”Real-world” attenuation of muff-type hearing protectors:
The effect of spectacles

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ABSTRACT

A study has been carried out to investigate how much spectacles influence the attenuation of ear muffs. Measurements have been performed using broad-band stationary noise on real persons with four different safety spectacles.

It is concluded that spectacles introduce a very significant reduction in the attenuation. Depending on the spectacle and person, the effect can be from “moderate” to “severe”.

Particularly important is the reduction at low frequencies (150-400 Hz). This is due to the side bars introducing a leakage that makes the ear muff act as a kind of Helmholtz resonator with a frequency 200-300 Hz (depending on muff volume). However, also at 3-5 kHz the opening seem to produce a resonance which – for some spectacles and persons – can reduce the attenuation significantly.

The “spectacle effect” varies a lot from person to person and spectacle to spectacle. However, it is very consistent over the three different Peltor muff models tested. For optimum attenuation *a good fit and thin side bars* (particularly small width) is essential. Unfortunately, many safety spectacles have rather thick bars which may produce almost disastrously poor muff attenuation – even with the very best muffs available.

1. INTRODUCTION

It is well known from several studies that label data (obtained from laboratory measurements) of hearing protection devices (HPD) overestimate the attenuation that can be expected under “real world” conditions.

An extensive field study by Giardino&Durkt [1] investigated a total of 780 HPDs on workers in the mining industriy. When comparing field results with laboratory data, the main observations were as follows:

- The average noise attenuation in the field is considerably *lower*
- The spread in the field is considerably *larger* (typically 4-8 dB rather than the 2-3 dB obtained in laboratory data)

Combined, this means that some people get very low practical attenuation values. Thus, Giardino and Durkt observe that 32% of those in the study operating diesel engines had a practical noise attenuation of less than 10 dBA. For 8% the reduction was less than 5 dBA.

The reasons for the difference between field and lab results are probably several. European Standard prEN458 lists the following main factors:

- Poor fitting
- Long hair
- Wearing of spectacles or other PPE (Personal Protection Equipment)

A particular concern, to be discussed here, is the use of spectacles, particularly safety glasses. Having rather thick frames, they tend to introduce a significant leakage which quite obviously will contribute to reduced attenuation. Despite the fact that safety glasses are mandatory in many high-noise environments, little reliable data exist on how they affect the noise attenuation of ear muffs.

2. METHOD AND EXTENT OF STUDY

2.1. Spectacles

Measurements have been made on four types of spectacles (safety glasses). The spectacles are somewhat arbitrary chosen, but should present a fairly representative variation in terms of appearance and spectacle thickness.

Type 1 and 2 have rather thin side bars, type 3 and 4 are thicker.

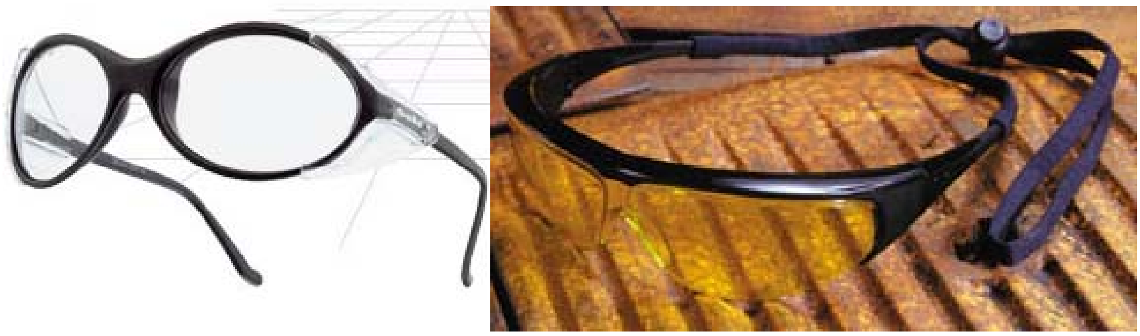


Figure 1. *Spectacle No. 2, "Bollé Boaci" (left), no. 4 "Millennia 9" (right).*

2.2. Muffs (hearing protector models)

The tests were made on three Peltor models:

1. Peltor H9 — a light-weight type
2. Peltor H520 (Optime II) — a medium type
3. Peltor H540 (Optime III) — heavy type, designed for maximum noise protection

Only one sample (both muffs) of each protector was used. All were in very good condition (2 and 3 were actually brand new). All protectors were of the headband type, see Figure 2.

Figure 2. *Left: light-weight hearing protector similar to HP1.*
Right: HP3, the new "state-of-the-art " Peltor H540

2.3. Test persons

Six real persons were used for the test, four males and two females. Both females had long hair. The test persons represent a fairly wide range in head shape ("narrow" to "round") and size (55-61). Most test persons were familiar with using HPDs. They put the muffs on themselves without assistance from the test leader. The test persons were sitting in a chair and not moving during each measurement.

2.4. Equipment and method

1/3-octave Leq levels were measured using a Brüel&Kjær 4182 probe microphone, see figure 3. A flexible probe tube - fastened to the ear of each test person with tape - was chosen to avoid variations in positioning between measurements.

The microphone has somewhat limited dynamic range. This turned out to be of importance at frequencies above 800-1000 Hz. The dynamic limitation is probably due to the part of the tube outside the cup picking up extranous noise.

For each test person, measurements were made

- Without HPD
- With HPD but no spectacle
- With HPD and spectacle

The noise was produced using a Norsonic 811L loudspeaker in a small rather reverberant room with pink noise input. Total A-weighted level outside the cup was about 95 dBA. The direct sound had an angle of incidence of about 30 degrees from ear-ear axis.

Figure 3. *Left: Happy author and test person with BK 4182 probe microphone, silk scarf (borrowed from the secretary!) and spectacle no. 4. Right: The BK 4182.*

3. PRESENTATION OF MEASUREMENT RESULTS

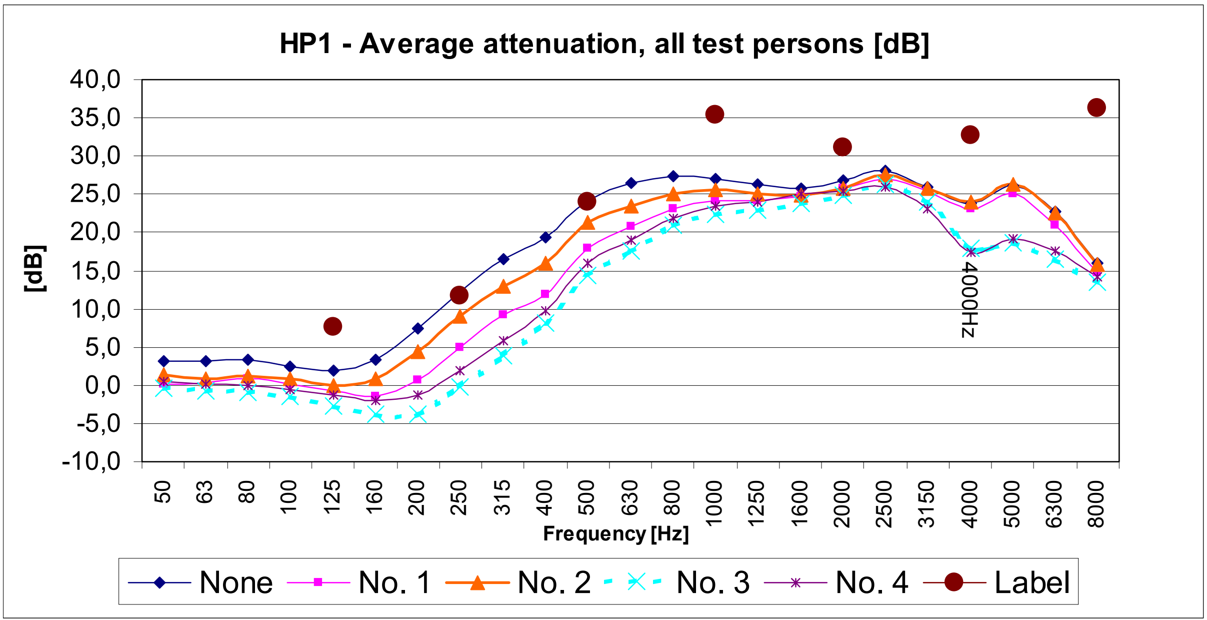
3.1. Average attenuation

Figure 4 presents the the average attenuation (dB-average for all test persons) for HP1 and HP3. The following situations are shown:

- No spectacle – laboratory data (large disks and no lines, octave band only)
- No spectacle (upper curve)
- Spectacle no. 1-4

The lab data presented throughout in this report is the manufacturer's stated "assumed protection values" (APV), which is the lab average minus one standard deviation. For our "field" data, however, no deduction has been made.

In general, the results for protector HP2 turn out to be very similar to HP1 (although marginally better). Thus to save space, these data have for the most part been omitted.



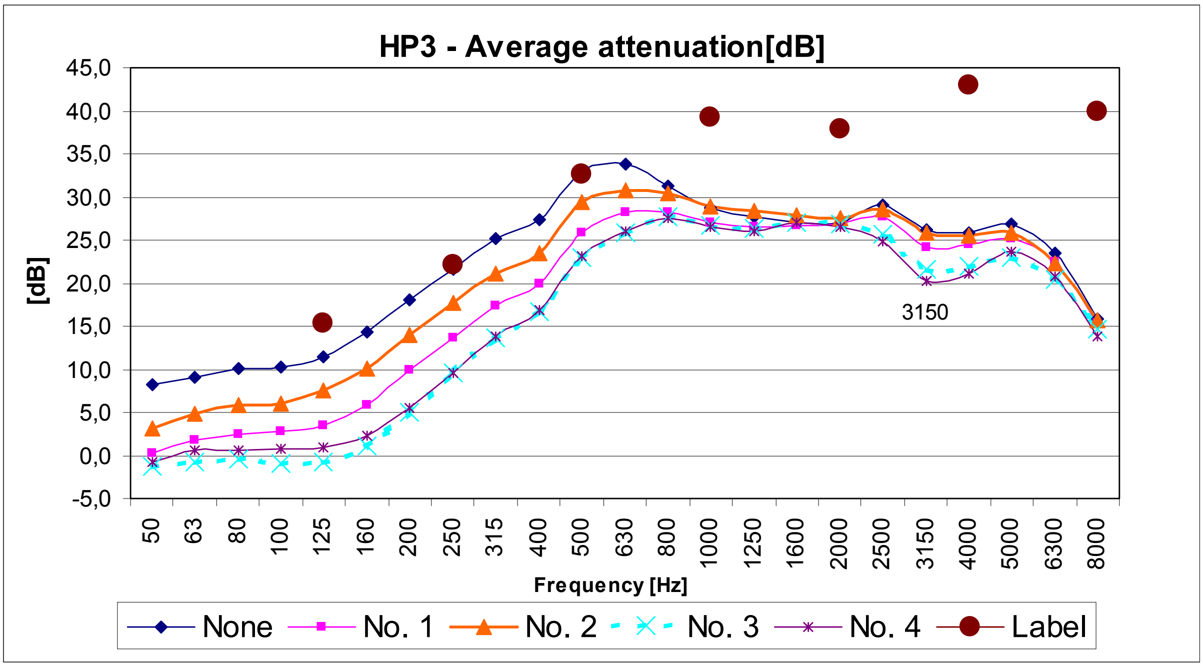
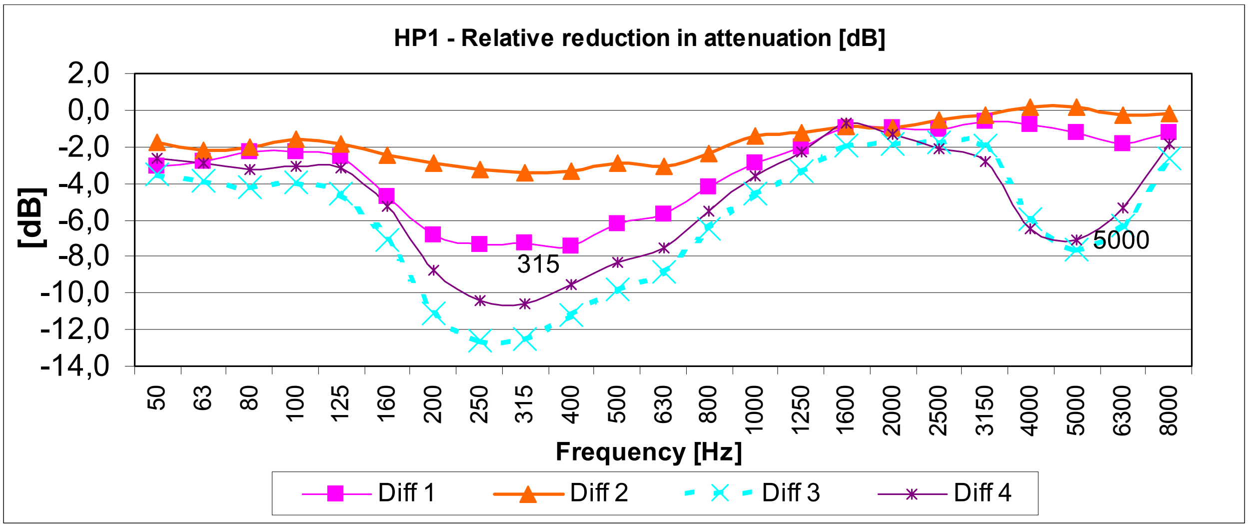


Figure 4. *Average attenuation values for protector HP1 (top) and HP3 (bottom).*

3.2. Reduction in attenuation – "spectacle effect"

Figure 5 presents the average *reduction* in attenuation for each hearing protector and spectacle.



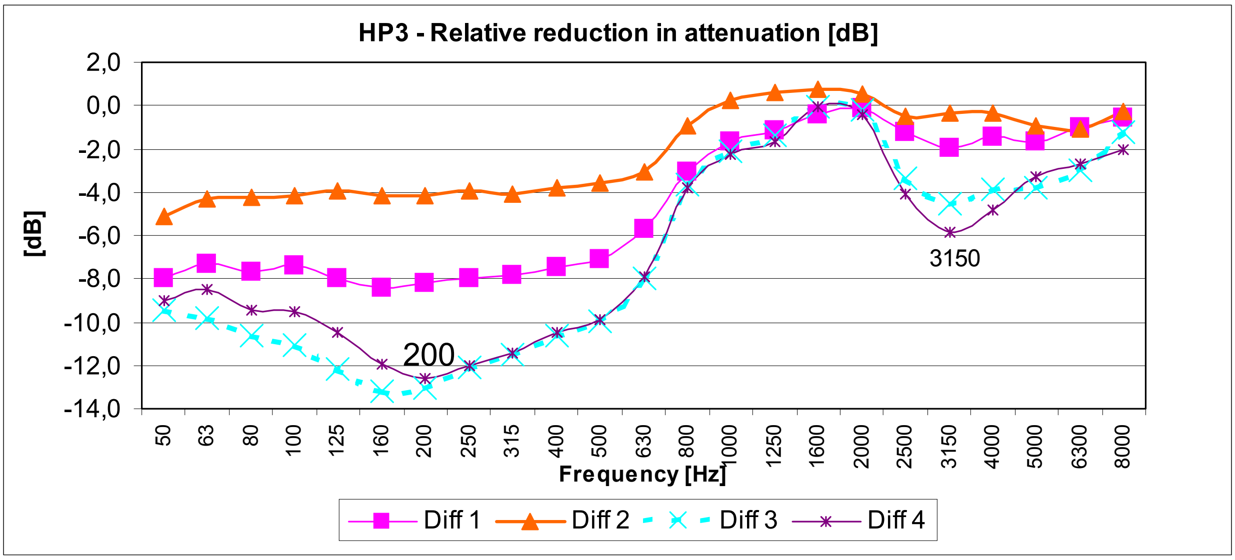


Figure 5. *Average reduction in attenuation values due to spectacles for protector HP1 and HP3.*

3.3. Spread – variation between test persons

There is a large spread in attenuation values between the test persons.

Figure 6 shows the standard deviation obtained with hearing protector HP1 for the various spectacle alternatives.

Figure 7 shows the attenuation values for each test person using HP1 and the poorly performing spectacle no. 4.

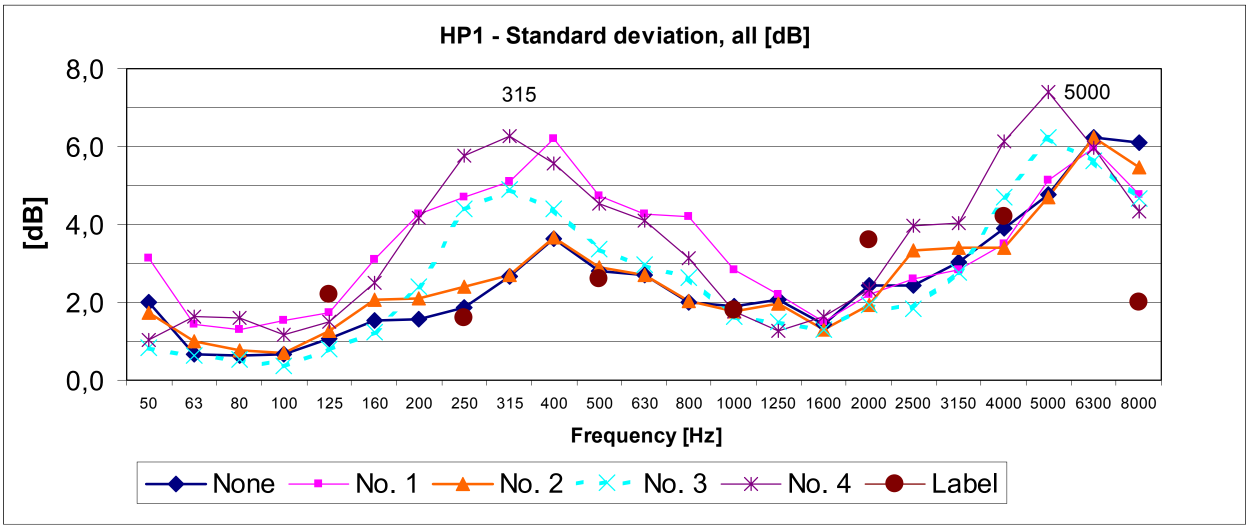


Figure 6. *Standard deviation in average attenuation values for HP1.*

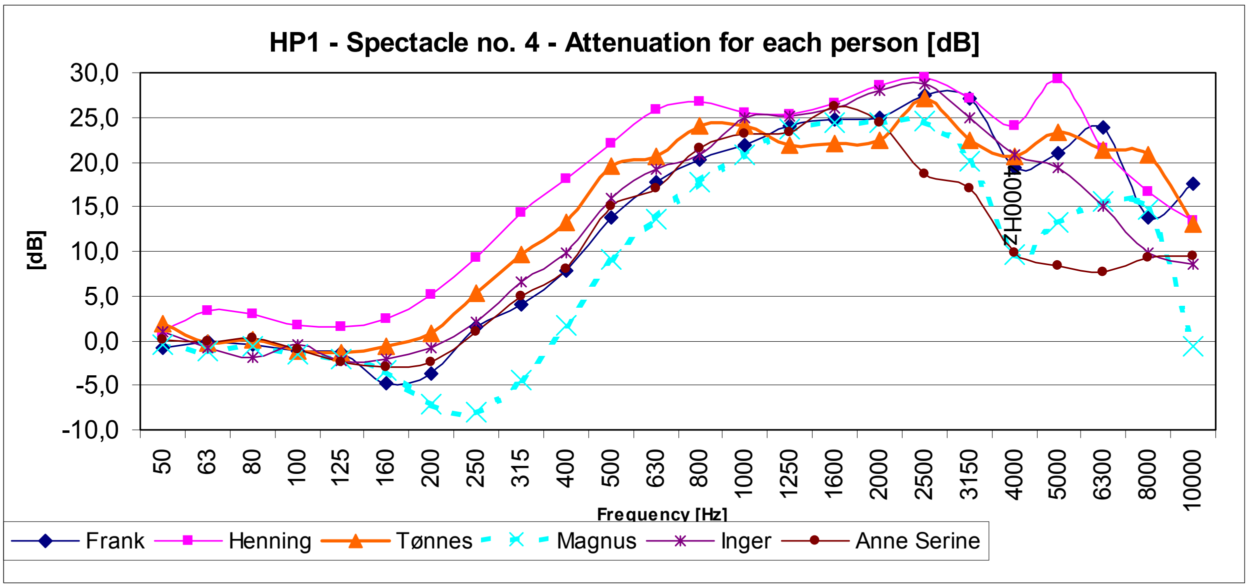


Figure 7. *Attenuation for hearing protector HP1 for each person using spectacle no. 4.*

3.4. System limitation – attenuation without spectacle

Figure 8 shows the attenuation – for each test person - of HP3 without spectacle. Label data are shown for comparison.

This measurement, made on the best protector (HP3), gives information about the the dynamic capability of the measurement chain as well as individual variability.

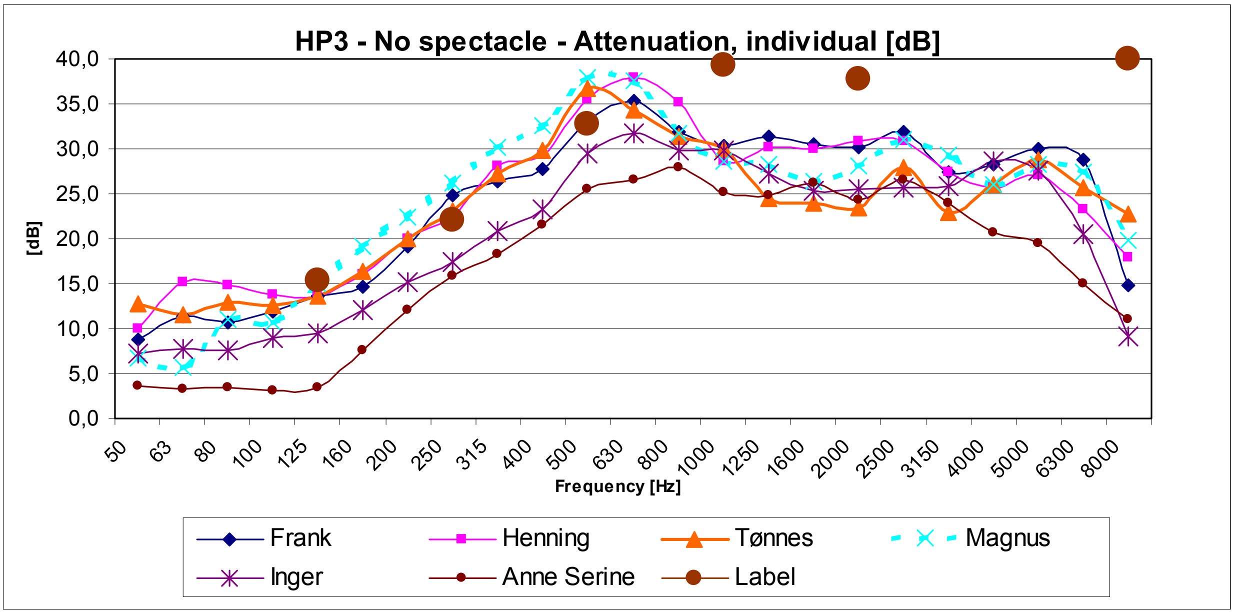


Figure 8. *Attenuation without spectacle, HP3, indicating insufficient dynamic range of measurement chain above 800 Hz.*

3.5. Effect of hair (?) – male/female difference

Figure 9 shows the difference in average attenuation, for each protector, between the females (2 persons) and males (4 persons).

It is believed a major reason for the generally lower attenuation values of the females is long hair. If so, the "hair effect" is to reduce attenuation over a broad range (at least below 800 Hz but probably even higher), as particularly evident on the HP3. Also, there is a very pronounced cutoff at 5 kHz for all protectors.

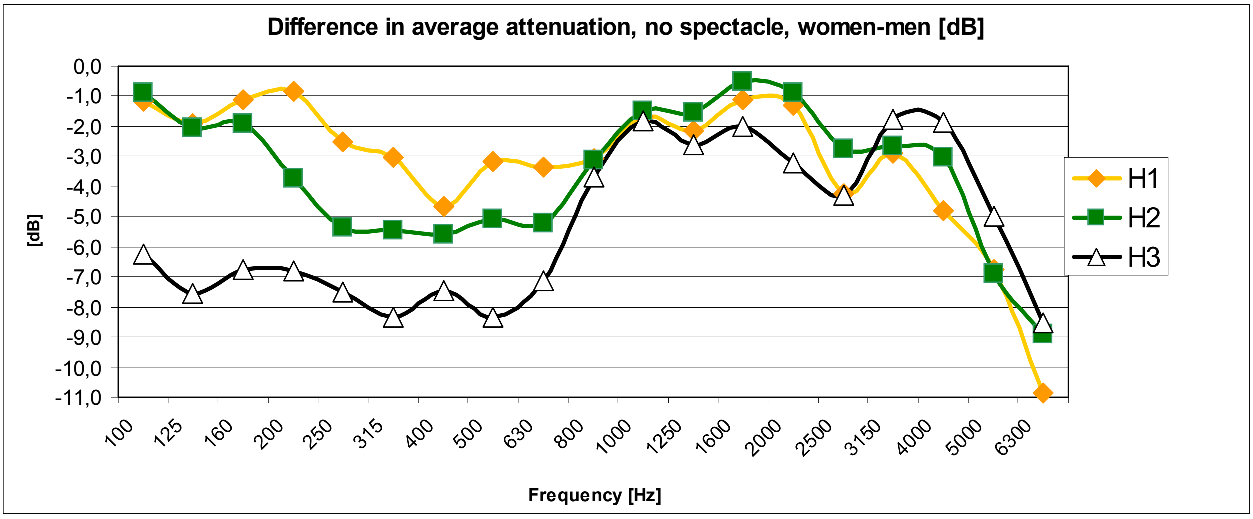
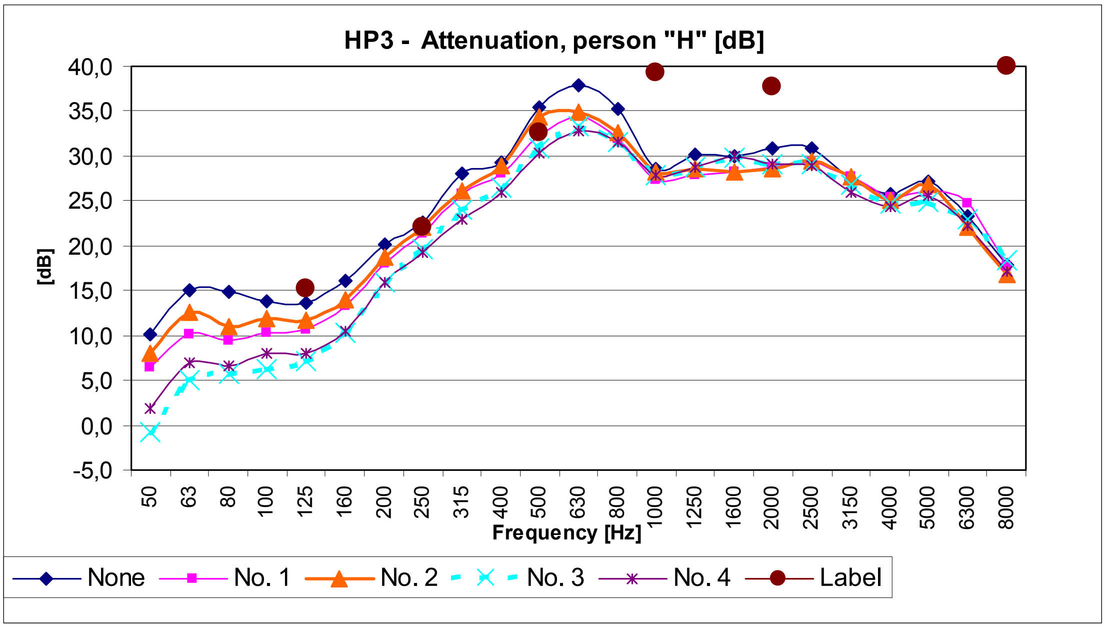


Figure 9. Difference in attenuation between females and males.

3.6. Effect of head shape (?) – an indication

The two males with the biggest difference in attenuation were person "H" and "M". Their results for HP3 are presented in Figure 10. In particular, the performance of spectacle 4 on "M"is poor.



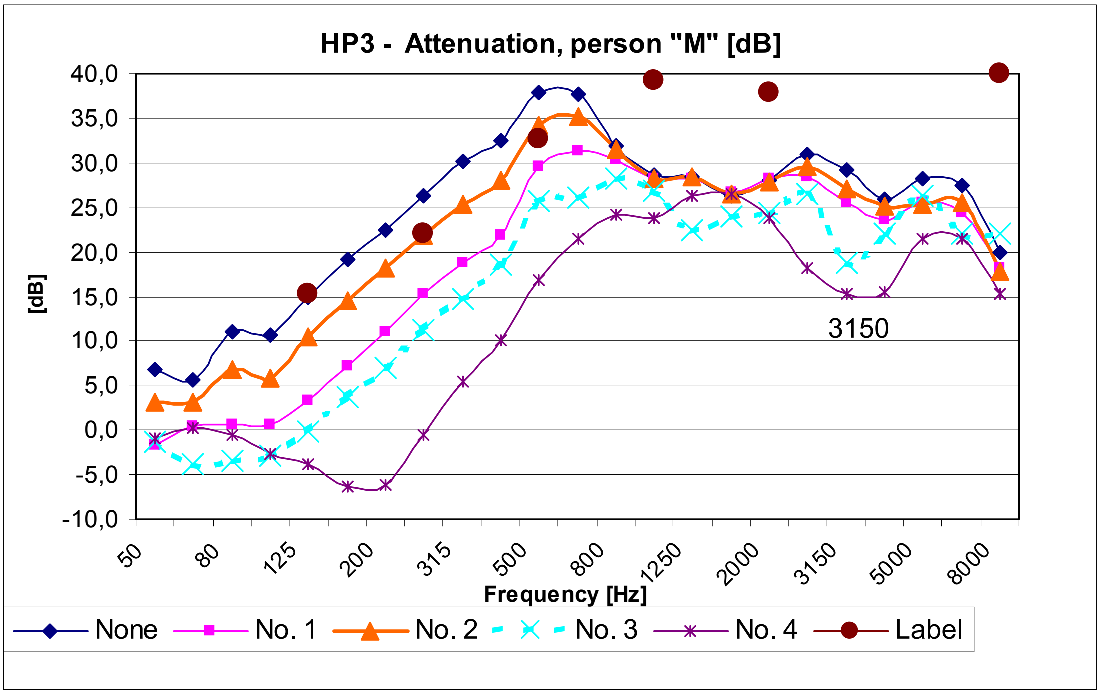


Figure 10. *Attenuation for the two short-haired people with the overall best ("H", top) and worst ("M", bottom) results.*

4. EVALUATION AND DISCUSSION OF MEASUREMENT RESULTS

4.1. System limitation - consequences

The measurement chain itself is believed to have sufficient dynamics and accuracy up to about 800 Hz for all protectors. From 800-1000 Hz onwards, however, the dynamic range is generally not sufficient to measure the real attenuation correctly for the better combinations of protector, spectacle and person (!).

The effect of this is that the data become somewhat blurred and the full spectacle effect is not revealed. Still, interesting effects of the poorer spectacles can be observed at the higher frequency end, particularly at 4-5 kHz.

4.2. Measured attenuation – without spectacles

The attenuation values in dB at some selected frequencies are summarized in the table below.

Protector	Lab/field	125 Hz	250 Hz	500 Hz
HP1	Lab (APV)	8	12	24
	Field	2	12	24
HP2	Lab (APV)	13	18	30
	Field	4	16	27
HP3	Lab (APV)	15	22	33
	Field	12	22	33

Without spectacles, then, the average attenuation values at 250 and 500 Hz correspond well with laboratory data. At 125 Hz, however, HP1 and HP2 fail to produce the "promised" attenuation.

4.3. Spectacle effect(s)

As expected, spectacles reduce the average attenuation for all protectors. The effect varies from "moderate" to "severe". In general spectacle no. 2 produce the best results on all persons, whereas spectacle 3 and 4 are poor.

The difference plots for each protector have basically the same shape. For spectacle no. 3 and 4 there are two very obvious dips (see Figure 5) at the following frequencies:

Protector	Frequency 1	Frequency 2	
HP1	315	5000	[Hz]
HP2	250	4000-5000	[Hz]
HP3	160-200	3150	[Hz]

The individual variation is *very large*, particularly for spectacle no. 3 and 4. Standard deviations run up 6-8 dB. For some combinations of spectacles and persons, a *negative* attenuation (i.e. amplification) is observed at 100-300 Hz. Other persons retain a significant positive attenuation with all spectacles.

Subtracting the standard deviation from the average attenuation (over all persons) give the attenuation values in Table 4.3. From these values, the following tentative observations are made:

- With spectacles, no positive attenuation can be assumed from any protector below 200 Hz.
- With HP1 and HP2 there is practically no attenuation at 250 Hz with spectacles 1, 3 and 4. With spectacle no. 2, however, the attenuation is 7-8 dB.
- Even at 4 kHz spectacle 3 and 4 produce significantly poorer attenuation.

Table 4.3-1. Average attenuation values for HP1 (minus one standard deviation)

Spectacle	**Lab/field**	**125 Hz**	**250 Hz**	**500 Hz**	**4000 Hz**
None	”APV” (Avr. – SD)	1	10	20	> 20
No. 1	”APV” (Avr. – SD)	**-3**	0	13	> 20
No. 2	”APV” (Avr. – SD)	**-2**	7	17	> 20
No. 3	”APV” (Avr. – SD)	**-4**	**-4**	10	13
No. 4	”APV” (Avr. – SD)	**-3**	**-4**	11	12

Table 4.3-2. Average attenuation values for HP2 (minus one standard deviation)

Spectacle	**Lab/field**	**125 Hz**	**250 Hz**	**500 Hz**	**4000**
None	”APV” (Avr. – SD)	2	11	21	> 20
No. 1	”APV” (Avr. – SD)	**-3**	3	15	> 20
No. 2	”APV” (Avr. – SD)	**-2**	8	18	> 20
No. 3	”APV” (Avr. – SD)	**-5**	**-1**	13	15
No. 4	”APV” (Avr. – SD)	**-5**	**-1**	14	14

Table 4.3-3. Average attenuation values for HP3 (minus one standard deviation)

Spectacle	**Lab/field**	**125 Hz**	**250 Hz**	**500 Hz**	**4000**
None	”APV” (Avr. – SD)	7	18	28	> 25
No. 1	”APV” (Avr. – SD)	**-2**	8	20	> 25
No. 2	”APV” (Avr. – SD)	3	13	23	> 25
No. 3	”APV” (Avr. – SD)	**-5**	3	18	19
No. 4	”APV” (Avr. – SD)	**-4**	2	17	18

The large individual variations suggest that head shape is important, particularly the area close to the ears. A “round” head shape is preferable and a bigger head may be better than a small. Spectacle no. 4, which shows the largest variation between persons, is very stiff and does not adapt well to different head shapes sideways.

In addition to a good fit, the side bars should be thin. In particular, we believe the *width* to be important. The width of the spectacles used in the studty at crossover are approximately: 3 mm (no. 1), 2 mm (no. 2), 5-6 mm (no. 3) and 4 mm (no. 4).The best results are obtained with the spectacle with the narrowest bar.

5. PHYSICAL EXPLANATIONS

5.1. Low-frequency dip is Helmholtz resonator

Spectacles seem to significantly reduce the attenuation of ear muffs at 200-400 Hz and 3-6 kHz.

We believe the reduction at 200-400 Hz can be explained essentially as an Helmholtz resonator effect. The spectacle makes an opening into the otherwise enclosed muff volume.

The resonance frequency of a Helmholtz resonator can be written

$$f_0 = \frac{C_0}{2p}\sqrt{\frac{S}{Vd}} \qquad (0.1)$$

where

C_0 is the velocity of sound, S is the duct area, D is "tube" length and V is the cavity volume

Measurements made on spectacle 4 with protector HP3 suggests

$$S = 2h^2 \qquad (0.2)$$

where h is the width (horizontal dimension) of the spectacle bar.

The "tube" length d ≈ 30-40 mm. Actually, the spectacle produce two "tubes", one on the upper side and one on the lower, the upper being slightly longer and thus giving a lower resonance. Each duct has an approximately triangle-shaped cross section.

For spectacle 4 t his all gives $f_0 \approx$ 220 Hz. This fits well with the measurements. The larger the muff volume, the lower the resonance frequency (other factors equal). This is also in good accordance with the measurement results, as HP1 has a resonance at 300 Hz, HP2 at 250 Hz and HP3 at about 200 Hz.

5.2. High-frequency dip

The reason for the high-frequency dip is less obvious than the low-frequency one. We suggest the 3-5 kHz dip is due to a resonance related to transmission through narrow, long tubes. The effect is here only described quantitatively.

In such tubes, i.e. being much longer than they are wide, and with diameter much smaller than the wavelength of sound, the air will act as a piston (moving mass). There will be an internal resonance when the wavelength is approximately twice the tube length. At this frequency, the transmission through the tube will be very efficient, hence giving a leakage.

For the hearing protector seals, the tube length(s) produced by the spectacle bar will be approximately 35-50 mm on the upper side (and 30-40 mm on the lower side) depending on the sealing width and the crossover point. This can produce a dip in the frequency area 3.4 –5.7 kHz.

6. CONCLUSIONS

Safety spectacles have been shown to significantly reduce the typical attenuation obtained with ear-muff type hearing protectors.

With spectacles having thin side bars (2-3 mm) and a generally good fit to the head, the reduction can be kept at a moderate level. However, of four spectacles tested, two performed poorly on most test persons. These types are also told to be popular.

Spectacles in particular reduce the attenuation at low frequencies by introducing a leakage that create a “Helmholtz resonator effect”. The resonance frequency is in the 200-300 Hz range (depending on muff volume) but the attenuation is reduced in a much broader frequency range. At resonance, the attenuation can be negative (i.e. the muff acts as an amplifier) if the spectacle side bars are thick and/or the fitting is poor.

If optimum noise protection is to be achieved in combination with safety spectacles, as much emphasis must be put on the choice of spectacles as on muffs. The spectacles should fit the individual well and have thin side bars (particularly the *width* is believed to be important). Further, it seems the side bars ought to curve downwards behind the ear (like normal spectacles), not be straight.

Even well-fitting spectacles with thin bars will reduce the noise attenuation of ear muffs. The effect of this must be taken into consideration in hearing protection programmes so that sufficient margins are allowed. In very high-noise environments, alternatives may be to use double protection (i.e. ear plugs in addition to muffs). Helmets with integrated eye protection also exist, possibly avoiding the need for side bars crossing the muff seal altogether.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

[1] Dennis A. Giardino / George Durkt jr.: Evaluation of muff-type hearing protectors as used in a working environment, AIHA Journal (57), march 1996.