Audio Engineering Society

Conference Paper 9

Presented at the AES 8th International Conference on Audio Forensics
2024 June 27-29, Denver, Colorado, USA

Examining tell-tale sounds in forensic gunshot recordings

Robert C. Maher

Electrical and Computer Engineering, Montana State University, Bozeman, MT 59717-3780

Correspondence should be addressed to `rmaher@montana.edu`

ABSTRACT

This paper describes some practical aspects for forensic analysis of tell-tale sounds in gunshot audio recordings. Gunshot recordings obtained from a microphone located sufficiently close to the scene of the shooting incident have the potential to reveal relatively quiet sounds associated with the firearms' mechanical action: trigger, hammer, and cocking mechanism, the ejection of spent cartridges, and the positioning of new ammunition by the gun's automatic or manual loading system. In some cases, close recordings may provide clues about the type of firearm and ammunition used. However, audio recordings of gunshots typically contain the extremely loud report of the muzzle blast, background noise, and reverberation that may limit the ability to identify and classify tell-tale sounds. Examples are presented to show the features and some limitations of acoustic gunshot sound analysis from close recordings.

1 Introduction

Gunshot sound interpretation has become an important facet of audio forensic analysis in the United States criminal justice system, due to the persistent problem of firearm use in this country [1]. Gunshot sounds are captured by law enforcement body-worn cameras [2], dashboard recording systems, and 911-emergency call center recordings. Many jurisdictions in the U.S. have ShotSpotter acoustic gunshot detection and localization systems designed to record and collect gunshot sounds [3][4]. Furthermore, it is increasingly common to have recordings from private surveillance systems installed at residential and commercial locations, and from user-generated recordings from bystanders [5]. For all these reasons, gunshot audio is among the important considerations for contemporary audio forensic analysis [6].

This paper is organized as follows. First, we summarize the common acoustical attributes of firearm handling and gunshot sounds. Next, we consider experimental and case study results involving several firearm types, pointing out several important considerations when analyzing tell-tale firearm sounds obtained relatively close to the gun. The results are intended to help audio forensic examiners seek tell-tale sounds from firearms that may be useful in forensic cases involving these subtle, but often distinctive, sounds.

2 Firearm sounds

Common firearms of interest in audio forensic analysis include handguns and rifles (Figure 1).

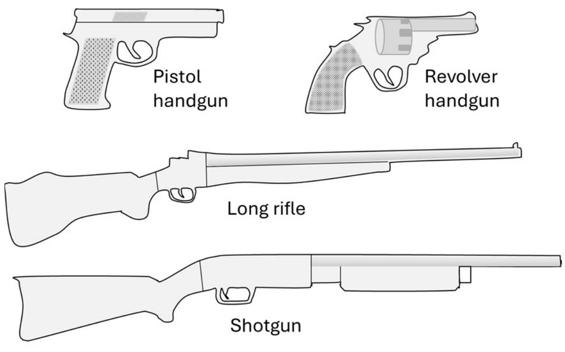

Figure 1: Common firearm types.

To address questions about acoustical interpretation of recorded gunshots, it is important to understand several basic principles of gunshot acoustics.

2.1 Muzzle blast

A conventional firearm uses ammunition consisting of a cartridge containing a bullet crimped onto a hollow casing filled with a gunpowder propellent. Rapid combustion of the gunpower creates a hot, expanding gas mixture that propels the bullet out of the gun barrel. The abrupt sound of the expanding gas emitted from the barrel as the bullet leaves the gun propagates in all directions, but most of the acoustic energy is emitted in the direction the gun barrel is pointing. The impulsive sound energy emanating from the barrel is referred to as the *muzzle blast*, and typically lasts for less than 3 milliseconds [7][8][9].

The muzzle blast acoustic disturbance propagates outward through the air at the speed of sound (e.g., 343 m/s at 20°C), and encounters the surrounding ground, walls, obstacles, and other physical surfaces, causing acoustic reflections, diffraction, and reverberation.

The direct sound of the muzzle blast is the primary acoustical signal from the firearm. Depending upon the location of the microphone, the recording of a gunshot is likely dominated by the muzzle blast sound. In some cases, the direct sound path may be obscured, and the received signal will exhibit propagation effects due to wind, multi-path reflections, and possibly other atmospheric effects and alterations due to the physical surroundings. Thus, a microphone recording a gunfire incident will generally encounter a mixture of direct, diffracted, and reflected sounds.

It should be noted that some handguns and rifles may be equipped with an acoustic *suppressor*. Suppressors are designed to reduce the audible report (and often the visible combustion flash) of the muzzle blast to reduce the likelihood of detection and/or to prevent hearing damage. In the United States, suppressors are highly regulated and relatively uncommon for use by ordinary firearms owners, but many law enforcement agencies use suppressors for tactical purposes.

2.2 Mechanical action

For some firearms the sound of the mechanical *action* may be detectable and distinctive. The functions of the firearm's action include the way ammunition cartridges are loaded, held in place and fired, and then the way spent cartridge casings are removed/ejected. The sound of cocking the trigger and the positioning of new ammunition by the gun's semi-automatic or manual loading system may also be distinctive for certain firearm types and models.

In audio forensic analysis, the challenge for the examiner is often that the mechanical action is significantly quieter than the high amplitude of the muzzle blast sound, so the recording microphone must be located close enough to the firearm to capture these subtle, tell-tale sounds, while not being overwhelmed by the muzzle blast and its reverberation [7].

Most handguns and rifles eject the spent cartridge manually or semi-automatically after firing. One firearm-related tell-tale sound that may be important for certain investigations is the 'clink' of an ejected spent cartridge contacting the pavement or some other surface near the gun. Shotguns and other firearms with a manual pump-action design emit the expended cartridge in a way that may cause a sound if the cartridge lands on a hard surface. On the other hand, firearms such as revolvers typically hold the spent cartridges in the gun's cylinder after firing. Thus, an observation of the spent cartridge 'clink' can potentially be useful for distinguishing different types of firearms.

2.3 Other gunshot-related sounds

The muzzle blast and tell-tale sounds of the mechanical action represent the common features of interest in gunshot audio forensics, but for some firearms and ammunition loads, the bullet may travel at supersonic speed, causing an acoustic shock wave propagating outward from the bullet's path. The shock wave and possibly its acoustic reflections may be detected if the microphone is located down range along the bullet's path. The shock wave cone trailing the bullet has a *Mach angle* that depends upon the bullet's speed and the local speed of sound [10]. The basic geometry is shown in Figure 2.

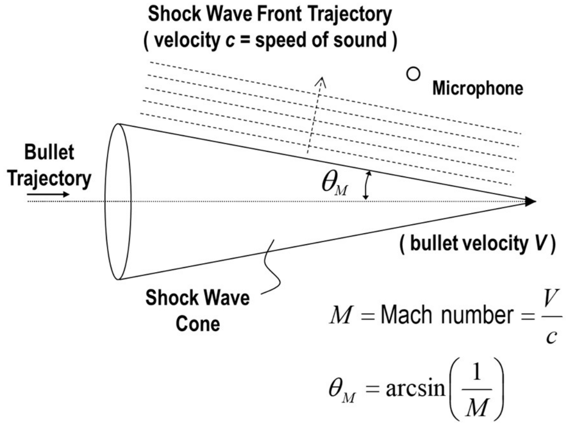

Figure 2: Shock wave geometry for a supersonic bullet.

If the tell-tale shock wave signature is detected down range as a separate signal preceding the arrival of the muzzle blast, it may be possible to estimate the distance between the shooting position and the microphone. As explained in ref. [11], if a supersonic bullet is fired toward the microphone, the acoustical information at the microphone will include the passage of the bullet's ballistic shock wave due to the bullet traveling at average velocity V from the gun to the microphone, then the arrival of the muzzle blast sound that travels through the air at the speed of sound, c. If the speed of sound c (temperature dependent) and bullet's average speed V are known or can be estimated, the time difference between the shock wave and the muzzle blast at the microphone can be used to estimate the distance between the firearm and the microphone:

$$distance = \frac{t_{diff}}{\left(\frac{1}{c} - \frac{1}{V}\right)} \tag{1}$$

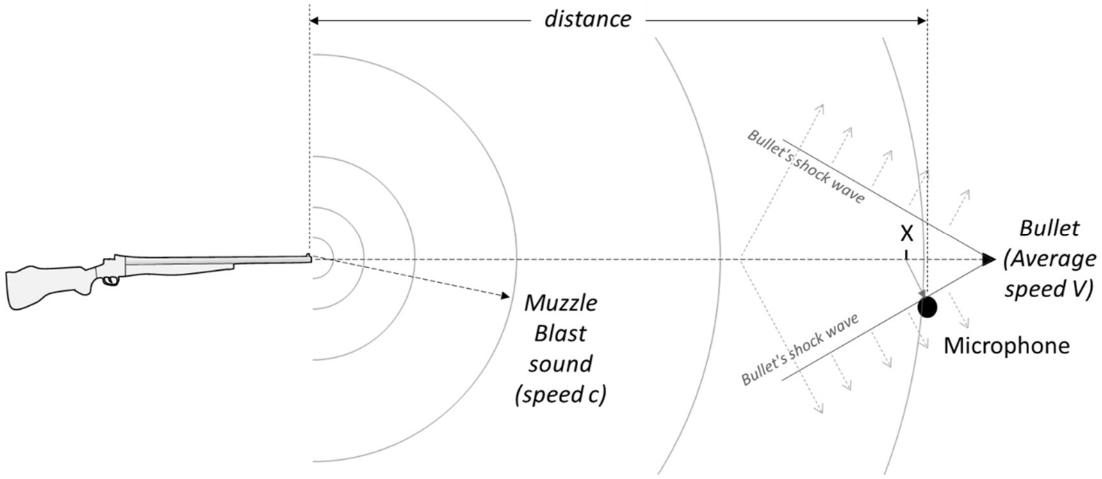

Figure 3: Relative timing of arrival of shock wave and muzzle blast at the microphone for a supersonic bullet with trajectory close to the microphone position.

Another possible tell-tale acoustic signal related to gunshots is due to vibration carried through the ground or other solid surfaces. The loud sound of a gunshot report may result in vibratory signals in surfaces and structures around the area of the shooting.

3 Example: Tell-tale "racking" sounds

An example of a sound associated with manipulating certain firearms is known as *racking the action* or *racking the slide*. Racking is used to ready the gun for first firing, or for clearing a misfire condition. Sliding the hand-operated mechanism of a manual pump-action shotgun backward and forward is one example of racking, and pulling backward on the slide of a pistol and releasing it is another example. The racking movement generally extracts and ejects a cartridge from the firing chamber and loads a new cartridge into position, ready to fire.

An example of the mechanical action sound of a pump-action shotgun is shown in Figure 4. Following the muzzle blast from firing the shotgun, the marksman *cycles*—pulls backward and pushes forward—the sliding grip under the barrel, ejecting the spent cartridge and loading a fresh shotgun shell into the firing chamber.

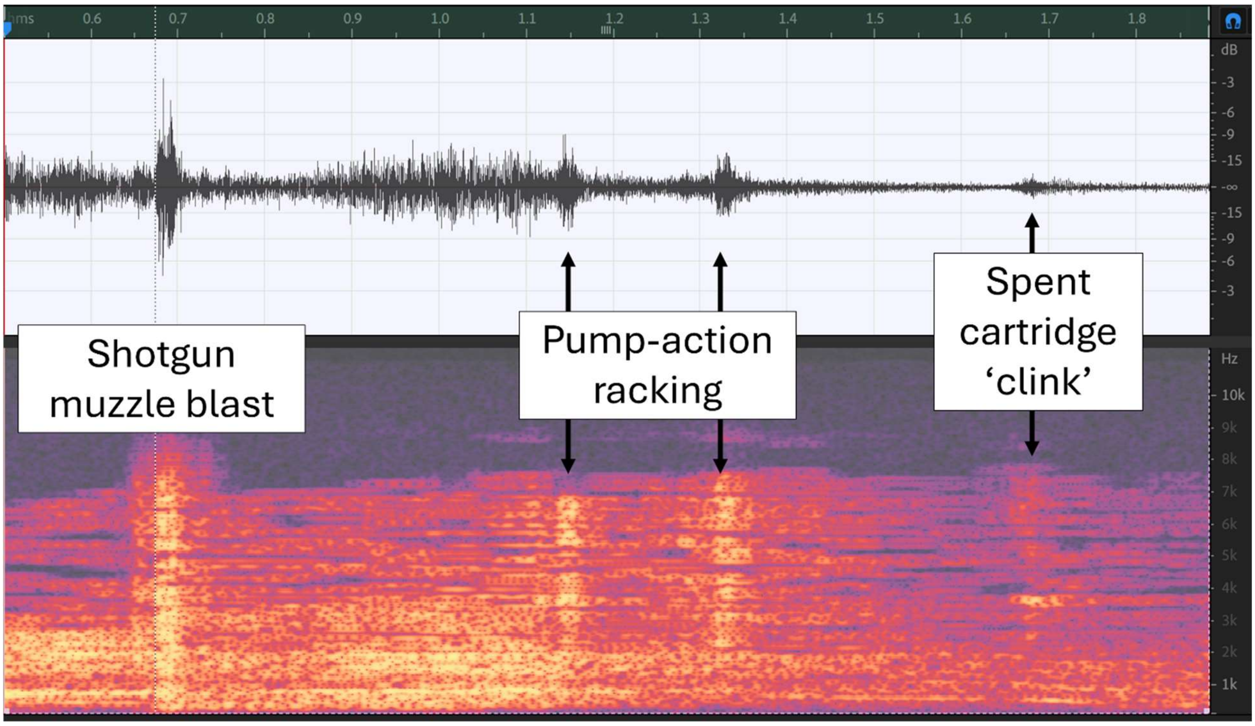

Figure 4: Example pump-action shotgun racking. Upper panel is the time waveform (1.9 seconds in duration), lower panel is the corresponding spectrogram (linear scale 0-10kHz).

The example shown in Figure 4 also includes the sound of the spent shell striking the pavement, making an audible 'clink' sound, as discussed in the next section.

An example semiautomatic pistol slide racking sound is shown in Figure 5. If observed, the sound may be helpful to discern details about the firearm's handling around the time of the shooting.

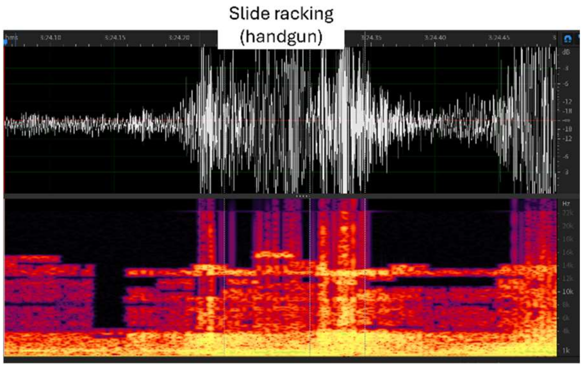

Figure 5: Slide racking sound, semiautomatic pistol. Upper panel is time waveform (450 ms duration), lower panel is spectrogram (linear scale 0-22kHz).

4 Example: Tell-tale cartridge ejection sounds

We conducted a shooting range experiment involving three simultaneous recording devices capturing the sound of a semiautomatic pistol (Glock 42, .380 caliber). This particular firearm ejected a spent cartridge after each shot, and the cartridge fell to the ground, producing an audible 'clink' sound that was picked up by one of the three recording devices: the "Memo Recorder 1" (Olympus brand, model WS-853) that was located in the pocket of the marksman (upper panel of Figure 6).

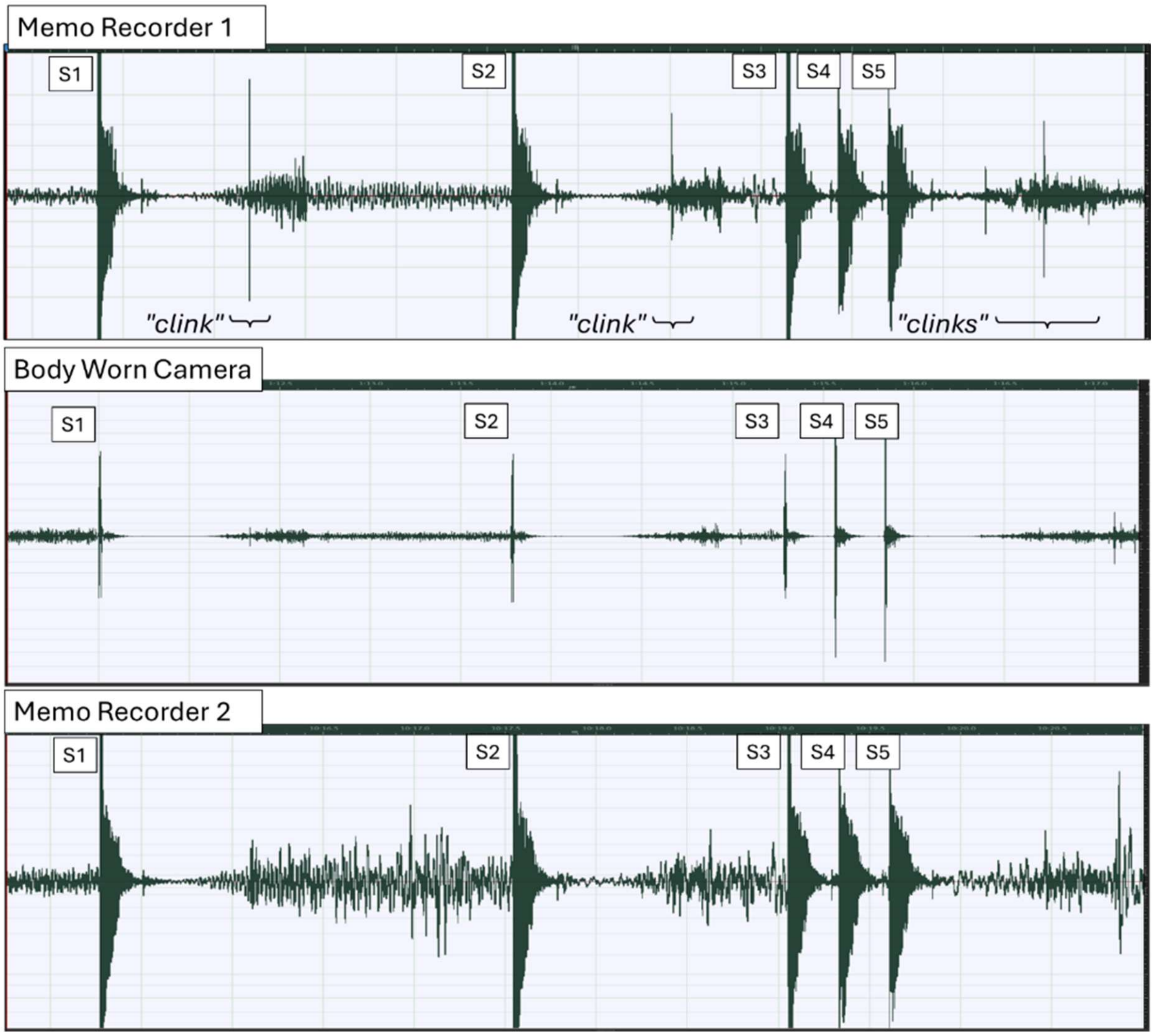

Figure 6: Five shots from a Glock 42 pistol with three simultaneous recordings, 6 seconds duration.

In this observation, the time between the shot and the sound of the cartridge striking the ground was approximately 800 ms. This time duration might differ if the gun was fired closer or farther from the ground, and could differ from one pistol type to another if the behavior of the ejection port differed, or if the physical size and weight of the cartridge differed. Thus, the characteristics of that tell-tale sound could possibly be useful for a firearms expert to interpret in the context of a particular incident with known or suspected firearms.

The absence of sound attributable to a spent cartridge striking the ground may mean that the firearm did not eject the cartridge, such as a revolver that retains the spent cartridges in its cylinder. However, the lack of this tell-tale sound does not necessarily mean that no cartridge was expelled, since the cartridge may have fallen relatively silently on a soft surface such as grass or carpet.

An important observation from the recordings of Figure 6 is that the other two recording devices that simultaneously captured the gunshots do not show the sound of the cartridge striking the ground in such a clear manner as “Memo Recorder 1,” even though all three recorders were located within a radius of 1 meter of the gun. This discrepancy appears to be due to the automatic gain control circuitry and/or settings of the “Body Worn Camera” (Panasonic brand, model Arbitrator) and “Memo Recorder 2” (Olympus brand, model VN-702PC) [12]. The very loud report of the pistol’s muzzle blast evidently caused those two recorders to go into a gain-limiting mode for about 1 second before recovering, and the amount of gain reduction was sufficient to miss the audible sound of the cartridge ‘clink’ on the ground.

The lesson here is, of course, that audio forensic examiners must understand the potential limitations and idiosyncrasies of the recording devices. The absence or relative subtlety of the ‘clink’ in the “Body Worn Camera” and “Memo Recorder 2” recordings could imply that the sound did not occur, yet its presence in the “Memo Recorder 1” data helps describe the actual situation.

5 Conclusions

This paper has considered several forensic aspects of common tell-tale firearm sounds.

In some cases, the type of firearm may be known, and the audio forensic task is to confirm the number of shots and account for any misfires. In other cases, however, ascertaining the identity of the firearm may be the focus on the investigation, in which case the presence of tell-tale sounds may provide useful clues for the investigation.

These tell-tale sounds are often specific to a particular firearm type and model, and therefore may be useful in forensic examination of audio in which determining or confirming the identity of the firearm is of importance.

References

[1] Federal Bureau of Investigation, Crime Data Explorer, URL: https://cde.ucr.cjis.gov/LATEST/webapp/, accessed March 9, 2024.

[2] U.S. National Institute of Justice, "Research on Body-Worn Cameras and Law Enforcement," URL: https://nij.ojp.gov/topics/articles/research-body-worn-cameras-and-law-enforcement, January 7, 2022, accessed March 9, 2024.

[3] SoundThinking™, ShotSpotter gunshot detection technology, URL: https://www.soundthinking.com/law-enforcement/gunshot-detection-technology/, accessed March 9, 2024.

[4] R. Calhoun and S. Lamkin, "Determining the Source Location of Gunshots from Digital Recordings," Express Paper 18, Proc. 153rd Audio Engineering Society Convention, New York, NY (2022).

[5] B.F. Miller, F.A. Robertson, and R.C. Maher, "Forensic handling of user generated audio recordings," Preprint 10515, Proc. 151st Audio Engineering Society Convention, Online (2021).

[6] D.R. Begault, S.D. Beck, and R.C. Maher, "Overview of forensic gunshot analysis techniques," elib 20475, Proc. 2019 Audio Eng. Soc. International Conference on Audio Forensics, Porto, Portugal (2019).

[7] R.C. Maher, "Acoustical characterization of gunshots," IEEE SAFE 2007: Sig. Proc. Apps. Public Security & Forensics, pp. 109-113 (2007)

[8] R.C. Maher and S.R. Shaw, "Deciphering gunshot recordings," Proc. Audio Engineering Society 33rd Conference, Audio Forensics—Theory and Practice, Denver, CO (2008).

[9] R.C. Maher and T.K. Routh, "Advancing forensic analysis of gunshot acoustics," Preprint 9471, Proc. 139th Audio Engineering Society Convention, New York, NY (2015).

[10] R.C. Maher and T.K. Routh, "Wideband audio recordings of gunshots: waveforms and repeatability," Preprint 9634, Proc. 141st Audio Engineering Society Convention, Los Angeles, CA (2016).

[11] R.C. Maher, "Interpretation of audio forensic information from the shooting of journalist Shireen Abu Akleh," Express Paper 22, Proc. 153rd Audio Engineering Society Convention, New York, NY, (2022).

[12] R.C. Maher and S.R. Shaw, "Gunshot recordings from digital voice recorders," Proc. Audio Engineering Society 54th Conference, Audio Forensics—Techniques, Technologies, and Practice, London, UK (2014).