SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2024
ORGANIZATION AND MANAGEMENT SERIES NO. 210

ANALYSIS OF THE CHANGE IN DIRECTIONALITY OF A GUNSHOT NOISE AFTER APPLYING A GUN SILENCER

Arkadiusz BOCZKOWSKI

Silesian University of Technology, Faculty of Organization and Management; Arkadiusz.Boczkowski@polsl.pl, ORCID: 0000-0002-5042-5862

Purpose: The purpose of the article is to present the results of research conducted by the author on the effectiveness of gunshot noise reduction and changes in the directionality of the sound source after applying selected models of acoustic silencers for different firearm calibers and types of ammunition. Based on the conducted research, a trend was identified for changes in the directional characteristics and frequency spectrum of the sound, and positive environmental effects associated with these changes were highlighted.

Design/methodology/approach: To determine the changes in directionality and the spectral characteristics of sound generated during a gunshot after applying a firearm silencer, a field research experiment was planned and conducted. Measurements were taken of acoustic pressure levels as a function of octave frequencies during test shots with firearms of various calibers, both with and without silencers. The obtained results were subjected to detailed analysis.

Findings: The conclusions and findings from the conducted research may be used in modeling the acoustic impact of shooting ranges. With knowledge of the directional characteristics of the sound source and by incorporating it into simulation models, the accuracy of noise prediction across the entire computational area is significantly improved.

Practical implications: The obtained research results allow for more accurate modeling of noise emissions to the environment from gunshots in places such as sports shooting ranges, hunting ranges, and military training grounds. Modeling that incorporates the directionality and spectral characteristics of the sound source allows for the inclusion of phenomena like sound absorption and reflection, thus increasing the accuracy of acoustic calculations. Another very important aspect is the potential use of these research findings in the design and improvement of new silencer constructions.

Originality/value: The author’s original achievement was the planning and conducting of a research experiment involving the recording of transient sound level changes at designated control points and based upon this determining the directional characteristics of noise emitted during gunfire with the use of silencers. The research was conducted for three typical types of firearms in common civilian and military calibers.

Keywords: noise, gunshot noise, gun silencer, noise directionality, noise reduction, environmental protection, silencer design.

Category of the paper: Research paper, Technical paper.

1. Introduction

In recent times the number of military and civilian shooting ranges in Poland has been growing rapidly. This is partly due to high civilian interest in shooting sports and partly due to the geopolitical situation and the need for intense shooting training for uniformed services, the military, and local units of the Territorial Defense Forces (WOT). Existing shooting ranges are typically used extensively, which leads to significant acoustic disturbance for residents living nearby.

The impulsive noise generated during a gunshot poses a serious risk not only to the health of shooters but also significantly impacts the environment. Its particular disturbance and effect on the acoustic climate is most noticeable in residential areas located close to military, sports, and hunting shooting ranges.

One of the most effective ways to reduce gunshot noise is to use silencers, which lower the overall energy of the acoustic wave emerging from the barrel, thereby reducing both noise and firearm recoil. The use of a silencer also changes the directionality and frequency characteristics of the sound that propagates after a shot. Though this information is generally known, silencer manufacturers do not provide any quantitative or even qualitative information describing these changes. Why? Because they do not have it. They do not conduct this type of research, as it is costly and to the average silencer user this information is simply unnecessary. Therefore, they limit themselves to specifying sound attenuation by indicating noise reduction in dB(C), which further misleads the average user, as they equate this value with the perceived (by ear) difference expressed in dB(A), and these are two different values.

Understanding the change in the directionality characteristics of the sound after using acoustic silencers is especially important for environmental acousticians, who can use this information to model the propagation of impulsive noise associated with shooting at firing positions, and thus estimate or predict the impact of this noise on the surrounding environment. With this knowledge they can design more effective noise protections, such as by appropriately shaping acoustic barriers or improving the construction of the silencers themselves.

2. Review of existing research

The literature contains many publications on the use of firearm silencers and their effect on reducing noise emitted to the environment. These studies primarily focus on silencer effectiveness, defined as the decrease in sound level in the area around the shooter’s head (or at other points in the environment) before and after using the silencer.

These studies provide information on the potential to mitigate the negative impact of gunshot noise on shooters' hearing by using silencers and other items such as specialized subsonic ammunition (Murphy et al., 2017). A great deal of attention is given to analyzing the effectiveness of hearing protection for shooters using silencers and demonstrating their significantly greater effectiveness compared to individual hearing protectors (Branch, 2011) and (Boczkowski et al., 2020). Research results are often used to design and improve internal silencer constructions, such as by using fluid dynamics simulation tools (Kilikevičius et al., 2023), or numerical analysis of various internal baffle constructions and determining their effect on sound level reduction with distance (Gurdamar et al., 2023; Huerta-Torres et al., 2021).

The analysis of firearm shot recordings for forensic use, such as identifying the direction of the shot or the type of firearm, also receives significant attention in the literature (Maher, Shaw, 2010). Many resources are also available on the theoretical basics of silencer construction, design, and application (Rusiecki, 2013), as well as reviews of available market solutions along with analyses of their advantages and disadvantages (Sweeney, 2016).

Significantly less attention in the literature is devoted to analyzing the impact of silencers on noise emitted to the environment, specifically regarding the change in the directional characteristics of sound emitted during gunfire. Yet it is precisely this change in the directionality of the sound source that makes the resulting noise considerably less audible from behind and to the side of the shooter. Additionally, the effectiveness of noise reduction is influenced by changes in the sound's spectral characteristics after using a silencer. This area of research is not yet sufficiently explored, and it is precisely this niche that the author's research seeks to fill. Knowledge of the change in the sound source's directionality after using a silencer can be used in acoustic modeling of shooting range impacts on the external environment, as well as in designing silencers with increasingly directional noise characteristics.

3. Description of conducted research

A research experiment was conducted to determine the effectiveness of gunshot noise reduction, the changes in directionality and the changes in the frequency characteristics of the sound source after applying a silencer. The experiment consisted of determining the maximum and average sound level at the shooter's ear (point U) before and after applying the silencer, as well as the average sound level at 8 measurement points (P1-P8) evenly distributed around the shooter at a distance of 10 m and at a height of 1.5 m. The placement of measurement points is shown in Figure 1.

The noise measurements were conducted at the HUBERTECH shooting range in Jaworzno in December 2020 under conditions of free-field acoustic environment, that is in open terrain with negligible influence of reflections from buildings.

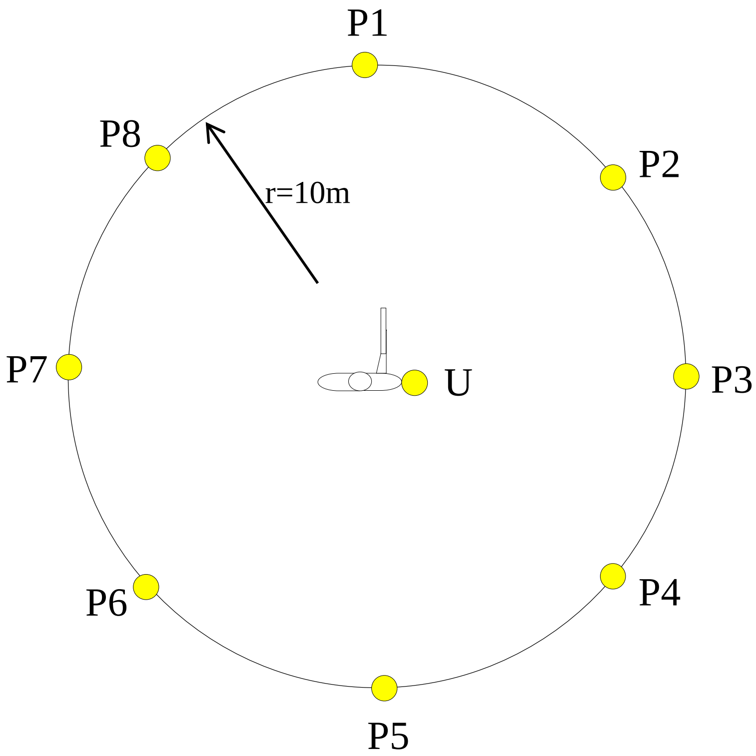

Figure 1. Placement of measurement points in relation to the shooter firing a gun.

The tests were conducted during target shooting with the following types of firearms (Figure 2), calibers, and silencers:

1. Ruger American Predator bolt-action rifle in .308 Win caliber using GGG FMJ ammunition weighing 9.55 grams (147 grains), with an initial velocity of 842 m/s, initial energy of 3375 J and an A-Tec H2 0.3 acoustic silencer with a nominal effectiveness of 33 dB(C).
2. AR-15 DPMS Panther Arms carbine in .223 Rem (5.56x45 NATO) caliber using GGG ammunition weighing 4.99 grams (77 grains) with Sierra HPBT projectile and an initial velocity of 855 m/s, initial energy of 1825 J, and an A-Tec AR 40-3 acoustic silencer with a nominal effectiveness of 28 dB(C).
3. Glock 45 pistol in 9x19 mm caliber using Selier&Bellot Luger FMJ ammunition weighing 8.0 grams (124 grains), with an initial velocity of 360 m/s, initial energy of 518 J, and an A-Tec PMM-6 M13.5x1 LH acoustic silencer, for which the manufacturer specifies effectiveness at 36 dB(C) for a wet silencer and 28 dB(C) for a dry silencer.

Figure 2. Guns used during noise measurements: a) Ruger American Predator bolt-action rifle, b) AR-15 DPMS Panther Arms carbine, c) Glock 45 pistol, d) A-Tec H2 0.3 silencer, e) A-Tec PMM-6 silencer.

To ensure the appropriate bandwidth of the measurement apparatus a measurement set was used consisting of a 1/8-inch Brüel & Kjær type 4138 microphone with a sensitivity of 1 mV/Pa, a frequency range from 6.5 to 140 kHz, a dynamic range from 52.2 to 168 dB, and a polarization voltage of 200V, a Svantek SVAN 945A sound level meter and a UA-0036 adapter which allowed for connecting the two devices. The configured measurement set is shown in Figure 3.

Figure 3. Measurement set for recording impulse signals.

During field noise measurements for each of the 3 types of firearms described above (bolt-action rifle, carbine, pistol), the transient changes in acoustic pressure were recorded with a time resolution of 2 ms (0.002 s). The recordings were made at each of the 8 measurement points (P1-P8) and additionally at the shooter's ear. The following sound levels were recorded in real time, parallel to each other: L_A, L_{Amax}, L_{Amin}, L_C, L_{Cpeak}, along with changes in their frequency spectra in octave bands. The recorded acoustic waveforms served as the basis for processing the results using SvanPC software and determining the relevant indicators describing the recorded sound. An exemplary course of changes of the transient sound level A at the shooter's ear during a 0.30" caliber bolt-action rifle shot without a silencer and with an A-Tec H2 silencer is shown in Figure 4.

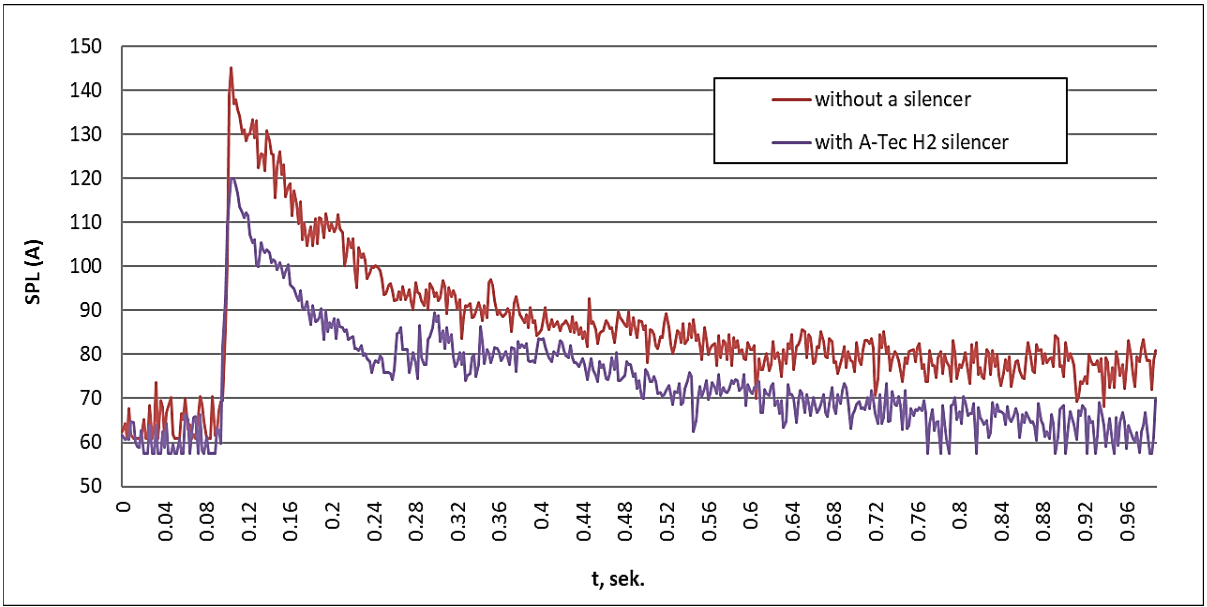

Figure 4. Change in sound pressure level corrected by A characteristics.

4. Achieved test results

The compilation of measurement results and acoustic level calculations at the shooter's ear and at the 8 measurement points P1-P8 during shots fired with and without acoustic silencers for each of the three types of firearms (bolt-action rifle, carbine, pistol) is presented in Table 1. The symbols in the table represent:

- $L_{Aeq,1s}$ – the average sound level A measured from 10 ms before the shot until 1 second after the shot, that is until the complete sound attenuation,
- L_{Amax} – the maximum sound level A reached at the moment of the shot,
- L_{Cpeak} – the maximum peak sound level C reached at the moment of the shot.

Table 1.
Compilation of measurement results and calculations of sound levels obtained during the conducted test shots

Ruger American Predator bolt-action rifle, cal. 308 Win, silencer A-Tec H2 0.3							
ID point	without silencer			with silencer			Silencer effectiveness in point U
	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	
U	121.9	144.5	155.3	101.3	120.2	130.7	$L_{Aeq,1s}$ 20.6 dB(A) L_{Amax} 24.3 dB(A) L_{Cpeak} 24.6 dB(C)
P1	116.4	137.6	150.2	110.8	136.7	148.7	
P2	116.3	136.5	147.4	102.0	125.2	136.3	
P3	111.9	133.7	143.8	86.3	107.1	115.5	
P4	102.8	123.3	132.6	82.9	101.1	109.2	
P5	100.7	121.1	128.2	80.0	96.1	102.7	
P6	103.0	125.2	135.6	82.6	102.3	111.6	
P7	113.0	131.9	142.7	86.2	106.6	116.2	
P8	116.1	136.4	146.6	102.2	126.5	137.7	

AR-15 DPMS Panther Arms carbine, cal. 223 Rem, silencer A-Tec AR 40-3							
ID point	without silencer			with silencer			Silencer effectiveness in point U
	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	
U	121.6	144.1	152.3	105.7	128.8	138.1	$L_{Aeq,1s}$ 15.9 dB(A) L_{Amax} 15.3 dB(A) L_{Cpeak} 14.2 dB(C)
P1	120.7	139.3	147.3	107.0	133.3	145.5	
P2	119.5	140.4	145.9	97.9	122.8	134.6	
P3	113.8	134.5	141.6	87.2	106.2	115.9	
P4	106.1	125.6	133.6	82.5	102.2	109.2	
P5	102.6	120.1	128.3	80.6	99.3	105.8	
P6	105.3	124.6	132.8	82.9	102.8	110.0	
P7	111.0	130.3	139.9	89.4	107.4	114.9	
P8	117.8	137.9	144.4	98.4	122.9	134.5	

Glock 45 pistol, cal. 9x19 Luger, silencer A-Tec PMM-6 M13.5x1 LH							
ID point	without silencer			with silencer			Silencer effectiveness in point U
	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	$L_{Aeq,1s}$	L_{Amax}	$L_{C,peak}$	
U	121.4	145.9	153.9	100.8	122.2	129.9	$L_{Aeq,1s}$ 20.6 dB(A) L_{Amax} 23.7 dB(A) L_{Cpeak} 24.0 dB(C)
P1	118.9	141.1	152.9	115.9	141.1	152.3	
P2	110.9	130.6	140.1	97.8	115.5	121.0	
P3	108.2	127.1	137.2	80.9	101.1	111.6	
P4	106.1	124.1	129.4	80.8	95.5	106.1	
P5	103.8	121.0	125.7	76.0	94.2	105.2	
P6	106.2	124.3	131.2	80.5	94.0	105.3	
P7	108.5	127.5	137.0	80.3	100.6	110.9	
P8	112.2	130.4	139.9	96.9	114.7	120.7	

The analysis of the presented results (at point U) has shown that the use of silencers allows for a reduction in the noise level at the shooter's ear, significantly reducing the shooter's exposure to harmful noise. In the case of silencers used on the bolt-action rifle and the pistol, a reduction of approximately 24 dB in the maximum transient sound level A and peak sound level C was achieved, along with a reduction of the average sound level A in 1 second by 20 dB. In both cases, this result is lower than the manufacturer's specified silencer performance, but it is entirely satisfactory for the shooter and allows for a clearly noticeable difference in the gunshot loudness. For the AR carbine silencer, a reduction in the average sound level of about 15 dB was achieved, however it is mainly due to the small size of the silencer used and the construction of the carbine itself.

During the conducted test shots, it was possible to notice that the spectral characteristics of the noise changed after using the silencer. The gunshot noise without a silencer contains many low and mid-frequency components (the noise itself is very unpleasant and penetrates the entire body), while after using the silencer, the mid and high-frequency characteristics clearly dominate, and the shot is softer and more ear-friendly. An example of the spectral characteristics of the noise is shown in Figure 5.

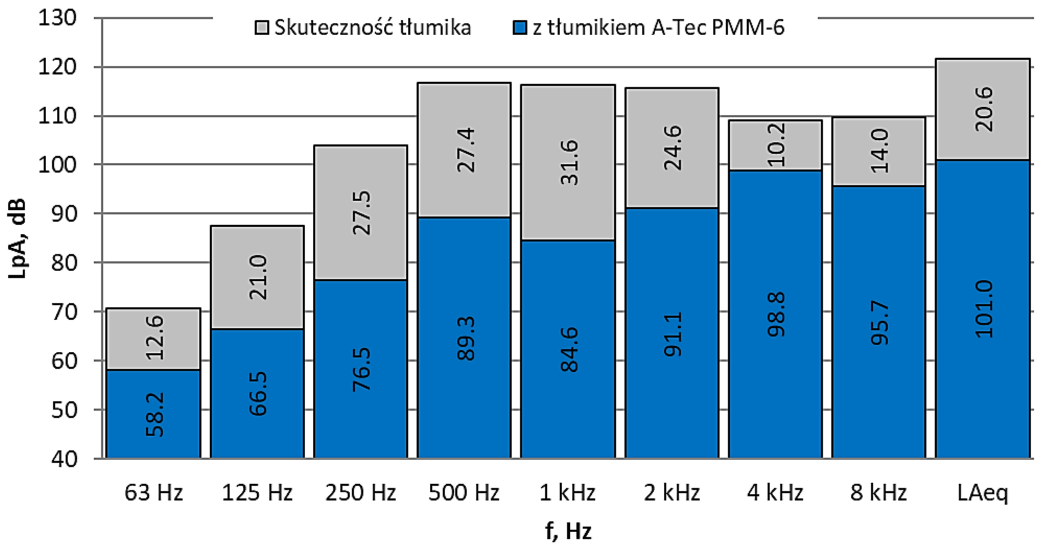

Figure 5. Spectral characteristics of noise while shooting a Glock 45 pistol.

A very important aspect of using silencers is that they also change the directional characteristics of the sound source from omnidirectional to highly directional, with the dominant direction being determined by the shooting direction. The decrease in sound level in the shooting direction is minimal, while in the opposite and perpendicular directions it is significant. An example of the directional characteristics obtained when shooting with the Ruger American Predator bolt-action rifle is shown in Figure 6, with the AR-15 carbine in Figure 7, and with the Glock 45 pistol in Figure 8.

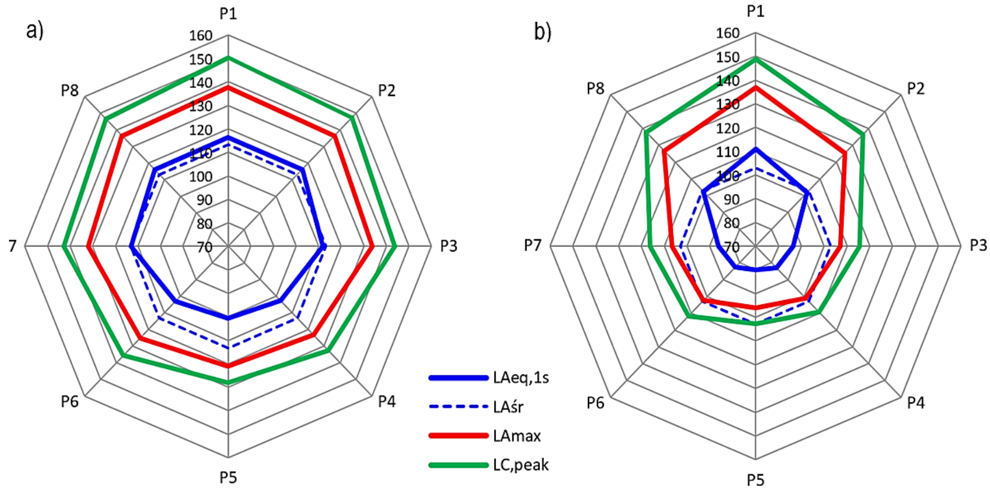

Figure 6. Directional characteristics of noise while shooting a Ruger bolt-action rifle (.308 Win): a) without a silencer, b) with an A-Tec H2 silencer.

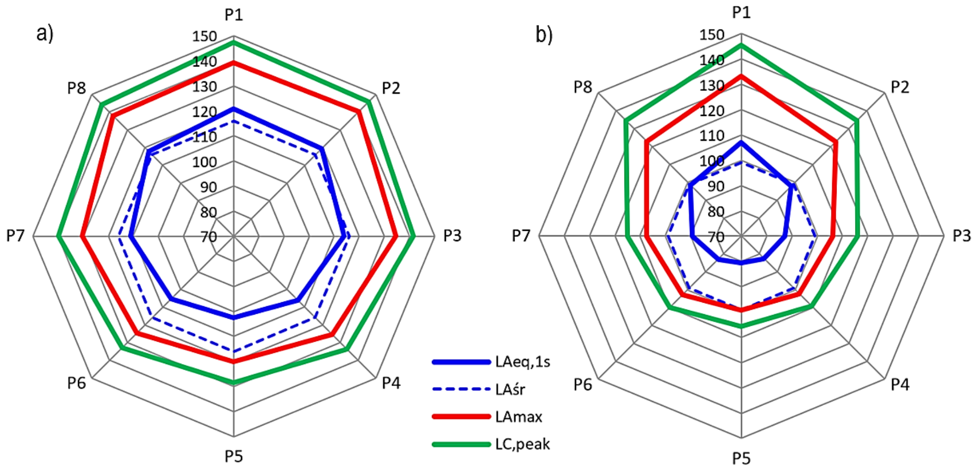

Figure 7. Directional characteristics of noise while shooting an AR-15 carbine (.223 Rem): a) without a silencer, b) with an A-Tec AR 40-3 silencer.

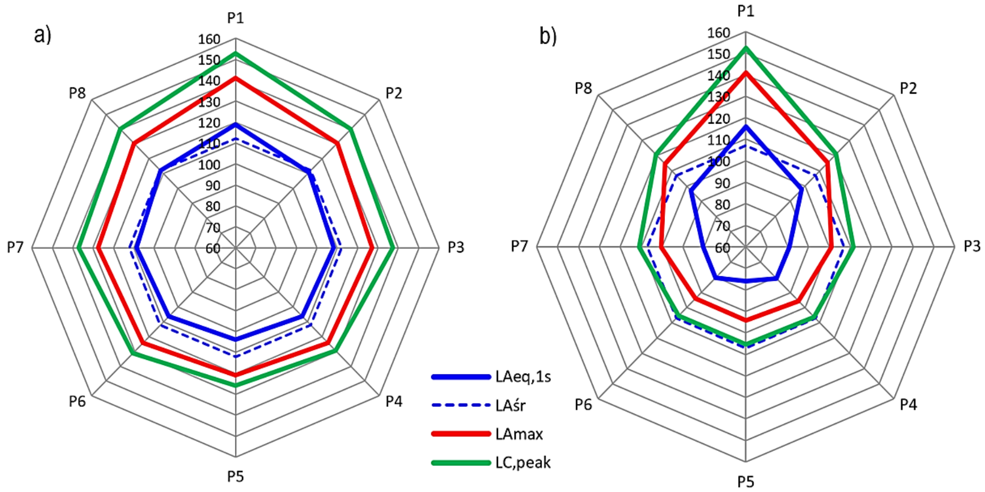

Figure 8. Directional characteristics of noise while shooting a Glock 45 pistol (9x19): a) without a silencer, b) with an A-Tec PMM-6 silencer.

A comparison of the obtained results of the change in sound source directionality during shots fired with different types of guns, with and without a silencer, is presented in Figure 9.

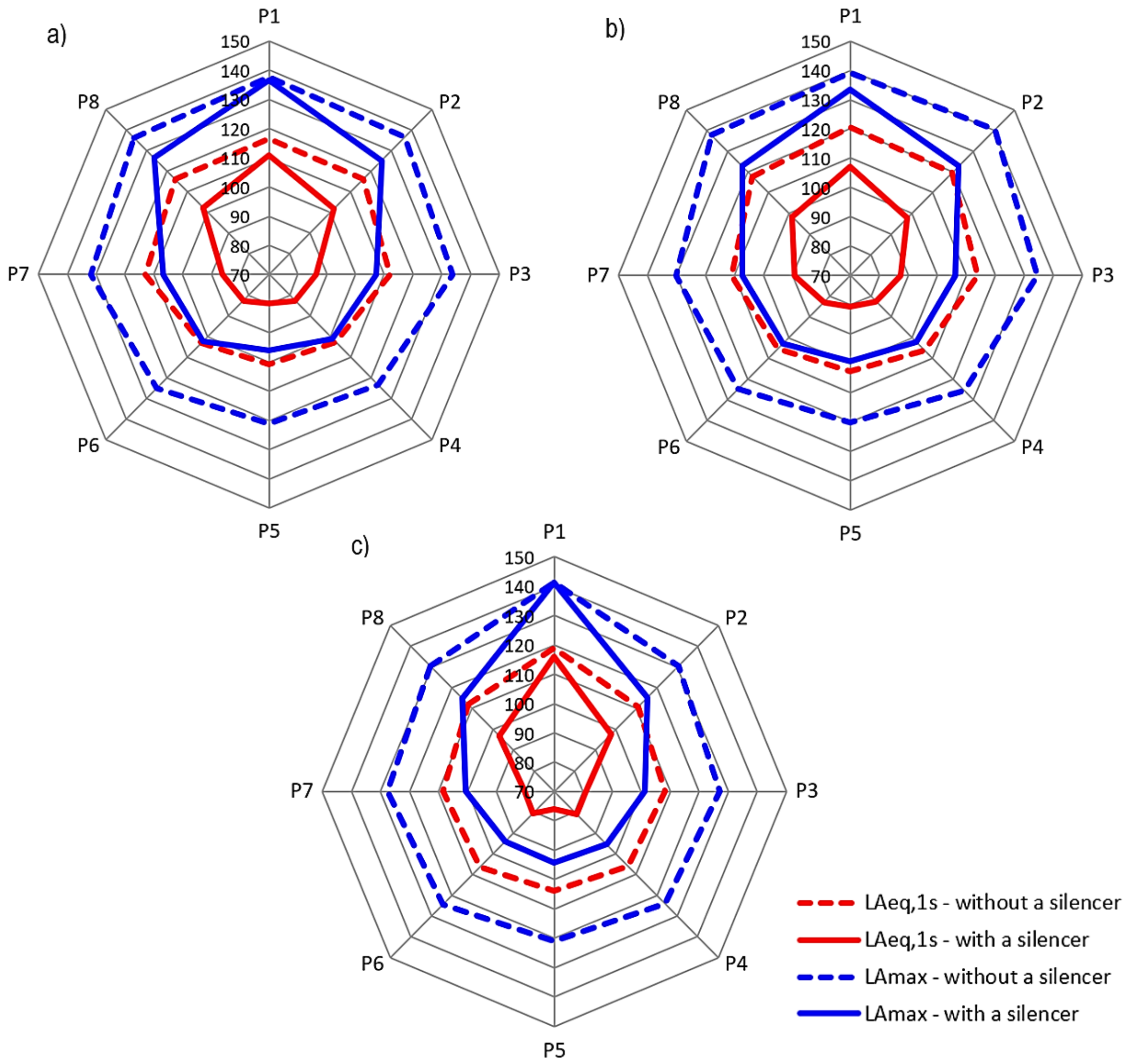

Figure 9. Comparison of directional noise characteristics while shooting with and without a silencer: a) Ruger American Predator bolt-action rifle in .308 Win caliber, b) AR-15 carbine in .223 Rem caliber, c) Glock 45 pistol in 9x19mm caliber.

In each of the analyzed and presented cases, a clear change in the directionality of sound propagation during the shot with the silencer was observed. A shot fired without a silencer has characteristics similar to a circular pattern shifted towards the shooting direction. In general it can be stated that in directions perpendicular to the shooting direction the sound level reduction is on average 10 dB, and in the opposite direction, it is 20 dB. After using a silencer, the gunshot noise propagates in a much more directional manner. In directions perpendicular to the shooting direction, the noise level is lower than the highest level by an average of 30-35 dB, and in the opposite direction, by 40-45 dB.

5. Conclusions

The obtained test results have allowed for determining the change in the directionality of gunshot noise after using a silencer and have provided a justification for using silencers during sports and hunting shooting. Due to the protection of the shooter's hearing and the protection of the external environment, especially the population residing in the immediate vicinity of shooting ranges, the use of such solutions should be required.

Unfortunately, the current Polish legislation, except for a few cases such as sanitary culling of animals to combat infectious diseases, does not permit the use of silencers, considering guns with silencers as particularly dangerous weapons. Among the public, there is often a belief that a shot with a silencer is inaudible, which is clearly untrue. Perhaps in subsonic calibers or sporting calibers like .22LR, significant noise reduction during a shot can be achieved, but it does not mean that it will be inaudible.

Understanding the directionality of the source during a shot is of paramount importance due to the possibility of a more precise assessment of the impact of noise on the external environment, especially using computational methods for noise propagation in the environment. This allows for a more accurate modeling of noise emission from shooting ranges, taking into account the placement of firing axis as well as the type and intensity of shooting.

Another critical aspect of knowing the directionality characteristics during a gunshot with a silencer is the potential for improving silencer construction. Currently, focus should be placed on reducing noise emission from the silencer in the direction of the shot, as there is a clear pattern of minimal attenuation in this area, with practically zero or very slight sound reduction. In contrast, highly satisfactory noise reduction results are achieved in the lateral and rearward directions relative to the shooter.

References

1. Boczkowski, A. (2020). *Acoustic modelling of sport and hunting shooting ranges in the aspect of shaping noise emissions into the environment. Monograph. Multidisciplinary aspects of production engineering. Engineering and Technology*. Warszawa, Sciendo, pp. 308-319.
2. Boczkowski, A., Adamski, M., Bień, J., Chwalny, K., Nosek, M., Paszek, P., Pisarska, M. (2020). Analysis of options to reduce noise exposure to shooters on sport shooting ranges. Multidisciplinary aspects of production engineering. In: P. Hąbek (ed.), *Multidisciplinary Aspects of Production Engineering, 2021, vol. 4.* Warszawa, Walter de Gruyter (Sciendo), pp. 330-342.

3. Branch, M.P. (2011). Comparison of Muzzle Suppression and Ear-Level Hearing Protection in Firearm Use. *Otolaryngology-Head and Neck Surgery. Vol. 144, Iss. 6*, pp. 950-953.
4. Gurdamar, O., Ozbektas, S., Sungur, B. (2023). Analysis of the Effect of Circular Ring Baffles in Suppressor on Flow Field and Far Field Noise Levels at 9 mm Semi-Automatic Pistol. *Defence Science Journal, Vol. 73, No. 5*, pp. 531-540.
5. Huerta-Torres, J.K., Verduzco-Cedeño, V.F., Flores-Herrera, L.A., Sandoval-Pineda, J.M. (2021). Numerical and Experimental Analysis of Sound Suppressor for a 5.56 mm Calibre. *Defence Science Journal, Vol. 71, No. 1*, pp. 12-17.
6. Kilikevičius, A., Giedraitis, V., Kilikevičiene, K., Matijošius, J., Selech, J., Buckiunas, G., Rucki, M. (2023). Performance Analysis of Different Gun Silencers. *Applied Science, No. 13*.
7. Konopka, W., Pawlaczyk-Łuszczyńska, M., Zalewski, P., Miłoński, J. (2002) Ocena i analiza środowiska akustycznego u żołnierzy narażonych na hałas impulsowy. *Medycyna pracy*, pp. 391-396.
8. Maher, R., Shaw, S. (2010). *Directional aspects forensic gunshot recordings*. AES 39th International Conference, Hillerød, Denmark, 2010 June 17-19.
9. Murphy, W., Flamme, G., Campbell, A., Zechmann, E., Tasko, S., Lankfort, J., Meinke, D., Finan, D., Stewart, M. (2017). The reduction of gunshot noise and auditory risk through the use of firearm suppressors and low-velocity ammunition. *International Journal od Audiology, Vol. 57. Iss., sup1: The River of Aural Serenity*.
10. Rusiecki, M. (2013). *Tłumiki do broni palnej*. Warszawa: PUW Roksana.
11. Sweeney, P. (2016). *Gun Digest Book of Suppressors*. E-book.