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POTENTIAL FACTORS IN RESISTANCE TO NOISE-INDUCED HEARING LOSS

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INTRODUCTION

Individual variations of susceptibility to noise-induced hearing loss are a well-known characteristic of field studies, and are manifested as a wide dispersion of hearing threshold levels (HTL) in groups of people exposed for comparable periods of time to the same or equivalent noise environments. In principle, the susceptible fraction of an exposed population could be identified retrospectively as those with the greatest shift of hearing threshold, provided the population were screened to exclude other causes of hearing loss. On the hypothesis that the individuals of this fraction possess some innate quality differentiating them from the less susceptible, it might be possible to identify this predisposing factor, and subsequently use it as a test for as-yet-unexposed individuals. In practice, it is difficult if not impossible to be sure that a high hearing threshold level is the result of noise exposure alone. High hearing threshold levels are therefore not sufficient proof of a particular susceptibility to noise, since other causes can lead to the same result.

A novel approach is adopted here, which sidesteps the contaminating influence of hearing loss unrelated to noise. The principle is to study the opposite end of the susceptibility distribution, that is, the noise-resistant fraction readily identifiable in an ageing population exposed to noise [1]. Such "hearing survivors" retain acute hearing threshold levels in spite of noise exposure known to be pathogenic for the majority of the population. Considering the obvious fact that a person's hearing does not improve with accrued noise dose (or age), the clearly identifiable residue of survivors must necessarily have had better than average hearing in their youth. Some characteristic, auditory or otherwise, may be common to the survivors and to young acute ears, the population from which the survivors must have been derived. The object of this study [2] was to seek such a characteristic.

EXPERIMENTAL PROCEDURE

Two groups of normal subjects were studied: 81 young males aged 16-27 years (group Y); and 50 older males aged 45-65 years (group O). All the men were screened otoscopically, and by extensive questioning for adverse indications in their otological and noise-exposure histories. The following tests were then carried out on both ears of each subject:

1. Pure-tone audiometry at frequencies from 250 Hz to 8 kHz, using the self-recording technique, yielding hearing threshold levels H.

2. Brief-tone audiometry, also by the self-recording technique, using 4 kHz tone bursts of duration t, ranging from 1.5 to 400 ms. The results for $1.5 \leq t \leq 40$ ms were expressed as linear relations of threshold shift

(relative to the 400 ms burst) upon log t, yielding a slope of $-k$ dB/decade and an intercept of τ (auditory integration time).

3. Octave masking tests, again by the self-recording method, using a 2 kHz tone as the masker and a 4 kHz pulsed probe tone. The results yielded a linear relation between 4 kHz threshold shift against masker level, with a slope of b dB/dB and an intercept known as the threshold of octave masking (TOM).

4. Tympanometry. The middle ear equivalent air volume was determined for each test ear, to confirm normal conductive function.

5. Immittance audiometry to determine the threshold and growth of the contralateral acoustic reflex, for different stimuli, namely a 4 kHz tone and an octave band of noise centred at 500 Hz. A plot of volume change against stimulus level gave ℓ, the reflex growth expressed in mL/dB, and the acoustic reflex threshold (ART).

RESULTS AND DISCUSSION

The Y group exhibited HTL's quite close to the expected range of normal, on both sides of audiometric zero. As a result of their selection, the O group had somewhat better HTL's than the norm for their age group.

Descriptive statistics of k, b and TOM showed significant differences between the Y and O group means. The remaining variables, notably integration time τ and acoustic reflex growth ℓ (for the noise stimulus), did not show significant differences between the subject groups.

The data ensemble for each group was analysed in several stages by parametric statistical methods. First, considering individuals within each group, correlation analyses were performed between the mean left-right HTL's and items of personal data, such as eye colour and handedness. No significant correlations, which could bear upon noise-induced hearing loss, were found. Second, correlation analyses were performed between all audiometric, audiological and psychoacoustical measures, for the individual ears of the Y and O groups. The following relations between variates were found to be statistically significant (and non-trivial) for both groups:

$H_{4k} : k$ $\quad$ $H_{4k} : b$ $\quad$ $\log \tau : k$ $\quad$ $k : b$ $\quad$ $\mathrm{ART} : \log \ell$

These results suggest that there is no interaction between the psychoacoustical and neuromechanical properties of the ear. In other words, cochlear function (measured primarily by k and to some extent by b) would seem to be independent from the reflex self-protection of the ear.

Looking at the psychoacoustical variates in more detail, the relation between hearing sensitivity (H_{4k}) and the measures of cochlear function (b and k) was examined by regression analysis. It was shown that the threshold and its dispersion consist of components identifiable with distinct auditory processes. Considering the O sample, which had the wider range of H_{4k}, approximately two-thirds of the threshold variance was accounted for by an expression in k, b and log τ. The remaining threshold variance was attributed to conductive (non-cochlear) factors of no direct relevance to the assessment of cochlear health.

Although no statistical link was found between the cochlear and reflex variates for the data mass, this did not preclude the possibility that a few individuals (or ears) might be found for which both types of measures were consistently favourable or unfavourable; such outliers, at opposite ends of the variate distributions, would be the robust and susceptible ears. Ears within each group were therefore rank-ordered on the basis of single and lumped variates, and tested by non-parametric statistics. Correlations of rank, free from any artefacts imposed by the physical scales of measurement, identified a small number of consistent outliers, and demonstrated the statistical independence of three properties of human hearing: conductive efficiency; cochlear function; and reflex function.

CONCLUSIONS

From this research on normally-hearing males of widely differing ages, it is possible to anticipate which tests might be included in a battery to predict susceptibility to noise-induced hearing loss. Suitably shortened tests on each ear would obtain measures of threshold shift for brief tones and masking slope for 4 kHz tonal stimuli, plus acoustic reflex threshold and growth for noise stimuli. Low values of the brief-tone shift and masking slope would flag an ear as 'suspect susceptible', with extreme values possibly indicating an existing sub-clinical hearing loss. Also suspect would be high values of the reflex threshold, linked with low growth of the reflex magnitude. These postulates should be investigated further, using hearing survivors who have resisted the pathogenic influence of a known high noise exposure.

ACKNOWLEDGEMENT

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EFFECTS OF IMPULSE NOISE AND CONTINUOUS STEADY STATE NOISE ON HEARING THRESHOLDS

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In the present day Finland, it is a standard practice to provide a workplace with large numbers of employees with a health clinic of their own which also attends periodical medical examinations. In noisy workplaces, especially in industry, the hearing of employees is screened in a standard way, usually using a manual pure tone audiometer of a modest model. Compared with the more sophisticated evoked-potential audiometer, a pure tone audiometer is a modest method to be used, but as seen in the present paper, it can be very effective and informative when used with a great care.

Experience has shown that impulse noise may be more harmful to hearing than continuous, steady state noise. The criteria for hearing damage induced by steady state noise are well established, but it is uncertain whether the established criteria are also valid for exposure to impulse noise.

The quality of impulse noise as an auditory stimulation differs from that of continuous noise. Impulse noise that results from hammering, stamping, pressing, and gunfire can be characterised by its instantaneous, short duration. In conditions where several workers hammer, press, or chisel impulses may occur abruptly and randomly in varying frequencies at the rate of several tens per second.

In perception psychology a hearing threshold is the value given to the scale of intensity or the pitch of a tone stimulus which is the minimum sufficient to cause the sensation of tone stimulus. The hearing threshold in man varies with the frequency of the sound, the greatest sensitivity being in the range of 4000 Hz. Intense sound stimulation can raise the hearing threshold and temporarily induce impaired hearing (NITTS). The hearing of those who work in noisy environments may be impaired by about 30 dB, such impairment resulting from the raised hearing thresholds caused by eight hours of exposure to 90-100 dB continuous noise. The corresponding raised thresholds caused by eight hours of exposure to impulse noise may be as high as 50 dB.

The cumulative effects of long periods of exposure to high noise levels may also lead to a noise induced permanent threshold shift (NIPTS) and to permanently impaired hearing. Exposure for 10-15 years to high levels of continuous industrial noise seems to raise thresholds at about 4 kHz. Exposure to high levels of impulse noise can induce hearing loss in a much shorter time and can be seen within a wider range of frequencies. The

International Organisation for Standardisation defines the risk of work noise induced hearing loss as the percentage of workers whose hearing thresholds are raised because of noise, on average, 25 dB at frequencies of 500, 1000, and 2000 Hz. At present noise induced hearing loss (2026 new cases in 1985) comprises about half the verified cases of occupational diseases in Finland if occupational skin diseases are excluded from the statistics.

The purpose of this study was to compare the hearing effects induced by exposure to impulse noise with those induced by exposure to continuous steady state noise. In addition the effects of daily exposure to both types of noise were compared by testing the hearing thresholds of groups of workers several times during the workday.

METHODS

Subjects

Groups exposed to impulse noise. Platers and welders born in 1940 or later who had been exposed to impulse noise in the ship section assembly shop of a shipyard for three to 10 years were selected for hearing test. None of them had any occupational disease or hearing loss according to their periodical medical examinations.

Three groups of ten workers each were selected from these 99 workers. The subjects (Ss) were selected on the basis of duration of employment in conditions where they were exposed to impulse noise. The other criteria for selection were that they should be working as a plater, and their age. The aim was to select groups with a shorter (group 1), an intermediate (group 2), and a longer (group 3) duration of exposure to impulse noise. As there were not enough platers for group 1, seven welders were included. All workers wore some sort of ear protectors, usually earmuffs (Silenta Pop or Silenta Super). Hence the workers' individual levels of noise exposure were about 15-25 dB lower than the measured noise levels would indicate.

Group 1 had been exposed for three to four years (mean age 24.6 years, SD 2.46), group 2 for five to six years (mean age 28.3 years, SD 2.83), and group 3 for seven to 10 years (mean age 30.1 years, SD 2.23). All the men worked in the same large shop on an assembly line within close proximity of each other.

Group exposed to continuous steady state noise. Twelve men from a cable factory exposed to steady state noise were selected in the same way as the impulse noise groups; however, their duration of exposure to noise was comparable with that of group 2. The adjustment made it possible also to compare the effects of shorter and longer durations of exposure to impulse noise with the effects of an intermediate duration of exposure to continuous steady state noise.

The mean age of this group was 28.3 years (SD 4.87). The subjects had been exposed to steady state noise, on average, for 5.42 years (SD 1.58), mostly within this cable factory. All worked in the same large shop and attended machines that drew stranded cables from rods and fine wire made of different metals. Only some of the tested workers wore ear protectors, and none used protectors for the entire duration of exposure.

Control group. Ten healthy male workers from the ship drafting office of the same shipyard as the groups exposed to impulse noise served as the control group. The mean age of the controls was 23.8 years (SD 3.36). Their hearing was normal. All the controls worked in a large open plan office.

Each of the subjects was asked to refrain from drinking alcohol or beer and from staying up late on the days before testing.

Levels of noise exposure
The levels both of impulse noise and continuous steady state noise were measured under work conditions near the workers, recording the noise on a tape recorder for further analysis. The shop at the shipyard had several sources of noise. The background noise, which was continuous and varied between 80 dB and 85 dB (A), was generated from the ventilation system and from the transformers of the welding machines. Hammering with a sledge hammer generated impulses with a build up time of several tens of milliseconds (under 100 msec). The peak levels were 130-140 dB, sometimes 150 dB, with a B-duration of several hundreds of milliseconds (300-800 msec). Pneumatic scaling hammers gave rise to peak noise levels of 120-125 dB. The strike rate was 50 per second. The sound level (RMS) was 15 dB lower than the peak level. Grinding generated continuous noise with peaks of 115-120 dB. The overall equivalent level of the average noise dose for 10 minute periods was 100 dB; the lowest was 86 dB and the highest 111 dB. Because of the hammering, the platers were exposed to noise with L_{eq} values somewhat higher than the welders.

The cable factory also had several sources of noise. Machines pulling rod cable generated continuous and steady state noise, the levels of which were 95 dB at the front end of the machine and 92 dB at the back. Machines pulling the fine wire gave rise to noise levels of 93 and 94 dB. Cable stranding machines generated noise levels of 92 dB at the middle of the machines, and 88 dB between the feeding wheels. The electrical welding of copper cables generated noise levels as high as 84 dB in the background and 86 dB close to the workers. Cleaning the copper cables gave rise to levels of 82 dB at the cleaning pool and 84 dB in the background.

Measurement of hearing thresholds

Hearing thresholds were measured with a manual pure tone audiometer (Madsen) three times a workday about 10 minutes after exposure on two separate weekdays. Measurements were taken immediately before going to the job site at (0700) "morning", before lunch (1030) "midday", and at the end of the workday (1530) "afternoon". Exposure to noise lasted for three hours between the morning and midday measurements, and for three and a half hours between the midday and afternoon measurements. There was a one hour lunch break after the midday measurement.

The hearing thresholds were measured in both ears at frequencies of 1, 2, 4, 6, and 8 kHz. The series were both descending and ascending, with steps of 5 dB. The scale of the test tone instensities started at -10 dB (sound pressure level, SPL) and ended with 80 dB. The threshold value was defined as the specific value at which the Ss reacted by lifting the index finger of his right hand successively on at least two of the four test presentations. The right ear was always tested first, and the measurements were done by the same tester in a quiet audiometer room at the clinic of either the shipyard or the cable factory. After testing the noise level in the audiometer room, the frequency of 500 Hz was omitted from the threshold measurements because the background noise exceeded the highest permissible level of the ISO standard at this frequency.

Each subject had to walk about 500 m from his job site to the clinic for testing. The two test days were balanced so that those tested on Monday returned on Thursday. Tuesday was paired with Friday and Wednesday with the next Monday. The hearing thresholds of the control group were tested in the same manner, although the Ss in the control group began work one hour later than the exposed groups.

Statistical analysis

The data from the left and right ears were analysed separately by two-way analysis of variance (Anova 2).

The Anova was performed using a morning, midday, and afternoon measurement as the first factor and the tested frequency as the second factor in order to see the effects of daily exposure within the groups. The Anova also was performed using the group as the first factor and the tested frequency as the second. This Anova was carried out separately for the three measurements to see whether the groups differed already in the morning measurement.

RESULTS

Differences within the groups

Figures 1, 2, and 3 show the audiograms from the left and right ears, pooled from the first and second day for the morning, midday and afternoon tests. None of the groups had significant differences between the hearing thresholds measured in the morning, at midday, and in the afternoon. Each group, however, showed significant differences between the hearing thresholds of the tested frequencies in the morning, midday, and afternoon measurements in both ears ($p < 0.01$). No significant interactions, however, were found between the measurements and the frequencies.

As seen figures 1, 2 and 3, the control group had the highest thresholds in the morning and the group exposed to continuous noise had the highest thresholds in the afternoon. The hearing thresholds of the groups exposed to impulse noise varied between the measurements. Impulse noise group 1 had the highest thresholds at 6000 Hz ($p < 0.01$). In the left ear the thresholds were, on average, 13 dB and in the right ear 16 dB. Impulse noise group 2 also had the highest thresholds at 6000 Hz ($p < 0.01$). The average values were 26.25 dB for the left ear and 21.25 dB for the right ear. Impulse noise group 3 had the highest thresholds asymmetrically. In the left ear the values were highest at 4000 Hz 19.00 dB ($p < 0.01$). In the right ear they were highest at 6000 Hz, on average, 20.75 dB ($p < 0.01$).

The group exposed to continuous noise also had the highest threshold values asymmetrically. In the left ear the highest values were found (15.20 dB) at 6000 Hz ($p < 0.01$). In the right ear none of the frequencies had significantly deviating threshold values, but the thresholds were highest at 8000 Hz (7.90 dB).

Contrary to expectations, the thresholds of the control group also varied with the frequencies. The highest threshold values were found at 6000 Hz for the left ear 5.50 dB ($p < 0.01$) and 7.50 dB for the right ear ($p < 0.01$). All the groups had the lowest threshold values at 2000 Hz. The values varied in the left ear between -0.5 and +9.75 dB; the control group had the lowest values, and group 3 the highest. The corresponding values for the right ear were between -1.25 and -6.25 dB; again, the lowest values were found for the control group and the highest for group 3.

<u>Differences between the groups</u>

The groups' hearing thresholds for both ears differed significantly ($p < 0.01$). These differences could be seen from the morning measurement up to the afternoon measurements. The frequencies differed significantly ($p < 0.01$) with regard to the hearing thresholds for both ears. The interactions between the groups and the frequencies, however, were significant only for the left ear ($p < 0.01$). The groups' thresholds for the left ear differed at all frequencies even at the start of the workday ($p < 0.01$). The groups' thresholds for the right ear also differed at every frequency (except 1000 Hz) in the morning and in the afternoon.

Morning hearing thresholds

The results from the morning, midday, and afternoon measurements are summerized in table 1. The morning thresholds of none of the groups differed at 1000 Hz in the right ear. When the groups exposed to noise were compared with the control group, it could be seen that the group exposed to continuous noise had higher thresholds than the control group only in the left ear at 8000 Hz ($p < 0.01$). Moreover, these two groups did not differ significantly at all in the right ear thresholds. This was also the case with the control group and group 1.

Table 1. Summary of significant p-values (Newman-Keuls) for the differences of the hearing thresholds between groups measured in the morning, midday, and afternoon. L = left ear, R = right ear.

Group	Frequencies/ Measurements	1000 L/R	2000 L/R	4000 L/R	6000 L/R	8000 L/R
				Control group		
Contin n	Morning					L
	Midday					L
	Afternoon	L				L
(1) Imp n	Morning					
	Midday	L				
	Afternoon	L				
(2) Imp n	Morning		R	L R	L R	L R
	Midday			L R	L R	L R
	Afternoon	L		L R	L R	L R
(3) Imp n	Morning	L	L R	L R	R	
	Midday	L R	L R	L R	R	
	Afternoon	L R	L R	L R	R	
				Continuous noise group		
(1) Imp n	Morning					
	Midday					L
	Afternoon					
(2) Imp n	Morning			L	L R	R
	Midday			L	L R	
	Afternoon			L	L R	
(3) Imp n	Morning	L	L R	L R	R	
	Midday	L	L R	L R	R	
	Afternoon		L R	L R	R	
				Impulse noise group 1		
(2) Imp n	Morning			L	L	
	Midday			L	L	L
	Afternoon			L	L	L
(3) Imp n	Morning	L	L	L R	R	
	Midday	L	L R	L R		
	Afternoon	L	L R	L R		
				Impulse noise group 2		
(3) Imp n	Morning	L	L		L	L
	Midday	L	L		L	L
	Afternoon	L	L R		L	

0.05 > p < 0.01

Impulse noise group 2 at 4000-8000 Hz (in the left ear) and at 2000-8000 Hz (in the right ear), and group 3 at 1000-4000 Hz (in the left ear) and at 2000-6000 Hz (in the right ear) had higher thresholds than the control group (0.05 > p < 0.01).

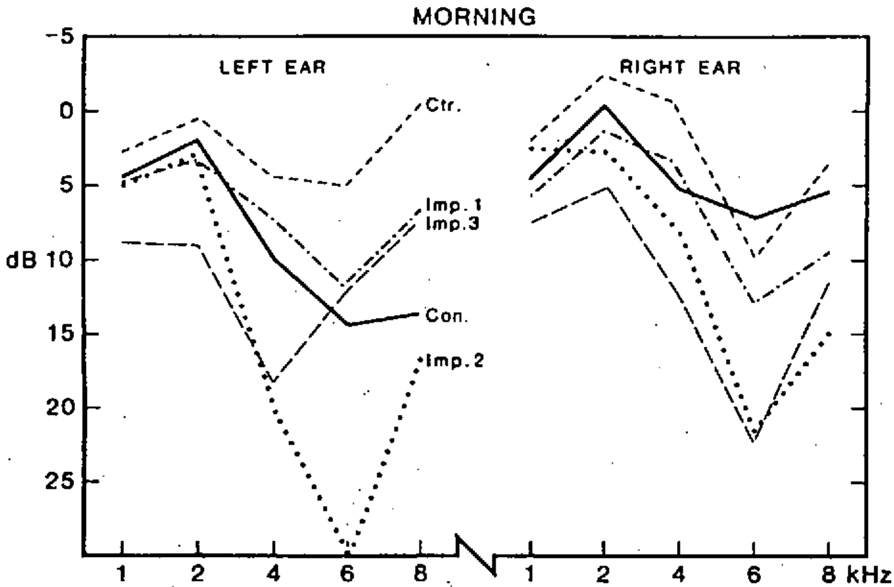

Fig. 1. Average hearing thresholds of the left and right ear for controls (ctr.), three impulse noise groups (1-3) and continuous noise group (con.) at frequencies of 1-8 kHz measured in the morning.

When the groups exposed to noise were compared with one another, impulse noise group 2 at 4000 Hz and 6000 Hz (in the left ear) and at 6000-8000 Hz (in the right ear), and impulse noise group 3 at 1000-4000 Hz (in the left ear) and at 2000-6000 Hz (in the right ear) had higher thresholds than the group exposed to continuous noise ($0.05 > p < 0.01$). The group exposed to continuous noise and group 1 showed no significant differences in the right ear.

The impulse noise groups also differed from one another. Group 2 had higher thresholds than group 1 at 4000-6000 Hz only in the left ear, and group 3 had higher thresholds than group 1 at 1000-4000 Hz (in the left ear) and at 4000-6000 Hz (in the right ear; $0.05 > p < 0.01$). At 1000 Hz and 2000 Hz group 3 had higher thresholds than group 2 in the left ear ($p < 0.05$), but at 6000 and 8000 Hz these differences were reversed: group 2 had higher thresholds than group 3 ($0.05 > p < 0.01$).

Midday hearing thresholds
At midday the thresholds of the groups in the left ear did not differ much from the morning thresholds. The only change was found between the control group and impulse noise group 1. At 1000 Hz group 1 had higher thresholds than the control group ($p < 0.05$).

The thresholds of the right ear also showed few changes from the morning. At 1000 Hz group 3 had higher thresholds than the control group at midday ($p < 0.05$). Impulse noise group 2 no longer differed significantly from the control group at 2000 Hz, but there was still a difference at 4000-8000 Hz ($p < 0.01$).

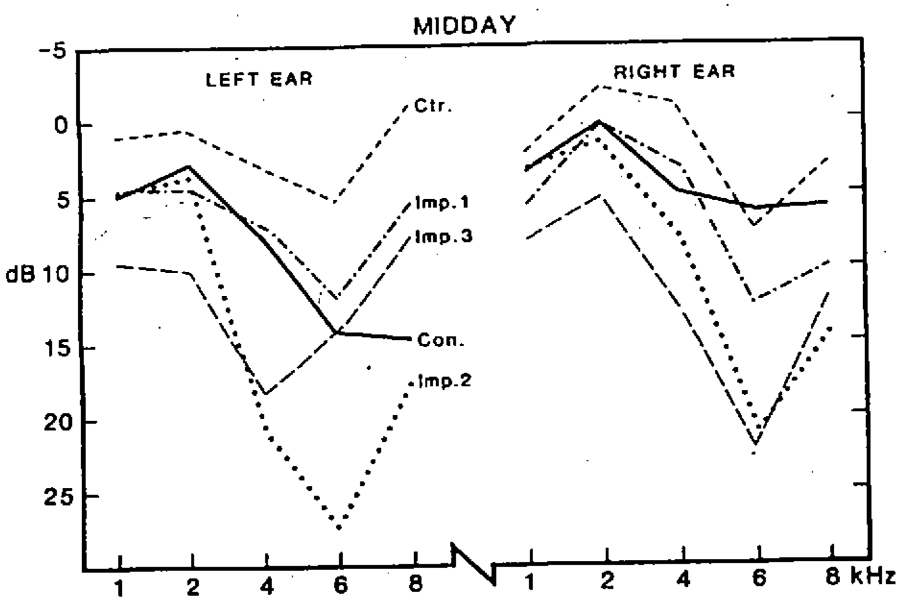

Fig. 2. Average hearing thresholds of the left and right ear for controls (ctr.), three impulse noise groups (1-3) and continuous noise group (con.) at frequencies of 1-8 kHz measured in the midday.

The midday differences between the group exposed to continuous noise and those exposed to impulse noise were similar to the morning differences. Group 1 had higher thresholds than the group exposed to continuous noise at 8000 Hz in the left ear ($p < 0.05$). In the right ear the difference found between group 2 and the group exposed to continuous noise at 8000 Hz in the morning disappeared. The groups exposed to impulse noise did not have higher thresholds than the group exposed to continuous noise systematically, but the direction of differences depended on the tested frequencies and the ear.

The differences between the groups exposed to impulse noise changed somewhat from the morning. In the left ear thresholds the change was that group 2 had higher thresholds than group 1 at 8000 Hz ($p < 0.01$) in addition to those differences already found in the morning. Between the other impulse noise groups there were no other changes from the morning in the left ear thresholds. Instead, the differences found in the right ear between groups 1 and 3 were no longer present at 6000 Hz, but were at 2000 Hz ($p < 0.05$). Groups 1 and 2 had no significant differences throughout the day in the right ear.

Afternoon hearing thresholds
There were a few changes from the midday results, mainly in the left ear at 1000 Hz or at 8000 Hz. In the left ear the group exposed to continuous noise had higher thresholds than the controls at 1000 Hz, as it also had at 8000 Hz in the morning ($p < 0.05$). When compared with the controls, impulse noise groups 1 and 2 also had higher thresholds than the controls at 1000 Hz ($p < 0.05$).

When compared with the group exposed to continuous noise, impulse noise group 1 no longer differed from it at 8000 Hz as it had at midday. Group 2 had differences similar to those measured at midday at 4000-6000 Hz when compared with the group exposed to continuous noise ($p < 0.01$). The differences between the group exposed to continuous noise and groups 2 and 3 remained the same as at midday ($0.05 > p < 0.01$), except that group 3 no longer differed at 1000 Hz. Groups 2 and 3 no longer differed at 8000 Hz, but they did differ at 1000-2000 Hz and at 6000 Hz, as they had in the morning and at midday ($p < 0.05$).

In the thresholds of the right ear, the differences between the controls and groups 2 and 3 remained as they had been at midday. This was also the case with the group exposed to continuous noise and group 2, and with groups 1 and 3 in the way that the groups exposed to impulse noise had higher thresholds than the controls or the group exposed to continuous noise ($0.05 > p < 0.01$): group 2 at 4000-8000 Hz and group 3 at 1000-6000 Hz compared with the control group and at 6000 Hz (group 2) and at 2000-6000 Hz (group 3) compared with the group exposed to continuous noise.

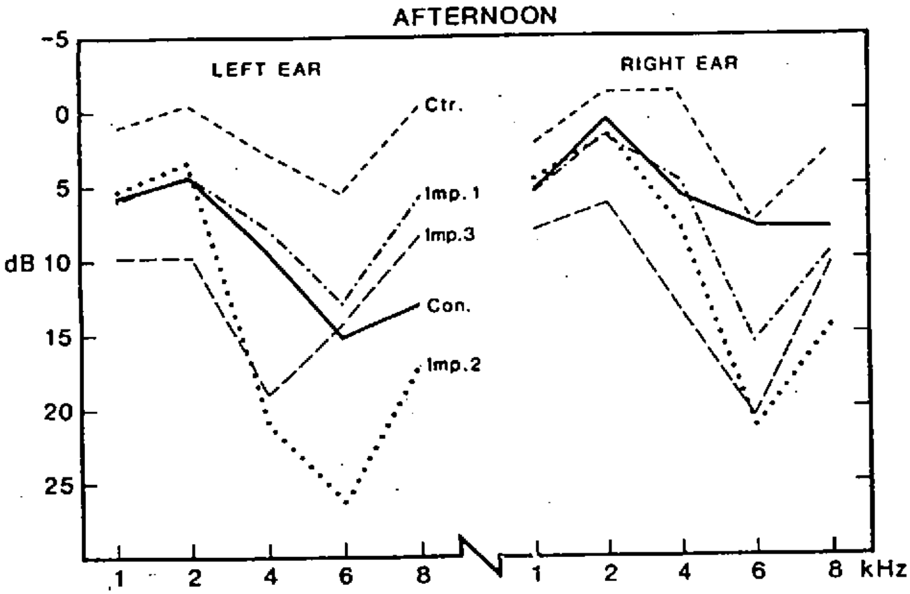

Fig. 3. Average hearing thresholds of the left and right ear for controls (ctr.), three impulse noise groups (1-3) and continuous noise group (con.) at frequencies of 1-8 kHz measured in the afternoon.

The only change from midday between the groups exposed to impulse noise was that impulse noise group 3 now had higher thresholds than group 2 at 2000 Hz ($p < 0.05$); this or other differences were not found earlier in the day between these two groups.

DISCUSSION

Main results
We measured the hearing thresholds of three groups exposed to impulse noise, of one exposed to continuous steady state noise, and of a non-exposed group. We compared the differences both within and between the groups with regard to the hearing thresholds measured three times on two workdays.

The threshold audiograms of the groups varied with both the frequency and the duration of exposure. The audiograms of group 1 who had the shortest duration of exposure to impulse noise showed that the thresholds were highest at 6000 Hz symmetrically in both ears. Group 2 with the intermediate duration of exposure to impulse noise also had the highest threshold values symmetrically at 6000 Hz. Group 3 with the longest duration of exposure to impulse noise had asymmetrical effects. The thresholds were highest in the left ear at 4000 Hz and in the right ear at 6000 Hz. The groups exposed to continuous noise had asymmetry in the highest threshold values. The right ear showed no significant differences between any frequency, but the left ear differed at 6000 Hz. The control group was no exception in this respect, they also had the highest threshold values in both ears at 6000 Hz. With regard to the differences between the groups, the audiograms showed, in general, that the longer the duration of exposure to noise, the higher the hearing thresholds.

Interpretation of results

The results indicate that the longer the duration of exposure to impulse noise, the wider the region of the frequencies which showed raised threshold shifts in both ears. This effect could already be seen in the threshold measurements in the morning, before the workday began. The same effect may be seen in the threshold shifts of the groups exposed to impulse noise when compared with one another. We are inclined to suggest that: (1) The effects on hearing of exposure to impulse noise for three to four years do not differ from those of exposure to continuous noise of a nearly equivalent noise level for about five years. (2) Exposure to impulse noise for five to six years can induce NIPTS both at 4000 and 6000 Hz, but more prominently at 6000 Hz. (3) Exposure to impulse noise for seven to 10 years may result in permanently raised thresholds within the entire range of audiometric frequencies (1000-8000 Hz).

It has suggested that permanent noise induced hearing shift always develops in the basal area of the cochlea, which means around the regions of 4000 to 6000 Hz. These two regions are sensitive to high levels of exposure to impulse noise, and considerable destruction may be seen already after a relatively short duration of exposure. Group 1 had the shortest duration of exposure to impulse noise but, compared with the group exposed to continuous noise or with the control group, no systematic differences were found in the threshold shifts in either ear, nor were there uniform differences either at the beginning or at the end of the workday. This may indicate that the temporary threshold shift induced by impulse noise take more than three to four years to become permanent.

Impulse noise group 2 had already developed permanent threshold shifts at 4000 and 6000 Hz after five to six years' exposure. The thresholds of impulse noise group 3 showed that permanent threshold shifts at all the frequencies tested were induced within seven to 10 years of exposure. Most of the changes reported in the hearing level at 3000, 4000, and 6000 Hz occur initially after 15 years' exposure to steady state continuous noise. At 500, 1000, and 2000 Hz, changes in the hearing level are essentially a linear function of the duration of exposure. The best indicator of susceptibility to noise induced changes in the hearing level would probably be early evidence of the permanent threshold shift at 4000 Hz.

The present results did not show clearly any temporary threshold shifts during the workday when the thresholds were measured in the morning, at midday, or in the afternoon. Nor were the hearing thresholds of any of the three groups exposed to impulse noise or the group exposed to continuous noise significantly raised as a function of the duration of exposure over the two workdays. Nor did the controls' hearing change significantly over the workday. These findings can be further evidence that after some years of exposure to high levels of noise reversible daily temporary threshold shifts no longer occur as in the early phases of exposure or after a very short duration of exposure.

The development of permanent threshold shifts in one or both ears suggests that occupational exposure to noise can induce both symmetrical and asymmetrical changes in the hearing level, depending on the duration of exposure and the range of noise. In our study the findings could be related to the complexity of the exposure to noise and to the type of work done at the worksites. Other individual factors such as the work positions and the type of ear protectors or the way they were used might play an importat part in the development of the symmetrical or asymmetrical changes in the hearing level. Slight changes in the orientation of the head relative to the source of sound may bring about considerable differences in sound pressure at the eardrum or beyond.

Sources of errors

In this study the levels of exposure to impulse noise and continuous noise were not equal and within both workplaces, noise was generated from several sources. In the shipyard workshop the noise was a mixture of continuous noise and impulse noise; in the cable factory the noise was rather steady and continuous, but nevertheless had some features that could be characterised as impulse noise. When we take into account that the groups exposed to impulse noise wore ear protectors but the group exposed to continuous noise did not, the levels of noise exposure were more comparable than the noise levels measured would indicate. Hence, we concluded that the levels of noise exposures of the various groups could be compared with one another.

The effects of age on hearing could be considered as another possible source of the threshold differences found between the groups. The differences, however, were not thought to result from presbyacusis even though the workers' ages and the durations of exposure correlated significantly at 4000 Hz (r_{xy}= 0.40, $p< 0.01$, df 102). No frequencies higher than 4000 Hz were correlated with age. It is also evident that the longer the exposure to noise, the older the workers. It is also well known that higher frequencies (over 4000 Hz) are more sensitive to the effects of the aging processes than lower frequencies. One reason for not taking the age differences of the groups into account was that the oldest noise exposed workers in our groups were in their early 30s, and few in number. The other reason was that group 3 was, on average, 9.3 years older than the control group, and yet the groups had no significant differences in hearing level at 8000 Hz, although differences would be expected if age mattered.

The fluctuations from the morning to midday and then to afternoon (or reversed) in the threshold values seen mainly at the lower frequencies in the intergroup differences could imply some amount of temporary threshold shift due to the day's exposure. Because these fluctuations were not systematic and because there were also interindividual variations within the groups, we suspected that these irregularities might originate from random variations within the Ss, and from a 5 dB scale of the audiometric equipment. Since the standard deviations in groups 2 and 3 were rather wide at certain frequencies, it seemed evident that besides exposure to noise individual factors such as the way earmuffs were worn in combination with work positions might have been highly important to the development of permanent changes in the level of hearing induced by impulse noise.

CONCLUSIONS

On the basis of our results we concluded that exposure to high levels of impulse noise (despite the use of ear protectors) is more detrimental to hearing than are high levels of continuous noise (even continuous with slightly impulsive features). Impulse noise seems to produce permanent threshold shifts at certain frequencies after a clearly shorter duration of exposure than continuous noise. The frequencies most sensitive to impulse noise are 4000 and 6000 Hz. Only later, as a function of the duration of exposure, are the lower frequencies sensitised. Therefore, it is reasonable to assume that the qualities necessary for ear protectors to protect hearing from impulsive noise differ from those necessary to protect from continuous noise. In future studies it would be more realistic to study not only the effects of exposure to noise but attention should be paid also to subjective characteristics and individual factors of work conditions.

For references, see S. Mäntysalo and J. Vuori, 'Effects of impulse noise and continuous steady state noise on hearing', Brit. J. of Indust. Med., Vol. 41, no. 1, 122-132, (1984).