MEDICINSKA FAKULTETEN
Lunds universitet
Institutionen för logopedi, foniatri och audiologi

Field investigation of real-world attenuation provided by insert-type hearing protectors

Jenny Lindqvist
Linda Sandberg

Audionomutbildningen, 2002
Vetenskapligt arbete, 20 poäng

Handledare: Sten Harris och Per Hiselius

ACKNOWLEDGEMENTS

This study was performed in collaboration with Bacou-Dalloz and the authors would like to express thanks for given us this opportunity to do research on this subject.

We would like to thank Sten Harris, who has been our instructor, for his guidance and support during this study.

We would like to thank Per Hiselius for given us support and encouragement during the work on this study. He has given us ideas and advice on how to proceed in our work.

We also would like to thank Anders Jönsson for his thoughts and support.

The authors are thankful to those people who have given us assistance with the English language.

Furthermore would we like to thank all the participating companies and each and every test subject. This study couldn't be done without Your participation.

ABSTRACT

The purpose of this study is to see how much attenuation the hearing protection device (HPD) wearer gets using an insert-type HPD at work in real-world situations and to see if there is a relation between how the wearer puts his HPD in place and the surrounding noise level.
Five different companies were selected and all together there were 43 participants. The test subjects work in such an environment that the use of hearing protectors was considered necessary.
To determine the effectiveness of earplugs as they are worn in the workplace, portable equipment was used. The Real-ear attenuation at threshold (REAT) method was used to determine the subjects' binaural threshold levels, with and without the HPDs inserted. The difference between these two results is a measure of the attenuation. The test frequencies span between 250 Hz to 8000 Hz. To see if there was any relation between the sound levels and how the test subjects inserted their hearing protectors there was also done a sound level measurement. The HML-method was used to establish each subject's attenuation. This method is based on three attenuation values, H, M and L (High, Medium and Low).
When the attenuation is put in relation to the sound level one can see that the attenuation appears to increase with the sound level. Our results imply that those exposed to high sound levels are more careful when applying their earplugs, which corresponds to our hypothesis that was: Users who work in a noisy environment would be more cautious how the HPDs are used than HPD wearers who work in a less noisy environment.
When overprotection is defined according to European standard EN 458, e.g. < 70 dB(A) inside the HPD, 33 out of 43 (77%) of our test subjects are overprotected.
Estimation of the surrounding sound level is difficult. Our results show that the HPD wearer himself cannot determine whether the sound level is at a dangerous level or not.
Our study indicates that there is a need on the market for an earplug that only provides an attenuation of approximately 10 dB for those who work in the borderline of 85 dB(A).

1 INTRODUCTION

The major concern of many industries is the prevention of noise-induced hearing loss. The ideal method to achieve this is of course to reduce the noise level at the source. However, this is not always possible. To get some protection many workers choose to wear hearing protection devices (HPDs). One of the most common ways to get protection is to use foam or reusable earplugs (Lempert, Edwards, 1983).

The noise reduction provided by HPDs is commonly referred to as its 'attenuation'. However, attenuation is not a precisely defined acoustical term. When we refer to the term attenuation in this study we mean the insertion loss. Insertion loss is the difference between the sound pressure levels (SPLs) when measured at a reference point with and without the HPD (Berger, 1986).

We have chosen this topic to see how much attenuation a HPD wearer gets from his HPDs when working in a real-world situation. Our personal experience indicates that the use of HPDs mirrors the wearers' knowledge about hearing, which will influence the motivation to use HPDs. Other factors that may influence are e.g. the attitude and accessibility of hearing protectors at the work place. The comfort, sizes available and ease of insertion and removal are all important in analyzing the effectiveness of earplugs (Lempert et al, 1983). Also the instructions provided by the manufacturer about the insertion of the earplugs can influence the HPDs attenuation.

How much protection is the user actually provided from his HPDs? What is the difference, if any, between expandable foam plugs and reusable plugs? Can we see any variation in the provided attenuation between those with normal hearing and those with a hearing impairment? It is important to document the effectiveness of the HPDs since many wearers rely on them for their hearing protection. If the wearer is receiving less attenuation than the earplug is supposed to provide, the user is placed in the very unfortunate situation of thinking his hearing is being protected, while in fact he may be sustaining some permanent loss of this vital sense (Edwards, Hauser, Moiseev, Broderson and Green, 1978). On the other hand too much protection creates a problem in communication (warning signals or work instructions) for some wearers who might be overprotected (Ohlin, Michael, Bienvenue, Rosenberg, 1981).

We are also interested to see if there is a correlation between how the wearer puts his HPDs in place and the surrounding noise level. There are no such previous studies what we know of. Our hypothesis is that a HPD wearer who works in a noisy environment is more careful when inserting the earplugs, compared to a wearer who works in a less noisy environment.

2 PURPOSE

The purpose of this study is to see how much attenuation the wearer gets using an insert-type HPD at work in real-world situations. Another matter of interest is to see if there is a relation between how the wearer puts his HPDs in place and the surrounding noise level.

3 BACKGROUND

The HPD packages in Europe are labelled with SNR (Single Number Rating) ratings and some HPD wearers depend upon the SNR when the chose their HPDs. One of the most difficult problems in hearing conservation is the difference between the labeled attenuation of HPDs and the much lower attenuation actually attained by wearers using insert-type HPDs at work. Several studies have clearly shown differences between laboratory and real-world data (Edwards et al, 1978; Ohlin et al, 1981; Lempert et al, 1983; Doswell Royster, Berger, Merry, Nixon, Franks, Behar, Casali, Dixon-Ernst, Kieper, Mozo, Ohlin, Royster, 1996).
The manufacturers data are collected in laboratories under controlled conditions using motivated and experienced HPD wearers. The test subjects are often paid for their time and they are tested for a relatively short period of time. Issues of human comfort, compliance with workplace rules and regulations and long-term wearability are not addressed (Hager, 2002). These measurements will therefore come to represent the best-fit condition, and the values printed on the packages are the ideal attenuation. It has never been demonstrated that any group of HPD wearers working under real-world constraints can attain and maintain attenuation matching laboratory values (Doswell Royster, 1996). Even though properly worn earplugs can provide adequate protection in a noisy environment, they are often worn incorrectly. For example, the expandable foam plugs provides, on average, the greatest attenuation but they are usually not fully inserted and are often not held in place during expansion to prevent outward slippage. This means that the laboratory attenuation data provided by distributors may greatly overestimate a user's actual protection (Padilla, 1976; Edwards et al, 1978; Ohlin et al, 1981; Lempert et al, 1983; Berger, 1988; Michael, 1999).

A wide range of HPD attenuation values may be observed in the workplace. From essentially no attenuation at all for devices poorly fitted by users who are unable or unwilling to wear their HPD properly, to much higher levels of protection that may be obtained under ideal conditions in workplaces with the most successful hearing conservation programs (Merry, Sizemore and Franks 1992; Berger, Franks, Behar, Casali, Dixon-Ernst, Keiper, Merry, Mozo, Nixon, Ohlin, Royster, J.D., Royster, L.H., 1998).

ISO standards have recognized the importance of comfort and the need for more realistic and real-world achievable fitting conditions. A representative standard is the current version of ISO 4869. It specifically mentions comfort by recommending subjects to fit and adjust the HPD for 'best attenuation with reasonable comfort' (ISO 4869-1:1990(E); Doswell Royster et al, 1996).

There is also a need for some improvements in the hearing conservation program for the ideal attenuation to be attained. To receive more protection from the HPD the wearers must be individually fitted and trained in how to use their HPD in a proper way. Today a majority doesn't get any personal advice on how to use their HPDs. There must be more time spent on educating wearers in the proper use of their HPD (Ohlin et al, 1981; Lempert et al, 1983; Doswell Royster et al, 1996).

4 METHOD AND MATERIAL

4.1 Subjects

55 persons at 5 different companies participated in the study. 14 females and 41 males (aged 20-62) were recruited with the assistance of either the company nurse, a safety representative at the company or the personnel manager. The subjects have been selected without regard to size and shape of head, pinnaes or ear canals. The only inclusion criterion is: the subjects must use HPD of insert type continuously at work All subjects work in production companies with such sound conditions that HPDs are considered required.

The results are based upon 43 subjects. Five females and seven males were rejected from the study because of an initial problem with the 'patient switch'. These test subjects' results were therefore unreliable and we choose to reject them.

4.2 Equipment

The FitCheck is an insert-type hearing protector measurement system developed by Dr Kevin Michael at Michael & Associates, Inc..
The FitCheck hardware/software system has been designed to measure the attenuation provided by insert-type HPDs on the individual wearer.

The FitCheck system uses a set of large circumaural headphones that are designed to not affect the HPD. These headphones are used to conduct audiograms on individuals who wear insert-type HPD; both with the HPDs fitted and with the ears open. The attenuation provided at each frequency is calculated by subtracting the open threshold from the occluded threshold (Michael and Byrne, 2002).

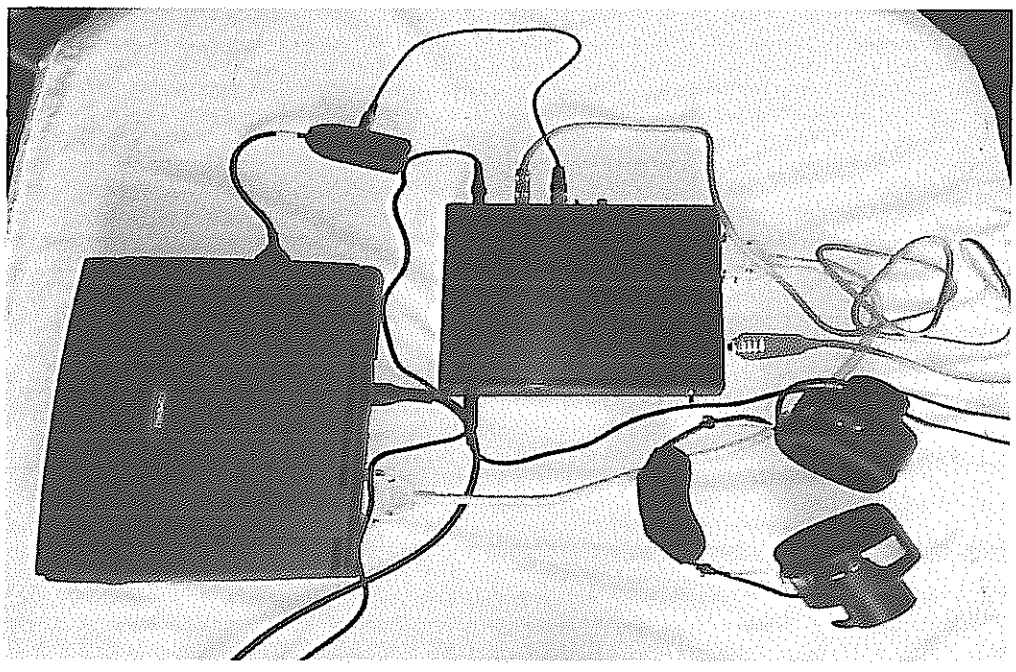

Figure 1. The FitCheck equipment used in our study.

The hardware used in the FitCheck consists of a commercial 16-bit IBM PC sound card (In fig. 1, between the computer and the black box), circumaural headphones and a black box. The black box contains the Békésy audiometer. The PC parallel printer port is used for data communication from the PC to the FitCheck hardware. A patient switch and a 12-volt DC power source are also included.

FitCheck software includes database functions to store all attenuation measurements. The database is recorded in Microsoft ACCESS format, allowing the data to be conveniently manipulated using spreadsheet programs.

4.3 Real-ear attenuation at threshold (REAT)

Virtually all-available manufacturers' reported data are derived with this method. The absolute threshold shift technique is often labeled 'real-ear attenuation at threshold' (REAT) (E.H. Berger, 1986).

We have chosen 'the headphone' REAT-method in our study. The sound field is established inside a set of large circumaural headphones, which stand off from the ears and do not affect hearing protector fit. This makes the testing considerably more portable and also less sensitive to ambient noise since the headphones provide attenuation during both the open and occluded ear tests.

The idea is very simple – determine a test subject's binaural threshold of hearing without wearing HPD (open threshold) and then re-measure the subjects hearing threshold level while wearing the HPD (occluded threshold) using the headphones seen in fig 1. The difference between the two thresholds is the measure of the HPDs attenuation. A fundamental requirement of accurate REAT measurement is that the test room must be sufficiently quiet.

The test signal consists of a pink noise filtered through one-third-octave bands.
The test shall be performed at the following center frequencies according to ISO 4869-1:1990(E): 63 Hz (optional), 125, 250, 500, 1000, 2000, 4000, 8000 Hz.

4.4 Hearing protectors

The test subjects used HPDs produced by Aearo Ear, Bilsom, MSA, Würth and North.
30 workers used foam plugs and 13 reusable plugs.

4.4.1 Foam plugs

Aearo Ear classic, Würth, North and MSA (six-angular) are unisized foam plugs. Bilsom 303 is an expandable cone formed foam plug and comes in two different sizes, large and small. These kinds of earplugs will expand and adjust to the shape of the ear canal. By rolling the earplug to a thin cylinder, pulling the outer ear with the opposite hand and placing the HPD in the ear canal the HPD wearer can find the optimal position.

The labelled SNR values by the manufacturer are:

Aerao Ear classic, SNR 28
Würth, SNR 28
MSA, SNR 29
Bilsom 303, SNR 32

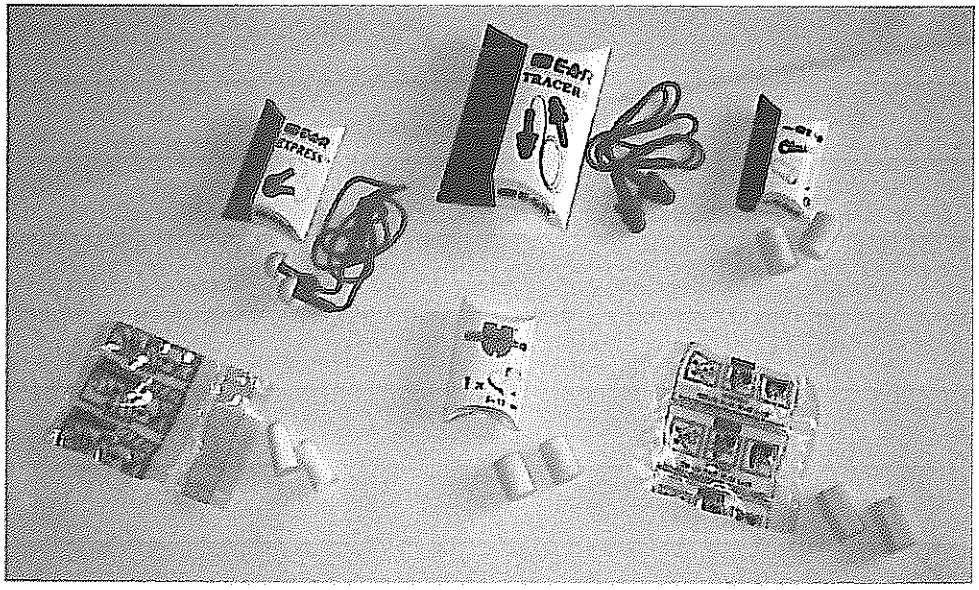

Figure 2. From left to right, the top row: Aearo Ear express, tracers and classic. Below: Bilsom 303, Würth and MSA. North is not present on this figure.

4.4.2 Reusable plugs

Aearo Ear tracers and Aearo Ear express are reusable earplugs in soft plastic. Eleven subjects used Aearo Ear tracers, which contain metal fibers. The earplug has three flanges and a rounded tip. Two subjects used Aearo Ear express and these earplugs have a rounded foam top. The Aearo Ear tracers should be twisted in the ear canal until a seal is obtained and Aearo Ear express should be placed in the opening of the ear canal.

The labelled SNR values by the manufacturer are:

Aearo Ear tracers, SNR 25
Aearo Ear express, SNR 28

4.5 Test procedures

The test has been performed on site at the participating companies in a normal furnished office and a normal quiet room. The sound level in the room was approximately 53-55 dB(A).

Absolute acoustic calibration of the equipment was not required since only differences in hearing threshold levels were of interest. Care was taken to always listen to the test signals at

the start of each test day to make sure that the equipment was operating properly. The same two experimenters always carried out this test.

The test never begun until the subjects had been at work for at least thirty minutes. This was to ensure that the subjects were performing their ordinary duties and that the earplugs were fitted as usual.
The test subjects sat in a relatively quiet environment for two minutes and during this time they answered a questionnaire, see Appendix E (Swedish) and F (English).

Before the test day the experimenter informed the participating company about the purpose of this study. Written test instructions have been provided along with the information to the potential test subjects. Already at this point an effort had been made to explain the consequence if the subject re-adjusted or pulled out their earplugs before the test.
The subjects participating in the study were informed in the morning of the test day just so they didn't know exactly when they were to be tested. The subjects were then again alerted not to touch their earplugs until the test experimenter said that the test was finished.
When a subject entered the test room he or she was immediately asked not to remove or adjust the earplugs until the test was done. Twelfth test subjects, in spite of the instructions, still re-adjusted or pulled out their earplugs before the test (marked in the Appendix G with bold text). Then they were instructed to refit the earplugs 'as they normally would'. The experimenter instructed each subject that the purpose was not a control of the subject but a test to estimate the noise reduction obtained by their earplugs.

The subjects received the following verbal instructions while wearing their earplugs: "You will hear a low pulsating sound. As long as you can hear the sound press the button and hold it down until you no longer hear the sound. Then release it immediately and press the button again when the sound can be heard. The sound will start in the low frequencies and then get higher. We start while wearing the earplugs and then we do the test again without the earplugs. Each test takes about five minutes."
Written instructions were also at hand to clarify the verbal instructions.

The experimenter placed the headphone on the subjects to make sure that care was taken in positioning them so that the earplugs were not disturbed. Then the test was performed at 250, 500, 1000, 2000, 4000 and 8000 Hz. Some authors have reported data beyond this frequency range and their results showed attenuation to be relatively constant below 125Hz (Berger, 1986).

The time required for a complete test and to fill out the questionnaire was about twenty minutes.

4.6 Measuring sound levels

When measuring the sound level at the workplace we used the HML 323 sound level meter, which has Type 2 accuracy. With this instrument we could measure A-weighted L_{eq} (equivalent sound level) and 'A' and 'C' differences.

The instrument was kept still at "ear-height" while measurements were made. Care was taken to keep the unit away from our body and large objects, which could have caused sound

reflections and therefore give incorrect readings. To avoid doubts two or three measurements were made in different positions.

Calibration of the equipment was performed before and after every set of measurements.

4.7 The HML-method

The HML-method is an international standardized method. This method is based on three attenuation values, H, M and L (High, Medium and Low), determined from the octave band attenuation data of a HPD.
This method looks at the difference between the A-weighted and C-weighted levels of noise exposure. These two levels in combination with the H, M and L rating of the HPD give a very good estimate of the dB(A) level of the protected ear. Four methods including the HML-method, are discussed in EN 458:1993.

The computer program Bilsom XPrt – Expert Protection Technology has been used for this calculation. Through this program information is obtained about the individuals' total attenuation provided by the HPD and the estimated sound level at the ear under the protector.

4.8 The EN 458 rating

The European Union has developed guidelines for sound levels under HPDs to maximize communication ability (EN 458:1993).). Using octave band analysis A-weighted sound levels under the HPD are calculated. The EN 458:1993 rating tells us if the subject is provided with sufficient attenuation. The 'sufficient attenuation' group can be categorized in good, acceptable and overprotected.

The EN458:1993 recommended acceptable limits are presented in table 1.

Table 1. The EN 458:1993 rating scale

L(ear), the A-weighted sound level at the ear under the hearing protector >85dB(A) is insufficient protection
L(ear) 80dB(A) to 85dB(A) is acceptable
L(ear) 75dB(A) to 80dB(A) is good
L(ear) 70dB(A) to 75dB(A) is acceptable
L(ear) less than 70dB(A) is overprotection

5 RESULTS

5.1 Foam plugs in comparison with reusable plugs

Figure 3-6 compares the attenuation provided by expandable foam plugs and reusable plugs versus the measured sound level at the subjects workplace.
The enlarged symbol, in all figures, is a person using foam plugs and is the only one with insufficient attenuation i.e. a sound level more than 85 dB(A) at the ear.

5.1.1 Attenuation at 250 and 1000 Hz

As shown in figure 3 it is evident that reusable plugs provide better attenuation than foam plugs at 250 Hz. Seven subjects, using foam plugs, have less than 10 dB attenuation. These subjects' attenuation compared with the sound level indicates that only one subject, marked with a larger symbol did not receive sufficient attenuation.

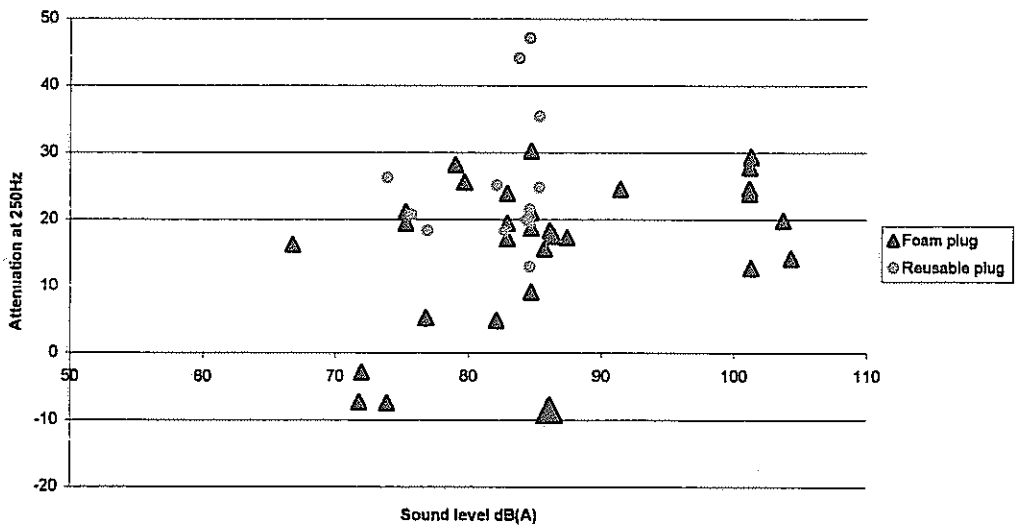

Figure 3. The provided attenuation at 250 Hz vs. measured sound level at the test subjects' workplace. A comparison between expandable foam plugs and reusable plugs.

Figure 4 demonstrates that the attenuation increases for expandable foam plugs at 1000 Hz, while remains almost the same for reusable plugs.

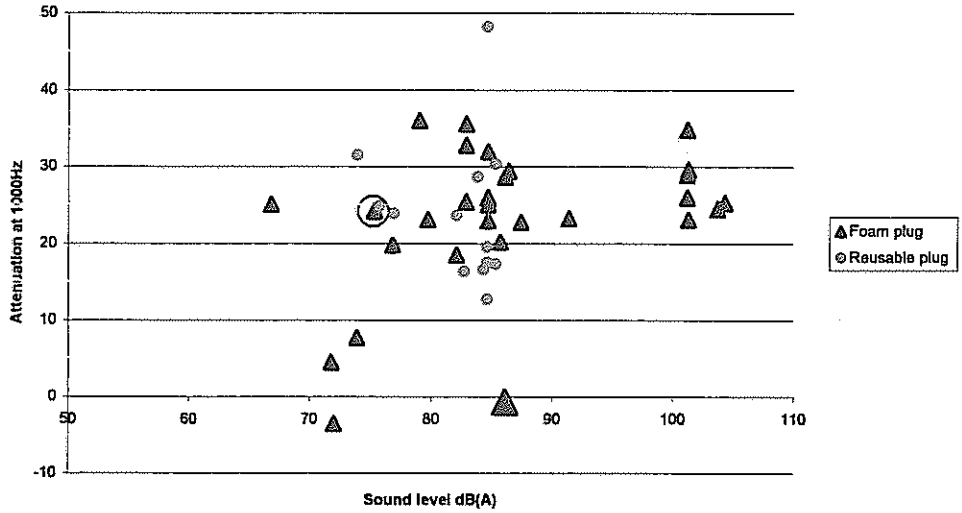

Figure 4. Provided attenuation at 1000 Hz vs. measured sound level at the test subjects' workplace. A comparison between expandable foam plugs and reusable plugs. The encircled symbols contains two values at the same spot.

5.1.2 Total attenuation

Figure 5 shows the total attenuation provided by the subjects HPD. All reusable plugs and 23 out of 30 foam plugs give attenuation between 19-39 dB. Three subjects receive amplification instead of attenuation.

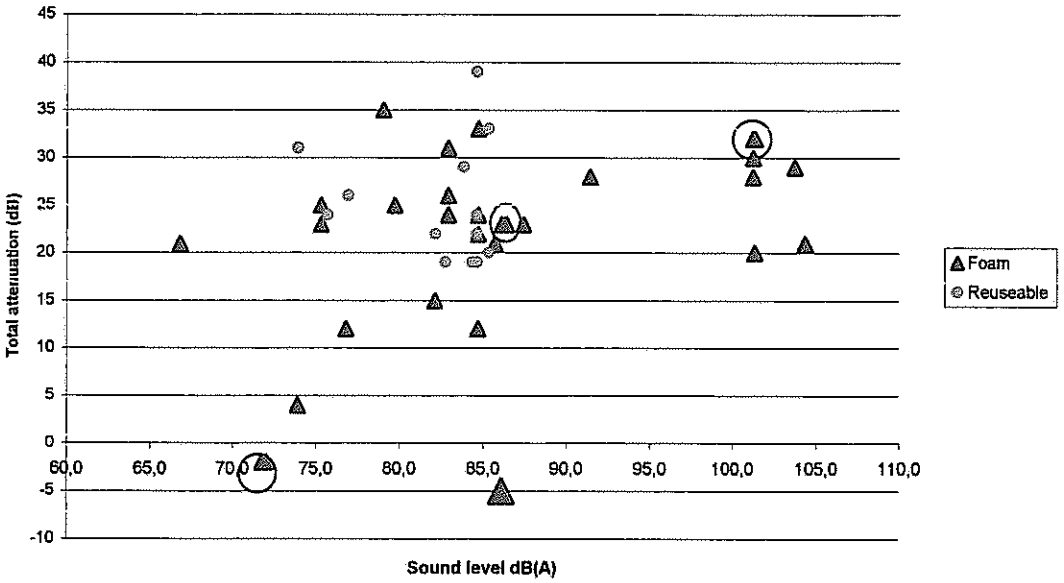

Figure 5. The total attenuation provided to the user according to the HML method vs. the measured sound level at the test subjects' workplace. A comparison between expandable foam plugs and reusable plugs. The encircled symbols contain two values at the same spot.

5.1.3 Sound level under the HPD

The level under the HPD is calculated in accordance with the HML-method. The EN 458:1993 rating indicates if the respective HPD provides each individual with sufficient attenuation in proportion to the surrounding sound level. See table 1.

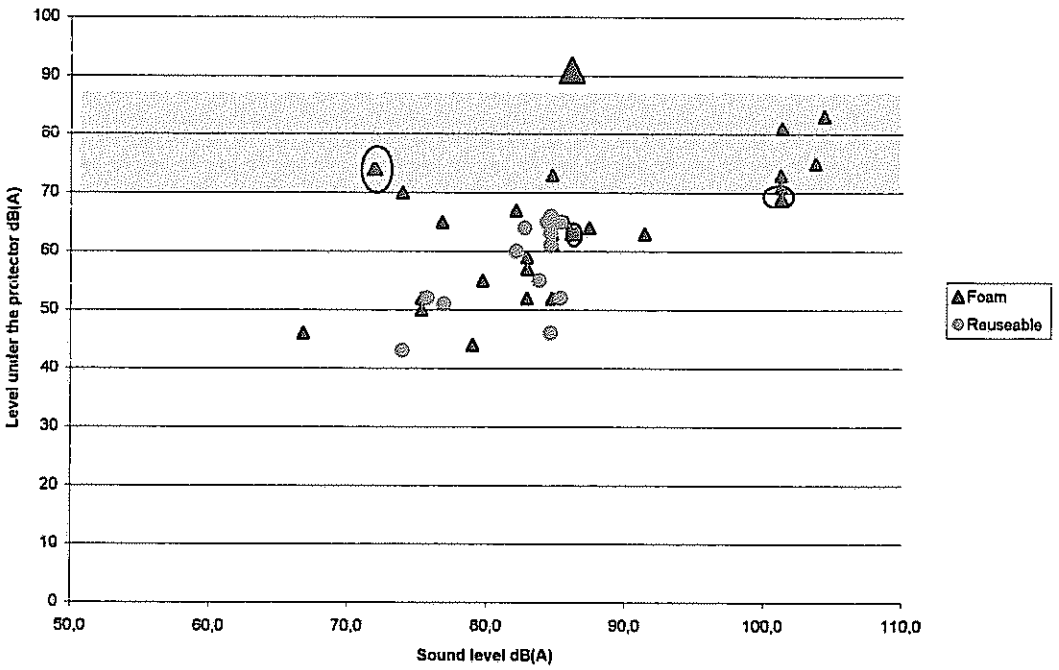

Figure 6. Calculated sound level under the individual's protector according to the HML method vs. the measured sound level at the test subjects' workplace. A comparison between expandable foam plugs and reusable plugs. The encircled symbols contain two values at the same spot.

Figure 6 indicates that all thirteen subjects using reusable plugs are overprotected i.e. have a sound level less than 70 dB(A) at the ear. Only one subject using foam plugs has well adjusted attenuation in proportion to the sound level at his or her workplace and only the one, marked with a larger symbol, has insufficient protection. Eight subjects have acceptable attenuation and all the others using foam plugs are overprotected. See table. 1.

5.2 Foam plugs

Since all thirteen workers using reusable plugs work at only two different companies and approximately at the same sound level this tend to make the analysis more difficult. Therefore have we chosen to look especially at those 30 using foam plugs.

5.2.1 Total attenuation

As indicated by figure 7 total attenuation increases with surrounding sound level. The total attenuation is centred between 20-25 dB. However, all seven test subjects' who are exposed to levels above 100 dB(A) receive sufficient attenuation without exceptions. A least squares linear regression was performed and analyzed using the statistical toolkit included in Microsoft Excel. The analysis shows that even though the linear model is not well suited (R^2=0.20) for explaining the relation between attenuation and external sound levels, there is still a significant correlation between the two since p<0,02.

Furthermore, the data was divided into two groups according to figure 7, treating those exposed to more than 100 dB(A) separately. A t-test, as well as an F-test, was performed comparing these two groups. Both tests showed significant differences.
The t-test showed, p<0,02, that the mean attenuation for the +100dB group was greater than that of the other. The mean value for the +100dB group was 27 dB, compared to 19 dB for the other group.
The F-test showed, p<0,03, that the variance of the +100dB group was smaller than that of the other. The variance for the +100dB group was 25, compared to 124 for the other group.
These results imply that those exposed to high sound levels are more careful when applying their earplugs, and as a result the attenuation attained is higher and more consistent.

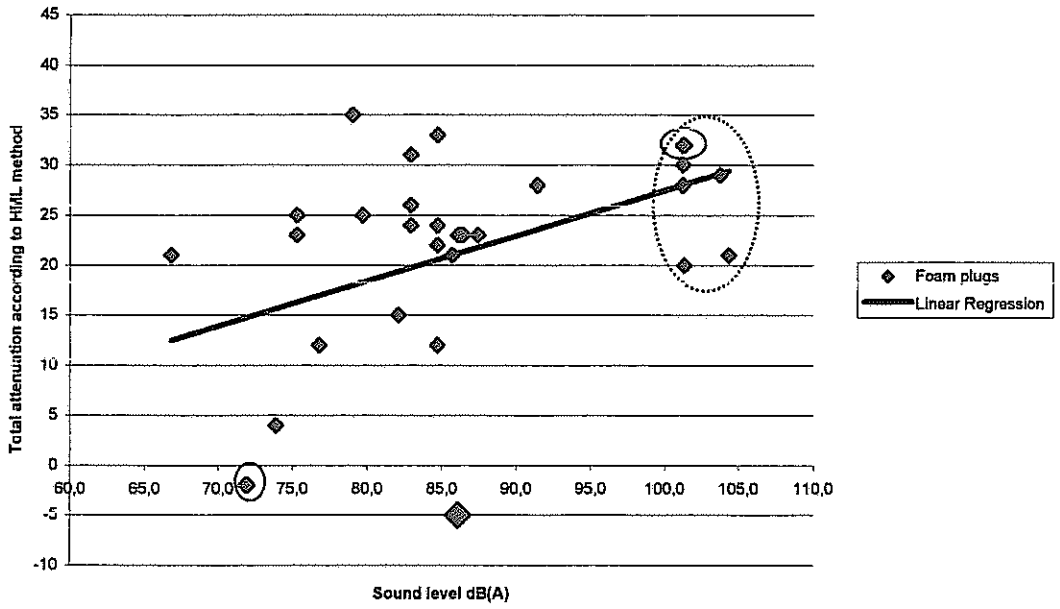

Figure 7. The total attenuation provided to the subjects according to the HML method vs. the measured sound level at the test subjects' workplace. The large encircled area contains the +100 group. The encircled symbols contain two symbols at the same spot.

5.3 Hearing impairment in comparison with normal hearing

Our definition of hearing impairment is based on question 1 in the questionnaire (Appendix E (Swedish) and F (English)). These answers are self-estimations of their hearing.

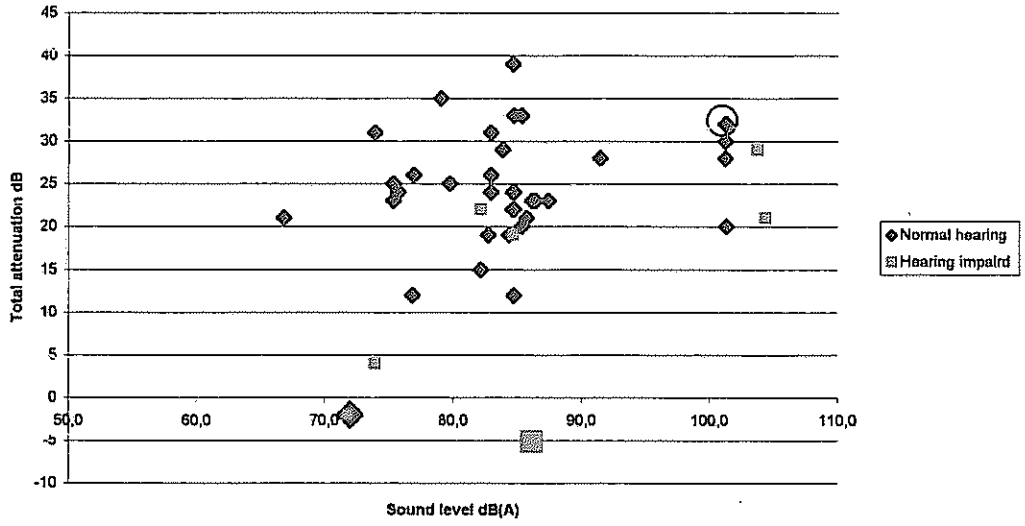

Figure 8. The total attenuation provided by HPDs vs. the measured sound level at the test subjects' workplace. A comparison between hearing impaired and normal hearing subjects. The encircled symbol contains two vales at the same spot.

As shown in figure 8, the total attenuation provided to the hearing impaired does not seem to differ from that of subjects with normal hearing. Three hearing impaired subjects has less than 10 dB attenuation but in relation to the surrounding sound level only one hearing impaired, marked with an enlarged symbol, gets insufficient attenuation.
Out of the subjects with normal hearing, there is one subject who has received less than 10 dB of attenuation. In comparison with the measured sound level this person is one out of two, both at a total attenuation of –2 dB, who has an acceptable attenuation.

5.4 Measurement of industrial noise

Figure 9 indicates that 35 out of 43 (81%) of the subjects in this study were exposed to sound levels around and below 85 dB(A). AFS:1992 recommend that hearing protectors should be used if the sound level is over 85 dB(A). Seven subjects work in sound levels over 100 dB(A).

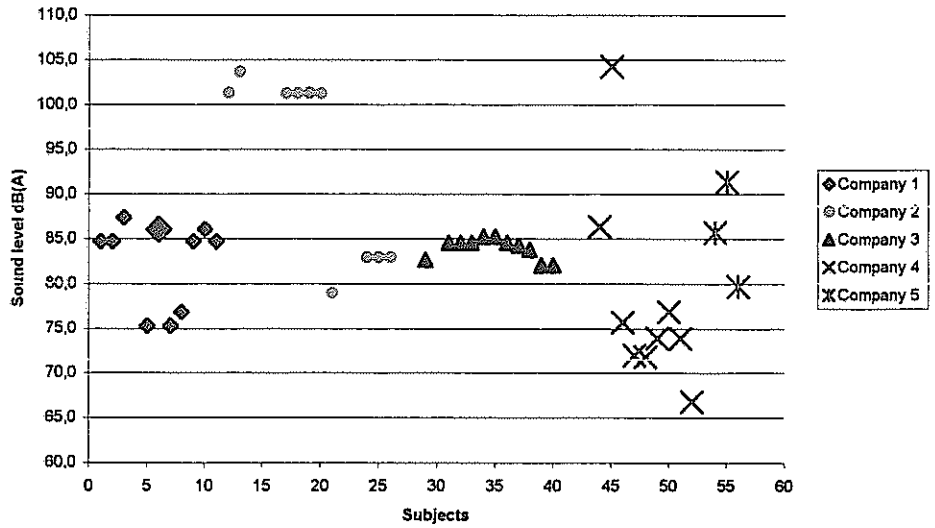

Figure 9. Result of the measured sound level for each individual subject.

5.5 Self-estimated sound level vs. actual sound level

As shown in figure 10, it is clear that it is difficult to estimate the surrounding sound level. Most variations of the self-estimated sound levels can be seen in the region of 85 dB(A).

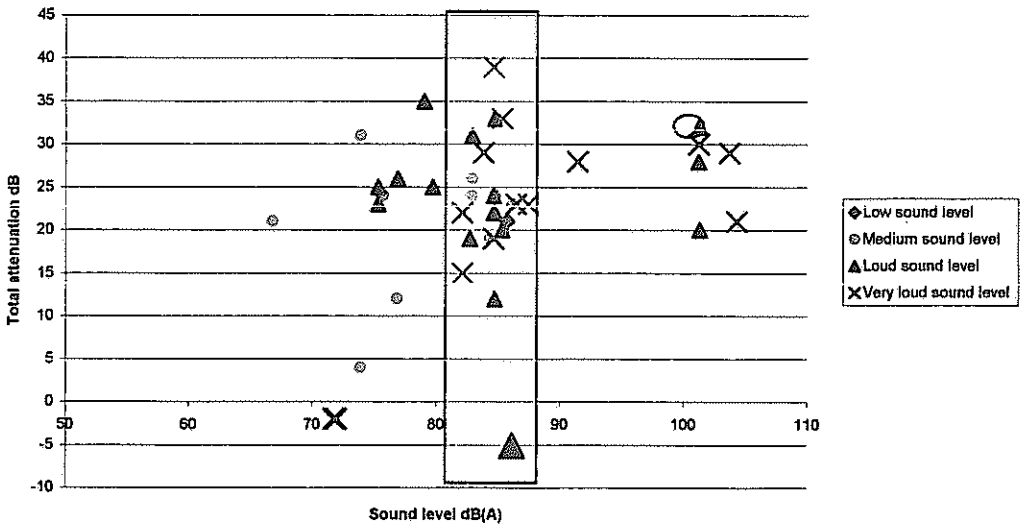

Figure 10. The total attenuation provided to the user according to the HML-method vs. the measured sound level at the test subjects workplace. A comparison between the subjects self-estimated sound level and actual sound level. The encircled symbol contains two values at the same spot.

5.6 Questionnaire

In this part we bring up some of the questions that we find interesting. The complete results of the questionnaire are presented in Appendix H (Swedish) and I (English).

Question 1: How do you estimate your hearing?	
	34
Normal	8
Mild hearing impairment	0
Sever hearing impairment	1
Other: Don't know	
Question 2: Do you suffer from tinnitus?	
Yes	9
No	32
Other: Sometimes	2
Question 3: What kind of earplugs do you use?	
Foam plug	30
Down plugs	0
Reusable plugs	13
Question 8: How many times do you remove your earplugs per day?	
1 time	1
2 times	0
3 times	2
4 times	11
More than 5 times	26
Other: often	1
Don't answer	2
Question 9: Why do you remove your earplugs?	
Warm, sweaty	2
Itchy	5
Pain, uncomfortable	2
Break	39
Communication	19
Other:	
I don't remove them	1
When I am in a non noisy	
Environment	3
Don't answer	1
Question 18: How would you estimate the comfort on your earplugs?	
Very good	12
Good	26
Bad	3
Very bad	1
Other: between good and bad	1

Question 19: In what ways would you like to improve your earplugs?	
They hurt and feel tight	2
Less warm	1
Less itchy	1
Smaller plugs would fit better	2
They are occasionally hard to shape	1
Another kind of plug containing metal fibers	1
A plug who attenuates better, easier to hear the phone	1
Don't answer	34
Question 21: How would you rate the sound level at your company?	
Silent	0
Low	1
Medium	9
Loud	19
Very loud	14

6 DISCUSSION

6.1 Method

6.1.1 Subject selection

Today many production companies are depending on a small number of employers for financial reasons and to be profitable. This resulted in some trouble for us because it was difficult to find companies who had time to participate in our study. Several of the companies we visited used line production in the manufacturing, and since a shut down in the production process would create major problems we had too adjust our approach when we should pick up the test subjects from their place of work. We were almost always dependent on the presence of a substitute. The subject who had been tested should send up the next one and so on.

A question that came up in the beginning of this study was: How does hearing loss and cerumen effect the result? We thought that it shouldn't affect in a negative way because a possible hearing loss will affect both the occluded and open thresholds. In an article written by Alice Suter, Barry Lempert and John Franks (1990) the result indicates that hearing-impaired HPD wearers received slightly more attenuation than normal hearing HPD wearers at all frequencies using the REAT-method in laboratory environment. Their conclusion of the results provided support to the observations that HPDs are capable of providing as much attenuation to hearing-impaired wearers as do to normal hearing individuals (Suter, Lempert, Franks, 1990). This observation was done on earmuffs and there is no reason to assume differently for HPDs of insert type.
Twelfth subjects were rejected since their test result was unreliable because of a problem with the patient switch. The switch was replaced but there was no time to re-test these subjects.

6.1.2 Real-ear attenuation at threshold

A fundamental requirement of accurate REAT measurement is that the test room must be sufficiently quiet. This especially concerns REAT 'in sound field', since high ambient noise levels will tend to mask and hence, elevate the open threshold while leaving the occluded threshold unaffected. This reduction in threshold shift results in lower measured attenuation values (Berger, 1986).

We chose to use the headphone REAT-method. The main disadvantage is that only insert-type of HPDs can be tested. The method is however ideally suited to in-field measurement of HPDs to determine real-world performance since this method facilitates the use of actual HPD wearers as test subject (Berger, 1986).

A factor that contaminates REAT data is the masking of occluded threshold as an effect of physiological noise. This noise, which is vascular and/or muscular in origin, is primarily a low frequency phenomenon. The physiological noise is amplified due to the occlusion effect, which occurs when the ear is covered. This results in an amplification of 5 dB(SPL) at 125 Hz and therefore it will slightly overestimate the attenuation at low frequencies.

6.1.3 Test procedures

According to ISO 4869-1:1990(E) the test shall be performed at 63 Hz (optional), 125, 250, 500, 1000, 2000, 4000 and 8000 Hz. Some authors have reported data beyond these frequencies range and their result showed attenuation to be relatively constant below 125Hz (Berger, 1986) and based on work of Berger and Rowland (1989) the frequencies 3150 and 6300 Hz is omitted from our test.
We chose to exclude both 63 and 125 Hz. Exclusion of 125 Hz was made because the high risk of masking from both environmental noise in the test room and physiological noise. Even though headphone REAT is less sensitive to ambient noise since the headphones provide attenuation during both the open and occluded ear tests, we think that the reliability of this frequency is unpredictable.

If the subjects of any reason didn't wear their earplugs or if the earplugs were not properly in place, the subjects hearing receptors could have been exposed to too much noise. This can cause temporary threshold shift (TTS), which can be explained as a temporary increase in hearing threshold ($SAME_{(a)}$, 1990). This is a reversible phenomenon and to avoid a recovery from this under the test, which can affect the test result, the subjects were left in relative quietness for two minutes.

Twelfth test subjects, in spite of the instructions, still re-adjusted or pulled out their HPDs before the test. This could have an effect of the results reliability since the subject may be more careful with the re-insertion. However, they insert the HPDs in a quiet room. The silence makes it difficult for the subject to know if the HPDs are in the right position. The results show no differences between those twelfth subjects and the other subjects who had not re-adjusted their HPDs. What is the cause of their action and could we have prevented this? This study is depending on the test subject's participation and although we instructed the subjects several times not to adjust their HPDs, people sometimes acts irrationally and there is nothing we can do about it.

Due to the nature of the subject panel and limitations of their time and availability, no repeated measurements were possible.
The subjects were, if they wanted, informed about their test result and advice was given to improve the fit of their HPD.

6.2 Accuracy of measurement

The REAT-method works essentially the same way as the Békésy-method. This measurement method does not take into consideration the accuracy in the test subjects' answers. Some persons want to be certain that they really do hear a sound and some are more affected then others of internal noise. Likewise can both tinnitus and large asymmetry between the ear affect the test result. Tinnitus can make it harder for the test subject to hear the presented sound, especially at high frequencies and if the sound is continuous. Large level variations in the test result may indicate that the test subject has tinnitus and the test results should be careful interpreted if there is asymmetry present (SAME $_{(a)}$, 1990).

The size of the dB changes (in level) has an impact on the accuracy of the test result. Originally when Békésy audiometry was introduced the dB changes, in levels, were 2 dB. On the equipment in use today it's possible to make the dB-level changes in smaller steps (SAME $_{(a)}$, 1990). In our study the dB-level changes were made in steps of 1.5 dB. The presented sound level swung around the subjects' tone threshold six times at each frequency. The FitCheck also automatically will start a re-test if the subjects' answers are too inconsistent.

The environment in which the measurement is being conducted is very important to achieve reliable results. If the background noise is too high it will mask the test sound and this leads to an underestimation of the attenuation. The rooms in which our measurements were conducted were not always optimal because they weren't soundproofed. Therefore it is essential to measure the sound level of the background noise (SAME $_{(a)}$, 1990). Our background noises were measured to approximately 53-55 dB(A) and 71-74 dB(C).

The equipment needs to be calibrated from time to time. Portable equipment, in daily use, need to be calibrated more often than ordinary equipment because it may be exposed to rough handling or suchlike. This can have an impact on the electronics (SAME $_{(a)}$, 1990).

6.3 Questionnaire

The English version of the questionnaire is just a translation of the Swedish version and has therefore not been used.

Many questions in our questionnaire (Appendix H (Swedish) and I (English) are based on the test subjects own judgement such as if they have a normal hearing. Almost everybody marked the 'normal-box' except those who had a known hearing loss.

Most of the test subjects in our study had used HPD for more than ten years.
The main reason for using HPDs was that they thought it was impossible to work without them due to high sound levels. There were also a few of the test subject that were in their early twenties. These subjects have been working for six months and have been using earplugs from day one. A reason for removing the earplugs was when they were on their break/breaks. Noticeable is that there was one subject who kept the earplugs inserted during the breaks.

The question about their environmental sound level is also a matter of judgement. One person may estimate the sound level as loud when another thinks it is very loud. It is clear that it is difficult to estimate the surrounding sound level (fig. 10). Most variations of the self-estimated sound levels can be seen in the region of 85 dB(A). This result shows that the HPD wearer by himself cannot determine whether the sound level is at a dangerous level or not. It is noticeable that all the subjects that have estimated their sound environment to be loud or very loud use their earplugs 6-8 hours a day while the subjects that estimated the sound to be medium use the earplugs about four hours a day.

Worth mentioning is that approximately 25% of the participating subjects have some kind of tinnitus. In recent years this is a problem that has been given more attention. All information about how high-level sounds make tinnitus worse motivates the use of HPDs.

The subjects answer to the question 19, in what ways the test subject would like to improve the earplugs, gave us a few suggestions such as: less itchy and warm, earplugs in size small, better possibility to hear a telephone call and earplugs that are easier to shape.

The HPDs are manufactured in different materials and quality. If the wearers have the opportunity to try different sizes and several designs they will have a chance to find and choose earplugs that are comfortable and fit well.

6.4 Result discussion

This study is based on a limited number of test subjects. The knowledge that they were to be tested may be enough for them to wear the earplugs somewhat better than usual but we don't think that this is the case. Except for one subject, who nowadays uses earmuffs, all subjects are provided with sufficient attenuation.

When the attenuation is put in relation to the sound level one can see that the attenuation appears to increase with the sound level (fig. 7). Our results imply that those exposed to high sound levels are more careful when applying their earplugs, which corresponds to our hypothesis that was: Users who work in a noisy environment would be more cautious to how the HPDs are used than HPD wearers who work in a less noisy environment.

Our results also show that 33 out of 43 (77%), of our test subjects are overprotected (fig. 6). According to table 1, all subjects are overprotected if the level at the ear is below 70 dB(A). Even though some of our test subjects received less than 10 dB of attenuation they still got sufficient protection for the sound environment they work in. The result shown in fig. 8 indicates that the total attenuation provided to the hearing impaired is not different than for the subjects with normal hearing. However, an overprotected hearing-impaired HPD wearer

may have less residual auditory perception and this can leave them at great risk of missing auditory cues for equipment or co-workers and can put them at greater risk of industrial accidents (Hager, 2002).

A high percentage of the subject's work-areas have A-weighted noise exposure levels at or below 85 dB(A) (fig. 9). AFS:1992 recommend that hearing protectors should be used if the sound level is over 85 dB(A). It is not forbidden to have sound levels over 85 dB(A). What is said in the law is that the employer should provide hearing protection and has a hearing conservation program to active reduce the surrounding sound level.

The actual surrounding sound levels in our study were between 67 and 104 dB(A). Since 28 out of 43 (65%) work in sound levels below 85 dB(A) and 24 subjects have an attenuation between 12-39 dB, it is evident that most test subjects are getting to much attenuation. Therefore it is not critical to attain the highest level of attenuation to protect the subject. However, some people can risk hearing loss at levels around 80-85 dB(A) since the individual of the susceptibility. Therefore it is important to have such an attenuation that the sound level at the ear is below 80 dB(A)(Neuberger, Körpert, Raber, Schwertz, Bauer, 1992.) Only three subjects in our study have over 80 dB(A) at the ear as shown in figure 6.

The right way to get reasonable results is to look at the attenuation values and compare them to the environmental sound levels at the workplace. Results in other studies indicate that the HPD wearer gets insufficient attenuation using earplugs in real-world situations. The reason for this can be that other studies haven't compared the obtained attenuation values to the sound levels the wearers were exposed to.

A person who works in a sound level at about 85 dB (A) does not need 39 dB of attenuation (the highest value in our study). Such attenuation will affect the ability to communicate and this was a common reason for not using HPDs, see question 9 (Appendix H (Swedish) and I (English)).
The feeling of being 'cut off' from their environment lowers the motivation to use HPDs.
The logical thing to do when you cannot hear what is being said to you is to remove the plug. If this is repeated in a noisy industrial environment it can affect the hearing sense. If they are removed even for a short period of time it can severely damage your hearing sense. This damage is irreversible, and will result in a permanent hearing loss. A person who has to remove his plugs on a daily basis can therefore after a few years notice that he is having a hard time of hearing, even though he or she has been using hearing protection.

Those who seem to obtain much greater protection than needed from standard earplugs and those who work in borderline of 85 dB(A) could perhaps use earplugs specially designed to give less attenuation. There should be an earplug on the market that only provides an attenuation of approximately 10 dB. This is not possible in practice since such earplug may have less than 12 dB attenuation at 1000-8000 Hz. Such a device is not to been sold as HPD in Europe according to EN 352-1:1993. Even for these relatively low noise exposures levels there can still be the problem of attaining sufficient attenuation if the earplugs are worn incorrectly, as for one of our test subjects. This particular subject, marked in all of our figures with a larger symbol, is exposed to 86 dB(A) but is provided a total attenuation of -5 dB. The subject is an experienced HPD wearer who previously used earplugs but has now chosen to wear earmuffs instead.

A negative value of the attenuation means that the subject actually gets an amplification of the sound level. More sound will reach the eardrum when using earplugs. This is a common phenomenon at low frequencies if the earplug is not proper fitted. The negative attenuation is most evident at 250 Hz.

The HPD packages are labelled with a SNR value. Can we rely upon these values when we choose a HPD? SNR calculations based on the attenuation of the individuals in this study, varies between 1 and 42. The SNR value given by the manufacturers is in the region of 25-32. Initially the SNR value functions as a guide when choosing HPDs, but we cannot only rely on the SNR value. The reason for this is the many different fitting techniques.

Figure 3 illustrates the attenuation at 250 Hz. This frequency shows how well the HPD fit. The sound will travel through this passage and affect the earplugs attenuation. To get the best insertion it is very important to pull the outer ear upwards with the opposite hand while inserting the earplug. The expandable foam plugs should be rolled between the fingers and this is not always done correctly. To prevent the outward slippage the foam plug should be held in place while expanding.

It is apparent that the reusable plugs attenuate better at 250 Hz (fig 3). All the reusable plugs provide more than 10 dB of attenuation. One reason for this may be that the reusable plugs are easier to insert than the foam plugs. When reusable plugs are properly inserted the subject should feel like there is a seal and tightness between the ear and the plug. Unfortunately, there is a strong relationship between the tightness of fit and discomfort for most earplugs.
When reusable plugs and expandable foam plugs are compared one should notice that the reusable plugs are more hygienic since less hand contact is needed directly on the earplug. When rolling the foam plug it can be contaminated e.g. by oil. Foam plugs must be exchanged when soiled. A person who has reusable plugs can easily wash those if necessary.

During our study it soon became clear to us that not all the HPD wearers were pleased with the HPD that they used. Some subjects complained over the fact that the HPDs weren't comfortable. Another complaint, regarding both the foam and the reusable plugs, was that they are often difficult to insert. To our surprise, at four out of five companies the subjects only had one sort of HPD to choose from and these earplugs were only available in one size. One size of HPDs does not fit each individual due to anatomic differences and the size is very important in order to get good attenuation. If the HPD is too big it will cause pain in the HPD wearers' ear and if it is too small the HPD wearer wouldn't get enough attenuation. This is one reason for having a large variety of HPDs to choose from. Each individual should have the opportunity to try different sizes and several designs so that they can choose the one that is comfortable and fits well. When the HPD wearer is fitted with proper HPDs they will be motivated to use them.

Only three persons in this study have had help when they chose their HPDs. All the others had chosen what they were offered by the company.
We think that it is important that the wearers do get some help from someone who is competent on this matter and it is very important to help those who never used HPD before. Even those who have been working for a longer period need some guidance occasionally because it is well known that users with long-term experience of HPDs do not regularly read or necessarily follow the insertion instructions (Lempert and Edwards, 1983).

All employees must have the knowledge about what happens if they are exposed to high-level noises even for a short period of time. To be able to give this kind of 'service' to the employees, the changes have to come from inside the company. If the management has an effective hearing conservation program and are well informed on the subject of hearing and prevention of hearing loss, they can influence their employees to protect themselves.

There should of course be other things done to prevent hearing losses, e.g. trying to keep the sound environment at safe levels. The opportunity of regular hearing control should be offered. This problem does concern everyone who is working in the company.
There is a lot that can be done. It takes some work but it is in everyone's interests.

7 CONCLUSION

The purpose of this study is to see how much attenuation the HPD wearer gets using an insert-type HPD at work in real-world situations and to see if there is a relation between how the wearer puts their HPDs in place and the surrounding noise level.

When the attenuation is put in relation to the sound level our results show that 33 out 43 of our test subjects are overprotected because the sound level becomes less than 70 dB(A) at the ear when using HPD.

Our results imply that those exposed to high sound levels are more careful when applying their earplugs, which corresponds to our hypothesis that was: Users who work in a noisy environment would be more cautious how the HPDs are used than HPD wearers who work in less noisy environment. The results also show that the HPD wearer himself cannot determine whether the sound level is at a dangerous level or not.

There seems to be a need for an earplug on the market that only provides an attenuation of approximately 10 dB for those who seem to obtain much greater protection than needed from standard earplugs and those who work in a sound level near 85 dB(A).

Each individual should have the opportunity to try different sizes and several designs so they can choose an earplug that is comfortable and has the best fit. When the HPD wearer is fitted with proper HPDs they will be motivated to use them.

We think that it is important for manufacturers to design easy-to-use products. The HPDs must be made of relatively soft and compliant material. This is necessary for user comfort, safety and for the purpose of achieving a proper seal against the ear canal without leaving the ear canal sore.

The design of the instructions is vital since only 3 out of 43 of the participated subjects have been educated about proper use and insertion technique. The manufacturer should provide clear and precise fitting instructions together with illustrations.

REFERENCES

Arbetarskyddsstyrelsens författningssamling, AFS 1992:10 Buller

ANSI (1974), ANSI S3.19-1974 (ASA STD 1-1975), *American National Standards method for the measurement of real-ear protection of hearing protectors and physical attenuation of earmuffs*, American National Standards Institute, New York.

Arlinger, S., Hagerman, B., Hellström, P-E., Ivarsson, A., Ivarsson, U., Jakobson, B., Johansson, B., Lundin, R., Nilsson, L., Olsson, H., Persson, L., Poulsen, T., Starck, J., Svensson, E., (1997), *Med örat i centrum, förebyggande hörselvård.*, Falköping.

Berger, E.H., (1986), Methods of measuring the attenuation of hearing protection devices, *J. Acoust. Soc. Am. 79(6)*, 1655-1687.

Berger, E.H., (1988), Can real-world hearing protector attenuation be estimated using laboratory data?, *Sound and Vibration 22(12)*, 26-31.

Berger, E.H., Rowland, L.D., (1989), Is it necessary to measure hearing protector attenuation at 3.15 and 6.1 kHz?, *J. Acoust. Soc. Am. 85(4)*, 1590-1594

Berger, E.H., Franks, J.R., Behar, A., Casali, J.G., Dixon-Ernst, C., Kieper, R.W., Merry, C.J., Mozo, B.T., Nixon, C.W., Doswell Royster, J., Royster, L.H., (1998), Development of a new standard laboratory protocol for estimating the field attenuation of hearing protection devices. Part III. The validity of using subject-fit data., *J. Acoust. Soc. Am. 103(2)*, 665-672

Doswell Royster, J., Berger, E.H., Merry, C.J., Nixon, C.W., Franks, J.R., Behar, A., Casali, J.G., Dixon-Ernst, C., Kieper, R.W., Mozo, B.T., Ohlin, D., Royster, L.H., (1996), Development of a new standard laboratory protocol for estimating the field attenuation of hearing protection devices. Part I. Research of Working Group 11, Accredited Standards Committee S12, Noise, *J. Acoust. Soc. Am. 99(3)*, 1506-1526.

Edwards, R.G., Hauser, W.P., Moiseev, N.A., Broderson, A.B., Green, W.W., (1978), Effectiveness of earplugs as worn in the workplace, *Sound and Vibration 12(1)*, 12-22.

EN 352-1:1993, Hearing protectors-Safety requirements and testing-Part 1: Ear-muffs

EN 458:1993 Hearing protectors – Recommendations for selection, use, care and maintenance. Guidance document

Hager, L., (2002) Hearing protection: Prevention is the answer, www.audiologyonline.com

Harvey, D.G., (1981), A method to increase the effectiveness of ear protection, *Sound and Vibration 15(5)*, 24-27.

ISO (1990), ISO 4869-1:1990(E), Acoustics – Hearing protectors – Part I: Subject method for the measurement of sound attenuation, International Organization for Standardization, Geneva, Switzerland.

Lempert, B.L., Edwards, R.G., (1983), Field investigations of noise reduction afforded by insert-type hearing protectors, *Am. Ind. Hyg. Assoc. J 44(12),* 894-902.

Merry, C.J., Sizemore, C.W., Franks, J.R., (1992), The effect of fitting procedure on hearing protector attenuation, *Ear and Hearing 13(1),* 11-18.

Michael, K., Byrne, D.C., (2002), Current state of insert-type hearing protector fit-testing: follow-on measurements in the steel industry and fit-testing in a mobile environment, *NHCA Spectrum 19(1),* 14-16.

Michael, K., (1999), Measurement of insert-type hearing protector attenuation on the end-user: A practical alternative to relying on the NRR, *NHCA Spectrum 16(4).*

Neuberger, M., Körpert, K., Raber, A., Schwertz, F., Bauer, P., (1992), *Hearing loss from industrial noise, head injury and ear disease. A multivariate analysis on audiometric examinations of 110 647 workers,* Audiology vol. 31 no 1, 45-57.

Ohlin, D., Michael, P.L., Bienvenue, G.R., Rosenberg, D.M., (1981), An earplug insertion and seating device, *Sound and Vibration 15(1),* 22-25.

Padilla, M., (1976), Ear plug performance in industrial field conditions, *Sound and Vibration 10(5),* 33- 36.

$SAME_{(a)}$: Almqvist, B., Arlinger, S., Bergholtz, L., Bjuréus, E., Ekström, L., Harris, S., Holmberg, M., Leijon, A., Lennart, I., Rosenhall, U., Wikström, I., (1990), *Handbok i hörselmätning,* SAME och LIC Förlag.

Suter, A.H., Lempert, B.L., Franks, J.R., (1990), Real-ear attenuation of earmuffs in normal-hearing and hearing-impaired individuals, *J Acoust. Soc. Am. 87(5),* 2114-2117.

APPENDIX A

Hej!

Vi är två studenter från Lunds Universitet som läser på audionomutbildningen.
Vår utbildning är inriktad på hörsel, röst, tal och språk. Detta är en fyraårig mastersutbildning som sista terminen avslutas med att vi studenter skriver en magisteravhandling på 20 poäng. Vi gör denna avhandling i samarbete med Bacou-Dalloz som bland annat tillverkar Bilsom hörselskydd.

I vår magisteravhandling kommer vi att undersöka hur hörselproppars dämpning ser ut i verkligheten. Det dämpvärde som är angivet på hörselproppens förpackning är uppmätt i laboratoriemiljö och vi vill se hur det uppmätta värdet förhåller sig till hörselskyddets dämpning i verkligheten. Vi kommer även att mäta ljudnivån på den plats där testpersonen arbetar för att se om ljudnivån kan ha någon påverkan på hur hörselskyddet används.

Vi kommer att använda oss av automatisk registrering av tontröskeln. Testtonens styrka styrs av testpersonen. När testpersonen hör tonen och anger det genom att trycka på en knapp, minska tonstyrkan automatiskt. När tonen inte hörs längre släpper testpersonen knappen och tonstyrkan ökar
Mätningen kommer att utföras två gånger. En gång med hörselskyddet i öronen och en gång utan hörselskydd. Genom detta får vi fram hur mycket hörselskyddet dämpar i testpersonens öra. Mätningen beräknas ta cirka tjugo minuter per person.

Vi använder oss av en portabel mätutrustning vilket gör att vi kan utföra mätningen på plats på ert företag i ett normal tyst rum.

Denna mätning är ingen kontroll av hur duktig varje enskild testperson är på att använda sina hörselskydd utan en kontroll av hörselskyddets dämpning. Vi vill veta hur dämpningen ser ut under en normal arbetsdag utan att lägga några värderingar på vad som är bra eller dåligt. Om inte testpersonen uppträder "som vanligt" blir undersökningen meningslös.
Arbetsgivaren kommer naturligtvis inte få några individuella resultat, utan bara den slutgiltiga sammanställningen.

Vi hoppas att er personal är intresserad av att delta anonymt i denna undersökning. Kontakta oss gärna för ytterligare information.

Med vänlig hälsning

Linda Sandberg
040-974272
0709-503 805
linda76.sandberg@swipnet.se

Jenny Lindqvist
046-138706
0733-248861
ynnej47@hotmail.com

Translation of Appendix A **APPENDIX B**

Dear Sirs,

We are two students from the University of Lund who are studying audiology, a program focusing on hearing, voice, speech and language. It is a four-year program and during the last semester we are writing a thesis, which we do in co-operation with Bacou-Dalloz who among other things produce Bilsom hearing protecting devices.

In our thesis we will investigate the true effects of earplug attenuation in the real-world. The attenuation values printed on the product packages are measured in a laboratory and we want to determine how these values in real-world relate to the earplug attenuation. We will also measure the sound level where the test subject works, to see if the sound environment may have an effect on how the earplugs are worn.

We will use automatic registration of the subject's tone threshold. The test subject controls the test sound. When the sound is heard and a button pressed the level of the sound will automatically decrease. When the sound no longer is detectable the subject will let go of the button and the level of the sound will increase. The measuring will be done twice. During the first test the subject is wearing the earplugs but not the second time. This way we can register the attenuation effect by the earplugs valid for the respective test person. The measuring will take about 20 minutes.

Using portable equipment we could do this measuring at your company. We do need however access to a quite room.

These measurements are not a check on how good the individuals are at using their hearing protectors but a control of the hearing attenuation by these protectors. We would like to register the attenuation values during a normal workday without assessing what is good or bad. If a test person don't act in a normal way then this study will be useless.

The company will not have access to the individual test results just a final and general report.

We hope that the staff in your company would be interested in participating anonymously in our study.

Please do contact us for further information

Sincerely

Linda Sandberg Jenny Lindqvist

Var vänlig och rör inte eller justera dina hörselskydd förrän mätningen är slutförd.

Denna mätning är ingen kontroll av hur duktig varje enskild testperson är på att använda sina hörselskydd utan en kontroll av hörselskyddets dämpning. Vi vill veta hur dämpningen ser ut under en normal arbetsdag utan att lägga några värderingar på vad som är bra eller dåligt. Om inte du som testperson uppträder "som vanligt" blir undersökningen meningslös. Arbetsgivaren kommer naturligtvis inte få några individuella resultat, utan bara den slutgiltiga sammanställningen.

Testinstruktioner

Syftet med denna mätning är att uppskatta dämpningen som du uppnår när du använder dina hörselskydd i en miljö med hög ljudnivå.

Vi vill att du innan mätningen börjar fyller i den enkät, om din användning av hörselskydd, som du har fått.

Vid själva mätningen kommer vi att använda oss av automatisk registrering av tontröskeln där testtonens styrka styrs av dig. Du kommer att få ett par hörtelefoner på dig och en knapp att trycka på.

- Du kommer att höra en svag **pulserande** ton.
- Så länge tonen hörs ska du hålla knappen intryckt.
- När tonen inte hörs längre ska du genast släppa knappen.
- Och åter trycka in den när tonen börjar höras.
- Tonen kommer att börja i basen och bli ljusare och ljusare.

Mätningen kommer att utföras två gånger. En gång med proppar i öronen och en gång utan proppar. Genom detta får vi fram hur mycket propparna dämpar i ditt öra. Mätningen beräknas ta cirka femton minuter.

Tack för din medverkan i vår undersökning.

Linda Sandberg & Jenny Lindqvist

Translation of Appendix C **APPENDIX D**

Please, do not touch or adjust your hearing protectors before the measuring is completed!

This measurement is not a control of how good individuals are at using their hearing protectors. It is just a control of the attenuation of the hearing protectors.

We would like to know what the attenuation is during a normal workday without putting any values to what is good or bad. If you as a test subject don't act in a normal way the study will be useless.
The company will not have access to the individual test results, just the final report.

The test instructions

The purpose of this study is to estimate the attenuation you will receive while using your hearing protectors in a noisy environment.

Before the measuring starts we would like you to fill out the questioner about your hearing protectors, which you have been given.

During the measuring there will be an automatic registration of the tone threshold and you will control the test sound.

You will have a pair of headphones on and a button to press.

1. You will hear a low pulsating sound.
2. Press the button when you hear the sound.
3. When the sound can no longer be heard then let immediately go of the button!
4. Press the button again when you again can hear the sound.
5. The sound will start in bass and get higher and higher.

The measuring will be conducted twice, firstly with the hearing protectors in the ears and then without the hearing protectors. By doing this we will get data on how much attenuation you will receive when you are wearing the protectors.

The measuring will take about 15 minutes.

Thank you for your co-operation and participation in our study.

Linda Sandberg and Jenny Lindqvist

APPENDIX E

Frågeformulär angående dina hörselskydd.

Ni deltar naturligtvis anonymt, men för att underlätta vårt arbete att sammanställa mätvärden och svaren från frågeformuläret önskar vi att ni fyller i nedanstående uppgifter. Dessa uppgifter kommer inte att tas upp i den slutliga rapporten.

Dina initialer:_____
Födelseår + månad:_____

1. **Hur uppfattar du din hörsel?**

   Normal ☐ Lätt hörselskada ☐ Svår hörselskada ☐

   Annat:_____

2. **Har du någon form av öronsus eller tinnitus?**

   Ja ☐ Nej ☐

   Annat:_____

3. **Vilken sorts proppar använder du?**

   Skumpropp ☐ Dunpropp ☐ Flergångspropp ☐

   Annat:_____

4. **Om möjligt ange tillverkare samt modell på dina proppar.**

   Ex. Bilsom 303S

   _____

5. **Hur länge har du använt denna typ av proppar med avseende på fabrikat och modell?**

   1 mån ☐ 6 mån ☐ 1 år ☐ 2 år ☐ 3 år ☐ 4 år ☐
   mer än 5 år ☐

   Annat:_____

6. Hur länge har du totalt sätt använt hörselskydd?

1 mån ☐ 6mån ☐ 1år ☐ 2 år ☐ 5 år ☐

mer än 10 år ☐

Annat:_____

7. Hur mycket använder du dina proppar totalt per dag?

2 timmar ☐ 4 timmar ☐ 6 timmar ☐ hela dagen ☐

Annat:_____

8. Hur många gånger tar du ur och sätter i dina proppar per dag?

1 gång ☐ 2 ggr ☐ 3ggr ☐ 4ggr ☐ mer än 5ggr ☐

Annat:_____

9. Av vilken anledning tar du propparna ur öronen?

Komfort: Varm, svettig ☐ Klåda ☐ Ont, obehag ☐

Rast ☐ Vid kommunikation ☐

Annat:_____

10. Hur har du valt dina proppar vad beträffar typ och storlek?

	Typ	Storlek
Har tagit vad företaget erbjöd	☐	☐
Har provat olika sorter och själv valt det som satt bäst	☐	☐
Har fått personlig hjälp vid val av proppar	☐	☐

Annat:_____

11. Om du har fått personlig hjälp med ditt val av proppar. Vem fanns till din hjälp?

Förestagssköterska ☐
Personal på ditt företag ☐

Annat:_____

12. Hur många varianter av proppar hade du att välja mellan?

1 ☐ 2 ☐ 3 ☐ 4 ☐ fler än 5 ☐

Annat:_____

13. Har du fått någon utbildning på att sätta i dina proppar?

1 gång ☐ 2 ggr ☐ 3 ggr ☐ Aldrig ☐

Annat:_____

14. **Har du läst isättningsinstruktionerna på förpackningen?**

Ja ☐ Nej ☐

15. Om svar ja, följer du instruktionerna?

Ja ☐ Nej ☐

16. Hur ofta tar du nya proppar?

1 gång/ dag ☐ 2 ggr/ dag ☐ Varannan dag ☐

1 gång/ vecka ☐ 2 ggr/ vecka ☐ 1 gång/ månad ☐

Annat:_____

17. Hur tycker du att dina proppar fungerar med avseende på dämpningen?

Mycket bra ☐ Bra ☐ Dåligt ☐ Mycket dåligt ☐

Annat:_____

18. Hur upplever du komforten på dina proppar?

Mycket bra ☐ Bra ☐ Dåligt ☐ Mycket dåligt ☐

Annat:_____

19. I vilket avseende önskar du att dina proppar vore bättre med tanke på komforten?

_____

_____

_____

20. Hur ser din arbetsdag ut?

Står på samma plats ☐ Roterar plats: 1gång ☐ 2ggr ☐ 3ggr ☐

Annat:_____

21. Hur uppskattar du att ljudmiljö generellt är på ditt arbete?

Tyst ☐ Låg ☐ Medel ☐ Hög ☐ Mycket hög ☐

Annat:_____

Tack för din medverkan!!!!
Linda & Jenny

Questionnaire regarding your hearing protectors

You are participating anonymously but to make our work easier when we compare the measurements and the answers from the questionnaire we would like you to please answer the following questions. These details won't be taken into the final rapport.

Your initials: _____
Birth year + month: _____

1. How do you estimate your hearing?

Normal☐ Mild hearing impairment☐ Sever hearing impairment ☐

Other:_____

2. Do you suffer from tinnitus?

Yes ☐ No ☐

Other:_____

3. What kind of earplugs do you use?

Foam ☐ Down ☐ Reusable ☐

Othert:_____

4. Name the manufacture, if possible

Ex. Bilsom 303S

_____

5. How long have you been using this kind of earplug considering manufacture and model?

1 month ☐ 6 month ☐ 1 year ☐ 2 years ☐ 3 years ☐ 4 years ☐
More then 5 years
Other:_____

6. How long have you been using hearing protectors in all?

1-month ☐ 6month ☐ 1year ☐ 2 years ☐ 5 years ☐

More then 10 years ☐

Other: _____

7. How long do you use your earplugs per day?

2 hours☐ 4 hours ☐ 6 hours ☐ entire day ☐

Other: _____

8. How many times do you remove your earplugs per day?

1 time ☐ 2 times ☐ 3times ☐ 4times ☐ more then 5 times ☐

Other: _____

9. Why do you remove your earplugs?

Comfort: Warm, sweaty ☐ Itch ☐ Pain, uncomfortable ☐

Break ☐ Communication☐

Other: _____

10. How did you choose your earplugs?

	Model	Size
I use what the company offered	☐	☐
I tried different models	☐	☐
I got help when choosing earplugs	☐	☐

Other: _____

11. If you got help when choosing earplugs, who helped you?

Company nurse ☐

Personnel at your company ☐

Other: _____

12. How many different kinds of earplugs do you have to choose from?

1 □ 2 □ 3 □ 4 □ more then 5□

Other: _____

13. Have you got any training on how to insert your earplugs?

1 time □ 2 times □ 3 times □ Never □

Other: _____

14. Have you read the instructions on how to insert the earplugs?

Yes □ No □

15. If you answered yes, do you follow the instructions?

Yes □ No □

16. How often do you take new earplugs?

1 time/day □ 2 times/day □ every other day□

1 time/ week □ 2-times/ week □ 1-time/ month □

Other: _____

17. How do you think your earplugs attenuate?

Very good □ Good □ Bad □ Very bad □

Other: _____

18. How would you estimate the comfort on your plugs?

Very good □ Good □ Bad □ Very bad □

Other: _____

19. In what ways would you like your plugs to improve?

_____

_____

20. What's a typical workday like for you?

Same place all day ☐ Rotating: 1time ☐ 2times ☐ 3times ☐

Other:_____

21. How would you rate the sound level at your company?

Silent ☐ Low ☐ Medium ☐ Loud ☐ Very loud ☐

Other:_____

Thank you for your co-operation!!!
Linda & Jenny

Rawdata

Subject	Sex	Earplug	250	500	1000	2000	4000	8000	X	Tot. Atten., dB	Sound level at the ear, dB(A)	Means dB(A)	Means dB(C)
1	m	Foam	18,7	22	25,1	35	34,6	37,3	ovp	22	63	84,7	93,7
2	m	Foam	9,1	10,4	23	28,7	25,4	33,9	acc	12	73	84,7	93,7
3	m	Foam	17,3	22,6	22,8	32	35,4	29,3	ovp	23	64	87,4	91,9
5	m	Foam	19,4	20,1	24,3	38	38,1	20,1	ovp	23	52	75,3	79,1
6	m	Foam	-8,5	-4,7	-0,7	1,3	9,4	9,7	ins	-5	91	86,1	95,4
7	m	Foam	21,2	24,4	24,2	33,7	42,1	31,9	ovp	25	50	75,3	79,1
8	m	Foam	5,3	7,2	19,8	29,3	30,5	24,4	ovp	12	65	76,8	80,7
9	m	Foam	30,3	35,6	32	40,5	39,2	49,8	ovp	33	52	84,7	93,7
10	m	Foam	18,3	28,9	28,6	27,8	44,3	40,2	ovp	23	63	86,1	95,4
11	m	Foam	21,1	29,2	26	30,6	43,8	44,6	ovp	24	61	84,7	93,7
13	m	Foam	29,4	32,3	29,6	41,9	48,1	44,5	ovp	32	69	101,3	103,7
17	m	Foam	19,8	25,3	24,5	32,5	37,9	36,2	good	29	75	103,7	104,1
18	m	Foam	23,8	28,3	26	34,1	39,1	22,7	acc	28	73	101,2	103,2
19	m	Foam	27,8	27,2	34,8	44,4	43,2	34,8	ovp	32	69	101,2	103,2
20[1]	**m**	**Foam**	**12,7**	**18**	**23,1**	**26,9**	**42,4**	**41,8**	**acc**	**20**	**81**	**101,3**	**103,7**
21	**m**	**Foam**	**24,6**	**29**	**28,9**	**36,7**	**46,2**	**49,3**	**acc**	**30**	**71**	**101,2**	**103,2**
24	f	Foam	28,2	39,5	36	35	47,1	37,9	ovp	35	44	79,0	82,8
25	**m**	**Foam**	**23,9**	**28,8**	**32,8**	**36,3**	**46**	**40**	**ovp**	**31**	**52**	**82,9**	**86,0**
26	**f**	**Foam**	**17,1**	**24,7**	**35,6**	**33,3**	**28,7**	**38,7**	**ovp**	**26**	**57**	**82,9**	**86,0**
27	**m**	**Foam**	**19,4**	**18,9**	**25,4**	**33,3**	**41,2**	**38,5**	**ovp**	**24**	**59**	**82,9**	**86,0**
29	f	Reusable	18,2	21,1	16,3	22,5	36,4	55,9	ovp	19	64	82,7	84,9
31	f	Reusable	19,5	17,4	17,5	27,5	22	29,8	ovp	22	63	84,6	84,1
32	f	Reusable	12,9	9,9	12,7	26,2	28,3	20	ovp	19	66	84,6	84,1
33	f	Reusable	47,1	58	48,2	35,5	53,5	47,8	ovp	39	46	84,6	84,1
34	m	Reusable	24,8	24,5	17,3	24,6	25,5	23,8	ovp	20	65	85,3	87,4
35	**m**	**Reusable**	**35,4**	**36,7**	**30,3**	**42,7**	**40,7**	**37,7**	**ovp**	**33**	**52**	**85,3**	**87,4**
36	**m**	**Reusable**	**21,5**	**18**	**19,5**	**29,8**	**26,6**	**45,4**	**ovp**	**24**	**61**	**84,6**	**84,8**
37	m	Reusable	19,9	20,3	16,6	17,1	24,9	36	ovp	19	65	84,3	89,7
38	m	Reusable	44,1	29,3	28,6	26,8	23,7	45,5	ovp	29	55	83,8	88,4
39	f	Foam	4,9	11,4	18,5	34,9	34,8	38,7	ovp	15	67	82,1	84,3
40	f	Reusable	25,1	17,4	23,6	30,4	34,4	22,7	ovp	22	60	82,1	84,3
44	**m**	**Foam**	**17,5**	**25,3**	**29,4**	**29,9**	**32,3**	**36**	**ovp**	**23**	**63**	**86,4**	**93**
45	**m**	**Foam**	**14,2**	**17,3**	**25,3**	**33,8**	**36,7**	**33,1**	**acc**	**21**	**83**	**104,3**	**108,2**
46	**m**	**Reusable**	**20,7**	**20,2**	**24,8**	**28,9**	**27,4**	**19,8**	**ovp**	**24**	**52**	**75,7**	**79,7**
47	**m**	**Foam**	**-2,8**	**1,2**	**-3,5**	**-2,2**	**7,8**	**6,4**	**acc**	**-2**	**74**	**72**	**77,6**
48	m	Foam	-7,3	-8,1	4,5	20,5	19,1	27,9	acc	-2	74	71,8	75,3
49	m	Foam	-7,5	-3,7	7,7	12,5	23,5	14,1	acc	4	70	73,9	74,7
50	m	Reusable	18,3	21,3	23,9	31	33,5	31,2	ovp	26	51	76,9	77,7
51	m	Reusable	26,2	25,5	31,5	34,2	32	39,4	ovp	31	43	73,9	74,7
52	m	Foam	16,2	23,7	25,1	28,9	34	43,6	ovp	21	46	66,8	75,1
54	m	Foam	15,6	16,6	20,2	31,8	25,3	20,1	ovp	21	65	85,7	86,8
55	m	Foam	24,5	21,6	23,3	32,3	36,8	39,6	ovp	28	63	91,4	91,3
56	**f**	**Foam**	**25,6**	**26**	**23,1**	**30,5**	**39,1**	**44,8**	**ovp**	**25**	**55**	**79,7**	**83,3**

[1] The subjects marked with bold text are those twelfth subjects who have re-adjusted their HPDs.

APPENDIX H

Svar på frågeformuläret, sammanfattning på svenska

1. Hur uppfattar du din hörsel?	
Normal	34
Lätt hörselskada	8
Svår hörselskada	0
Annat: vet ej	1
2. Har du någon form av öronsus eller tinnitus?	
Ja	9
Nej	32
Annat: ibland	2
3. Vilken sorts proppar använder du?	
Skumpropp	30
Dunpropp	0
Flergångspropp	13
4. Om möjligt ange tillverkare samt modell på dina proppar.	
Aearo Ear tracers	10
Aearo Ear classic	23
Aearo Ear express	3
Bilsom 303	2
Annat: Wurth, MSA, North	5
5. Hur länge har du använt denna typ av proppar med avseende på fabrikat och modell?	
1 månad	2
6 månader	4
1 år	4
2 år	2
3 år	6
4 år	1
mer än 5 år	22
Svarar ej	2
6. Hur läge har du totalt sätt använt hörselskydd?	
1 månad	0
6 månader	3
1 år	1
2 år	2
5 år	5
mer än 10 år	30
Svarar ej	0
Annat: 3 år, 7 år, 4år	2
7. Hur mycket använder du dina proppar totalt per dag?	
2 timmar	0
4 timmar	9
6 timmar	11
hela dagen	21
Svarar ej	1
Annat: Vid behov	1

8. Hur många gånger tar du ur och sätter i dina proppar per dag?	
1 gång	1
2 ggr	0
3 ggr	2
4 ggr	11
mer än 5 ggr	26
Annat: ofta	1
Svarar ej,	2
9. Av vilken anledning tar du propparna ur öronen?	
Varm, svettig	2
Klåda	5
Ont, obehag	2
Rast	39
Vid kommunikation	19
Annat: tar ej ur propparna	1
När jag inte vistas i bullrig miljö	3
Svarar ej	1
10. Hur har du valt dina proppar vad beträffar typ och storlek?	
Har tagit vad företaget erbjöd	24
Har provat olika sorter och själv valt det som satt bäst	15
Har fått personlig hjälp vid val av proppar	3
Svarar ej	1
11. Om du har fått personlig hjälp med ditt val av proppar. Vem fanns till din hjälp?	
Företagssköterskan	3
Personal på ditt företag	1
Annat: försäljare	0
12. Hur många varianter av proppar hade du att välja mellan?	
1 st	15
2 st	10
3 st	8
4 st	6
fler än 5	2
Svarar ej	2
13. Har du fått någon utbildning på att sätta i dina proppar?	
1 gång	6
2 ggr	0
3 ggr	1
Aldrig	36
Svarar ej	
14. Har du läst isättningsinstruktionerna på förpackningen?	
Ja	30
Nej	12
Svarar ej	1
15. Om svar ja, följer du instruktionerna?	
Ja	29
Nej	3
Svarar ej	1

16. Hur ofta tar du nya proppar?	
1 gång/dag	9
2 ggr/dag	13
Varannan dag	1
1 gång/vecka	4
2 ggr/vecka	1
1 gång/månad	5
Annat: tappat dem, gått i sönder, tvättar propparna, vid behov (flergångs)	7
efter varje rast (skum)	
Svarar ej	3
17. Hur tycker du att dina proppar fungerar med avseende på dämpningen?	
Mycket bra	15
Bra	26
Dåligt	2
Mycket dåligt	0
18. Hur upplever du komforten på dina proppar?	
Mycket bra	12
Bra	26
Dåligt	3
Mycket dåligt	1
Annat: sisådär (mellan bra & dåligt)	1
19. I vilket avseende önskar du att dina proppar vore bättre med tanke på komforten?	
Gör ont efter ett tag, spänner	2
Mindre varma	1
Mindre klåda	1
Mindre proppar skulle passa bättre	2
Ibland är de lite hårda och svåra att forma	1
Annan sorts propp med metall i	1
Bättre ljuddämpning, bättre möjlighet att höra telefonsamtal	1
Svarar ej	34
20. Hur ser din arbetsdag ut?	
Står på samma plats	21
Roterar plats:	
1 gång	1
2 ggr	0
3 ggr	4
Annat: lite hursomhelst, det olika, stort område	17
21. Hur uppskattar du att ljudmiljön generellt är på ditt arbete?	
Tyst	0
Låg	1
Medel	9
Hög	19
Mycket hög	14

Translation of Appendix H **APPENDIX I**

Answer to the questionnaire, a summary in English

1.How do you estimate your hearing?	
Normal	34
Mild hearing impairment	8
Sever hearing impairment	0
Other: Don't know	1
2. Do you suffer from tinnitus?	
Yes	9
No	32
Other: sometimes	2
3. What kind of earplugs do you use?	
Foam plugs	30
Down plugs	0
Reusable plugs	13
4. Name the manufacture, if possible.	
Aearo Ear classic	10
Aearo Ear tracers	23
Aearo Ear express	3
Bilsom 303	2
Other: Würth, MSA	5
5. How long have you been using this kind of earplug considering manufacture and model?	
1 month	2
6 month	4
1 year	4
2 years	2
3 years	6
4 years	1
more than 5 years	22
Don't answer	2
6. How long have you been using hearing protectors in all?	
1 month	0
6 month	3
1 year	1
2 years	2
5 years	5
more than 10 years	30
Don't answer	0
Other: 3 years, 4 years, 7 years	2
7. How long do you use earplugs per day?	
2 hours	0
4 hours	9
6 hours	11
all day	21
Don't answer	1
Other: when necessary	1

8. How many times do you remove your earplugs per day?	
1 time	1
2 times	0
3 times	2
4 times	11
more than 5 times	26
Other: often	1
Don't answer	2
9. Why do you remove your earplugs?	
Warm, sweaty	2
Itchy	5
Pain, uncomfortable	2
Break	39
Communication	19
Other: I don't remove them	1
When I am in a non noisy environment	3
Don't answer	1
10. How did you choose your earplugs?	
I use what the company offered	24
I tried different models	15
I got help choosing them	3
Don't answer	1
11. If you got help choosing earplugs, who helped you?	
Company nurse	3
Personnel at your company	1
Other: salesman	0
12. How many different kinds of earplugs do you have to choose from?	
1 model	15
2 models	10
3 models	8
4 models	6
more than 5	2
Don't answer	2
13. Have you got any training on how to insert the earplugs?	
1 time	6
2 times	0
3 times	1
Never	36
Don't answer	
14. Have you read the instructions on how to insert the earplug?	
Yes	30
No	12
Don't answer	1
15. If you answered yes, do you follow the instructions?	
Yes	29
No	3
Don't answer	1

16. How often do you take new earplugs?	
Once a day	9
Twice a day	13
Every second day	1
Once a week	4
Twice a week	1
Once a month	5
Other: when I lost them, when they break, when necessary (reusable plugs)	7
After every break (foam plugs)	
Don't answer	3
17. How do you think your earplugs attenuate?	
Very good	15
Good	26
Bad	2
Very bad	0
18. How would you estimate the comfort on your earplugs?	
Very good	12
Good	26
Bad	3
Very bad	1
Other: between good and bad	1
19. In what ways would you like to improve your earplugs?	
They hurt and feels tight	2
Less warm	1
Less itchy	1
Smaller plugs would fit better	2
They are occasionally hard to shape	1
Another kind of plug containing metal fibers	1
A plug who attenuates better, easier to hear the phone	1
Don't answer	34
20. What is a typical workday like for you?	
Same place all day	21
Rotating:	
1 time	1
2 times	0
3 times	4
Other: Large area, different from day to day	17
21. How would you rate the sound level at your company?	
Silent	0
Low	1
Medium	9
Loud	19
Very loud	14