

# Noise Attenuation and Proper Insertion of Earplugs into Ear Canals

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**Objectives:** The study was done to determine whether the noise attenuation attained with the use of earplugs can be improved by teaching the proper insertion of earplugs to users.

**Methods:** Fifty-four randomly selected male subjects were divided into an untrained group (25 persons) and a trained group (29 persons). The trained group was given a lecture on earplug insertion and allowed to practise the insertion procedure, whereas the untrained group acted as controls. The untrained group received this training afterwards. The success of the training was measured by the MIRE (microphone in real ear) and REAT (real ear at threshold) methods, visual evaluation and an analysis of the properties of the subjects' ear canals.

**Results:** According to the MIRE method, the averaged A-weighted noise attenuation was 21 dB for the untrained group and 31 dB for the trained group. With the REAT method the attenuation at 1000 Hz was 24 dB for the untrained group and 30 dB for the trained group. The visual evaluation of the earplug fit was 1.9 for the untrained group and 2.6 for the trained group (scales 0–3).

**Conclusion:** The results indicate that training in earplug insertion is important for good attenuation and for diminishing poor attenuation to a minimum.

*Keywords:* hearing protection; noise reduction; training

## INTRODUCTION

In Finland, most hearing loss among conscripts, of whom 1.5–2.5% suffer hearing damage during training, is caused by the shooting of blanks with assault rifles (Savolainen and Lehtomäki, 1996). Finnish assault rifles have a peak sound pressure level of 163 dB when blanks are shot (Ylikoski *et al.*, 1995). If the risk of hearing loss under such circumstances is considered and the limit value is considered to be 140 dB (measured as peak level), hearing protectors should have a peak attenuation level of >20 dB (Pääkkönen *et al.*, 1998). It has also been suspected that earplugs are not suitable for all conscripts and that some conscripts cannot insert earplugs into their ear canals properly. In addition, some studies indicate that field noise attenuation is significantly less than that measured in the laboratory

(Berger, 1981, 1988; Berger *et al.*, 1996). It is also suspected that the same situation exists in different areas of the work environment and in different industries.

The main goal of our study was to determine whether the noise attenuation attained with the use of earplugs could be improved. For this purpose a training programme was developed, visual ear canal evaluations were made and the measurements of noise attenuation were refined (Pääkkönen *et al.*, 2000a,b).

## MATERIALS AND METHODS

### *Test subjects*

Two groups of male conscripts (age 18–25 yr) participated in the test. In both groups the ear canals and eardrums of each man were carefully inspected and the diameter of the ear canals was measured with an E.A.R./Aearo EARGAGE earplug-sizing device. One group ( $n = 25$ ) acted as a control group and did

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not undergo training before earplug insertion. Each man selected either Bilsom 303S or 303L earplugs (Bilsom, Sweden), whichever he felt best fitted his ear. The men inserted the selected earplugs into their ear canals and the noise (85 dB) attenuation was determined by the MIRE (microphone in real ear) method. In addition, the noise attenuation was measured by the REAT (real ear at threshold) method with and without earplugs. In the other group ( $n = 29$ ) a lecture on the use and insertion of earplugs was given as a group and the men practised inserting the earplugs into their ear canals under the supervision of an occupational health nurse. The training session for the whole group took 30 min. The occupational health nurse helped individually if needed. Thereafter, the group went through the same measurement process as the control group.

In addition, all the subjects received information and training with respect to personal hearing protection, i.e. the control group underwent the same training as the test subjects after the completion of the tests. The Ethics Committee of the Finnish Defence Forces approved the research plan, the study was voluntary and the subjects signed an informed consent form.

#### Test methods

In the MIRE method, a miniature Sennheizer KE4-211-2 microphone ( $<5 \times 5$  mm) was fixed to the end of the earplug and inserted into the ear canal. The microphone was situated between the eardrum and the earplug. The microphone signal was transferred through thin insulated wires (diameter  $<0.1$  mm) to a measurement amplifier, a sound level meter (B&K 2203) and a plotter (B&K 2370) (Pääkkönen *et al.*, 2000a,b).

The test noise was initiated by a pink noise generator and an active loudspeaker (Fostex), which was located 80 cm in front of the test person at face level. The noise level was  $80 \pm 4$  dB in the frequency range 63–12500 Hz, and the A-weighted noise level was 85

dB. The noise level and duration (1 min) did not cause any risk of hearing loss.

The measurement room was a normal office room. In the MIRE measurements the test person inserted the ear plug with the microphone into the ear canal and the exposure noise level was measured. Then the A-weighted sound pressure level (SPL) was measured while the same microphone was at a distance of 5 cm to the side of the ear of the test subject. Finally, the microphone was inserted into the ear canal at the same distance from the eardrum as earlier (when the earplug was used) and the A-weighted SPL was measured. The earplug attenuation was determined by the TR (transmission reduction) method; in other words the SPL in the ear canal with earplug was subtracted from the SPL measured outside the earplug. The ear amplification (TFOE, transmission function of the open ear), equal to the SPL difference between the SPL in the ear canal without the earplug and the SPL outside the ear, was calculated. From the measurement results it was also possible to determine the insertion loss (IL) by summing TR and TFOE:

$$IL = TR + TFOE \quad (1)$$

The ear canal diameter was measured with an E.A.R./Aearo EARGAGE earplug sizing device. There are five spherical gauges, each with a specific diameter: XS (diameter 7 mm), S (8 mm), M (9 mm), L (10 mm) and XL (11 mm). An occupational health nurse also measured the hearing thresholds of both ears in an audiometric booth using the REAT method with and without the earplug. For this purpose a screening audiometer (Micromate 304; Madsen, Denmark) was used.

During both the objective (MIRE) and subjective (REAT) measurements, a physician visually classified the insertion of the earplug into the ear canal as follows: 0, no insertion at all; 1, poor insertion; 2, satisfactory insertion; 3, good insertion.

Table 1. Noise attenuation in the auditory booth as measured by the REAT method in comparison with the results of the A-weighted MIRE method

	REAT attenuation (dB)							MIRE method, A-weighted
	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	5000 Hz	8000 Hz	
Untrained								
Mean	22.4	23.6	31.4	33.6	35.6	39.6	42.2	20.9
SD	12.8	11.3	9.0	8.3	9.3	10.6	13.2	8.7
Mean – SD	9.6	12.3	22.4	25.3	26.3	29.0	29.0	12.2
Mean + SD	35.2	34.9	40.4	41.9	44.9	50.2	55.4	29.6
Trained								
Mean	28.1	30.3	35.0	39.0	40.0	46.4	49.8	30.6
SD	9.5	8.1	8.0	7.5	7.7	11.0	10.0	6.8
Mean – SD	18.6	22.2	27.0	31.5	32.3	35.4	39.8	23.8
Mean + SD	37.6	38.4	43.0	46.5	47.7	57.4	59.8	37.4

## RESULTS

A summary of the results is presented in Table 1 and Fig. 1. In the untrained group, 14 subjects selected the Bilsom 303S earplugs and 11 persons chose the Bilsom 303L. In the trained group the corresponding number was 21 for Bilsom 303S and eight for Bilsom 303L. The average ear canal diameter was  $9.4 \pm 0.9$  mm for the untrained group and  $8.9 \pm 1.0$  mm for the trained group. In other words, the ear canal diameters were similar in both groups.

In the untrained group seven of the 25 men showed noise attenuation of  $<15$  dB (IL). In the trained group all of the men had a noise attenuation value that was  $>15$  dB. Only four of the 54 men did not succeed in inserting the earplug with the microphone.

The noise attenuation (IL) was  $20.9 \pm 8.7$  dB for the untrained group and  $30.6 \pm 6.8$  dB for the trained

group. The REAT method gave an average noise attenuation of  $23.6 \pm 11.3$  dB at a frequency of 1000 Hz for the untrained group and  $30.3 \pm 8.1$  dB for the trained group. The attenuation improvement caused by training varied between 4 and 7 dB over all measured frequencies (Table 1). The ear amplification parameter was  $7.0 \pm 2.0$  dB ( $n = 53$ ) for the men when the two groups were combined.

## DISCUSSION

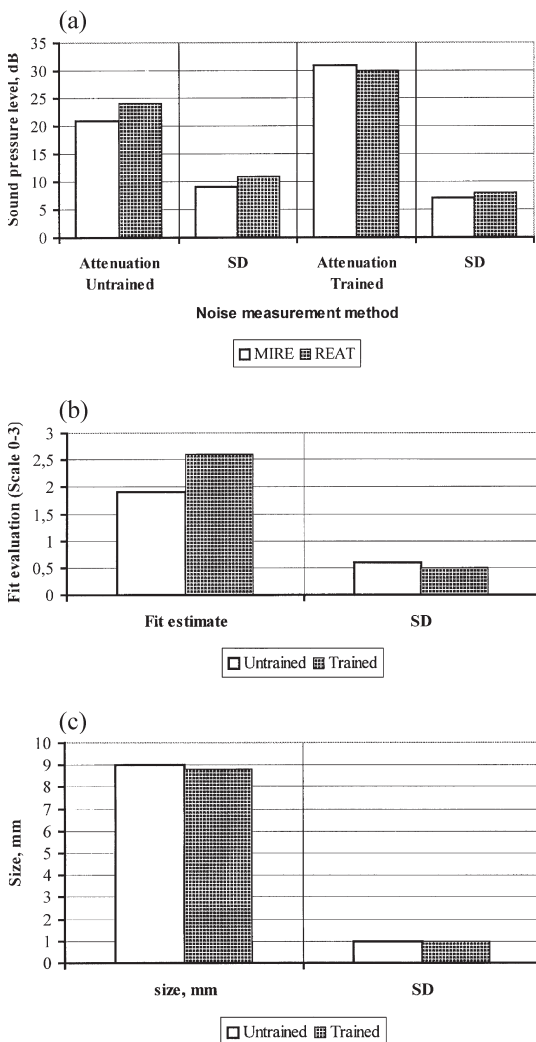
The measured noise attenuation was better ( $\sim 10$  dB by MIRE and 6 dB at 1000 Hz by REAT) for the trained than the untrained group, as was the visual insertion quality (from 1.9 to 2.6). The training was a significant parameter and the results firmly supported the earlier suspicion that earplug users cannot insert earplugs into their ear canals properly. However, some subjects (two in both groups) had difficulties in inserting the earplugs into their ear canal even after training. We have previously had similar results when testing men with difficult ear canals (Pääkkönen *et al.*, 2000b).

The trained men also showed a smaller deviation for noise attenuation than the untrained men (SD 6.8 dB for the trained and 8.7 dB for the untrained group; Fig. 1). A similar effect was found when the attenuation was measured by the REAT method. The frequency-dependent difference in attenuation remained the same over the frequencies (Table 1). This is surprising, because lower frequencies should be improved less if insertion of the sound insulation is improved. This might be connected with deeper insertion of the earplug into the ear canal. However, the effect needs further studies.

Should one use MIRE or REAT measurements in these types of tests? The MIRE microphone can to some extent affect fitting of the earplug. In this case REAT would be more useful. However, for practical reasons we simply measured A-weighted MIRE values, because MIRE is more convenient and quicker than REAT.

The smaller earplug (Bilsom 303S) seemed to fit better for the trained men than did the larger earplug ( $35/54 = 65\%$ ). This could be an effect of training. The importance of insertion depth can also explain this effect. Therefore, the insertion depth might be a useful parameter in future attenuation tests, if some more or less standardized measurement method could be developed.

According to visual inspection, poor attenuation or poor fit seemed to correlate with the shape of the ear canal and a very small diameter of the ear canal. However, this should be tested to determine the possible connection. The shape of the ear canal varies significantly and if good earplug insertion is desired, the pinna must be drawn downwards, backwards or



**Fig. 1.** Average noise attenuation by the MIRE and REAT (1000 Hz) methods and their standard deviations (a), earplug fit (b) and ear canal size (c) of the untrained and trained groups.

even upwards or, in some cases, the ear canal opening must be drawn forwards.

Four test subjects (14%) in the groups did not manage to insert their earplug properly into the ear canal. These persons were rechecked, but the insertion process remained unsuccessful. Therefore, it is vitally important to try to identify such persons so that they can use earmuffs or other types of hearing protectors than earplugs when exposed to high level noise.

Is the effect of training long lasting? Training improved the attenuation significantly in our study but the long-lasting effects need further study.

### CONCLUSION

The training improved the noise attenuation (~10 dB by MIRE and 6 dB at 1000 Hz by REAT) of earplugs and the visual insertion quality (from 1.9 to 2.6) for the men tested. Some subjects (14%) in the trained group, however, did not manage to properly insert the earplugs into their ear canal.

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