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AUDITORY DAMAGE RISK DUE TO INDOOR AND OUTDOOR SHOOTING

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ABSTRACT

Many different weapons can be used for military training. For a safe working environment, the maximum permissible exposure needs to be predicted, taking into account the use of hearing protection. In the ISO 17201 standard part 6, 'Sound pressure measurements close to the source for determining exposure to sound', it is described how to capture the time history of the sound pressure at locations of interest, such as for an instructor or shooter. This time-history is the basis for further assessment, like the calculation of an auditory damage risk criterium. The objective of this research is to compare the measurement results using the ISO standard without a person present, with measurements using a microphone close to the head of the shooter or instructor. The A-weighted sound exposure is calculated (ASEL) as well as the Auditory Risk Unit (ARU) using the AHAAH model. Both indoor and outdoor measurement have been conducted for several small fire arms. It was seen that the tail of the time history has a large effect on the results for the ARUs. In addition, tests were carried out with small portable sound absorbing screens to reduce the muzzle blast towards the shooter, instructor and the environment.

Keywords: *shooting noise measurements, auditory damage risk, muzzle blast mitigation*

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1. INTRODUCTION

To determine the auditory damage risk for shooting noise during military training, sound pressure measurements are needed close to the muzzle blast. Based on the time history of the sound pressure, the risk can be determined by applying an assessment method. This can be done by using the peak and time duration, the energy (such as the A-weighted sound exposure level: ASEL), or a physical model of the ear (such as the electroacoustic AHAAH model [2]). Each method yields different exposure variables, such as ASEL or Auditory Risk Units (ARU from the AHAAH model) [3].

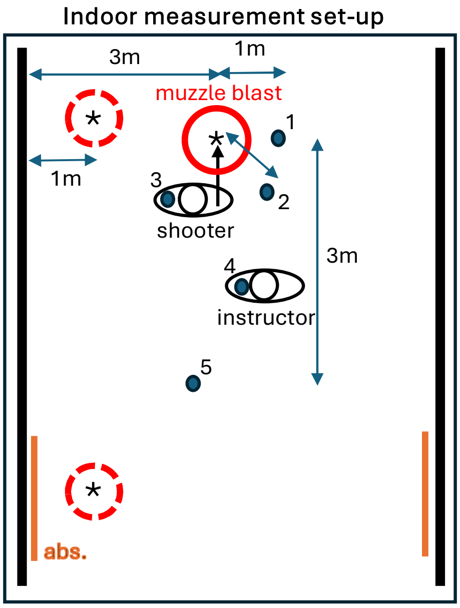

Figure 1. Measurement set-up using 5 microphones (blue markers) near the muzzle blast using 3 different firing positions (red circles).

In this paper measurement results are presented for different small caliber weapons, in an indoor and outdoor setting. The aim of these measurements is to compare the results for two different set-ups; one with a shooter present and one without a shooter; instead a weapon fixture is used. For the latter case the ISO 17201-6:2022 standard [1] is followed, in order to obtain measurements that are less dependent on the influences of the shooter and the microphone position close to the head of the shooter or instructor.

In Section 2 the ISO standard is introduced and in Section 3 the indoor and outdoor measurements are described. Section 4 discusses the results, with and without a shooter, using ASEL and AHAAH results.

Additional outdoor measurements were done, introducing two portable lightweight and sound absorbing screens, to reduce the muzzle blast exposure towards the environment and towards the shooter and instructor. The results for several positions of these screens are presented in Section 5.

2. ISO 17201-6 ON MEASUREMENTS

The ISO 17201 series 'Noise from shooting ranges' consist of 6 parts. The first part of ISO 17201 describes the measurement method to obtain the sound source energy and directivity of the muzzle blast or an explosive charge. The spectral levels can be used for the prediction of sound levels around shooting ranges (this is described in *part 3*). The standard is applicable to calibers of less than 20 mm or an explosive weight of less than 50 g TNT equivalent.

An important aspect for *part 1* of this standard is that the microphones are located at a distance where the peak levels are lower than 154 dB, so that the calculation of the source strength can be done with linear acoustic sound propagation models. As a result this standard cannot be used to determine the sound exposure levels close to the weapon (this is addressed in part 6).

ISO 17201 *part 6* is titled "Sound pressure measurements close to the source for determining exposure to sound" [1]. This part was added to the series to allow for sound exposure measurements at a short distance. It describes how to capture the time history of the sound pressure at the locations of interest, such as for an instructor or shooter. This time history is the basis for further assessment. The assessment itself is not within the scope of the standard.

The standard describes the requirements for a measurement system and the measurement set-up. A special case is described for the microphone position at the center of the head of the shooter. For a better reproducibility and comparison, the shooter should be removed and a weapons fixture should be used. The fixture shall be constructed in a way that minimizes reflections.

For part 6 the measured peak sound pressure levels can be higher than 154 dB, in contrast to the requirement for microphone positions used in *part 1* of ISO 17201, as (non-linear) propagation of the shockwave is not used in *part 6*.

Figure 2. Measurement set-up using 5 microphones close to hard walls (upper) and absorbing walls & ceiling (lower).

3. MEASUREMENT SET-UP

For the measurements, five microphones were used near the muzzle, see Figure 1. Microphones 1 and 2 are at 1 meter distance at the same height as the muzzle, at 90 and 135 degrees with respect to the firing direction. Microphone 3 and 4 are near the ear of the shooter and instructor, respectively, or at the center of the head when there is no person present. Microphone 5 is at 3 meters distance to the back and was added for a comparison with German measurements.

Figure 1 shows the set-up for the position in the center of the indoor shooting range. It also shows two other positions: close to the reflecting walls and close to the absorbing walls and ceiling.

Figure 3. Outdoor measurement set-up using 5 microphones.

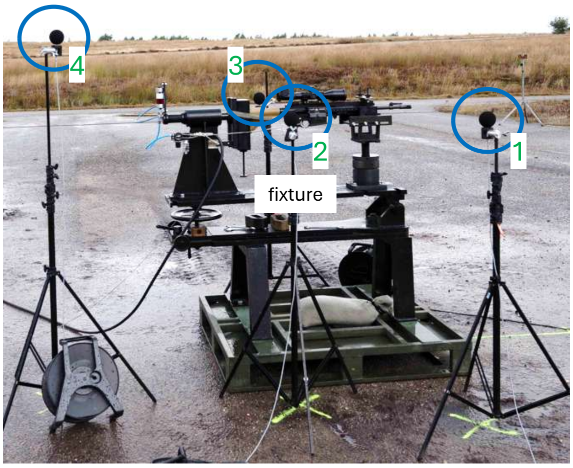

Figure 4. Outdoor measurement using a weapon fixture.

The photos in Figure 2, 3 and 4 give an impression of the indoor and outdoor measurements. Figure 2 shows two shooting positions: near the reflecting walls and ceiling as well as near the absorbing walls and ceiling. Figure 3 shows the outdoor set-up for a standing shooter (a prone position was also used), while Figure 4 shows the rifle in the weapons fixture. In this case the rifle was operated from a distance using a rope.

For the indoor measurements a 5.56 and 8.6 mm caliber rifle was used. For the outdoor measurements an additional 7.62 mm rifle was used. Standing and prone position were measured for both the 5.56 and 7.62 mm rifles. The 8.6 mm rifle was only used in a prone position. Also, a second shooter was included for 5.56 mm to capture possible differences.

At each position a series of 12 shots was measured. The average of these shots are presented in the next section.

4. RESULTS & COMPARISON

4.1 Indoor shooting

Figure 5 shows the (unweighted) sound exposure levels in octave bands for the 5.56 mm rifle, at the 5 microphone positions and for 4 different positions: 1) in the center of the indoor range using a shooter, 2) idem, using a fixture, 3) close to the fully reflecting walls using a shooter, and 4) close to the absorbing walls using a shooter.

Comparing the results for using a shooter (black line) and a fixture (blue line) shows that there is not a significant difference for the sound levels.

When moving the muzzle closer to the hard walls the sound levels are about the same, compared to the center position. The main difference can be seen in the interference pattern (due to the reflection) around 32 and 63 Hz. This can be seen best for the microphone at the shooter position (mic 3).

As expected, by using absorbing walls and ceiling the sound levels are reduced; the multiple reflections are damped. The largest reductions are for the instructor position and the microphone position that is 3 m to the back (mic 5).

On the right-hand side of the figures the results from the AHAAH model are given (in ARU). The results are calculated for 23 frequency bands and the maximum value is reported as the auditory risk. For microphones 3 and 4, at the shooter and instructor positions, a maximum value around 1500 ARU is obtained. Note that a dose above 500 ARU is unsafe, and that a daily limit of 200 ARU is recommended. In that case no temporary threshold shift is expected.

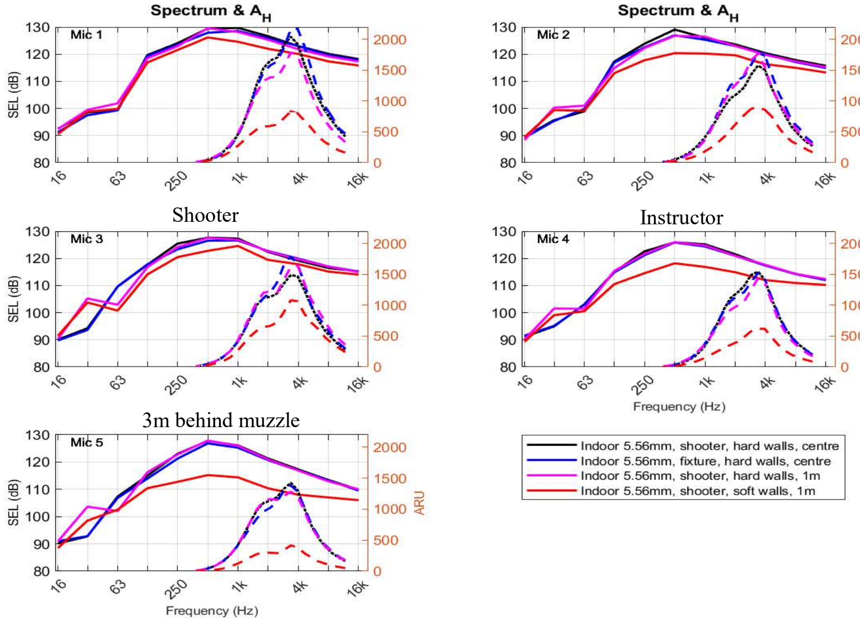

Figure 5. Indoor measurement results for a 5.56 mm rifle at 5 microphone positions and 4 different situations (see legend).

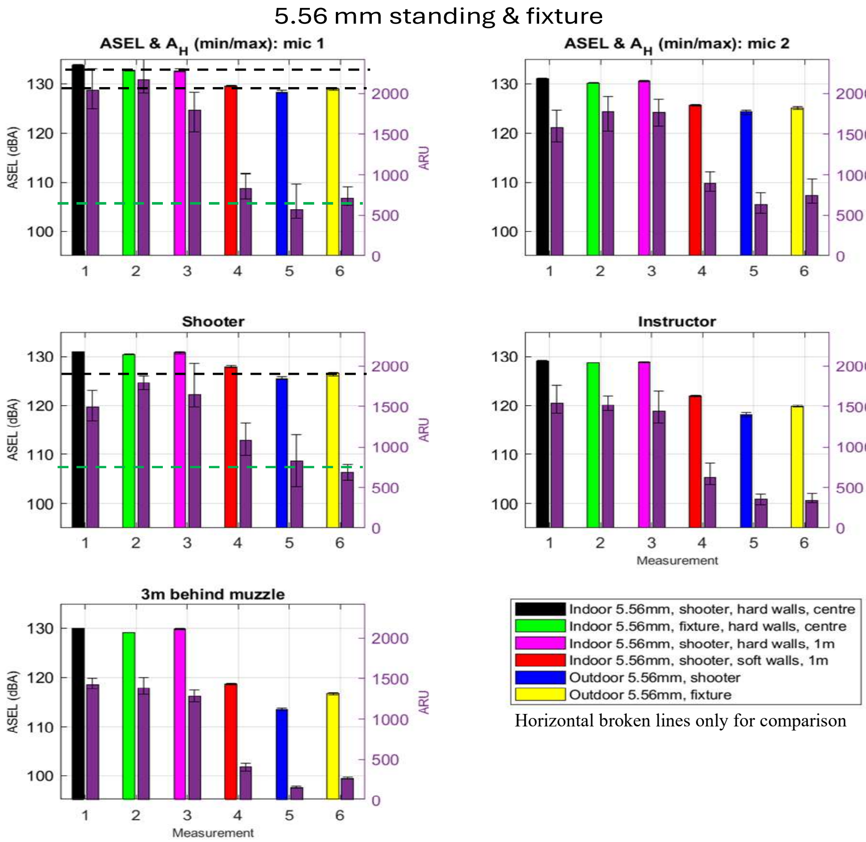

Figure 6. Indoor (& outdoor) measurement results for a 5.56 mm rifle at 5 microphone positions and 6 situations (see legend).

Comparing the ARU for the shooter position (mic 3) with and without a shooter shows a difference of about 200 ARU, while for the instructor position the difference is very small. Remember that the difference in sound levels is small when comparing the shooter and fixture (mic 3).

Figure 6 shows the single value results for the 5.56 mm rifle: the A-weighted sound exposure levels ASEL in dB(A) and the AHAAH (or A_H) results in ARU. Also included are the results for the outdoor measurements (blue & yellow bars), which only include the direct muzzle blast and the ground reflection.

For both the ASEL and ARU also the maximum and minimum values within a series are shown in black. Especially for the ARU the variation can be more than 20%. The ASEL variations are much smaller than 1 dB(A) (note that 1 dB = 26%).

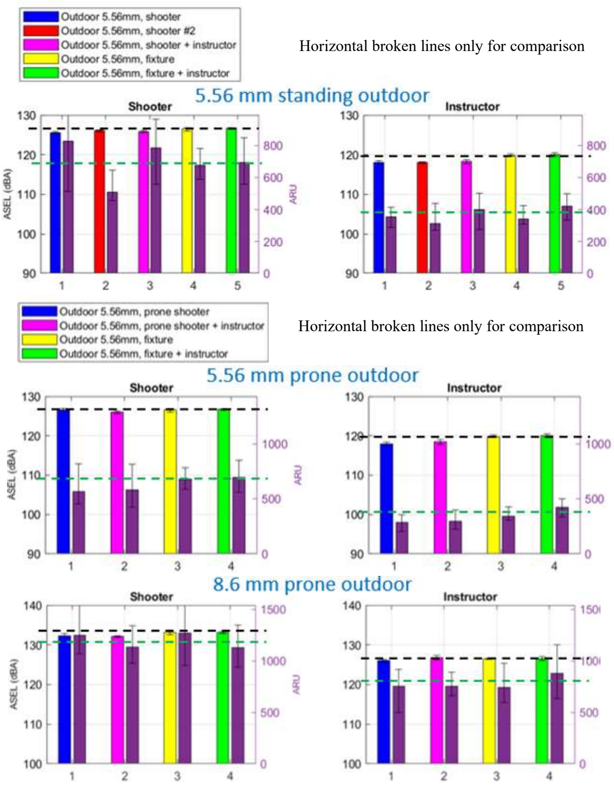

Figure 7. Outdoor measurements results for 5.56 and 8.6 mm weapons at shooter & instructor positions and for different situations (see legends).

The difference in dB(A) between using a shooter or a fixture is small. The ARU results are also in the same range; they can be higher, compared to a fixture, but also lower.

The indoor sound levels are around 6 dB(A) higher compared to outdoors (factor of 4). The ARU results can be up to 3 times higher, compared to outdoors.

4.2 Outdoor shooting

A selection of the outdoor results is given in Figure 7, at the shooter and instructor positions. In the upper figure there are five situations given for the 5.56 mm rifle: 1) with a shooter and no instructor present, 2) with another shooter (smaller), 3) with an instructor present, 4) with a fixture, and 5) with a fixture and an instructor present. It can be seen that the sound levels are within 1 dB(A), while the ARU show larger differences; 100 ARU or more. It is remarkable that for shooter #2 the ARU is substantially lower.

When using the prone position the differences when using a fixture (with a larger muzzle height) are small. The ARU results are a bit lower when using a shooter. The variation within a series is larger when using a shooter compared to using a fixture.

For the 8.6 mm rifle, used in the prone position, the results are similar, when comparing the shooter with the fixture.

4.3 Conclusions

To summarize the results for the indoor and outdoor measurements:

- Using a fixture instead of a shooter gives the same results in dB(A).
- The prone position gives slightly lower levels in dB(A) compared to using a fixture, around 1 dB(A).
- Within a series of 12 shots the ARU can differ up to a factor of two.
- The ARU results when using a shooter or a fixture are in the same range:
  - They can be higher, compared to a fixture, but also lower.
  - For the 7.62 mm standing position only, the ARU results with a shooter are more than a factor of 2 higher compared to using a fixture.

4.4 ARU growth as a function of time

With the AHAAH model one can visualize the ARU growth as a function of time, for example to see the differences between two situations. This is shown in Figure 8 for the 5.56 mm rifle, near the hard and near the absorbing walls, displaying a 1000 ms signal length. Figure 9 shows the corresponding time-pressure history, only for the first 30 ms. This shows that the reflections in the tail of the signal from the hard walls results in an ARU that is three times higher compared to the absorbing walls, where these reflections are much smaller (indicated with the green ellipse).

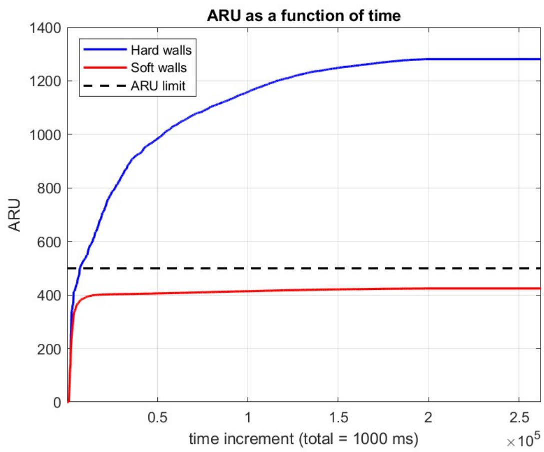

Figure 8. Growth of ARU as a function of time.

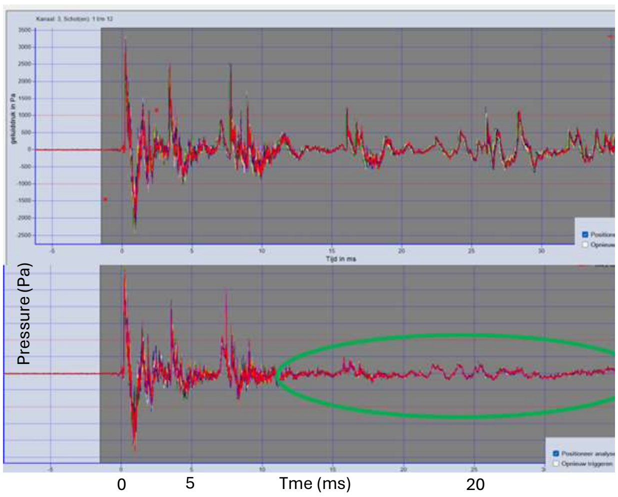

Figure 9. Muzzle blast and reflections (5.56 mm) for hard walls (upper) and absorbing walls & ceiling (lower).

5. OUTDOOR ABSORBING SCREENS

To reduce the contributions of the muzzle blast towards the environment, the performance of closely positioned screens was investigated. The screens are lightweight, so easy to move, and have absorbing panels on the side facing the muzzle blast. In addition the sound levels and auditory risk for the shooter and instructor were measured and compared to the situations without screens.

Two different rifles were used, with a 7.62 and 12.7 mm caliber. The 7.62 mm was used in kneeling and prone position. The 12.7 mm produces a very strong muzzle blast. It was seen that the thin surface layer covering the absorbing material did not remain intact when used close to the muzzle.

The absorbing panels (60 x 120 cm) consist of glass fiber core with a thickness of 5 cm. The are covered by a polyester film, so no gunpowder residue can penetrate the material.

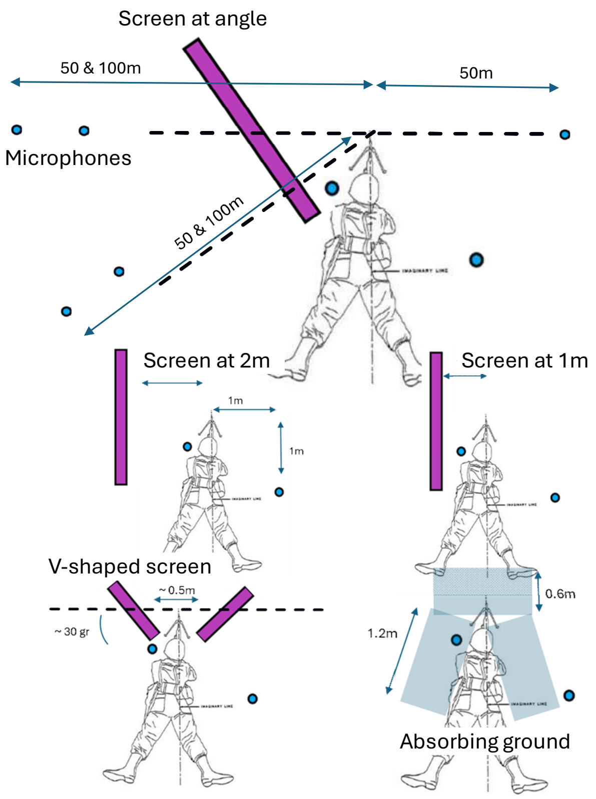

Figure 10. Four different positions of the absorbing screens and absorbing panels (in purple). One position with absorbing panels on the ground (in gray).

5.1 Measurement set-up

Figure 10 shows four positions for the absorbing screens. In fact, there are two screens each with a height of 180 cm and 120 cm wide. The upper figure shows the screen with an angle of 30 degrees w.r.t. the firing direction. The middle figures shows the screen at a distance of 2 and 1 meter from the muzzle. The lower figure shows the two screens in a V-shape (left) and using only the absorbing panels on the ground (right), to suppress the ground reflection. The photos in Figure 11 and Figure 12 further illustrate these set-ups.

Figure 11. Absorbing screen at 2m distance (upper) and at 1m distance (lower).

Figure 12. V-shaped absorbing screens.

As indicated in Figure 10, seven microphones were used: two for the shooter and instructor positions, four behind the screen at 50 and 100 meter from the muzzle (right-hand side, and one in the opposite direction (left-hand side).

5.2 Results

Single value results in dB(A) for the 7.62 mm caliber rifle in prone position are presented in Figure 13. The black bar results are for the situation without a screen and the colored ones for using a screen or an absorbing ground. The upper picture is for the shooter and instructor microphones, and also show the ARU results. It can be seen that using a screen has a small effect in dB(A), while the ARU can either be higher or lower (see also Table 1).

The middle picture shows the microphone position 50 m to the right, where a contribution due to a reflection may exist. This is not the case, the levels are the same or lower (especially for the V-shaped screens, shown in red)

For the microphones behind the screens larger reductions can be seen up to 10 dB(A).

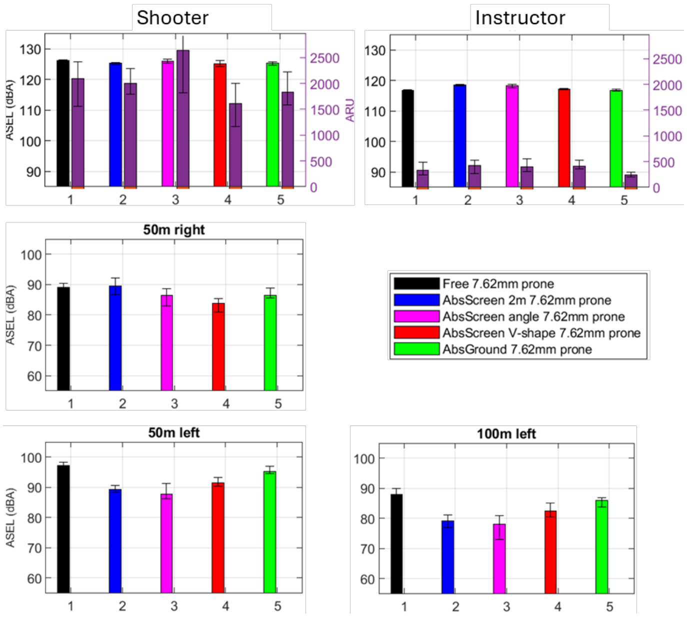

Figure 13. Measurement results in dB(A) and ARU without (black) and with absorbing screen/panels (color).

The differences, compared to the situation without a screen, are summarized in Table 1. The upper section lists the results in ARU for the shooter and instructor positions. The lower sections is in dB(A) for the microphones at 50 and 100 meters distance. When there is an increase the values are shaded in red.

The ARUs show quite a mixed result. For the shooter with a 7.62 mm rifle the results are positive, in general. While for the 12.7 mm rifle it is more negative in general. The instructor results are mostly negative as well. This is a bit surprising, as the other persons that were present behind the weapon observed a noticeable reduction, especially for the 12.7 mm rifle. Further investigation of these results is ongoing.

The reductions in dB(A) for the environment are more consistent. At 50 and 100 meter to the left, the reduction with a screen at 2 or 1 meter ranges between 6 to 10 dB for the 240 cm long and 180 cm high screen, both for the 7.62 and 12.7 mm rifles. While the reflection to the opposite side is between 0 and 1 dB.

The V-shaped barrier also provides a reduction to the left-hand side, between 5 and 6 dB.

The use of absorbing panels on the ground can reduce both the auditory risk in ARU and the sound exposure in dB(A). Only for the 12.7 mm rifle at the instructor an increase in ARU is measured, but this caliber produces a too strong muzzle blast for the absorbing panels to last.

Table 1. Reduction in ARU and dB(A) compared to the unscreened situation. Increase is shown in red.

Reduction w.r.t. unscreened				
Person (ARU)	Shooter 7.62mm	Instructor 7.62mm	Shooter 12.7mm	Instructor 12.7mm
Abs. screen at 2m	94	-100	62	-229
Abs. screen at 1m	150	-96	-747	-155
Abs. screen at angle	-545	-73	-439	-134
V-shape screen	485	-83	-407	30
V-shape screen (hard)			-698	-90
Abs. ground	260	87	670	-167
Environment (dB(A))	50m right 7.62mm	50 & 100m left	50m right 12.7mm	50 & 100m left
Abs. screen at 2m	-1	8, 9	-1	8, 6
Abs. screen at 1m	0	8, 9	-1	9, 7
Abs. screen at angle	2	9, 10	0	9, 7
V-shape screen	5	5	6	8, 7
V-shape screen (hard)			2	5, 5
Abs. ground	2	2	1	1, 0

6. DISCUSSION AND CONCLUSIONS

Sound pressure measurements close to the muzzle blast of small caliber weapons have been carried out for an indoor and outdoor shooting range. The A-weighted sound exposure and the auditory risk units (ARU) from the AHAAH model have been calculated. A comparison of measurements with a shooter and with a weapon fixture have been made, showing a good correspondence for the sound exposure levels in dB(A). For the ARU results larger variations were seen though. The AHAAH model shows a sensitivity for variations in the pressure-time history that is not seen for the A-weighted sound exposure level. Note that a similar observation was made for the measured dose-response relation functions in tactical training environments; for the $L_{Aeq,8h}$ levels a better prediction for the temporary threshold shifts (TTS) was found then when using the AHAAH model [4].

In addition, tests were carried out with small portable sound absorbing screens to reduce the muzzle blast towards the shooter, instructor and the environment. For the environment reductions up to 10 dB(A) were obtained, behind the screen. For the opposite direction the contribution due to reflection is between 0 and 1 dB(A). Again, the ARU results show large variations, with either a reduction or an increase for the shooter and instructor positions.

7. ACKNOWLEDGMENTS

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8. REFERENCES

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