS
ASSENS DENMARK

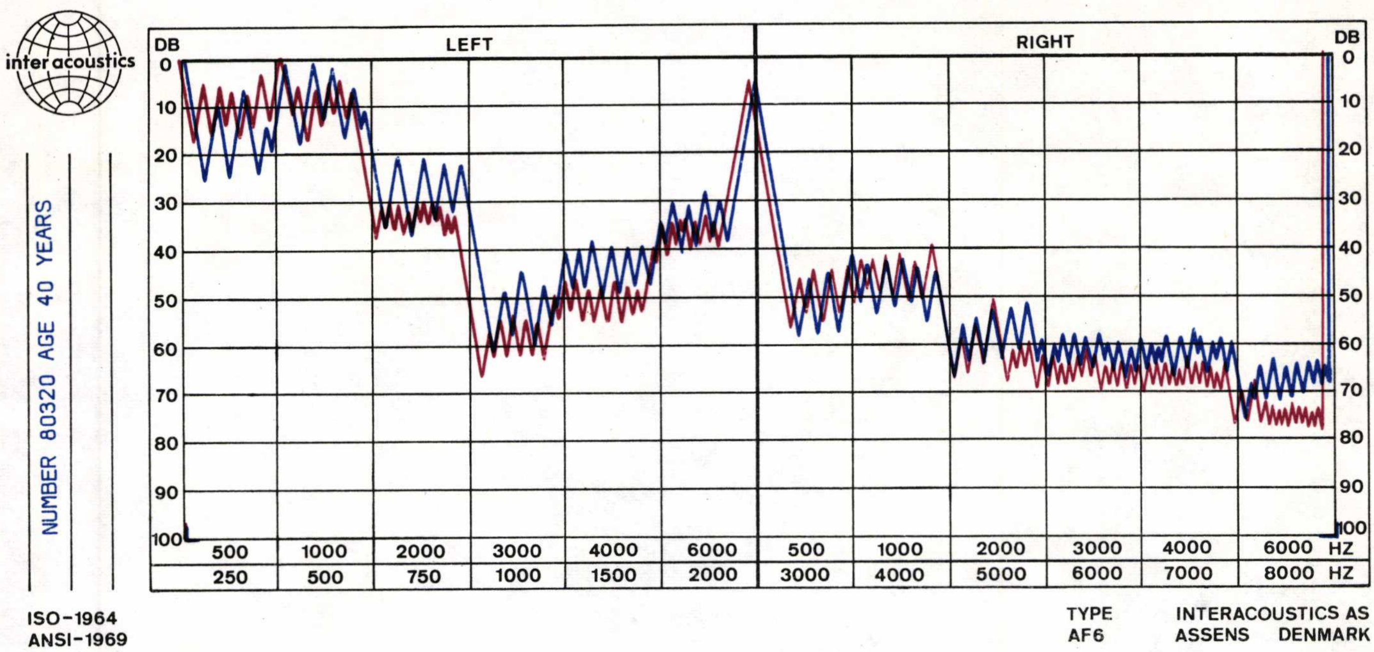
NUMBER 70597 AGE 53 YEARS

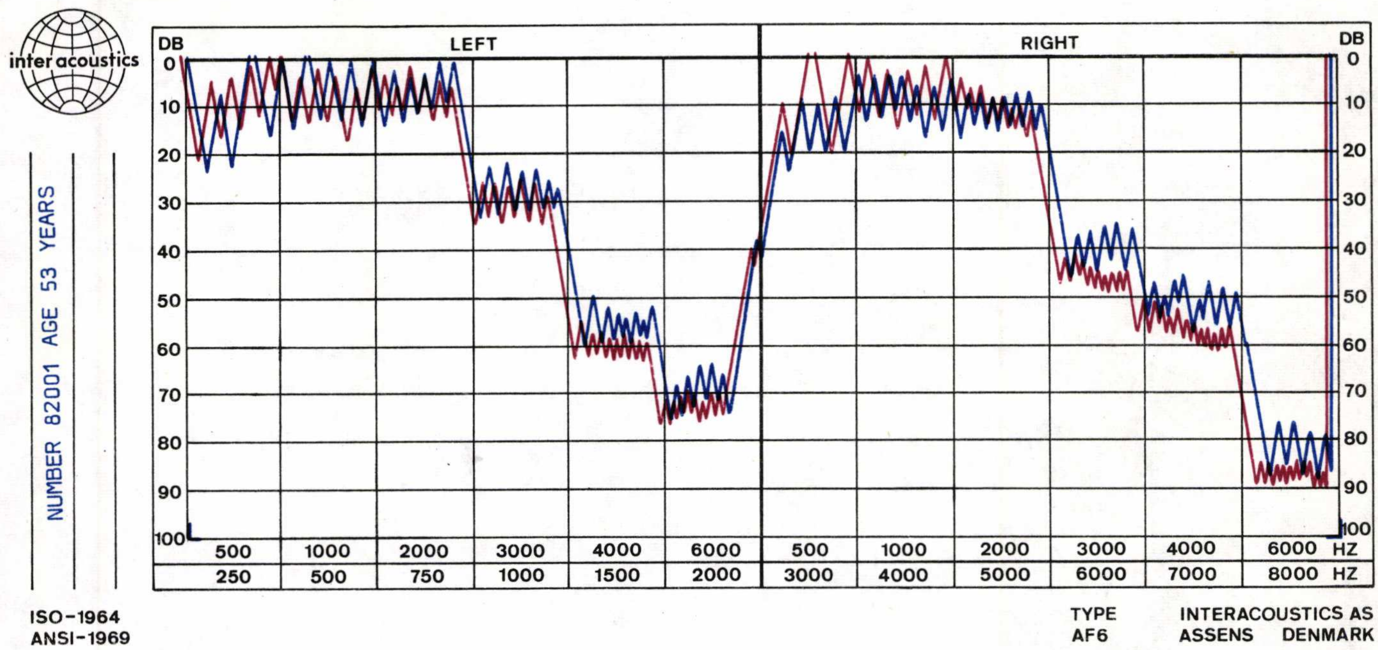


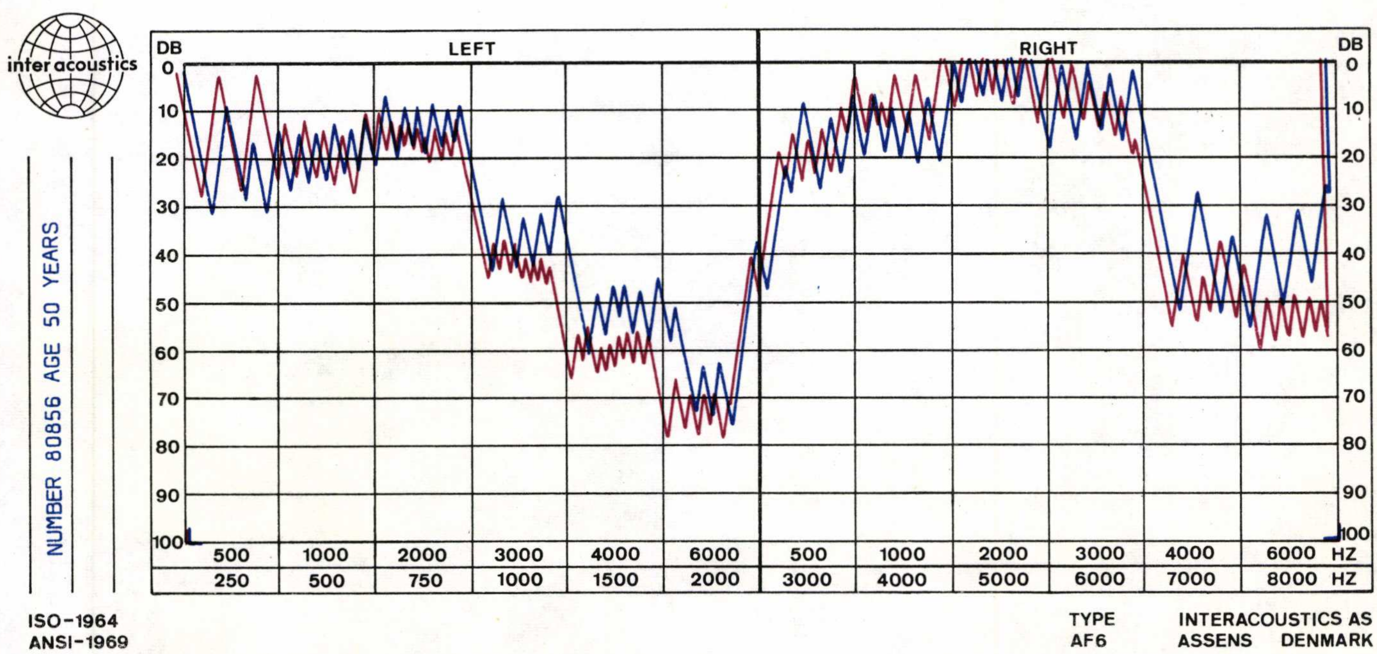
ISO-1964
ANSI-1969

TYPE AF6

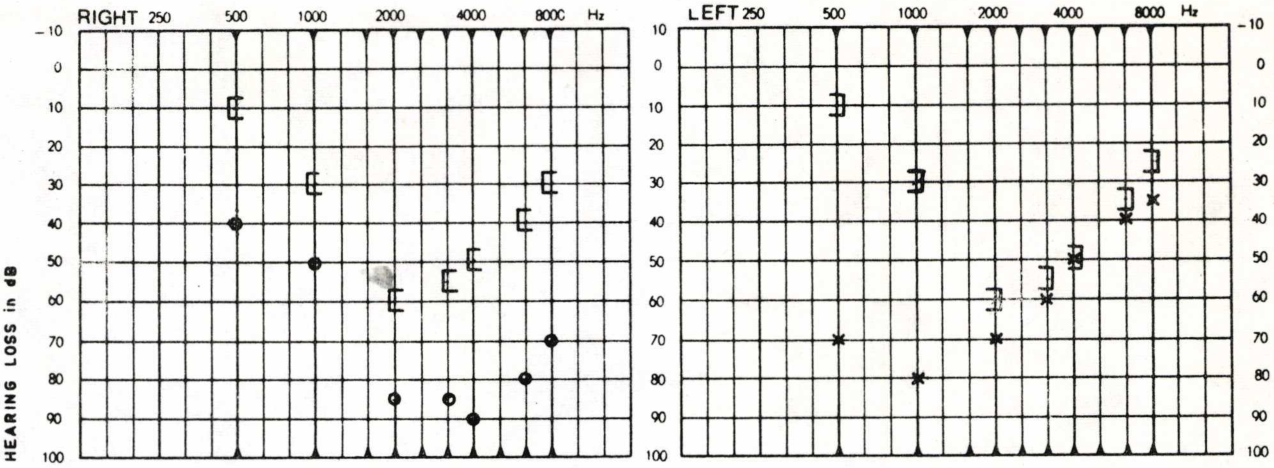
INTERACOUSTICS AS
ASSENS DENMARK


inter acoustics
NUMBER 80320 AGE 40 YEARS
DB
LEFT
RIGHT
0
10
20
30
40
50
60
70
80
90
100
500 1000 2000 3000 4000 6000
250 500 750 1000 1500 2000
500 1000 2000 3000 4000 6000 HZ
3000 4000 5000 6000 7000 8000 HZ
ISO-1964
ANSI-1969
TYPE
AF6
INTERACOUSTICS AS
ASSENS DENMARK

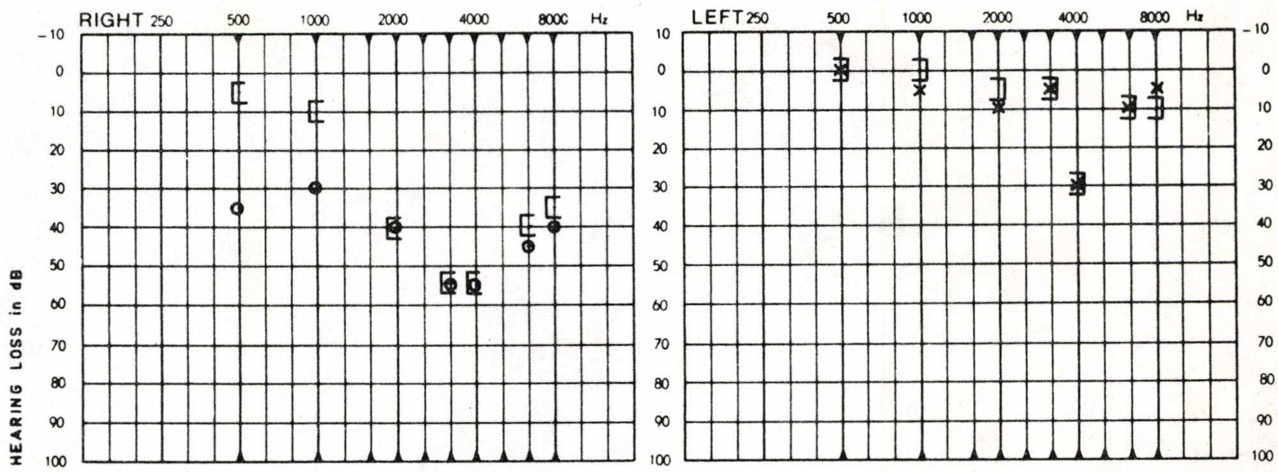

inter acoustics
NUMBER 82001 AGE 53 YEARS
DB
LEFT
RIGHT
0
10
20
30
40
50
60
70
80
90
100
500 1000 2000 3000 4000 6000
250 500 750 1000 1500 2000
500 1000 2000 3000 4000 6000 HZ
3000 4000 5000 6000 7000 8000 HZ
ISO-1964
ANSI-1969
TYPE
AF6
INTERACOUSTICS AS
ASSENS DENMARK


inter acoustics
NUMBER 80856 AGE 50 YEARS
DB
LEFT
RIGHT
0
10
20
30
40
50
60
70
80
90
100
500 1000 2000 3000 4000 6000
250 500 750 1000 1500 2000
500 1000 2000 3000 4000 6000 HZ
3000 4000 5000 6000 7000 8000 HZ
ISO-1964
ANSI-1969
TYPE
AF6
INTERACOUSTICS AS
ASSENS DENMARK

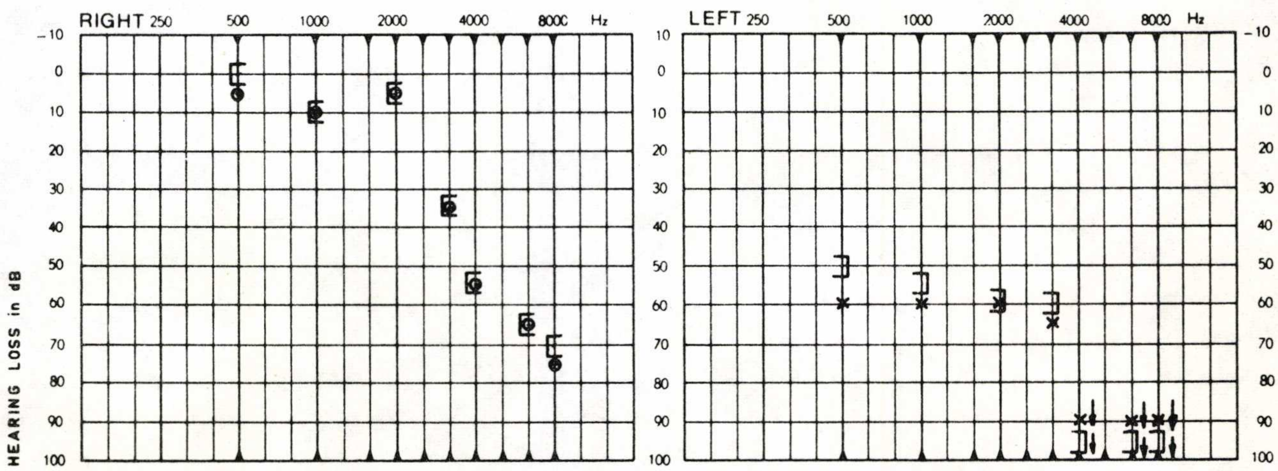
NUMBER 25229 AGE 43 yr



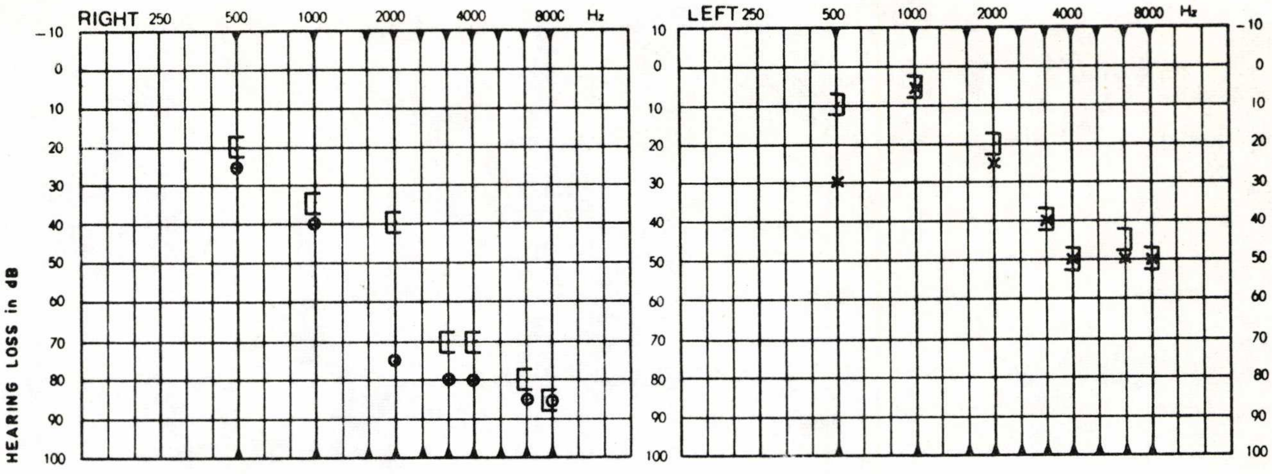
NUMBER 9993 AGE 37 yr



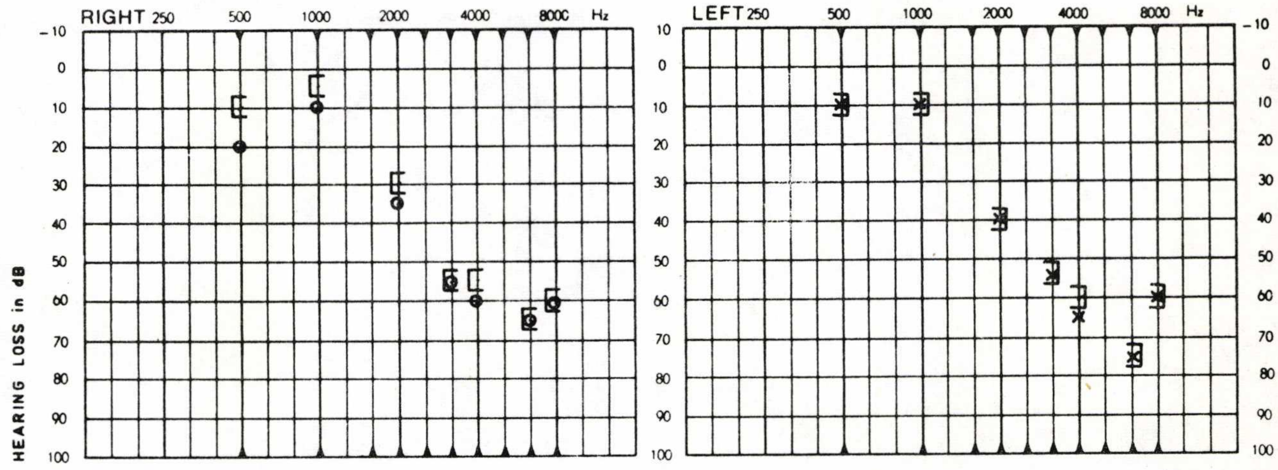
NUMBER 29282 AGE 51 yr



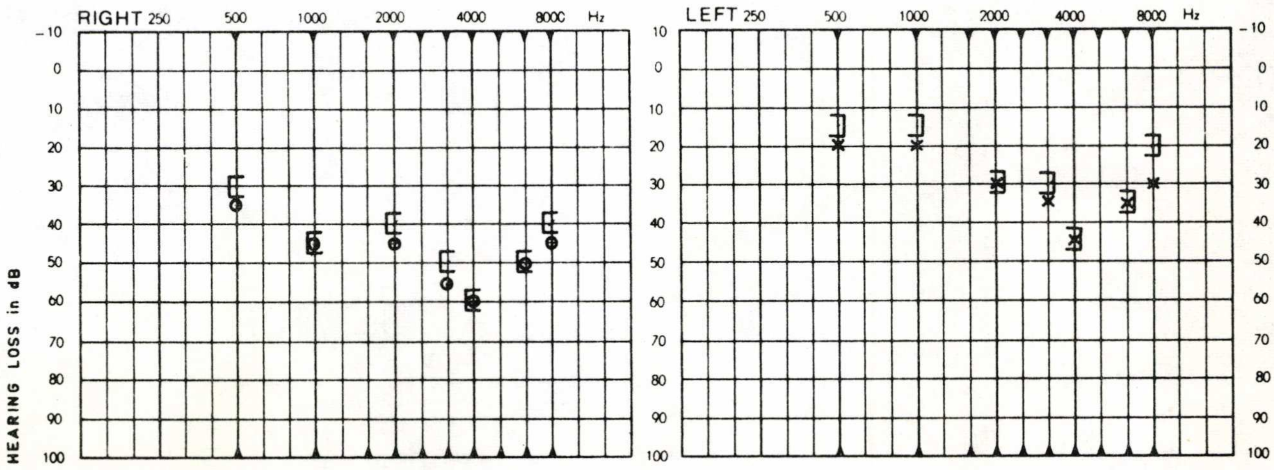
NUMBER 29978 AGE 55 yr



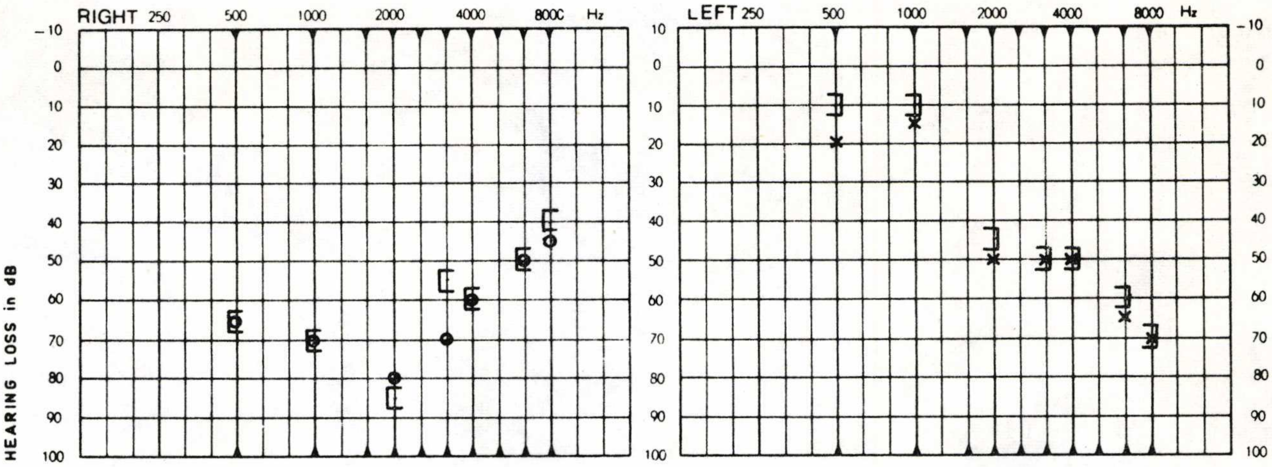
NUMBER 9651 AGE 52 yr



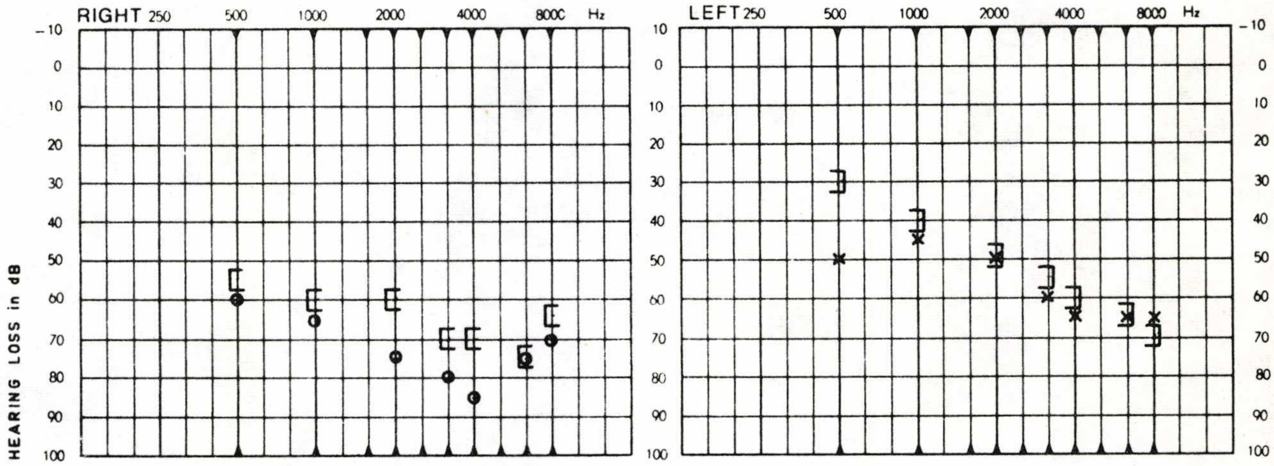
NUMBER 27293 AGE 52 yr



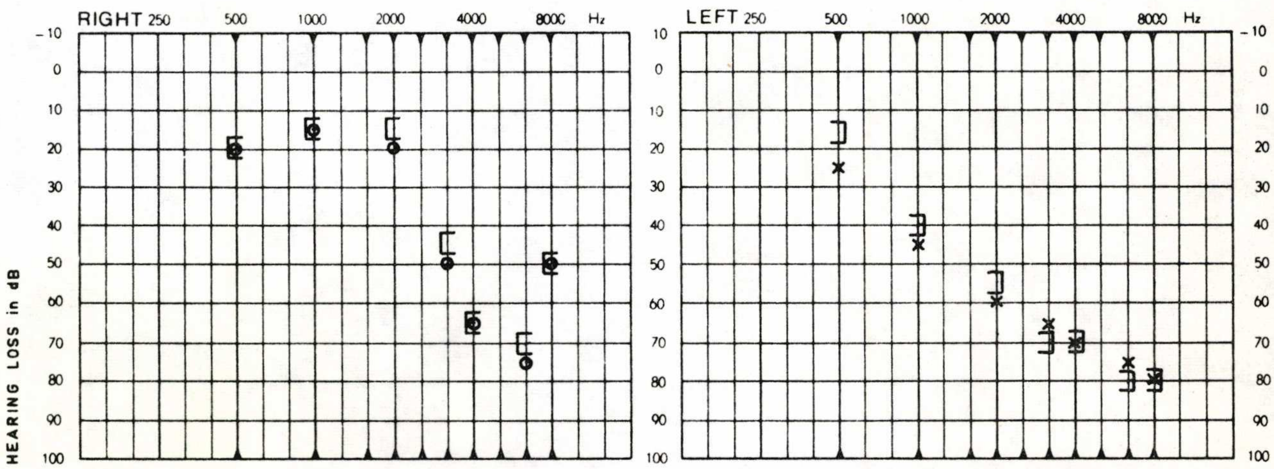
NUMBER 24087 AGE 37



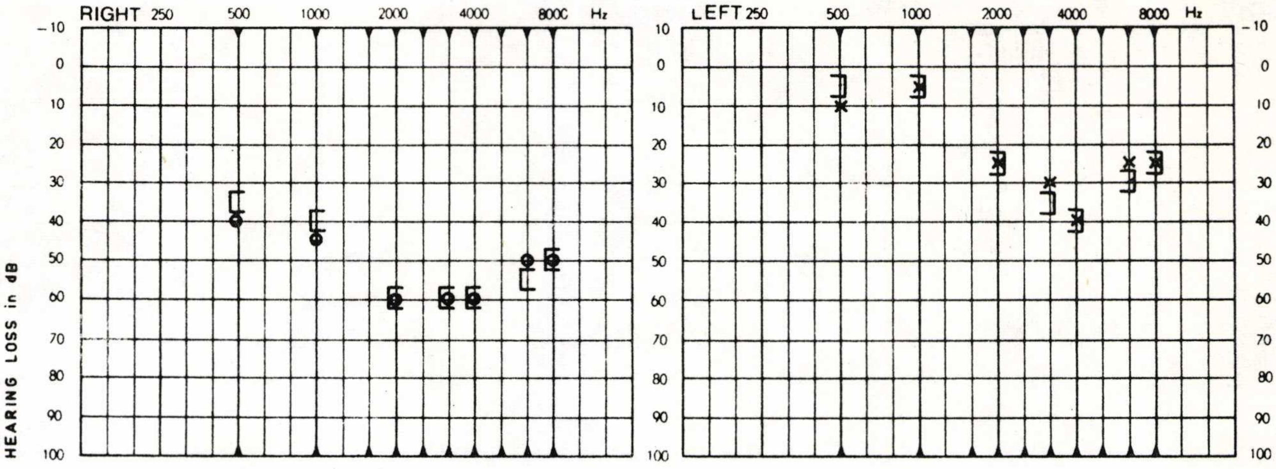
NUMBER 25005 AGE 52 yr



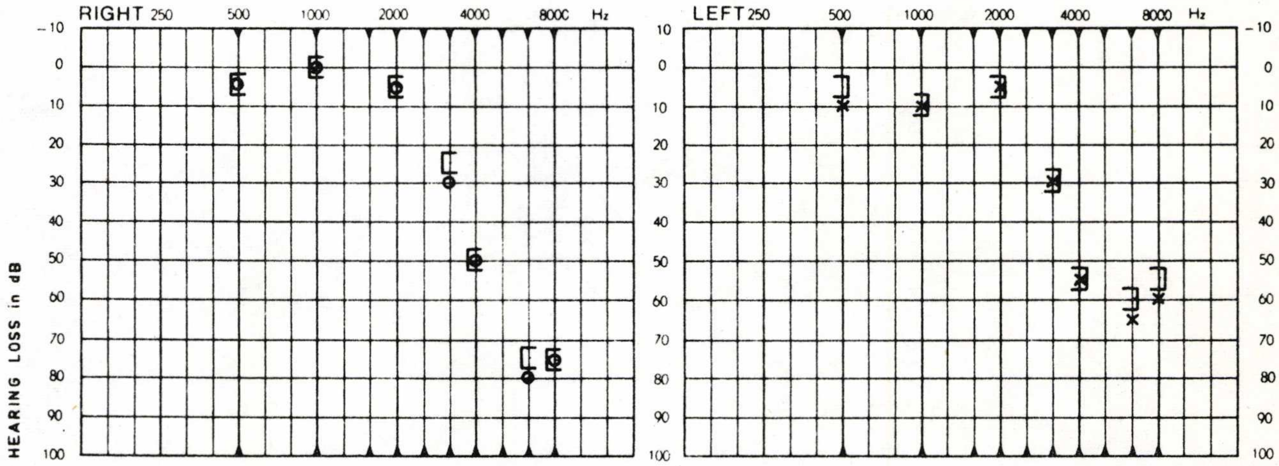
NUMBER 70597 AGE 53 yr



NUMBER 80320 AGE 40 yr



NUMBER 82001 AGE 53 yr



NUMBER 80856 AGE 50 yr