Understanding distance shooting and the type of firearm from the analysis of gunshot sounds

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Abstract

In order to study gunshot sounds, experimental shootings were conducted in an open shooting range to record the sound of gunshots. The results were tabulated for a total of 168 gunshots. Shots were fired using pistols, revolvers, submachine guns, rifles and shotguns in different calibres from selected distances relative to the recording devices. Both a conventional sound level meter (SLM) and a measurement microphone were used. These were placed at selected points behind the shooting position and the sound of each shot was recorded. At the same time, the signal received by the microphone was transferred to a computer connected through an appropriate audio interface with a pre-amplifier. The peak amplitude of the gunshot was calculated in the accepted engineering units (dB) of sound pressure level. The shortest distance for the recordings was 9.60 m and the furthest was 38.40 m. The experiment was carried out using the following calibres: 6.35 mm, 7.62 mm Tokarev, 7.65 mm, 9 mm Short, 9 mm Makarov, 9 mm Parabellum, .45 Auto, .22 LR, .32 S&W, .38 S&W, .38 Special, .357 Magnum, 7.62 mm Kalashnikov and 12 GA. A decrease of the peak amplitude, equivalent to the increasing of the distance, was observed as expected. Values appeared to follow the inverse square law. By analyzing a recorded gunshot sound it is possible to calculate the distance between that discharged firearm and the recording device. In addition, we noted the possibility of determining the sound amplitude of the gunshot coming from a certain type of weapon.

Keywords:

firearms, gunshot sound, decibel, distance, sound level meter.

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Introduction

The purpose of this study is to take measurements of gunshot sounds under close to real conditions in order to define and measure the change of the sound intensity relative to the distance. This was accomplished from the audio recording and the calculated peak amplitudes of the gunshot sounds. In addition, this study provided us with the opportunity to determine whether the type of firearm could be recognised from the sound of its gunshot.

The recording was done with a sound level meter (SLM) and the calculations were carried out using a microphone through the sound intensity, which is defined as the sound power per unit area as measured at a listener's location (Nave, 2009).

The most common approach to sound intensity measurement is to use the decibel scale which is logarithmic (Dater, 2002). The decibel (dB) units are based on the equation: the power to which 10 is raised to get x. The logarithm to the base 10 used in the equation is the power of 10 of the quantity (x) according to the basic definition of the logarithm. The factor of 10 multiplying the logarithm makes it decibels instead of bels, and is included because about 1 decibel is the just noticeable difference (JND) in sound intensity for the normal human ear.

Another consideration that prompts the use of powers of 10 for sound measurement is the rule of thumb for loudness: it takes about 10 times the intensity to sound twice as loud. Decibels provide a relative measure of sound intensity and measure the ratio of a given intensity (I) to the threshold of hearing intensity.

Methods and materials

The equipment consisted of the following devices, which were used for the experimental shootings:

- sound level meter (SLM), model 'CEL-440', with the 'CEL-250' electret microphone. The 'CEL-284/2/ England' calibrator was used for its calibration;
- measurement microphone, 'BERINGER model ECM800', Spezielle Studiotechnik GmbH/ Germany;
- audio interface, with pre-amplifier 'MOTU Ultralite'/England;
- a laptop (HP, model Compaq Presario/Intel Core 2 Duo);
- the 'Audacity-Win-1.2.6' and 'Pratt5032-winsit' software;
- digital Altimeter 'CANYON model CNS-DC2 Explorer', for the environmental conditions;
- digital Vernier Caliper 'Mitutoyo model CD-15DC'/(UK)Ltd/England;
- range finder 'LEICA model GEOVID 7 X 42 BDA'.

Shots were fired using various types of firearms (seven pistols, five revolvers, two submachine guns, one rifle and one shotgun) in different calibres, from selected distances relative to the recording devices. The firearms used and the respective ammunition for each calibre were the following (the barrel lengths for the firearms are written as they were measured and the brand, type of bullet and weight in grains/gr are written for the ammunition):

- semi-automatic pistol Walther, Model 8 (Germany) 6.35 mm (.25 auto) calibre, with barrel 7.375 cm (apr. 3 in.). Cartridge from 'GFL' (Italy), with FMJ bullet 50 grains (3.24 gr);
- semi-automatic pistol Tariq Ipak, licensed by 'Beretta' 7.65 mm (.32 auto) calibre, with barrel 8.985 cm (apr. 3.5 in.). Cartridge from 'Sellier and Bellot', with FMJ bullet 73 grains (4.75 gr);
- semi-automatic pistol Tokarev, TT33 (Russia) 7.62 mm Tokarev (7.62X25 mm) calibre, with barrel 11.582 cm (apr. 4.5 in.). Cartridge from 'Seller and Bellot', with FMJ bullet 85 grains (5.5 gr);
- semi-automatic pistol P. Beretta, Model 'MO1934' (Gardone V.T. 1937-XVI- Italy) 9 mm Short (.380 Auto) calibre, with barrel 8.650 cm (apr. 3.4 in.). Cartridge from 'MAGTECH' (USA), with FMC bullet 95 grains (6.15 gr);
- semi-automatic pistol Baikal 'AP 1631 1978' ('Izhevsky Mechanevsky' ex. USSR) 9 mm Makarov (9X18 mm) calibre, with barrel 9.340 cm (apr. 3.7 in.). Cartridge from 'Sellier and Bellot', with FMJ bullet 95 grains (6.10 gr);
- semi-automatic pistol Smith and Wesson, Model '5906' (USA-Springfield Mass.) 9 mm Parabellum (9X19 mm) calibre, with barrel 9.910 cm (apr. 4 in.). Cartridge from 'Sellier and Bellot', with FMJ bullet 124 grains (8 gr);
- semi-automatic pistol Colt 'M1911A1' (COLT'S PT.F.A. MFG.CO. USA), .45 auto calibre, with barrel 12.370 cm (apr. 4.9 in.). Cartridge from PMP (Pretoria Metal Pressings), with FMJ bullet 220 grains (14.26 gr);
- revolver Smith and Wesson, Model '34-1' (USA-Springfield Mass.) .22 LR calibre, with barrel: 5.025 cm (apr.2 in.). Cartridge from GFL (Italy), with lead bullet, ultrasonic;
- revolver Smith and Wesson, Model '30-1' (USA-Springfield Mass.), .32 SandW long calibre, with barrel 7.580 cm (apr. 3 in.). Cartridge from Remington (USA), with lead bullet, 88 grains (5.7 gr);
- revolver Smith and Wesson, Model '33-1' (USA-Springfield Mass.) .38 SandW calibre, with barrel 10.060 cm (apr. 4 in.). Cartridge from Magtech (USA), with LRN bullet 146 grains (9.46 gr);
- revolver LLAMA (Spain) .38 Special calibre, with barrel 5.365 cm 2.1 in.). Cartridge from Sellier and Bellot, with lead point bullet 158 grains (10.25 gr);
- revolver Smith and Wesson, Model '686-2' (USA-Springfield Mass.) .357 Magnum calibre, with barrel 10.477 cm (apr. 4 in.). Cartridge from Federal (USA), with semi wad cutter bullet 158 grains (10.25 gr);
- submachine gun Scorpion (ex-Yugoslavia) 7.65 mm (.32 auto) calibre, with barrel 11.200 cm (apr. 4.4 in.). Cartridge from Magtech, with FMC bullet 71 grains (4.60 gr);

- submachine gun Heckler and Koch, Model 'MP-5' (Germany, 'EBO'-Greece), 9 mm Parabellum (9X19mm) calibre, with barrel 22.4 cm (apr. 8.8 in.). Cartridge from Sellier and Bellot, with FMJ bullet 124 grains (8 gr);
- assault rifle (copy of type 56 /Albania, possibly) 7.62 mm Kalashnikov (7.62X39) calibre, with barrel 41.6 cm (apr. 16.4 in.). Cartridge from Sellier and Bellot, with FMJ bullet 123 grains (8 gr);
- semi-automatic shotgun Beretta Model 'ES 100' (Italy) 12GA calibre, with barrel 63.2 cm (apr. 25 in.). Cartridge from Jordan (Greece), with shot cells no 9 (35.5 gr).

Procedure

The experimental shootings were conducted in 2008, in an open shooting range, in the north-east of Athens. The altitude was measured to be 382 m (1253.28 ft) above sea level. During the shooting, as the environmental conditions were recorded, the temperature increased from 33.3 °C to 39.3 °C (91.94 °F to 102.74 °F), the humidity decreased from 45 % to 38 % and the barometric pressure remained almost constant from 990.6 to 991.1 mbar/hPa (equal to 0.978 atm).

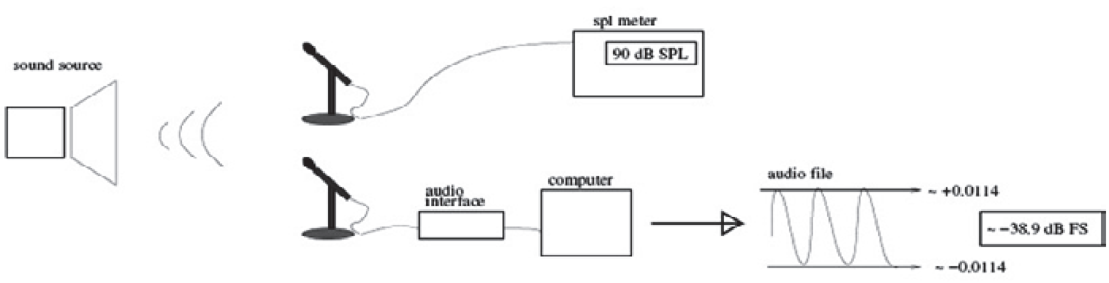
Both devices, the SLM and the measurement microphone were used.

They were placed at selected points behind the shooting position. The distances for the recordings were 9.60 m (31.5 ft), 14.40 m (47.25 ft), 19.20 m (63 ft) and 38.40 m (126 ft).

The calibration of the devices employed

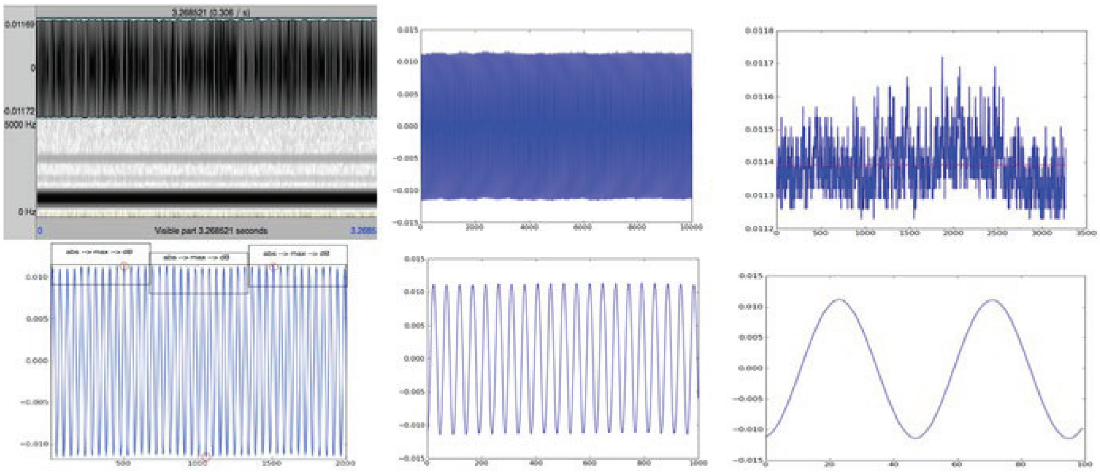
Before starting any measurements, it was necessary to calibrate the microphone associated with the sound level meter. This was done in the laboratory in order to avoid the possible interference of external sounds (Tsiatis, 2010). As shown in Diagram A, we ultimately produced a continuous sound, with a constant volume of 90 dB while the SLM remained stabilised.

Diagram A. — The procedure that followed is depicted: the calibration of the microphone associated with the sound level meter



As shown from the wave depiction (in Diagram B), when the SLM gives a sound intensity of '90 dB' in the audio file, this corresponds with a deviation of '0.0114 V', which is converted to '-38.9 dB (FS/full scale)'. According to this, the maximum peak of the wave depiction (recorded by the microphone) in '1', is equivalent in volume (90-(-38.9)) dB = 128.9 dB (Diagram B). In these (5) blue colour diagrams the voltage measurement appears on the yy axis and the time in msec. on the xx axis.

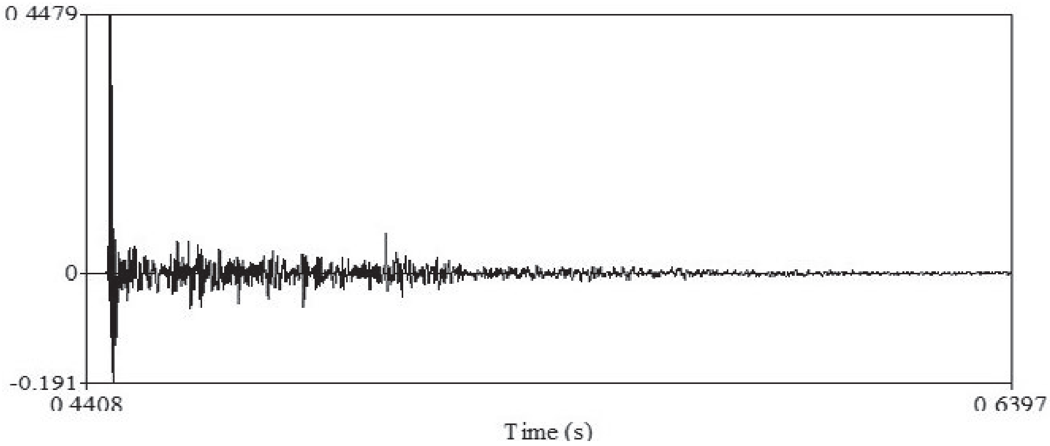
Diagram B — Sequential magnifications of the original wave depiction (visible part 3.268521 seconds).



Measurements and recordings

The sound of each shot was recorded by the SLM. The results were tabulated for a total of 168 gunshots. The average value for each set of shots by a particular firearm was calculated. At the same time, the signal for each gunshot received by the microphone was transferred to a connected computer through an appropriate audio interface with a pre-amplifier. Each sound wave was stored and depicted as a wave function (Diagram C).

Diagram C — Pistol 9 mm Makarov, fourth shot, from 19.20 m (63 ft), total time (xx axis): 198.9 msec., max of the peak (yy axis): 0.4479 V. Recorded gunshot sound from the SLM: 123.5 dB.



Since audible sound consists of pressure waves, one of the ways to quantify the sound is to state the amount of pressure variation relative to atmospheric pressure caused by the sound (Beranek, 1954, 1993). The standard threshold of hearing can be stated in terms of pressure and the sound intensity in dB can be expressed in terms of the sound pressure from the following equation (1):

$$I(dB)=10\log_{10}\left[\frac{I}{I_0}\right]=10\log_{10}\left[\frac{P^2}{{P_0}^2}\right]=20\log_{10}\left[\frac{P}{P_0}\right]$$

Where:
I0 = 1 pW/m2=10-12 W/m2, is the standard reference sound intensity, which is equivalent to the reference sound intensity level SIL= 0 dB. (Powell, Forrest, 1988).

P0 =2x10-5 Newton/m2: threshold of hearing (Hass, 2003).

The pressure, P, is to be understood as the amplitude of the pressure wave. The power carried by a travelling wave is proportional to the square of the amplitude. The factor of 20 comes from the fact that the logarithm of the square of a quantity is equal to two times the logarithm of the quantity. Since common microphones such as dynamic microphones produce a voltage which is proportional to the sound pressure, changes in sound intensity incident on the microphone can be calculated from equation (2): dI (dB) = 20 log10 [V2 / V1] (2)

Where (V1) and (V2) are the measured voltage amplitudes and (dI) gives the variation of the sound intensity in (dB) units.

Results

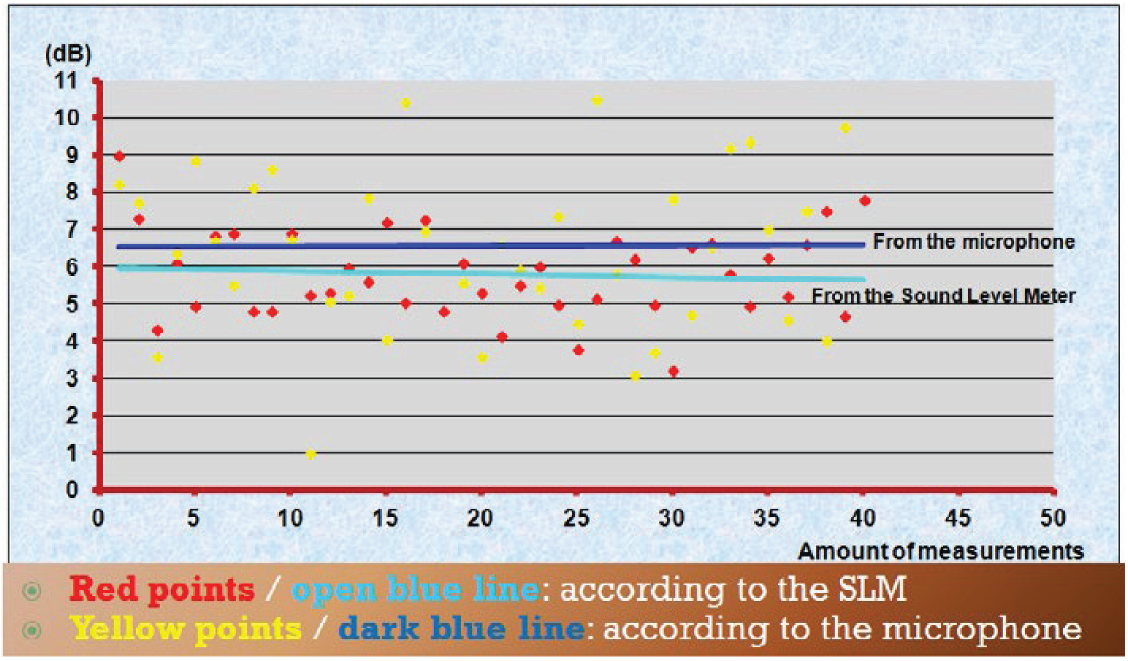
The shortest recording distance was 9.60 m (31.5 ft) =d. The next distance was 19.20 m (63 ft) =2d and for the furthest distance, 38.40 m (126 ft) =4d. The next step was to calculate the decreasing of the gunshots' sound intensities from d to 2d and from 2d to 4d. The results are shown in the following Table 1 and are depicted in Diagram D.

Table 1

Decrease in dB level with distance doubling (for all firearms used in the tests)

TYPE OF GUN / CALIBER		Derived from the Sound Level Meter		Derived from the Microphone	
		from d to 2d	from 2d to 4d	from d to 2d	from 2d to 4d
Pistol 6.35mm		6,1	4,67	11,62676399	4,023059387
Pistol 7.62mm TOKAREV		6,1	4,97	3,580653794	5,457293161
Pistol 7.65mm		4,94	3,76	6,372715908	7,391923353
Pistol 9mm SHORT		5,6	4,93	5,249248585	9,200935514
Pistol 9mm MAKAROV		7,2	6,24	7,880103206	9,393404581
Pistol 9mm Para		8,97	4,13	10,91138202	3,59843449
Pistol .45 AUTO		5,03	5,2	4,071345597	7,016220694
Revolver .22LR		5,3	7,8	5,603078472	9,793652905
Revolver .32 S&W LONG		4,8	7,5	6,972442461	7,530506363
Revolver .38 S&W		7,26	6,6	10,45155053	4,60105622
Revolver .38SPL		5,24	6,53	6,742177607	7,848551616
Revolver .357 MAG		5,3	6,64	0,990755622	4,737193786
Revolver .357 MAG (with cartridge .38SPL)		5,97	5,8	5,099718837	6,544444711
Submachine gun MP-5 9mm Parabellum	Single shots	7,3	5,5	8,238961234	6,611733968
	3-round bursts	4,3	6	7,759219255	5,917370808
Submachine gun SCORPION	Single shots	6,83	5,14	8,872326637	4,478183114
	3-round bursts	6,9	6,7	6,733453337	10,49201999
Assault Rifle 7.62mm Kalashnikov	Single shots	4,8	4,97	8,158351349	3,084281553
	3-round bursts	6,9	3,2	8,632749666	3,740469242
Semi-automatic shotgun 12 GA		4,8	6,2	5,522268365	5,816513895
AVERAGE :		5,982	5,624	6,973463≈ **6,973**	6,363≈ **6,364**
ERROR:		**0,266**	**0,268**	0,533830≈ **0,534**	0,45721≈ **0,457**

Diagram D — Decrease in dB level of the sound intensity, from both devices



Application of the inverse square law for the sound intensity

Over the distances employed in this study, the sound intensity from a point source of sound will obey the inverse square law if there are no reflections or reverberations. As a sound wave is transmitted in a spherical pattern, the sound energy is distributed over the ever-increasing surface diameter of the wave front surface. According to the inverse square law doubling of the distance from the sound source (in a free field situation), the sound intensity will drop by about 6 dB (Drumm, acc.2009). This acoustical phenomenon follows equation (3):

$$\frac{I_2}{I_1} = \left[\frac{d_1}{d_2}\right]^2$$

If we measure a sound level I1 (dB) at distance d1, then at distance d2, the inverse square law predicts a sound level I2 (dB), (Nave, 2009). It can also be calculated that 10 times the distance drops the intensity by 20 dB.

Fourier transform analysis for the sounds

Studying the wave depictions from the recorded gunshot sounds, we realise after their fast fourier transform (fft) analysis that there are similarities between gunshots produced from the same type of firearm and also differences when comparing gunshots produced from different types of guns. In the following diagrams one can indicatively see the results from fft. In these diagrams the frequency (Hz) is on the xx axis and the amplitude is on the yy axis.

Similarities between the same type of firearm

Comparing (i.e.) the following diagrams E-1 and E-2, we can observe the similarities between two shots from the same firearm (a semi-automatic pistol in 9 mm Parabellum) from the same distance.

Diagram E-1 — Semi-automatic pistol in 9 mm Parabellum calibre. Shot from a distance of 14.40 m (47.25 ft) in front of the recording microphone

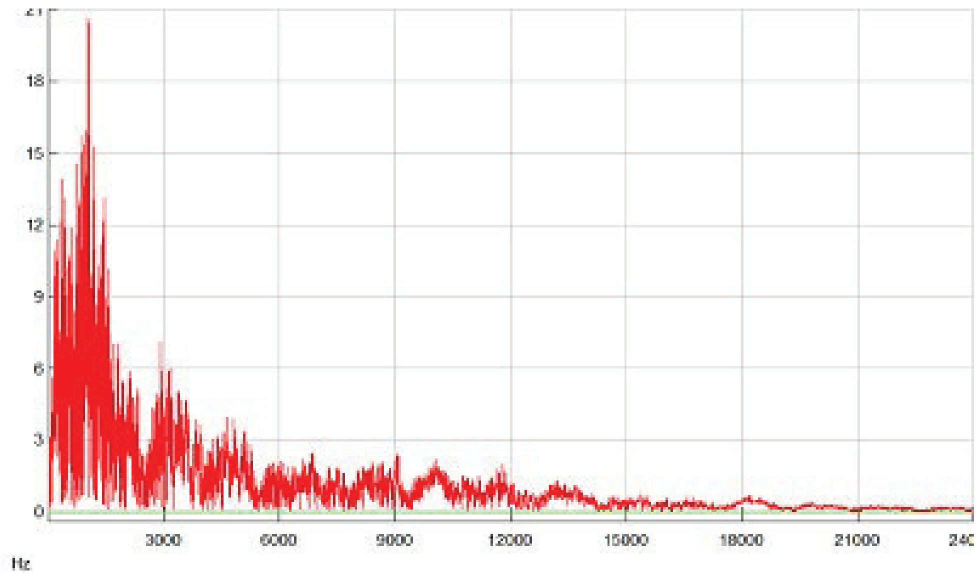
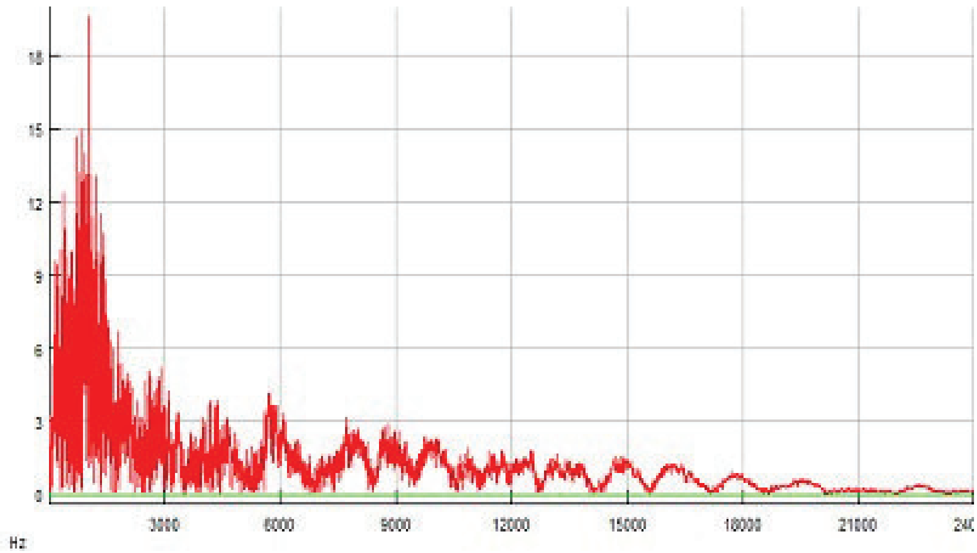


Diagram E-2 — Semi-automatic pistol in 9 mm Parabellum calibre. Another shot from the same distance 14.40 m (47.25 ft) in front of the recording microphone



Differences when comparing gunshots produced from different types of guns

Recorded gunshot sounds after their fast fourier transform (fft) analysis show differences after comparing gunshots produced from different types of guns, as it appears for instance, in diagrams F-1 and F-2, between a revolver in .38 SandW calibre (F-1) and a revolver in .22LR (long rifle) calibre (F-2) for two shots from the same distance (19.20 m (63 ft) in front of the recording microphone). In these diagrams the frequency (Hz) is on the xx axis and the amplitude is on the yy axis.

Diagram F-1 — Revolver in .38 SandW calibre. Shot from a distance of 19.20 m (63 ft) in front of the recording microphone

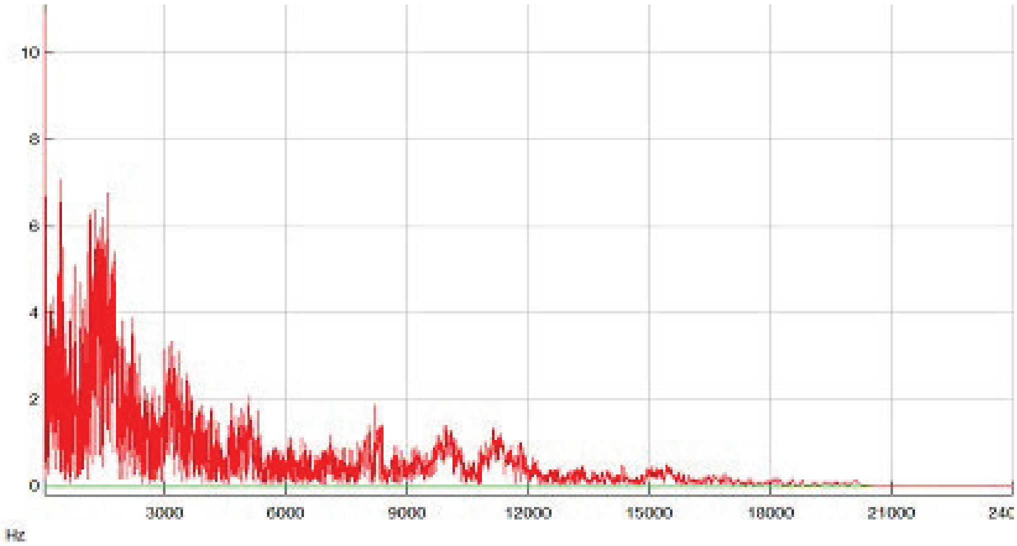
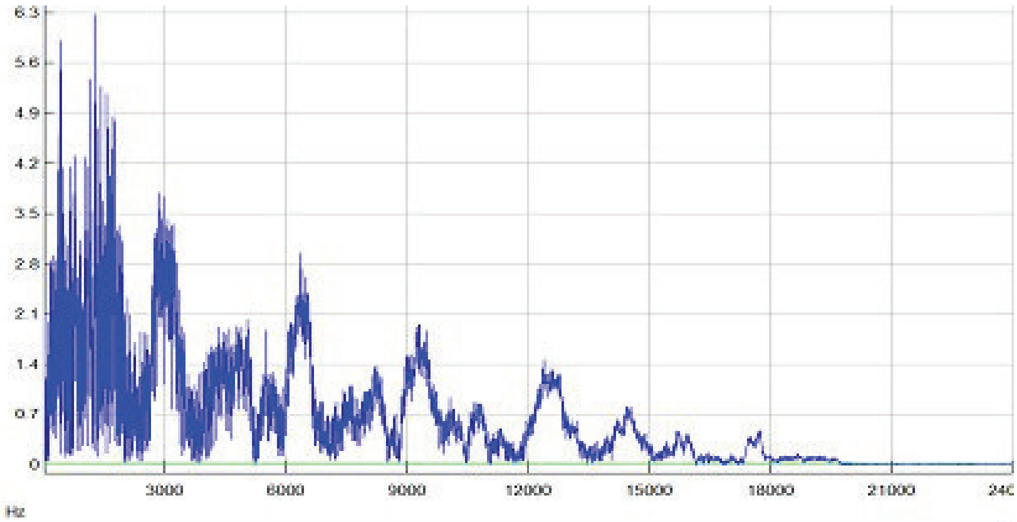


Diagram F-2 — Revolver in .22LR (long rifle) calibre. Shot from the same distance 19.20 m (63 ft) in front of the recording microphone.



Discussion

During these experimental shootings, we tried to simulate real conditions, supposing that somebody who fires a handgun is in a standing position, holding the handgun with the hands forward, with a gun height from 1.60 m (5.25 ft) (for pistols and revolvers) to 1.25 m (4.1 ft), (for submachine guns, rifles or shotguns).

The person taking the measurements was positioned directly behind the shooter with the measuring device at a nominal height of 1.2 m (4 ft), (in Dater, 2000 a height of 1.6 m above ground is mentioned). It should also be mentioned that the test area was not completely flat. Some obstacles existed in the field.

The total variation of the sound intensity (dI) was calculated (as the estimated value on average) by equation (4), (Papageorgopoulos, 1994):

$$x = \frac{\sum \frac{\overline{x_k}}{\sigma^2\left(\overline{x_k}\right)}}{\sum \frac{1}{\sigma^2\left(\overline{x_k}\right)}}$$

Where xk : average values, σ(xk) : standard deviation of xk, k = 1, 2, 3, …N (N= the amount of measurements)

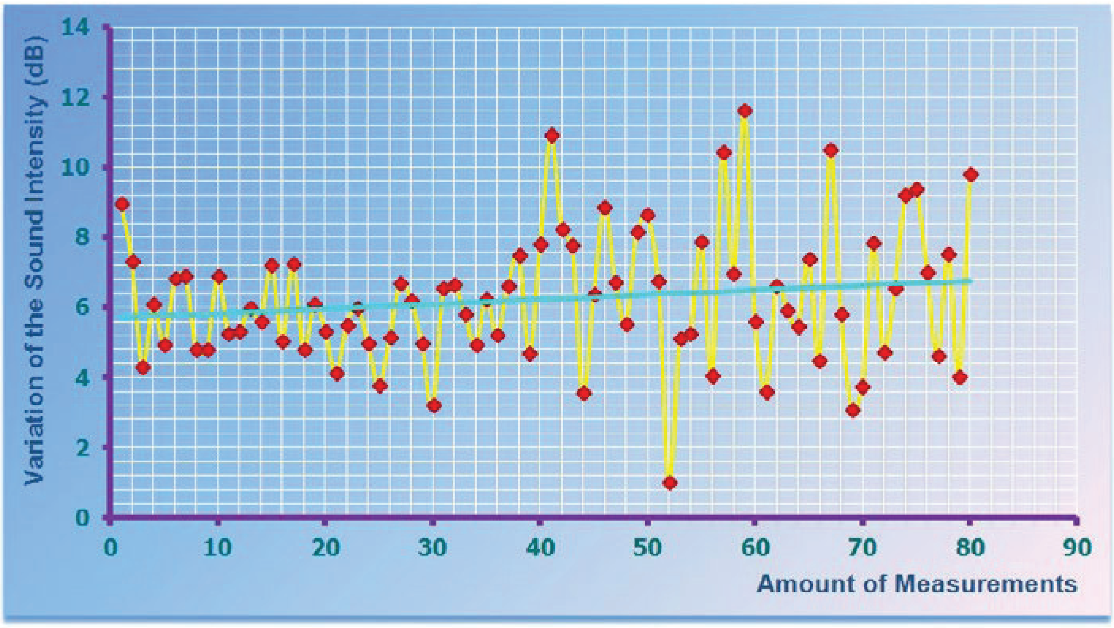
and its standard deviation (Sx) was calculated by equation (5):

$$S_x = \pm\left[\frac{\sum \frac{\left[\left(\overline{x_k}\right) - x \right]^2}{\sigma^2\left(\overline{x_k}\right)}}{(N-1)\sum \frac{1}{\sigma^2\left(\overline{x_k}\right)}} \right]^{\frac{1}{2}}$$

Where x: the value calculated from equation (4), xk : average values, σ(xk) : standard deviation of xk, k = 1, 2, 3, …N, N= the amount of measurements.

For every doubling of the distance from the sound source, the sound intensity diminished by dI= 5.9904±0.2325 decibels (on average).

Diagram G — Total calculated variation of the sound intensity



Applications

We have taken the measurements from the SLM for the peak values for the sound intensity for gunshots from the nearest distance d=9.60 m (31.5 ft). Decreasing (d) by half four times, we will have a calculated increase of dB level equal to 23.96 dB, approaching the source at 0.60 m (2 ft) (Table 2).

Table 2

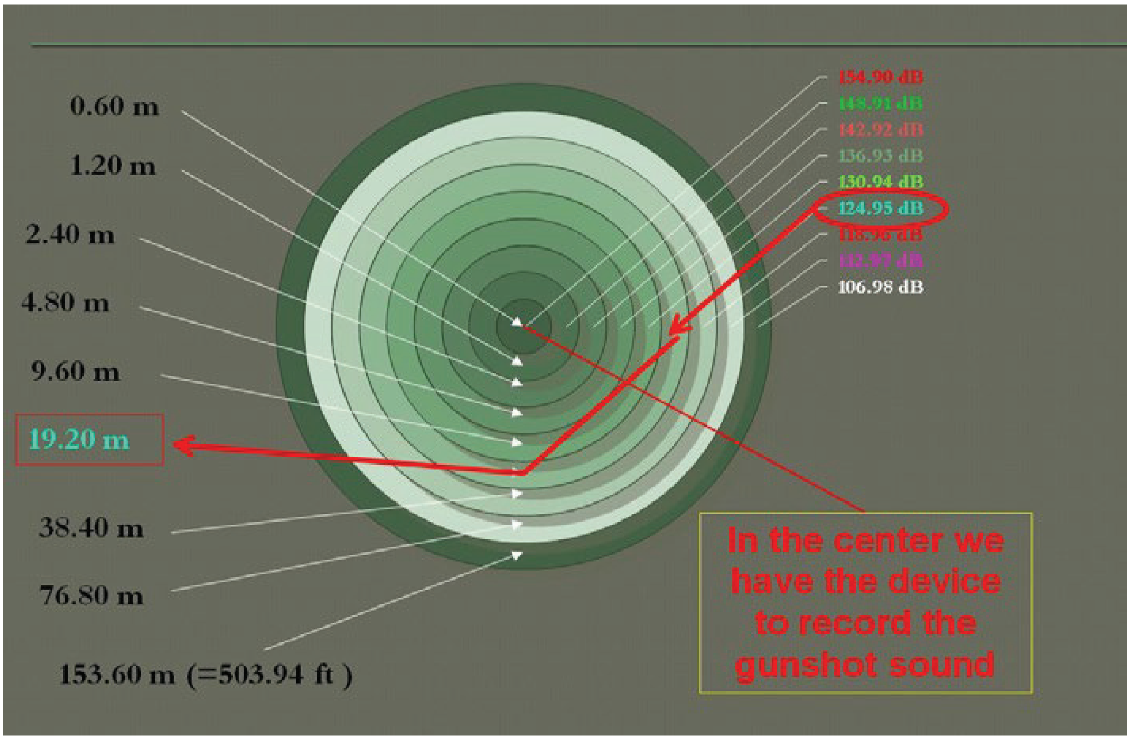
Gunshot sounds (dB) for all guns used from SLM 0.6 m behind gun

Type of gun	Pistol 9 mm Para	Pistol 7.62 mm Tokarev	Pistol . 32 Auto	Pistol .380 Auto	Pistol Makarov	Pistol .45 Auto	Pistol .25 Auto
Gunshot sound (dB)	154.9	154.4	152.2	154.9	154.1	156.9	149.2
Type of gun	Revolver .38SPL	Revolver .357MAG	Revolver .357 MAG with ammo .38 SPL		Revolver .38 SandW	Revolver .32 SandW L	Revolver .22LR
Gunshot sound (dB)	154.9	161.9	156.7		149.7	148	148
Type of gun	Shotgun 12GA	Submachine gun Scorpion .32 Auto		Submachine gun MP-5 9 mm Parabellum		Assault Rifle AK47 7.62 mm Kalashnikov	
Gunshot sound (dB)	154.5	single shot 154.7	burst 154.1	single shot 149.1	burst 148.7	single shot 153.6	burst 154.7

Calculation of the distance from a discharged firearm

A further application could be the calculation of the distance from a discharged firearm if one has access to a suitable audio recording. For example, we can calculate the distance from a 9 mm Parabellum semi-automatic pistol (Diagram H), as well as for any other type of gun from those we used in the tests (experimental shootings) by the same method.

Diagram H — Calculation of the distance from a discharged pistol in 9 mm Parabellum calibre



A suggestion about comparing gunshot sounds from two firearms

The idea is based on a Matlab code, which was produced by Dr Mahesha MG to record sound and displays the wave form in both time domain and frequency domain (Mahesha, 2012).

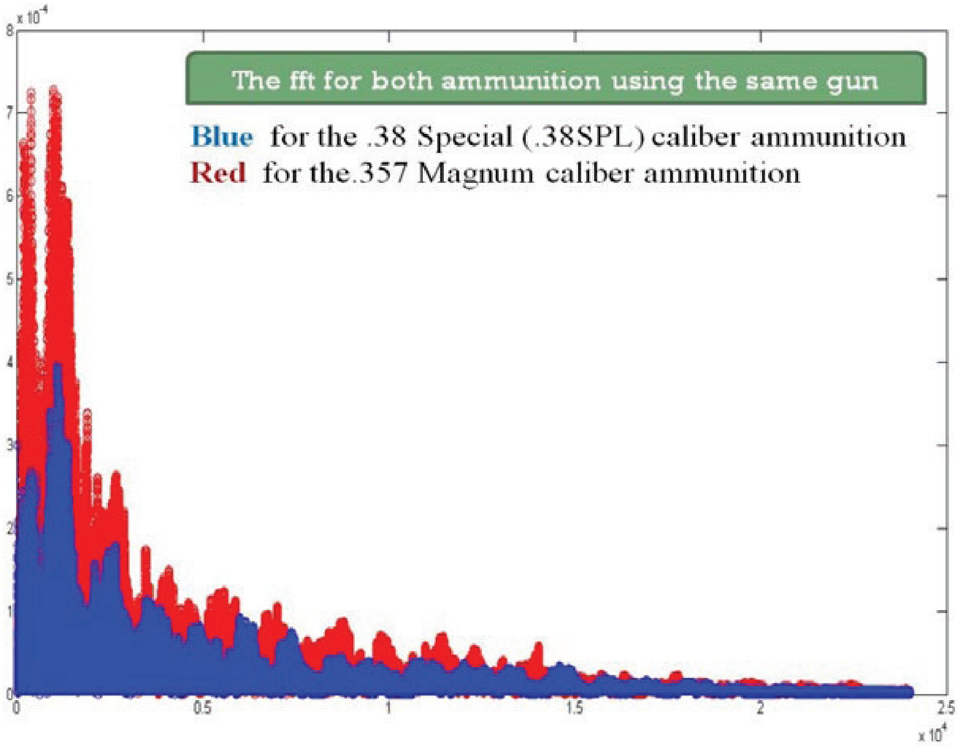
Through a fast fourier transform code in Matlab we can input two (2) recording gunshot sound depictions (in a .wav file format) and compare them.

It is acceptable that there are several different factors that stand to influence the dB level of a gunshot. Included among these factors are the length of the gun barrel (the shorter the barrel, the louder the sound), the powder charge in the ammunition and the speed/direction of any wind at the time of the shot. So an application could be the next example (Tsiatis, 2013): we recorded the gunshot sounds (dB) for a SandW revolver in .357 Magnum calibre, using two different ammunition (.357 Magnum/.38 Special) for the distances: 9.60 m (31.5 ft)/14.40 m (47.25 ft)/19.20 m (63 ft)/38.40 m (126 ft). The results were as follows:

- .357 Magnum calibre: 137.9/134.25/132.6/125.36
- .38 Special calibre: 132.7/126.15/126.73/120.93.

By using the above-mentioned fast fourier transform code in Matlab for the shots from 14.40 m (47.25 ft) we have the following results (Diagram I):

Diagram I — The fft depicts the single-sided amplitude spectrum of y(t). On the xx axis there is the frequency (Hz) and on the yy axis there is the amplitude (/Y(f)/)



As it appears, the powder charge in the ammunition stands to influence the dB level of a gunshot. The .357 Magnum is higher in powder charge than the .38 Special.

An aim originating from this study is for further data to be collected using other types of firearms, different brands of ammunition and bullet types. In addition, a further operation could be the creation of a database with .wav files including sound wave depictions and their mathematical analysis according to the fast fourier transform.

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