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Gunshot acoustics: pistol vs. revolver

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ABSTRACT

Audio forensic investigations may require interpretation of recordings containing gunshot sounds. These sounds are notable because of their impulsive nature: very high sound pressure and very short duration compared to other sounds relevant to forensic analysis. In this paper we examine the acoustical characteristics of muzzle blast sounds from two handguns: a Glock 19 pistol and a Ruger SP101 revolver. The muzzle blast sound of each handgun was recorded at several azimuth angles between 0 and 180 degrees with respect to the barrel using a quasi-anechoic methodology. Compared to the pistol, the revolver exhibits a more complicated acoustical pattern due to sound emanation from two sources: the cylinder-barrel gap and the muzzle.

1 Introduction

Gunshots are among the acoustical signals that may be of interest in audio forensic investigations. Gunfire may be recorded by an emergency call center as part of a telephone conversation, a dashboard or vest camera used by a law enforcement officer, a surveillance system at a business or private residence, or a bystander or newsgathering team with a cell phone or camcorder at the scene of an incident. Audio forensic questions for gunshot recordings include determination and/or corroboration of the sequence of events before, during, and after the shots, the shot timing, firearm position, type of firearm, and frequently the question of “who shot first?” when multiple shots have been recorded [1, 2].

Gunshot sounds present a challenge for recording and forensic interpretation. The very high peak sound levels, especially near the firearm, often overload the recording microphone and preamplifier, resulting in clipped and distorted waveforms. Even in the situation in which the recording system is sufficiently far away from the firearm so that the recorder is not overloaded, the recording will generally contain a mixture of the direct sound of the gun and reflections and reverberation from the acoustical surroundings. What’s more, many contemporary surveillance recording systems use digital data compression algorithms that may be optimized specifically for speech intelligibility and general audio purposes, but not for the very brief and high amplitude sound characteristics of nearby gunfire.

For these reasons, the common forensic audio questions about the type of firearm and “who shot first?” can be very difficult to answer because of the limitations of the recording. Thus, experiments under controlled conditions are needed.

In order to study the acoustical characteristics of the gunshot sound itself without interference from the reflections and reverberation of the environment and from the distortion and other limitations of the recording system, for research purposes we have developed a quasi-anechoic recording methodology. The procedure involves elevating the firearm and the recording microphones in an open outdoor area so that the firearm's muzzle blast can be recorded in its entirety before the first reflection (from the ground) arrives at the microphone [3, 4].

Distinguishing among different firearms based upon the gunshot sound is only possible if there are distinctive acoustic features the distinguish one shot from another. Our recent research using carefully-controlled gunshot recordings is starting to reveal the subtleties of these details.

2 Gunshot acoustics

A conventional firearm uses an ammunition cartridge consisting of a projectile mounted in a shell casing containing the primer and propellant material. The cartridge is positioned at the back end of the gun barrel and the gun's trigger mechanism causes a firing pin to strike the cartridge, igniting the primer material, and rapidly combusting the propellant. The ignited propellant creates heat and expanding gases that accelerate the projectile through the gun barrel and out of the firearm's muzzle. The high pressure gas and combustion debris emerges out of the barrel behind the projectile, causing the acoustical 'bang' referred to as the *muzzle blast*. The muzzle blast sound, lasting only a few milliseconds, propagates outward in all directions with highest sound levels typically observed in the direction that the firearm is pointing [5, 6].

3 Handguns: pistols and revolvers

Handguns are firearms designed to be operated with one hand: the gun has a hand grip, trigger, barrel, and mounted ammunition, and is fired by grasping the handle, pointing the gun, and pulling the trigger. Many modern handguns are repeating guns, meaning that they have multiple rounds of ammunition stored in an integral compartment or magazine that can be fired successively without manual reloading. Some repeating handguns are *semi-automatic*, which means the gun has a mechanism that automatically ejects a spent shell casing and positions a new round in the firing chamber after each pull of the trigger, without a manual cocking mechanism. Each pull of the trigger for a semi-automatic firearm shoots one bullet.[1]

There are two common types of repeating handguns that differ in the manner in which the ammunition is positioned into the firing chamber: pistols and revolvers. We use the term *pistol* (Fig. 1) to refer to a handgun that has a single firing chamber positioned at the back of the handgun's barrel, and *revolver* (Fig. 2) to refer to a handgun with a cylinder containing multiple firing chambers that are rotated into position behind the barrel for each shot.

Figure 1: An example pistol (Glock 19).

Figure 2: An example revolver (Ruger SP101).

[1] A *fully automatic* firearm shoots a rapid succession of bullets as long as the trigger is held down (i.e., a "machine gun").

Among the differences between pistols and revolvers is the manner in which the firing chamber connects to the gun barrel. A pistol typically has a closed chamber so that the expanding combustion gases are confined within the gun and the barrel until emerging from the muzzle. A revolver, with its multiple chambers rotated into position for firing, has a small gap between the firing chamber and the gun barrel at the point where the rotating cylinder and the back of the gun barrel meet (Fig. 3). Although designed to be small, the gap is often sufficiently large that some of the high pressure combustion gases leak out from the cylinder-barrel gap and cause a separate sound report before the muzzle blast [5]. The time interval between the report from the gap and the report from the muzzle is the ~200 microseconds required for the bullet to travel from the firing chamber to the muzzle.

Figure 3: Gap between cylinder and barrel for a revolver.

4 Gunshot recordings

To investigate the acoustical differences between gunshots from a typical contemporary pistol and a revolver, we obtained carefully-controlled recordings of a Glock 19 pistol and a Ruger SP101 revolver using the quasi-anechoic methodology described in our prior studies [3, 4].

Twelve microphones are located on a mounting rig of 3 meters radius surrounding the shooting position (Fig. 4).The microphones are G.R.A.S. type 46DP microphone sets, consisting of type 40DP 1/8" diaphragm 200 volt externally polarized condenser capsules, type 26TC ¼" preamplifiers, and type 12AA and 12AG power modules providing the 200 volt polarization and 120 volt preamplifier power.

The microphones provide ±2dB frequency response to 140 kHz, with dynamic range specification between 46 dB lower limit and 178 dB upper limit (132 dB dynamic range). A multichannel 16-bit digital audio recorder (500 kHz sampling rate per channel, National Instruments NI PXIe-1071 chassis equipped with a NI PXIe-8840 Core processor and NI PXIe-6358 data acquisition card) simultaneously records each microphone. The firearm shooting position is at the center of the microphone arc.

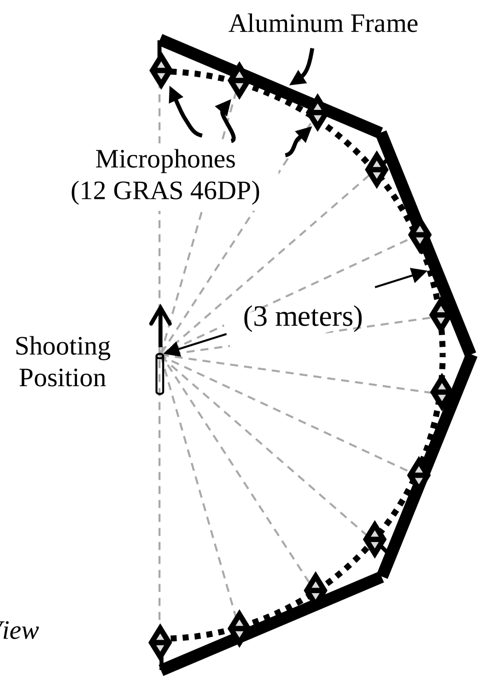

Figure 4: Microphone mounting frame surrounding the shooting position. The frame holds 12 GRAS 46DB 1/8" diaphragm microphones 3 meters from the shooting position and 3 meters above the ground.

Figure 5: Handgun data collection using the multichannel recording system at the shooting range.

As shown in Figure 5, the shooting platform and the microphone rig are both elevated 3 meters off the ground of the shooting range. This provides a sufficient time delay between the arrival of the direct sound at the microphones and the arrival of the first reflected sound from the ground, ensuring that the entire muzzle blast is recorded anechoically [3].

Ten test shots were recorded for both the Glock 19 pistol and the Ruger SP101 revolver. The ten shots were examined for consistency and repeatability [7].

5 Glock 19 pistol

Figure 6 shows an example of the quasi-anechoic signal recorded on-axis for the Glock 19 pistol. The waveform shows a sudden onset as the muzzle blast sound arrives at the microphone, including an impulsive peak attributable to the abrupt pressure disturbance emitted by the muzzle. The acoustic pressure declines and inverts rapidly with a secondary positive spike before returning to the ambient background pressure within about 2 milliseconds of the onset.

The quasi-anechoic pressure waveform recorded to the side of the firearm is shown in Figure 7 (98 degrees azimuth). The waveform is lower in amplitude than the on-axis report, but has similar general characteristics and duration.

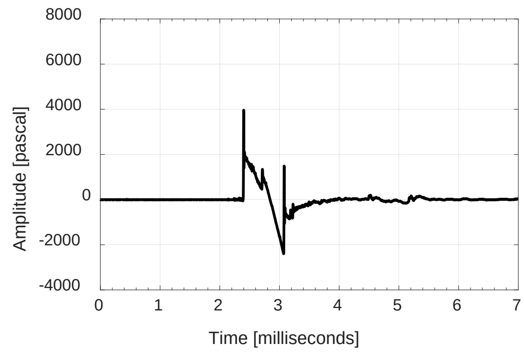

Figure 6: Glock 19 pistol waveform, on-axis (0° azimuth), 3 meters.

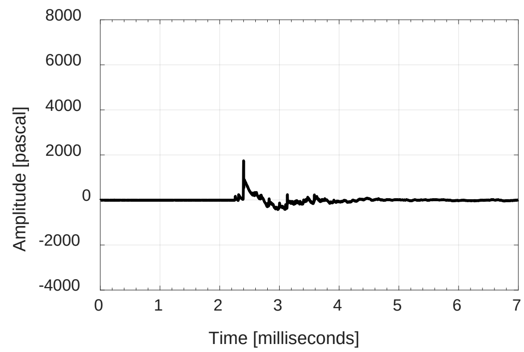

Figure 7: Glock 19 pistol waveform, 98° azimuth, 3 meters.

The Glock 19 waveforms as a function of azimuth are shown in Figure 8. The muzzle blast signatures differ with azimuth, primarily reflecting the directionality of the sound source: the level in front of the firearm (low azimuth angles) is higher than the level as the azimuth increases.

6 Ruger SP101 revolver

The Ruger revolver produces an on-axis sound waveform that is similar to the Glock 19 pistol, but exhibits a higher peak sound pressure and slightly longer duration. The on-axis waveform is shown in Figure 9.

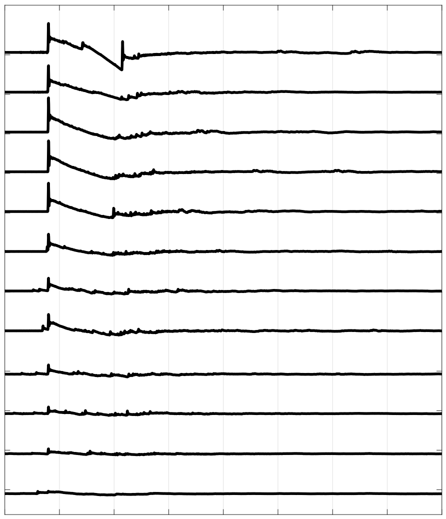

Figure 8: Glock 19 pistol waveforms as a function of azimuth, 3 meters.

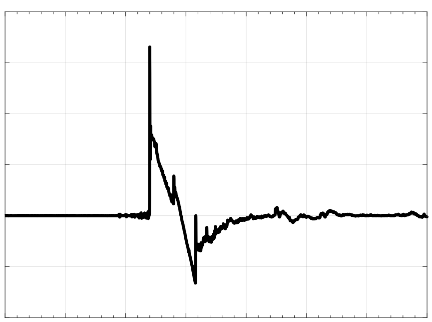

Figure 9: Ruger SP101 revolver waveform, on-axis (0° azimuth), 3 meters.

The quasi-anechoic pressure waveform recorded to the side of the revolver is shown in Figure 10 (98 degrees azimuth). The waveform is lower in amplitude than the on-axis report, and shows two distinct peaks in the recorded signal that are attributable to the sound emanating from the cylinder/barrel gap and the muzzle.

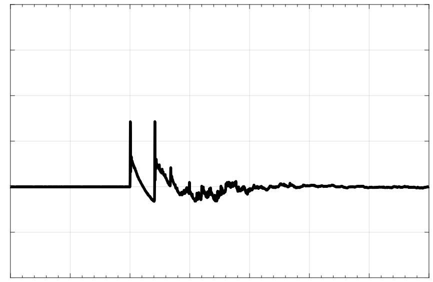

Figure 10: Ruger SP101 revolver waveform, 98° azimuth, 3 meters.

The Ruger SP101 waveforms as a function of azimuth are shown in Figure 11. The muzzle blast signatures differ with azimuth, and in particular, the secondary sound arrival due to the muzzle and the cylinder gap are quite visible, especially in the off-axis azimuths 82°, 98°, and 115°. The relative timing between the sound emanating from the gap and the sound emanating from the muzzle depends upon the length of the barrel, the speed of the bullet, and the orientation and distance with respect to the microphone.

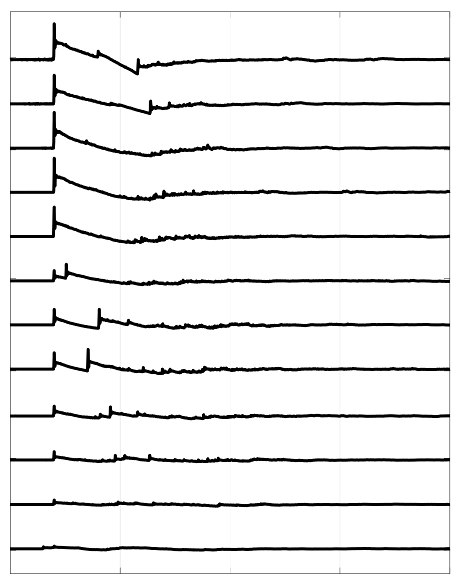

Figure 11: Ruger SP101 revolver waveforms as a function of azimuth, 3 meters.

7 Discussion

This observation of pistol and revolver waveforms indicates that under certain circumstances the firearms may be distinguishable because of the sound emanating from the cylinder/barrel gap. Specifically, if the position of the recording microphone with respect to the firearm results in a different time-of-arrival of the gap blast and the muzzle blast, the revolver may be distinguished by this feature [5].

In this experiment, the SP101 model 5719 revolver was chambered for .357 Magnum cartridges, and had a barrel length of 3 inches (7.62 cm). The estimated muzzle velocity was 335 m/s. While the acceleration profile of the bullet is not known, the time interval for a bullet to travel the 7.62 cm length of the barrel at 335 m/s is 227 microseconds. Thus, we expect the time interval between the sound emerging from the cylinder/barrel gap at the back end of the barrel and the sound emerging from the muzzle is at least 227 microseconds. The air temperature during the experiment was approximately 7 C, giving an estimated 335 m/s speed of sound.

Using the experimental conditions, firearm characteristics, and the geometry of the microphone array, it is informative to predict the relative timing between the gap sound and the muzzle sound as a function of azimuth.

7.1 Azimuth near 0°

The speed of sound and the speed of the bullet are approximately the same, meaning that the sound from the gap travels outward through the air in all directions and arrives at the muzzle of the revolver at roughly the same time as the bullet. This leads to the expectation that the gap sound and the muzzle blast sound will roughly coincide in the direction the muzzle is pointing (azimuth 0). This expectation is borne out in the recording (Figure 9).

7.2 Azimuth near 90°

To the side of the firearm, the microphone is approximately equidistant from the cylinder/barrel gap and the muzzle. Therefore, the sound emanating from the gap has approximately a 227 microsecond lead over the sound emanating from the muzzle, and we would expect that the microphone would receive the two impulses with a corresponding time delay.

The two impulses can be observed in Figure 10 for the 98° azimuth, and compared in Figure 11 for the 82°, 98°, and 115° azimuths.

7.3 Azimuth near 180°

To the rear of the firearm, the geometry is such that the sound from the gap is expected to lead the sound from the muzzle by approximately 454 microseconds: the muzzle blast starts about 227 microseconds after the gap impulse, but the muzzle is 3 inches farther than the gap with respect to a microphone to the rear of the shooter, so the muzzle sound must travel that additional distance, requiring another 227 microseconds. Thus, at azimuths behind the firearm the timing difference between the gap and the muzzle impulses is expected to approach half a millisecond.

The expected timing is depicted in Figure 12 [5].

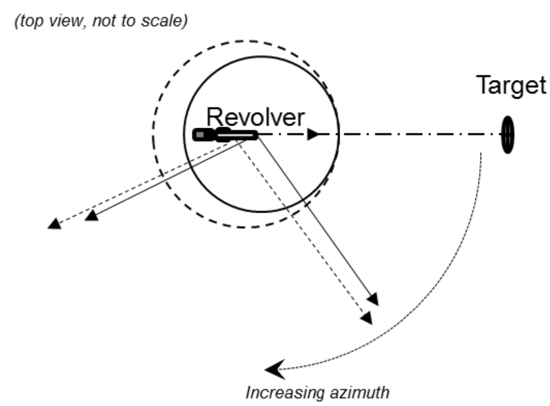

Figure 12: Understanding the timing difference between gap and muzzle impulses as a function of azimuth. Circles depict wavefront position for sound emanating from gap (dashed line) and from muzzle (solid line), taking into account the time delay between these sounds. The time delay at the microphone increases with azimuth.

8 Conclusions

This paper has described our empirical study of the differences between pistol and revolver gunshot sounds as a function of azimuth. The principal area of interest is the potential presence of two sound impulses in the revolver recordings: an impulse from the cylinder/barrel gap, and an impulse from the muzzle. These differences are detectable in our experimental recordings obtained under quasi-anechoic conditions, and the expected timing differences calculated from the geometry and estimated speed of the bullet in the barrel and the local speed of sound appear to match the observed timing in the recordings.

9 Acknowledgements

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