THE SOUND ATTENUATION AND THE AERODYNAMICALLY GENERATED NOISE INSIDE MOTOR CYCLE HELMETS

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The protective effect of motorcycle helmets is established in a number of articles (1, 2, 3). The helmet gives protection against direct violence to the head. In Sweden and in many other countries it is compulsory to wear a helmet when driving a motorcycle or a moped.

During the last few years, the number of motorcycles have increased in many countries. Consequently more and more people wear helmets. In order to improve the helmet design further studies are essential.

One of the disadvantages when using a helmet is the effect on the auditory capacity (4, 6, 7).

One of the arguments against the use of helmets, is that helmets attenuate sound. The helmet functions as a hearing protector with attenuation of the traffic noise and the warning signals (4, 5, 6).

On the other hand, the helmet reduces the level of the noise of the motorcycle itself. Motorcycles are reported to create average levels of noise ranging from 85 to 95 dB(A) (4).

The motorcyclist is also exposed to the noise induced by the speed wind (7).

Different opinions of how these factors influence the driver can be found in the literature.

Harrison found ear-noise levels of more than 100 dB(A) at moderate speeds for motorcyclists with or without helmets (5, 6).

At speeds below 18 m/s, the noise came from the motorcycle itself and at higher speeds the aerodynamically generated noise was dominating.

In 1975, Henderson investigated the detection of warning signals. He considered a signal to noise ratio 1:1 sufficient for detection (4).

Moorhem et al. studied the aerodynamical noise generated by the helmet at ear-level and the helmet transmission loss. They found that for a quiet motorcycle at typical speeds, the noise at ear-level is generated by the air flow (7).

An assessment of the possibility of hearing damage was carried out. The result was that only an extremely high usage of the motorcycle resulted in hearing damage risk for riders with or without helmets. Helmets did, however, give a significant protection. They discussed the fit of the helmet which influences the differences in the results.

There is a difference between Moorhem's and Harrison's results. The values at ear level measured by Harrison are higher and show a very small increase with the velocity. It has been suggested that the noise reported by Harrison is due to a relatively noisy motorcycle and not to the air flow around the helmet. Additional investigations for clarification seemed to be necessary.

The aim of the present study is to evaluate the attenuation of the sound when using a motorcycle helmet and to measure the aerodynamically generated noise inside a helmet when driving. The possibility of detecting certain signals was judged, when masking and attenuation effects were taken into consideration.

Two different studies were carried out:

The sound attenuation of the helmets.

The noise level at the ear canal when driving.
In the latter case, the noise was measured at two different speeds 70 km/h and 100 km/h, respectively.

The level and the spectrum for the signal horn of a car was determined. The Swedish requirements for signal horns of cars were studied and the possibility of hearing them are discussed.

Determination of the Attenuation of Noise by a Motorcycle Helmet

Method 1

The attenuation was determined on five full face and five open face helmets. All helmets were tested using the hearing threshold shift method with pure tones in an anechoid room. The test subjects are seated in front of a loudspeaker and are controlling the level of the test tone from the loudspeaker with a press button. This button is connected to a sweep Bekesy-audiometer and the threshold of hearing is recorded with and without a helmet.

For the noise levels in this experiment the helmets attenuate the noise in a linear operational mode. The attenuation obtained at threshold levels is therefore valid and no non-linear effects would be expected. Three helmets were tested with three directions 0°, 90° and 180°, with three subjects for each combination.

The sound field, plain progressive wave, will be distorted by the head and the helmet resulting in a difference between the sound pressure distribution for the uncovered head and the head with a helmet, respectively. The openings of the helmets will be of importance for the directionality, especially for higher frequencies.

Result 1

The attenuation as a function of frequency for an open face helmet is shown in Figure 1 for nine test subjects. The attenuation starts at 1.000 Hz and reaches the maximum value some 20 dB at 6.300 Hz.

In Figure 2 the same data are shown for a full face helmet which gives about 30 dB for the highest frequencies.

The effect of directionality is shown in Table 1 and 2. The attenuation with 0°, 90° and 180° are compared. The significance of the difference was statistically tested and is indicated in the tables.

The second study was a field study where the aerodynamically generated noise was measured.

Method II

Four full face and four open face helmets were tested on three test-drivers who used three different motorcycles (Rickman CR, Honda CX 500 and Honda CB 500). The sound was recorded by Nagra tape recorder from microphones placed at each ear.

The measurements were carried out on a sloping hill of an asphalt road. The engine of the motorcycle was switched off, when the sound was recorded. The noise from the engine of the motorcycle was measured as well and never exceeded the aerodynamically induced noise at 70 km/h.

The sound pressure levels at both ears were recorded when the speed of the motorcycle was in the range 70 ± 5 km/h and 100 ± 5 km/h. The recordings were analyzed subsequently in the laboratory and the sound pressure levels were averaged over the speed ranges given above.

The sound pressure level L_P inside the helmet was defined as

$$L_P = 10 \lg \left(\frac{10^{0.1L_{P1}} + 10^{0.1L_{P2}}}{2}\right)$$

where L_{P1} = the sound pressure level at the left ear

L_{P2} = the sound pressure level at the right ear.

The reproducibility of the test procedure was satisfactory, maximum 1 dB difference for one replication for frequencies 125 Hz - 10.000 Hz.

Result II

In table 3 some results of the sound level measurements for different helmets are given in dB(A).

The exponent k has been determined because aerodynamical noises often follow the relation

$$P_{out} = 10 \lg (v/v_0)^k \qquad (1)$$

where P_{out} = sound power generated by the air flow

v = speed of the flow

v_o = reference speed

For a dipole source like an aeroplane propeller is k = 6 and for a turbulent flow like that of a jet engine, k = 8.

Equation (1) can be rewritten as

$$L_P = C + k \cdot 10 \lg (v/v_o) \qquad (2)$$

where L_P = the sound pressure level inside the helmet

C = the constant (different for different helmets)

As the results in Table 3 come from measurements on one driver on one motorcycle on one occasion, they should be treated with great care as far as the individual results are concerned. Looking at the average results, however, some conclusions can be drawn.

Averaging on energy basis and applying equation (2) gives

$$L_{PA} = 87.9 + 42 \lg (v/50) \qquad (3)$$

where v = the speed of the motorcycle in km/h

A = A-weighted sound level values

Equation (3) is graphically illustrated in Figure 3. As a comparison, an example of a single helmet which has been measured at four different speeds, is also given in the graph.

The difference between open and closed air intake at the mouth was studied for two helmets. Another helmet with a different visor was studied too. There are no significant differences between different visors or between open and closed air intake.

Three different helmets were tested with three different drivers using the same motorcycle. The fit of the helmet is not very critical, although it may influence the result for some designs.

A test with different motorcycles was carried out as well. One motorcycle showed higher values. The differences are, however, small. They may be due to the different postures of the drivers. Another possibility is that the motorcycles affect the air flow which hits the helmet differently.

The ranges of the aerodynamically generated noise are measured in 1/3-octave bands inside the helmets. The results are shown in Figures 5 - 8. The maximum limits for daily noise exposure, according to current Swedish standards, are indicated in the figures.

Discussion

The aerodynamically generated noise inside full face helmets seem to be very high. Noise affects the human being in many different ways. One of them is the hearing damage (8). In Figures 5 - 8, the noise is demonstrated in the different frequencies with the limit for maximum daily exposure for octave bands. As a comparison, the octave level has to be calculated from the three relevant 1/3 -octave bands.

This implies that with a speed of 100 km/h, there is a hearing damage risk for the driver, if he is daily exposed a couple of hours for many years. Such a situation seems to be very rare.

When driving at 70 km/h, the risk seems to be limited to people with highly sensitive hearing organs.

The possibility to hear a signal horn is described in Figure 4. According to Swedish standards, signal horns should give 93 dB(A) at a distance of 7 m.

The attenuations of a full face helmet and an open face helmet used in this study are 5 dB(A) and 2 dB(A) respectively for a common signal horn of a car.

This means that a signal horn of this kind cannot be detected when driving at 70 km/h at a distance of 7 m.

As to speech communication, the speech interference level was calculated. Conversation with maximum voice level will be possible to hear at a distance of 25 cm.

Conclusion

1. The risk for hearing damage is very limited as was also concluded by Moorhem.

2. Acoustic warning signals are audible only at a low speed, due to masking from the engine noise and the aerodynamically generated noise. The helmets do not put the wearers at a disadvantage compared with a non helmet situation.

3. Further development of the aerodynamic design of motorcycle helmets is considered essential. Should it prove impossible to reach acceptable noise levels even by altering the helmet design, the possibility of using other technical solutions ought to be considered in order to enhance the possibility of catching necessary sound information from the surrounding traffic.

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TABLE 1. Difference in attenuation in different directions. (0° and 90°)
A = Full face helmet, B = Open face helmet.

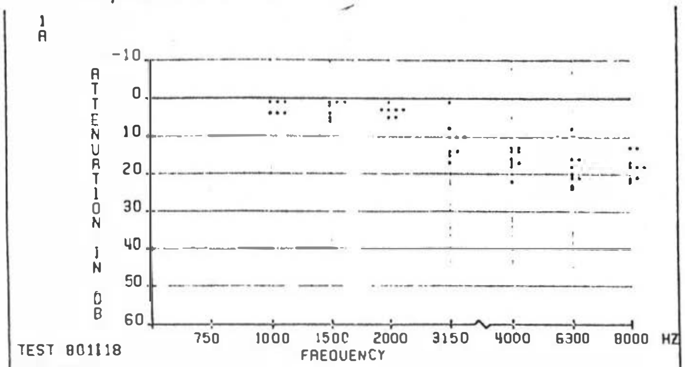
Subject Hz	A 0° $\bar{X}A(0-90^{\circ})$	$SA(0-90^{\circ})$	Test of significants $p > 0,05$	B $\bar{X}B(0-90^{\circ})$	$SB(0,90^{\circ})$	Test of significants $p > 0,05$
1000	0,8	1,69	NS	2,0	2,07	NS
1500	0,4	1,94	NS	2,3	2,85	NS
2000	6,8	2,37	S	5,3	2,99	NS
3000	4,4	2,29	NS	0,4	2,77	NS
4000	6,0	2,67	S	2,3	3,36	NS
5000	5,8	2,35	S	1,3	2,68	NS
6000	12,8	2,28	S	15,2	3,08	S

TABLE 2. Difference in attenuation in different directions. (0° and 180°)
A = Full face helmet, B = Open face helmet.

Subject Hz	A $\bar{X}A(0-180^{\circ})$	$SA(0-180^{\circ})$	Test of significants $p > 0,05$	B $\bar{X}B(0-180^{\circ})$	$SB(0-180^{\circ})$	Test of significants $p > 0,05$
1000	1,8	1,61	NS	3,0	1,58	NS
1500	1,4	1,91	NS	1,0	2,55	NS
2000	9,8	2,53	S	1,0	2,41	NS
3000	2,0	2,47	NS	2,7	2,58	NS
4000	10,[illegible]	3,17	S	0,7	3,03	NS
5000	5,8	2,09	S	2,8	2,63	NS
6000	1,6	2,67	NS	13,5	2,82	S

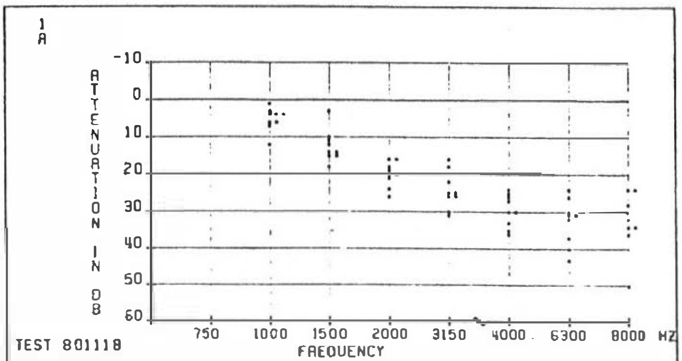
Helmet	v = 70 km/h	= 100 km/h	k
KiWi K2	93 dB	101 dB	5.3
KiWI Touring Cross K3	93	99	4.0
Nava Integral 1	94	100	4.0
Nava Integral ViP	95	103	5.3
Integralnava 2	97	103	4.0
AGV X 15 S	89	97	5.3
HA RS-10	90	97	4.7
Tommy, marked no: 3	85	95	6.7
Tommy, marked no: 2	87	96	6.0
Tommy 2000 with a peak	99	103	2.7
Average, energy basis	94.0	100.3	4.2
, arithmetic	92.2	99.4	4.8
Standard deviation, observations	4.4	3.1	1.2
, average	1.4	1.0	0.4

TABLE 3 A-weighted sound pressure levels at the ear and the speed exponent k for the helmets tested.



TEST 801118							
SUBJECTS 9							
RANGE	3	5	4	16	9	16	9
LOWER QUARTILE	1.0	1.0	2.5	8.5	13.3	16.0	14.0
STAND.DEV	1.6	2.1	1.4	4.8	2.9	4.9	3.3
MEDIAN	1.0	1.5	3.0	10.0	15.0	19.0	18.0
MEAN	2.5	2.9	3.3	11.0	16.0	18.6	17.9

FIGURE 1 The attenuation as a function of frequency for an open face helmet



TEST 801118							
SUBJECTS 9							
RANGE	11	15	10	15	12	19	26
LOWER QUARTILE	3.3	10.3	16.5	19.0	25.3	27.0	25.0
STAND.DEV	3.1	4.3	3.4	5.0	4.4	6.2	7.9
MEDIAN	4.0	13.0	19.5	25.0	28.5	31.0	31.0
MEAN	5.2	12.4	20.0	24.3	29.6	32.7	32.4

FIGURE 2 The attenuation as a function of frequency for a full face helmet

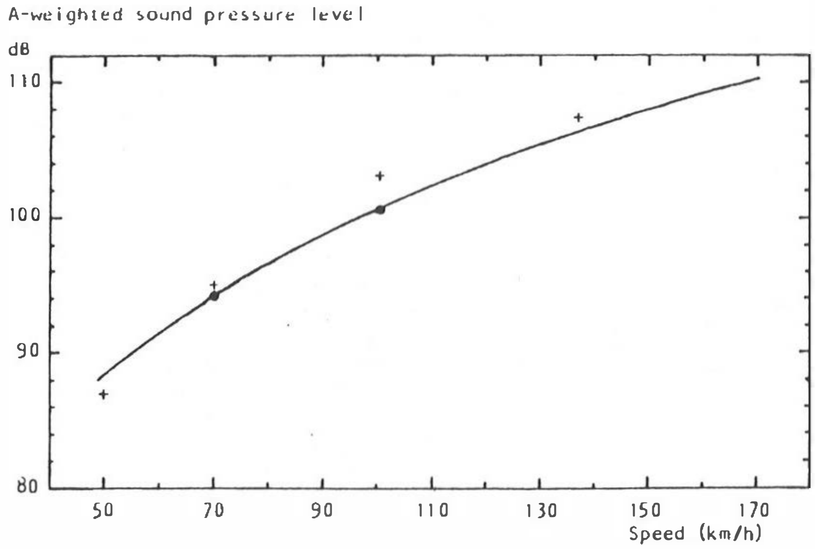


FIGURE 3 A-weighted sound pressure levels at the ear for an average helmet at different speeds. • measured average values, + measured values for a single helmet.

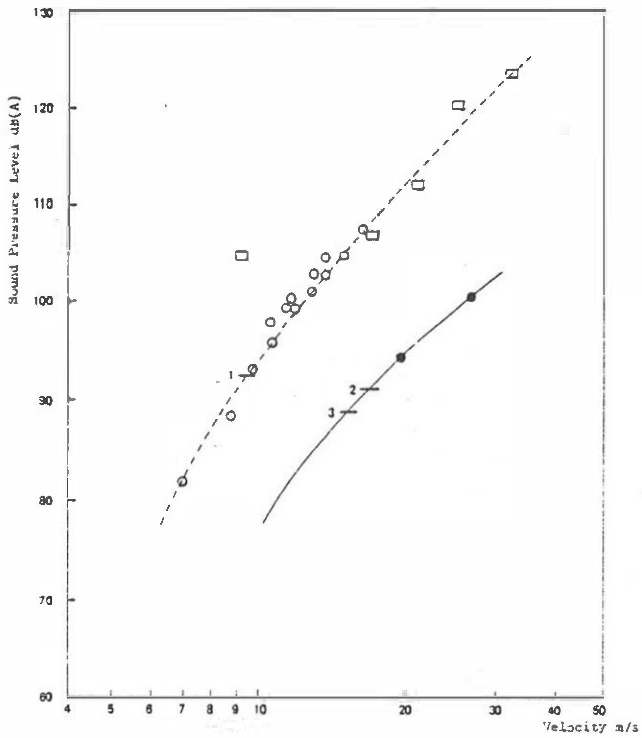


FIGURE 4 Aerodynamically generated sound levels measured at the ear on a bare head: O (Swaney) □ (Harrison) • the present study. The at ear noise level from a signal horn of a car: 1 = bare head 2 = open face helmet 3 = full face helmet

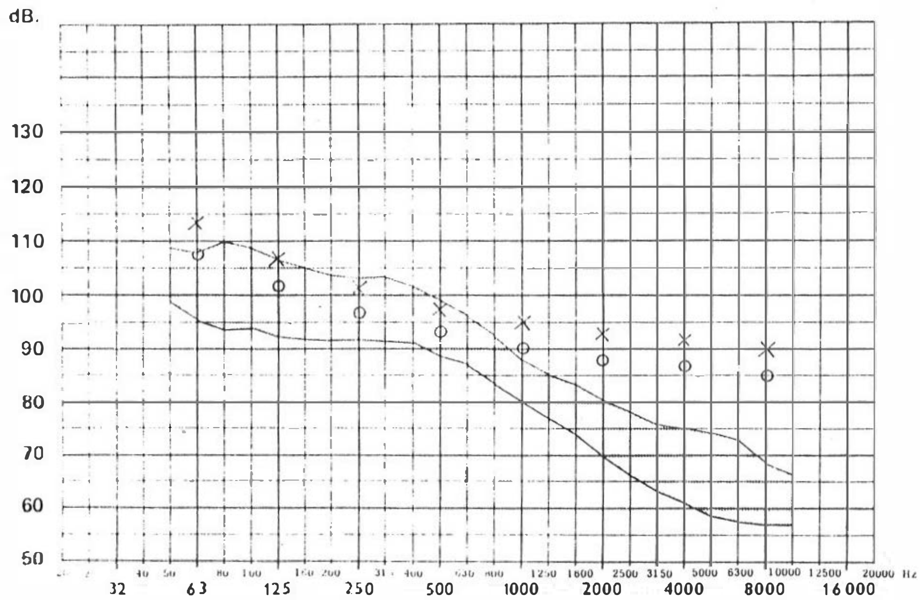


FIGURE 5 Shaded area: ranges of the aerodynamically generated noise with a full face helmet, when driving at 100 km/h. x and o indicate the limit for daily exposure 1-2 and 2-5 hours respectively according to Swedish standards.

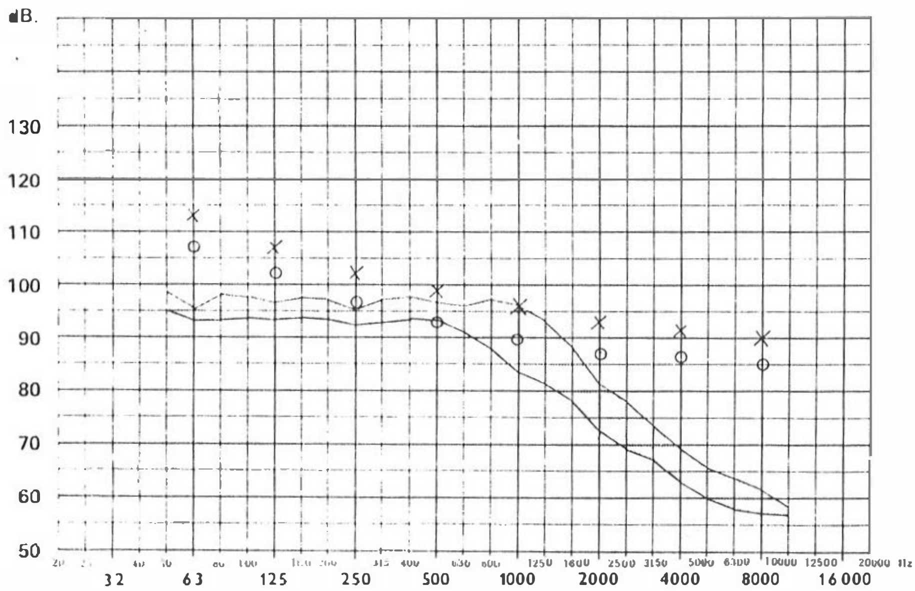


FIGURE 6 Shaded area: ranges of the aerodynamically generated noise with an open face helmet, when driving at 100 km/h. x and o indicate the limit for daily exposure 1-2 and 2-5 hours respectively according to Swedish standards.

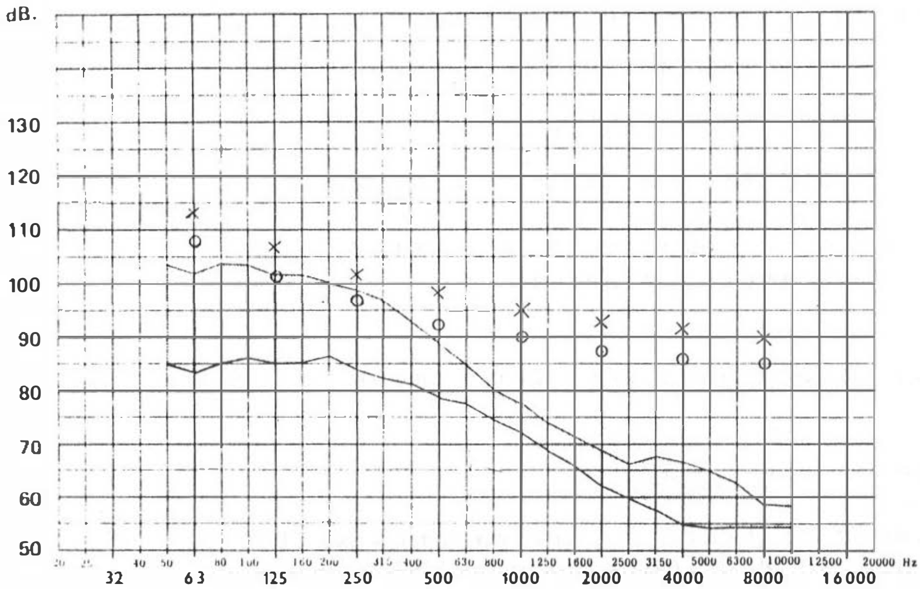


FIGURE 7 Shaded area: ranges of the aerodynamically generated noise with a full face helmet, when driving at 70 km/h. x and o indicate the limit for daily exposure 1-2 and 2-5 hours respectively according to Swedish standards.

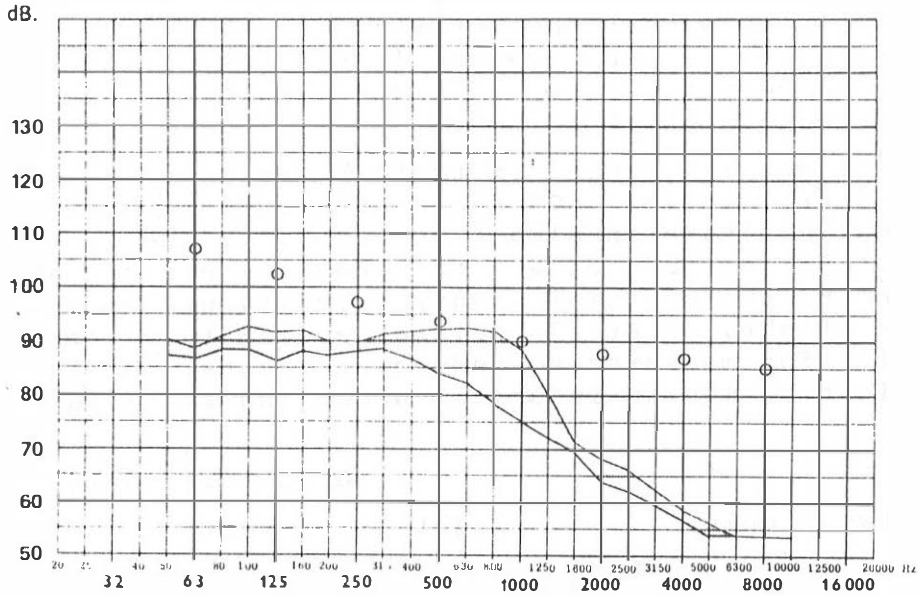


FIGURE 8 Shaded area: ranges of the aerodynamically generated noise with an open face helmet, when driving at 70 km/h. o indicates the limit for daily exposure 2-5 hours according to Swedish standards.