Bullet Hole Characteristics, Limiting Factors, and Reconstructing Shooter Location within a Crime Scene

by

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A Research Project Submitted to the
Forensic Science Forensic Research Committee
George Mason University
In Partial Fulfillment of
The Requirements for the Degree
Of
Master of Science
Forensic Science

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Spring Semester 2020
George Mason University
Fairfax, VA

Acknowledgments

I would like to thank my wife Brittany and daughter Caroline, for supporting me during this long process. Without their support, I would not have been able to complete this work. I would also like to thank Mr. Arthur Chancellor, Mr. Grant Graham, and Mr. Billy Barnes for their above and beyond support to complete this research. I would also like to think all of the others who assisted me along the way, both within the United States Army CID and the George Mason University, without your continued support none of this would have been possible.

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Abstract

Shooting scene reconstruction and the identification of where the shooter and weapon most likely were located, can be critical pieces of information for law enforcement and crime scene investigators. During an extensive literature review, the gap which appeared was identifying the most likely position of the shooter when accounting for limiting factors, such as room size and furniture. There are several ways to conduct shooting trajectory analysis, with individuals such as Haag, L., and Haag, M. (2011), Hueske (2009), Gardner and Bevel (2009), Gardner and Krouskup (2019), writing at length about the process of determining shooting trajectory and overall crime scene reconstruction. The trajectory analysis for this project was adopted from Gardner and Bevel (2009) and through coordination with the Virginia State Police and included using trajectory rods, angle finders, protractors, and lasers to determine the trajectory of the bullet. Then limiting factors along the path of the bullet, gunshot residue (GSR), and overall room size was accounted for, to identify the most likely position of the shooter. According to Gardner and Bevel (2009) and through coordination with certified crime scene experts, it was determined that shooter positions are broadly assigned to zones one through three. The results expected from this project are to refine zone 1 described as the most probable shooting location, identify the overall accuracy rate of shooting trajectory analysis, and to develop a predictive model statistical analysis to determine the impact of the limiting factors on predicting the shooter's distance. The conclusion anticipated from this research is when all factors are taken into account, a most likely shooter location could be identified within +- three through five feet.

Introduction:

According to the Pew Research Center (2019), in 2017, there were 39,773 gun deaths in the United States, as reported by the Center for Disease Control. With about 51% (23,854), self-inflicted gunshot wounds, or suicides, about 37% (14,542) tied to the crime of murder, and the remaining 12% (1,377) linked to such incidents as law enforcement shootings, unintentional shootings, and undetermined shooting circumstances. In most shootings, there could be a wealth of information obtained. Thus if the angle trajectory, gunshot residue (GSR) patterns, bullet hole characteristics, and limiting factors are accounted for during shooting reconstruction then, a shooter's location can be determined within +/- three through five feet. Shooting trajectory is a piece of the puzzle that may provide the best picture of what happened at a scene.

According to the National Institute of Justice (NIJ) report on Strengthening Forensic Science in the United States (2009), there is a need to inject more science into forensic science. It should no longer be an accepted practice to use such broad terms as most likely or probable. This transformation begins with identifying the questions to be answered and then developing protocol reference information to be collected from these scenes. Ultimately establishing quantitative measures, to ensure scientific analyses are being conducted, using established error rates, and alleviating unintended bias.

Some of the information a shooting scene reconstruction can provide may include corroboration for victim and witness statements, could confirm or refute suspect statements, and, if done correctly, may provide the most likely explanation to what happened at a scene. One gap in trajectory analysis literature is the introduction and analysis of limiting factors, such as the height and angle of the impact, within the room. The inclusion of these factors could better identify the most likely location of the shooter.

The factors contributing to the successful shooting scene reconstruction are endless; however, knowing the basics of the process is a critical part for anyone looking to explore the science behind shooting scene reconstruction. It is not the intent of this paper to be able to include all relevant factors, i.e., bullet mechanics, weapons mechanics, or alternate means to determine the most likely shooter location. This paper attempts to educate investigators on critical scene elements that may assist in completing the shooting trajectory analysis. While answering the following questions:

1. If the configuration of furniture and overall distance available within a space can place a numerical definition on zone 1 of the shooter placement zone?
2. How can the appearance of GSR and stippling around a bullet hole aide in developing this definition?
3. It was assumed no unnatural shooting positions were taken, and all furniture within a room was used for its intended purposes, i.e., sitting, what information can bullet wipe provide for determining the shooter's place within the scene?

Limiting factors, as defined in this research project, are those factors which limit the possible locations the shooter could have been during the act of shooting based on all available information at the scene. In this research project, the limiting factors are intentionally restrictive and based on the following assumptions:

1. That no shots were fired from outside of the shooting location;
2. There were no unnatural shooting positions.
3. For this research, the shooter will be either in a standing, sitting, or kneeling position.
4. The shooter would not be standing on top of any of the items located in the room.
5. The shooter would not shoot through any items in the room.

6. All furniture within the scene would only be used for its intended purposes (i.e., sitting.)

Shooting incidents have many layers, and this document is not intended to cover or discuss all of them. Instead, its intended purpose is to look at shooting scene reconstruction, while introducing several limiting factors, while remembering to remain in the role of a scientist and thoroughly exploring other ideas to what may have happened. (Haag, L. and Haag, M. 2011)

Lastly, this research took initial steps to introduce statistical predictive modeling, and begin compiling the most relevant independent factors a crime scene investigator could collect to provide the most scientifically reproducible opinion on shooter placement. Whoever is attempting to reconstruct a shooting scene should always maintain an open view of what took place and should not allow themselves to become fixated on what they perceived as most likely to have occurred thus, excluding other potential explanations. The evidence and facts must always guide all reconstruction efforts and, ultimately, the opinion of the investigator.

Body of the Text:

Overview of Crime Scene Analysis:

Crime scene analysis and reconstruction gained its roots with such innovators as Hans Gross, Edward Oscar Heinrich, and Charles O'Hara. (Gardner and Bevel, 2009) These criminal investigative minded individuals developed broad theories within their respective disciplines and shifted crime scene analysis and reconstruction toward a formalized process. With a goal in mind of propelling and refining their methods into scientific methodologies to determine what, and geographically where it most likely happened, further based on all facts sought to determine the sequential order the actions most likely took place.

When discussing shooting scene reconstruction, many of the same theories and methods applied so many years ago are still applicable today. A crime scene investigator's (CSI's) primary goal is to use sound implementation of the scientific method and thereby render quality and scientifically valid opinions. The CSI obtains this opinion through methodical and thorough scene documentation and the use of scientific methodologies, to complete their analysis.

Overview of Shooting Scene Reconstruction:

Shooting scene reconstruction has a long history both in the United States and throughout the world. Kelley (1963), notes one of the first times ballistics evidence was used at court was around 1921 in the trial of Sacco and Vanzetti. The case and the appeals process dragged on for years, due to the court's refusal to listen to and accept the forensic evidence. According to Kelly (1963), ballistics began to obtain its notoriety as legitimate science and garner a widespread acceptance in the United States in 1924 with the State of Connecticut v. Harold Israel.

This case was the first time in the United States; examiners were able to definitively link a fatal bullet to a weapon belonging to Mr. Israel. These two cases were the beginning of over 100 years of expert experimentation and testimony about firearms examinations. Almost certainly, as long as there have been firearms and shootings, there have been individuals interested in trying to document and reconstruct what took place once the trigger was pulled and the bullet left the barrel of the gun.

Shooting scene reconstruction involves more than sticking metal rods into bullet holes, as often depicted on TV shows. Hueske (2006), as well as many other authors, note, several factors, go into shooting reconstruction, such as but not limited to - latent fingerprints, gunpowder particles, primer residue, and ammunition components. Furthermore, the CSI should make every attempt to be physically present at the crime scene when conducting this analysis. The process becomes far more complicated if reconstructing is made only via photographs and sketches. Further, once the scene is initially searched, cleared, and released by law enforcement, any physical evidence, such as glass, and GSR, may be lost forever.

No one factor will reconstruct the scene or solve the case; however, Hueske (2006), notes trajectory or the path of the projectile while in flight, as one of the most important. Without proper documentation of the bullet trajectory during the initial scene examination, there may not be another chance to determine the bullet path. This may invalidate the analysis if it is unable to be reconstructed by a third party for a trial. Chain of custody or the positive control of the scene and all evidence from the time they are identified, up until case disposition, are imperative. Once positive control of the scene is lost by law enforcement, it may be hard to convince a judge and jury a secondary examination is an accurate representation of how the scene was initially found. Especially if discrepancies are due to sub-standard or incomplete documentation by the CSI. During the scene reconstruction, CSIs attempt to arrive at the most probable course of events. In scene reconstruction, proper documentation, evidence identification, scene evaluation, and preservation, coupled with good police work, is essential in obtaining as much information and facts as possible.

Elements of Shooting Trajectory and Scene Reconstruction:

Semi-automatic pistol:

For this study, semi-automatic pistols were utilized. A semi-automatic pistol is typically a single-barreled pistol that takes a magazine which is loaded with particular ammunition. For the initial shot, the hammer of the weapon can be manually locked back, or the trigger pulled to initiate the hammer action. Then with the force and operation of the slide, the hammer remains in the cocked position. With each trigger pull, one projectile exits the barrel, and another bullet is fed into the chamber from the magazine, seated, and fired until the trigger is no longer pulled or until all ammunition has been fired. Once the firer pulls the trigger the hammer slams forward, strikes the firing pin, which in turn strikes the center of the primer, a controlled explosion takes place, and the bullet is fired. The magazine in the weapon is spring-loaded and continues to feed ammunition into the chamber of the gun until there are no bullets left, at which point, if functioning correctly, will cause the slide of the weapon to stay locked in the open position.

Ammunition:

A cartridge is the complete unspent mechanism loaded into a weapon and fired. Wallace (2008), offers the Oxford dictionary definition of a round, as “a case containing a charge of propellant explosive for firearms or blasting, with bullet or shot if for small arms” (p. 9). For this study, centerfire ammunition was used, which is defined by Noedel (2009), as “those rounds of ammunition wherein the explosive primer is contained within a metallic cup that is located in the center of the cartridge head” (p. 132). After the explosive sequence initiates, gunpowder is ignited, gas builds up, and the bullet to exits the gun. A CSI must understand the essential characteristics of ammunition and ensure proper terminology is being utilized.

GSR:

There are two primary components of a shooting scene; these are the weapon and the ammunition. In addition to the bullet exiting the gun, there are other materials known as gunshot residue (GSR) that may follow behind the projectile as it exits the barrel. Heard (2008), defines GSR as the mixture of unburnt and partially burnt propellant, amorphous sooty material, a mixture of incandescent gases, primer discharge residues, and material from the base of the bullet. This soot and other materials may be deposited onto a target. Hueske (2006), notes GSR is a term with different meanings, due in part to the fact GSR and the patterns may include several materials or depending upon the type of ammunition used, may lack other components.

Ammunition contains different gunpowder configurations such as a spherical ball or a flattened ball which, will directly impact the CSI's ability to visualize GSR. Haag (2004), stresses the critical importance of having an understanding of small-arms propellant and how the make-up of this substance can assist CSI's in their analysis. At close distances typically within 36" visible GSR patterns may provide clues as to the distance from the target the shooter was placed the moment the shot was fired. The GSR pattern is reproducible, assuming the same firearm and ammunition is used. Stippling or tattooing are synonymous terms and are defined by Bell (2013), as a pattern left on the target surface as a result of burning powder impacting the surface, causing small burns. Stippling is another visible and reliable characteristic for the CSI to account for when determining the distance the shooter was from the target. The difference is that some of the materials in the GSR pattern may be easily removed, but the stippling is particularly resistant to wiping or washing away.

Given the parameters of the research, the focus will remain on shorter-range shots and those factors consistent with these shorter distances. The main difference between long-distance and short-distance bullet flight is the gravitational effects upon the bullet. Thus a round, in close quarters will not have the chance to reach its peak height, and most likely will not tumble, and according to Noedel, (2009), will only drop marginally within 15 feet, (.03" for a 9mm, .04" .40 S & W, and .06" for a .45 ACP). This is important for shooting trajectory as a whole, but for this research, all shots will occur within approximately 12'; therefore, only a mention of this action is necessary.

Bullet Hole Characteristics:

Noedel, (2009), states the importance of bullet hole characteristics, noting, the examiner must determine if the bullet perforated or penetrated a particular medium. Perforated defined as: the bullet passing entirely through a medium, such as a window, entering on one side of the glass and, exiting the other. Penetrating defined as: a bullet entering but not exiting a medium. Noedel, (2009) provides an example of how a bullet may perforate or penetrate, for instance, if someone shoots at a car door, and the bullet perforates the door and strikes the driver, but does not exit the body. Coordination with include Lt. John Defilippi, VA State Police (personal communication, October 2019), Mr. Billy Barnes, Wilson, NC PD, (personal communication, January 2020), and Mr. Don Mikko, Forensic Firearms Training Seminars, Inc. (personal communication, January 2020), revealed this characteristic is vitally important, to trajectory analysis as two bullet holes (i.e., entrance and exit) are required.

Thus, the bullet hole may help in determining the trajectory angle, the distance, and ultimately the most likely position of an individual within the room when the trigger was pulled. According to Mattijssen and Kerhoff (2016), the characteristics of the bullet hole may impact the CSI's ability to determine the angle the bullet was fired accurately. When a bullet is fired orthogonal or at 90 degrees to a particular surface, the resulting hole or defect will appear generally circular. According to Mattijssen and Kerhoff (2016), bullet defects may elongate and become elliptical, if the distance and angle of impact are increased, or if the bullet begins to tumble after striking an intermediary surface before impacting its final destination.

Biederman and Taroni (2006), note there is varying terminology used to describe the gunshot ranges of fire, such as close contact, contact, or distant. For this research, the following classifications will be used:

1. Close contact, which is when the weapon is pressed against the medium up to approximately 6” away, with possible stellate tearing, or a relatively dark and cylindrical GSR pattern, with some of the GSR particles, possibly being deposited inside of the bullet hole,
2. Intermediate-range, being when the weapon is approximately 6-12” away from the target, with the GSR pattern, beginning to spread out, become less defined, and less centralized,
3. Distant, being when the weapon is approximately 12-36” away, with the GSR pattern, creating a defuse and a larger, less defined, and lighter in color pattern.

Outside of the distant range, the likelihood of GSR having the ability to travel to the target is degraded dramatically. (Fisher, Miller, Braswell, & Wallace Jr., 2014)

These distances are not exact, with Heard (2008), providing ranges for close, up to 2” and distant as far back as 30”, and Gardner and Bevel (2009), noting up to approximately 5’, GSR may still be visible on a surface. In general, there is no exact measurement, with Hueske (2008), suggesting outside of an arm’s length, the investigator should not expect to find GSR on the target surface. For individual crime scenes, the CSI would have to conduct test-fires using the same ammunition, to determine the unique characteristics of any GSR pattern visualized at their shooting incident.

The next important aspect of the bullet hole is the possible presence of bullet wipe, defined as: the deposition of material left by a bullet as it passes through a medium. Bullet wipe may appear as a grey in color mark around the hole. The amount and size of the wipes are directly correlated to the angle the shot was fired. (Wallace, 2008) If a shot is fired at a piece of standard drywall at a generally 90-degree angle with nothing obstructing the path, the wipe will be reasonably uniform around the hole. If the bullet is fired at the same piece of drywall at an angle of 150 degrees, the bullet hole will become elongated and oblong shaped with the bullet wipe following the same general oblong shape. Bullet wipe may be an essential characteristic that may indicate an entry hole and may give the examiner a suspected point of origin. (Mr. Barnes, personal communication, January 2020)

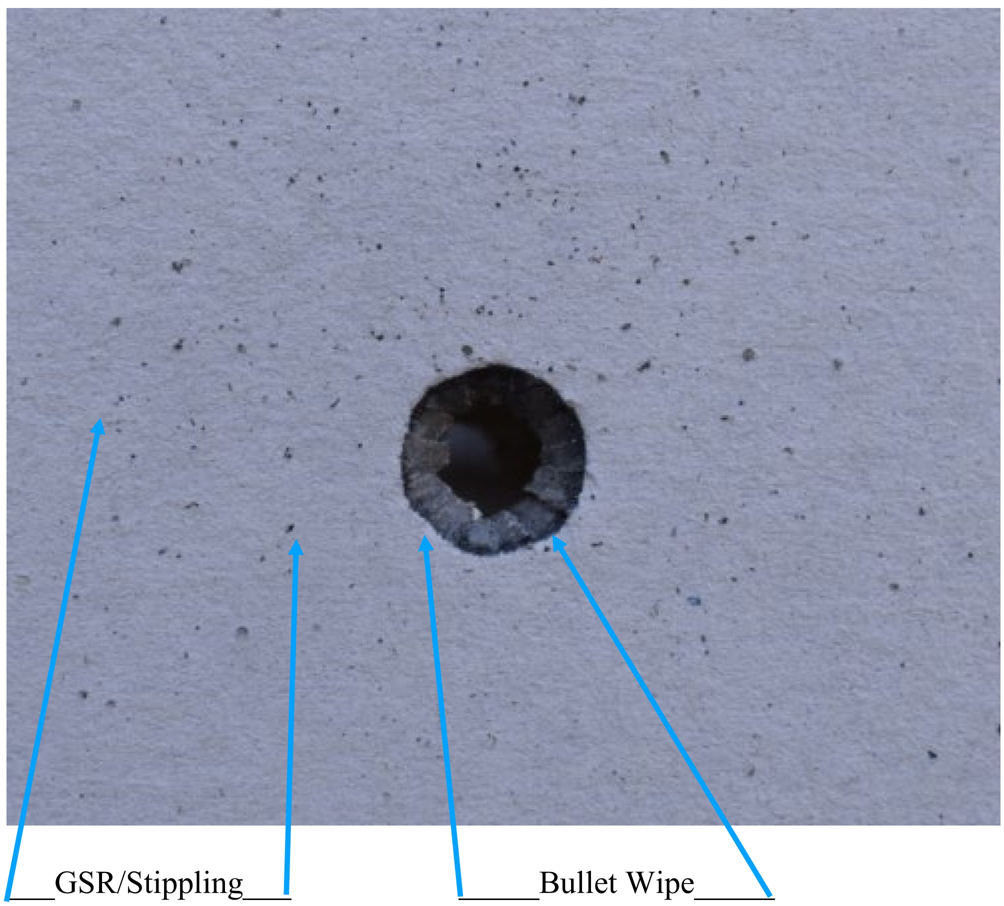

Figure 1: GSR and Bullet Wipe

What takes place after a weapon is fired and the projectile leaves the barrel of the gun, in many cases, is directly related to limiting factors. If the shooter is close to the individual within approximately 15' the bullet will follow a generally straight-line trajectory until it impacts a target. The gasses and other components exiting the barrel will form a cone shape which, is initially small in shape and over distance begins to expand until such point all of the materials strike an obstacle or lose forward momentum, at which point the path is altered or stopped.

During this research Lt. Defilippi, (personal communication, October 2019), Mr. Barnes, (personal communication, January 2020), and Mr. Mikko, (personal communication, January 2020), generally agreed on the trajectory analysis process and what factors were most important. With one dissenting on the importance of measuring the bullet hole. There are times; a bullet hole may not be circular. Such as a ricochet which results from a bullet fired at an extreme angle, or when the bullet strikes an intermediate object or surface and is deformed but continues along a path; however, an attempt should still be made to make this measurement.

This simple measurement could corroborate any found projectiles, or confirm or refute statements from those at the scene. The bullet hole size can be calculated by using the formula noted by Mattijssen and Kerhoff, (2016) as (a) = sin -1 (w/l), or by obtaining the width measurement using spreading calipers, or fitting an ellipse around the lead-in portion of the defect. For this research, the caliper method was utilized. What should be becoming clear is there may be a vast amount of information a bullet hole may provide.

30-Degrees **90-Degrees** **150-Degrees**

Figure 2: ***depiction of 30, 90, and 150-degree entrance holes. Even given the angles the smallest portion of each bullet hole, the width should be measured, which would provide an estimation of the caliber used. Additionally, the width could be divided by the length to obtain and estimation.***

Shooting Incident Zones:

Shooting incident zones are another vital factor in shooting scene reconstruction. These zones are described by Gardner (2005), as "given the associated evidence and artifacts the investigator should be lead to establish the most possible and impossible areas where the shooting events occurred within a given location" (p. 324). [1]Gardner (2005), Hueske (2008), and others delineate these zones as:

1. Zone 1: This area is considered to be the most probable location of the shooter at the time the events took place. Gardner (2005), notes the zone is situated at some point within the trajectory path, at or lower than the height of the shooter's shoulder height, and which should be considered by the investigator to be the most easily assessable for the shooter to have been in at the time of the incident.

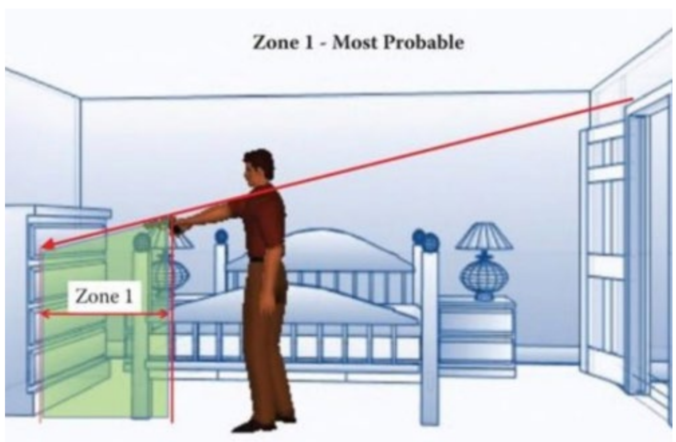

Figure 3 ***(Zone 1)***

2. Zone 2: This area is considered to be possible, but not a likely location of the shooter at the time the events took place given the positioning required to align toward the target. Gardner (2005), notes zone 2 is any position along the full length of the trajectory path, above the

[1] **The zones can be sliding and are not definitive. Some scenes may only have one zone given the factors present in the scene. For the analyst, this should be kept in mind, and they should not feel obligated to assign a zone for the sake of doing so.**

shooter's shoulders, which not impossible, but should be considered an uncommon stance and very awkward to do so in an effective manner.

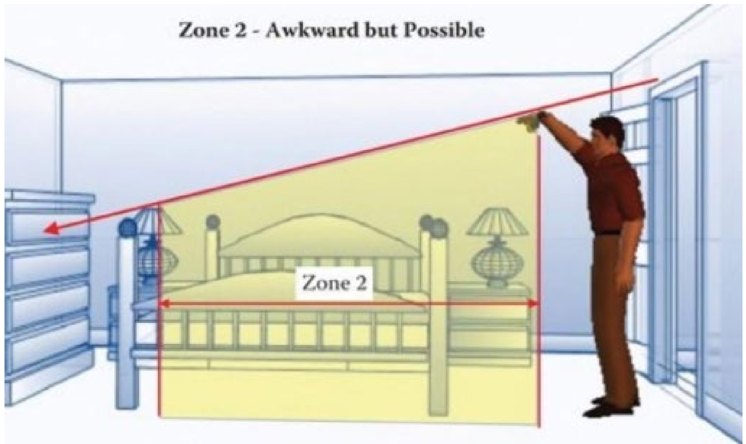

Figure 4 ***(Zone 2)***

3. Zone 3: This area is considered to be impossible and not supported by the evidence found by the investigator at the scene. Gardner (2005), notes this position is impossible because the shooter would not be able to attain such a position and align the barrel toward the target given such factors as the height of the trajectory, obstacles, or based on a host other evidential factors.

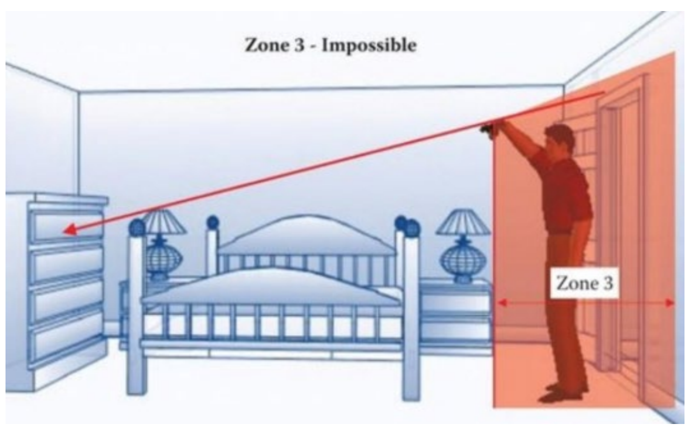

*Figure 5****(Zone 3)***

Methods for Shooting Scene Reconstruction:

Haag, L. and Haag, M. (2011) and Nordby (2013) reference the use of 3D scanning technologies, but most of the literature reviewed for this project noted; reconstruction research continues emphasizing using the traditional method of shooting scene reconstruction. Hueske (2009), Haag, L. and Haag, M. (2008), and Gardner and Bevel (2009), note the traditional method as, first documenting all bullet holes using notes, photographs, sketches, and fixing them into place. The bullet hole can be set into place using a triangulation method, which measures from two known points in the scene to the approximate center of mass of the bullet hole. Then, each defect should be analyzed and confirmed as a bullet hole. Confirmation as a bullet hole may be accomplished using visual characteristics i.e., bullet wipe or visible GSR or chemical analysis such as Dithiooxamide (DTO) and 2-Ntroso-1-Naphthol (2-NN) which test for the presence of copper or Sodium Rhodizonate (NaRho) which test for the presence of lead. (Noedel, 2009)

Then, trajectory rods can be inserted into the bullet hole, assuming there is an entrance and exit hole. (Mr. Barnes, personal communication 2020). If there are not, then the trajectory rods cannot properly be fit into the medium, thus rendering the angles inaccurate. Next, using angle finders and protractors, the up and down/left and right trajectories can be determined, with an acceptable margin of error of within +/- 5 degrees. Next, a laser can be affixed to the end of the trajectory rod and then using limiting factors, such as furniture, the maximum distance of the room, and presence of GSR, the analyst can render a scientific opinion about the most likely shooter location. Whether a CSI uses a 3D analysis or the traditional method, they must be meticulous in their approach to obtain the most accurate depiction of what took place when the trigger was pulled.

Photography:

For this paper, it is important to briefly discuss photography, for its importance in documenting shooting scene reconstruction, and the influence it serves in the reproducibility of findings. In some cases, there may be GSR patterns, as well as, other bullet hole characteristics on objects or bodies, with little information known about the type of weapon used. Through quality digital photography and according to the article Digital Photography (2003), these photographs may be able to be searched for known defects within a semi-computerized data retrieval system. This system is compiled from textbooks and other published journals on wounds. (Digital Photography, 2003) Nordby (2013), notes photographs are a means to ensure all data is observable. Photographs are vitally important during a shooting scene reconstruction, as the original scene may not be available for cross-referencing by a defense expert, leaving only the photographs available for any subsequent examination of the scene.

The crime scene analyst should expose, overall, mid-range, and close-up photographs with and without scale while conducting shooting scene reconstruction. Noedel (2009), notes, photographs of the angle finder, protractor, and the laser used during the reconstruction, must be included. Visualization of the laser may take alternate photographing techniques such as using low light, long exposure time and enhancing the laser with smoke, or by first taking a well-lit photograph that would not depict the laser. Then a second photograph obtained of just the laser, the two photographs could be overlaid to illustrate the path of the laser within the scene.

Robinson (2016), suggests GSR can be visualized using IR technology. The use of IR photography may visualize GSR and bullet wipe in certain circumstances, such as when a bullet passes through dark clothing, before entering a body, or when a round passes through a dark-colored piece of furniture before impacting a wall. These characteristics may not be able to be seen with the naked eye and using the IR technology; the CSI may obtain a critical clue about bullet trajectory and where a shooter may have been. During this research, the practice was abandoned, as it proved not be useful. IR photography may have been impacted by, iterations were not fired from close ranges, the background being was white, or the bright light conditions of the shooting area may have been factors in the unsuccessful usage of IR photography.

The purpose of this Research:

There is no shortage of reference material relating to shooting scene reconstruction; however, where there does seem to be a shortfall is determining the most likely position of the shooter based on limiting factors. This research attempts to explore and develop critical factors at a shooting scene, which may provide the CSI with additional data points to provide a more scientifically sound conclusion. The purpose of this paper was to focus on easy to understand methods that could be used by CSIs new to the process of trajectory analysis and provide them a baseline for variables they should consider and collect while conducting their investigation.

During the literature review limiting factors, such as room height and configuration, were seldom if ever addressed. Mr. Barnes noted it is just commonplace to assume limiting factors were important. (Personal communication, January, 2020). Therefore, it may be probative to take a more holistic approach to the shooting scene reconstruction and account for GSR patterns, possible bullet wipe, room configuration, and minimum/maximum distance to better fix the shooter's position within the room.

Materials Used:

Pistol Type	Muzzle Velocity	Recoil System	W/H/L	Barrel	Critical Angle
9mm Springfield XD	1150 fps	Dual Spring w/Full-Length Guide Rod	28 ozs/5.5”/7.3”	4” Hammer Forged, Steel Melonite 1:10 Twist	14-18 Degrees
Kimber 45 ACP	746 fps	Recoil Spring w/Full-Length Guide Rod	25 ozs/4.75”/6.8”	3” Steel Match grade 16 ramped twist rate	16-18 Degrees
40 S&W	1074 fps	Recoil Spring w/Full-Length Guide Rod	40.2 oz/5.4”/7.7”	3.9” 1:15 Twist	N/A

Figure 6 ***(Pistol Type)***[2]

TABLE 1—*Information about the cartridge types and firearms used for this study. V2 and E2, respectively, represent the mean bullet velocity and kinetic energy at a shooting distance of 2 m. The direction of rifling is denoted as R (right twist) or L (left twist).*

	Bullet			Firearm		Rifling	
Cartridge	V2 (m/sec)	Mass (g)	E2 (J)	Type	Model	Dir. (R/L)	Twist (mm)
.22 LR, LRN	270	2.6	95	Pistol	HS Sport King	R	1/406
.32 Auto, FMJ-RN	293	4.6	197	SMG	Skorpion	R	1/305
.380 Auto, FMJ-RN	296	6.1	267	SMG	MAC M-11	R	1/305
9 mm Luger, FMJ-RN	342	8.0	468	SMG	Steyr TMP	R	1/250
.38 Special, LRN	239	10.2	291	Revolver	S&W 586	R	1/476
.38 Special, SJHP	277	10.2	391	Revolver	S&W 586	R	1/476
.38 Special, FMJ-FP	268	10.2	366	Revolver	S&W 586	R	1/476
.45 Auto, FMJ-RN	237	14.9	418	Revolver	S&W 625	R	1/381

Figure 7 ***(Critical Angles)***

Ammunition Type	Weight/Type	Ammunition Type	Weight/Type	Ammunition Type	Weight/Type/Velocity
Remington 9mm	115 grain/ FMJ	Winchester 9mm	115 grain FMJ	Federal Premium 9mm Luger	124 grain/Hydra-Shok/JHP
Remington 45 ACP	230 grain/ FMJ	Winchester 45 ACP	185 grain/FMJ	Federal Premium 45 ACP	230 grain/ Hydra-Shok/JHP
Armscor 40 Caliber	180 grain/TMJ	Lawman 40 Caliber	180 grain/TMJ	Hornady 40 Cal	165 grain/FTX

Figure 8 ***(Ammunition Used)***

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[2] **The critical angles described are identified as the angles the particular bullet is most likely to ricochet when impacting, according to Mattijssen et al. (2018). Additionally, the 40 caliber weapon was not included in the study, but given the 40 cal is in between the caliber of 9mm and 45 cal, a logical inference can be made so long as the 40 cal is not fired at greater angles than 14-18 degrees the probability of ricochet is limited. Given this information, no shot will be fired within these ranges as it is not the purpose of this research to examine ricochets.**

Other Materials:

1. Drywall: 1/2” thick x 12” wide x 12” long
2. Nikon D5600 Digital Single Lens Reflective (DSLR) Camera
3. Fujifilm X-T1 IR Camera w/ Crime Lite
4. Sirchie Trajectory Analysis Kit
5. Husky 5 in. Digital Protractor

The weapons used for this research were those readily available to the researcher, and they provided a wide array of calibers with the intent of collecting data across a wide spectrum. The ammunition chosen was selected under a similar premise and consisted of two ball-type rounds and one hollow-point round for each of the three calibers. The Sirchie trajectory kit is a standard issued item for this type of work. Drywall was chosen as a medium due to its ease of access and ability to be manipulated. A digital protractor was selected, due to the accuracy of the tool, as opposed to a less precise 180-degree protractor. The photography equipment used was done for documentation and reproducibility purposes.

Methodology:

Many authors, researchers, and crime scene analysts have suggested a variance to some extent on what works best for each particular situation. Gardner and Bevel (2009), note crime scene reconstruction, should be broken down into a series of events, such as entry into an area, the encounter between the subject and victim, the commission of the crime, and the departure of the suspect. This research will be concerned with the commission of the crime portion, as well as the relevant information located within the scene.

The first step will be to collect relevant data pertinent to the scene, with the following questions in mind:

1. What happened, for example, was a gun fired?
2. If a gun was fired, what happened, did it penetrate a wall or furniture?
3. What was the most likely location/position of the shooter?

To answer these questions and the research hypothesis, 12 test fires will be conducted by:

1. Individually placing all three weapons loaded with ball-type Winchester and Armscor ammunition respectively, into a weapons mount and fired, from one and three feet at 30, 90, and 150-degree angles, into a standard piece of 12” x 12” drywall, with the horizontal and vertical angle, the presence of GSR and stippling, and the presence of bullet wipe being recorded.

2. One additional set of test-fires will be conducted from six feet and at 90-degrees, identical to step 1 above. These test-fires are being undertaken to demonstrate and reaffirm previous literature on GSR presence outside of approximately three feet, and that it will not be present.

After each iteration of test-fires, documentation of the bullet holes will be completed by:

[3]1. Obtaining crime scene photographs (i.e., overall, mid-range, and close-up photographs), under normal lighting conditions with and without scale, utilizing a Nikon D5600 Digital Single Lens Reflective (DSLR) Camera, to document the size and shape of the bullet hole, bullet wipe, and identify if any unknown fragments such as fabrics or fibers are present.

2. Then each bullet hole will be labeled with an alphabetic designator and photographed again.

3. Next, each bullet hole will be photographed under the Infrared Lighting condition utilizing a Fujifilm X-T1 Infrared Camera, to identify if GSR is present.

[3] **This method was derived from (Gardner and Bevel, 2009)**

Next, the following steps will be taken to conduct the trajectory analysis and render the scientific opinion of the shooter location:

4. The bullet hole will be fixed into its position in the wall by taking the length measurement of the wall and then taking two fixing measurements from opposing fixed corners of the room to the approximate center of the bullet hole.

5. Using a set of manual spreading calipers, the diameter of the hole will be recorded to determine caliber.

6. Next, a Sirchie trajectory rod will be fixed into the bullet hole, ensuring the use of both the entrance and exit hole, and secured with the supplied rubber bushings.

7. Next, to obtain the vertical angle a Sirchie No. LTF101 Ballistic Angle finder will be placed on top of the trajectory rod and the angle recorded.

8. Next, a Husky 5 in. Digital Protractor will be utilized to obtain the horizontal angle and the measurement recorded.

9. Once the trajectory angle is determined, a laser will be affixed to the end of the trajectory rod to visualize the flight path of the bullet, to confirm the known location of the test-fire.

With the test-fires complete, the blind trials will take place, by:

1. Configuring a 10' x 12' room with 8' to 9' foot ceilings with material as place holders to represent, one couch (measuring 8'L x 3'W x 3'6"H), one sitting type chair (measuring 4'L x 3'W x 4'H), and one coffee table (measuring 5'L x 3'W x 2'6"H), to be reconfigured after the 6th and 10th iterations of fire.

2. Next, a certified crime scene analyst, will randomly select a caliber and type of ammunition, load the firearm and secure it into a weapons mount and fire 18 individual iterations

of one through six shots per iteration, from a known distance, and angle, for a total 60 bullets fired, 20 from each weapon. Each iteration will be fired into a clean defect free piece of drywall, which will be placed on the north, south, or west wall. The east wall was not utilized as a safety precaution.

3. After each iteration is fired, the analyst will conduct a trajectory analysis to verify the angle and distance, and then record the weapon and ammunition type, distance and angle of fire.

4. Next, the researcher will enter the room and conduct the trajectory analysis as outlined during the test-fire portion.

5. To identify the most likely position of the shooter, bullet hole characteristics, GSR patterns, and the limiting factors will be examined to finally render the scientific opinion of the most likely shooter location.

Data: Analysis, Interpretation, Results, and Discussion:

Analysis and Interpretation:

The first set of independent variables or variables that can be manipulated, analyzed were the ammunition and the three-room conditions defined as:

Condition A: Couch was in the SWC of the room. Coffee table was approximately centered on the couch. Sitting Chair was in the NWC of the room. Iterations 1-6

Condition B: Couch was approximately centered on the E wall, with the coffee table approximately centered on the couch. The chair was in the SWC of the room. Iterations 7-10

Condition C: Couch was in the NWC of the room, and the coffee table was approximately centered on the couch. The chair was in the SWC of the room. 11-18,

To determine if either set of variables had a significant correlation to the dependent or constant variable (distance).

The test chosen for this analysis was the chi-square test which can give two separate outcomes, either a very small test result: meaning the observed data fit the expected data, and therefore there is a relationship, or a very large test result: meaning the data does not fit very well, and therefore there is no relationship. Generally speaking, a valid p-value for the chi-square test should range between 1-5% to reject the null hypothesis.

The chi-square test will only provide if there is a correlation between independent variables and dependent variables. The test will not elaborate on what independent factors were important. With limiting factors such as the furniture and the minimum and maximum distance of the room being the main focuses for this research and how they affected the ability to determine distance, additional analysis was required. To establish a correlation between all of the factors or refute a correlation, a correlation test with bootstrapping was conducted. Bootstrapping per IBM (2020), is a method of statistical analysis which estimates standard errors and confidence intervals for such measurements as the means, the median, and the proportion, and is best suited in conjunction with tests such as linear regression. Bootstrapping also runs these correlations several times in this researches case between 900-1000 iterations to determine how well the independent variables may fit into predictive models.

Merely analyzing the conditions and the ammunition would not lead to answering the research questions of this research. Therefore, several independent variables were selected from the collected data and the following formula developed:

[4]$\mathrm{Y} = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6$

[4] **Y(distance)= X1(1 - GSR/0 - Otherwise (O.W.) + X2(1 – Obj. Back wall/0 - O.W.) + X3(1 – Obj. Front wall/0 - O.W.) + (X4 - 1 - Up/0 - O.W. (Vertical Angle) + X5(1 - Bullet hole Short wall/0 - O.W.) + X6(1 - 10 Feet/0 - 12 Feet (Horizontal Angle) (Dr. Scott Bruce, personal communication, 2020)**

Once the formula was developed, Linear Regression and Neural Network 1 predictive models were selected to analyze the variables further. Linear Regression, according to IBM (2020), is a statistical analysis commonly used as a means of predictive analysis based on the value of another variable. The variable to be predicted in this research was distance and is considered the dependent variable, with all other inputs labeled as the independent variables. Therefore, the above independent variables were input into the IBM SPSS modeler to determine their ability to predict the distance value.

The second predictive tool utilized was a Neural Network 1 model, which, according to IBM (2020), is a statistical model simulating several interconnected processing units. It gets its name as it is designed in a way as the human brain processes information. It has the independent variables on the left (known as the input layer), and then nodes in the middle (known as the hidden layer), and then the dependent variable on the right (known as the output layer). The network learns by examining individual records and then generates a prediction for each record. Whenever the model makes incorrect predictions, the individual weights of the independent variables are changed, and the process repeats. The model continues to improve until the stopping criteria are met.

Results:

Figures 9 through 12 present the raw data distribution of the 18 iterations of fire. The visible GSR iterations were intentionally kept low. For this research, it would not have added any scientific validity to the study, if a large number of iterations contained visible GSR on the target, as visual GSR has been established as a reliable means to determine shooter location. Figure 13 depicts a simple histogram, annotating the difference between the known and unknown data and data plotted concerning the unknown data, to establish a standard deviation. The histogram shows the standard deviation between known and unknown distances is within the threshold of the original hypothesis listed as +/- three through five feet.

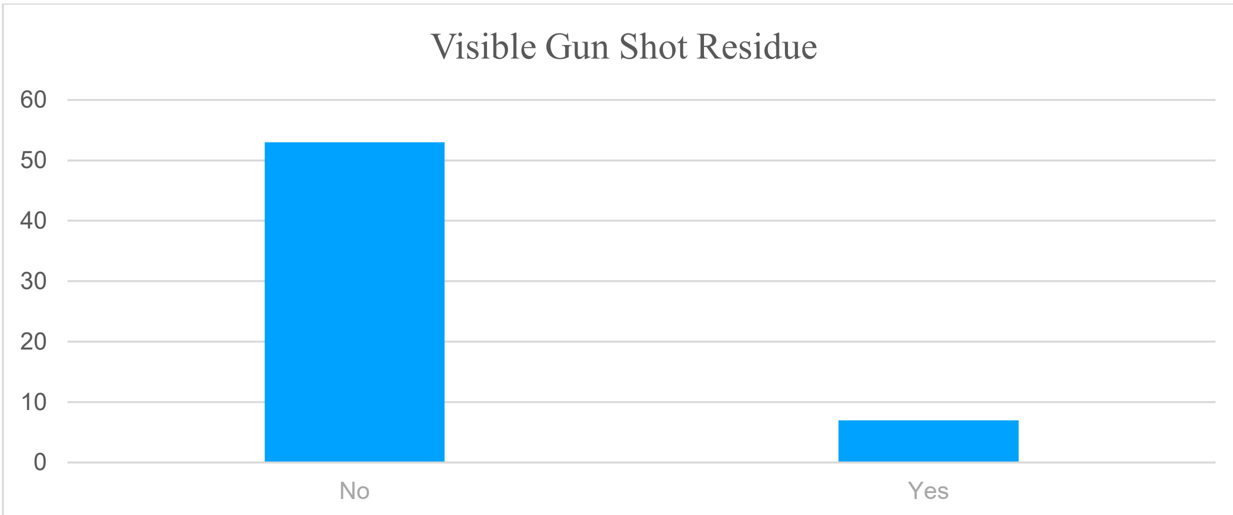

Figure 9 ***(Number of Iterations GSR was Visible vs. Not Visible)***

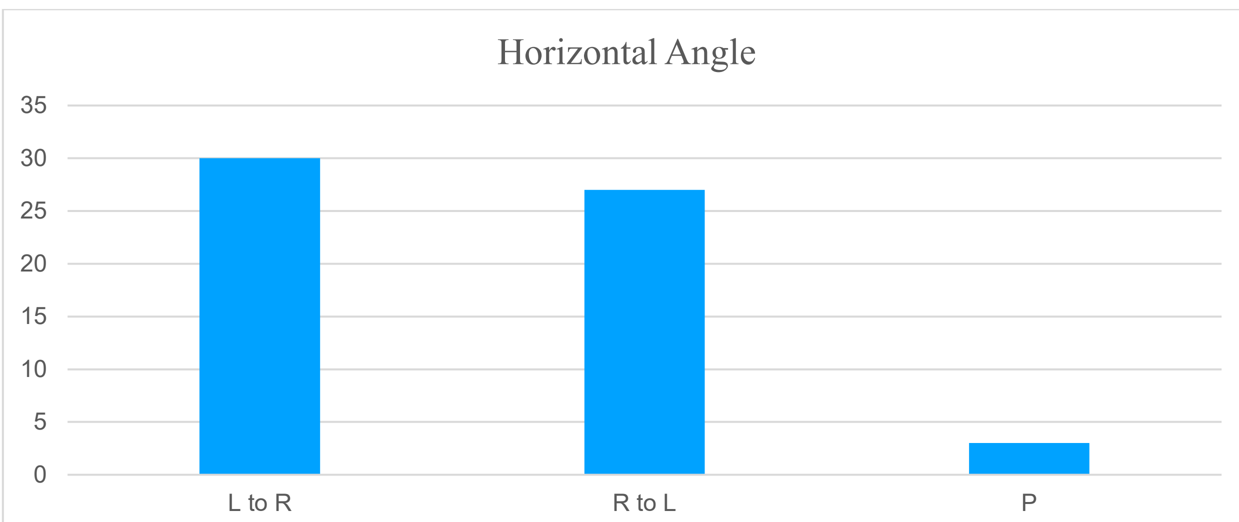

Figure 10 ***(Distribution of Left to Right, Right to Left, or Parallel)***

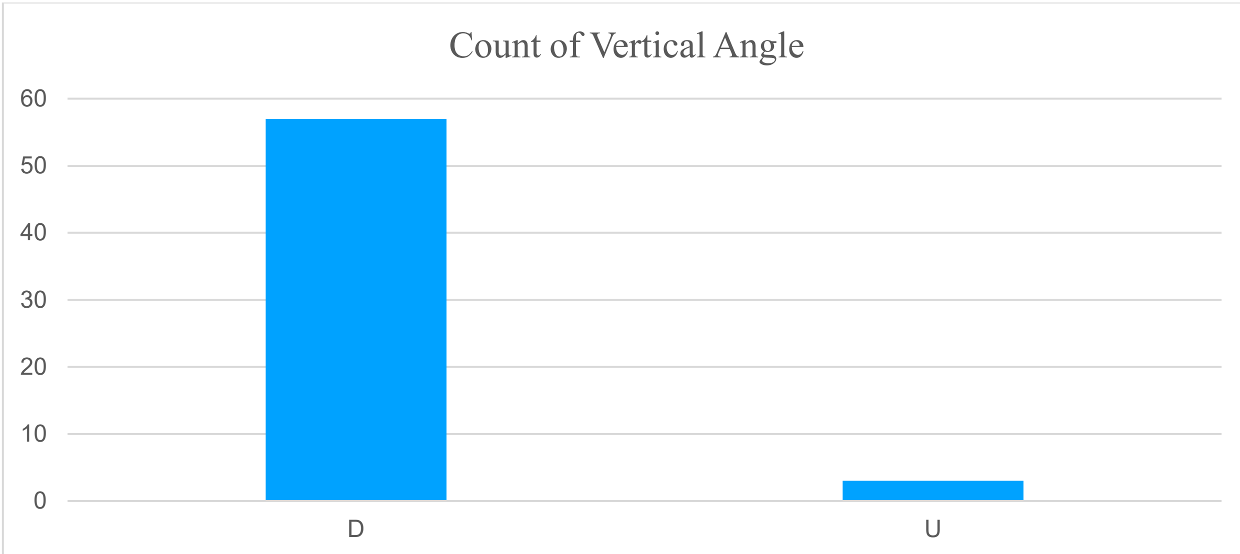

*Figure 11***(Distribution of Down vs. Up)**

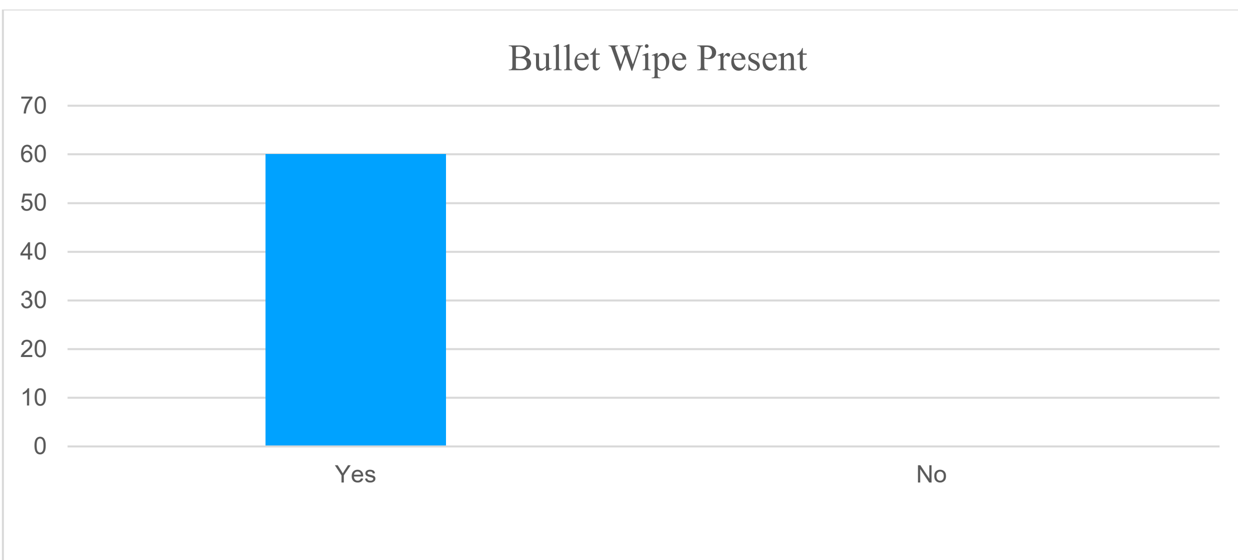

*Figure 12***(Bullet Wipe Present vs. Not Present)**

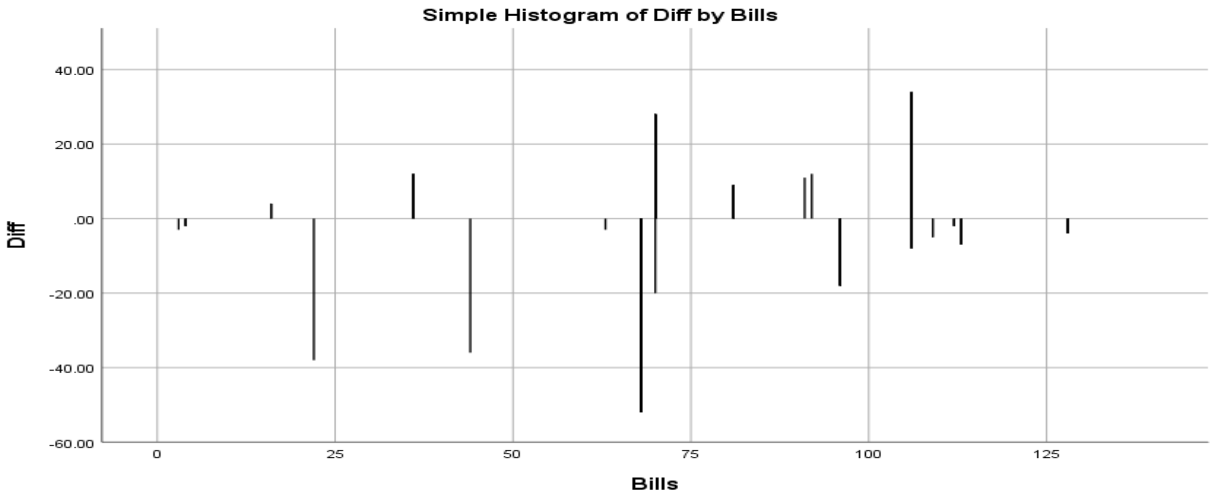

Figure 13 ***(Standard Deviation between the Blind Reconstructions and Known Distance) The Difference was calculated by determining the difference between the research data and the known data. The research data was recorded in a range of feet, and for this comparison, it was averaged to compare against the unknown data.***

Descriptive Statistics

	N	Minimum	Maximum	Mean		Std. Deviation	Variance
	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Statistic
Bills	60	3	128	78.05	4.565	35.360	1250.319
difference	60	-34.00	52.00	2.5833	3.05434	23.65880	559.739
Valid N (listwise)	60						

Figure 14 ***(Known Standard Deviation Compared to the Difference between the Researcher and Examiner are within 3-5')***

Table of MLSD by Condition				
MLSD	**Condition**			
Frequency Percent Row Pct Col Pct	**A**	**B**	**C**	**Total**
0 - 1'	1 1.67 20.00 11.11	0 0.00 0.00 0.00	4 6.67 80.00 10.00	5 8.33
0 - 2'	2 3.33 100.00 22.22	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 3.33
1' - 3'	0 0.00 0.00 0.00	3 5.00 100.00 27.27	0 0.00 0.00 0.00	3 5.00
2' - 5'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	6 10.00 100.00 15.00	6 10.00
4' - 10'	3 5.00 100.00 33.33	0 0.00 0.00 0.00	0 0.00 0.00 0.00	3 5.00
4' - 6'	1 1.67 100.00 11.11	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 1.67
4' - 7'	1 1.67 100.00 11.11	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 1.67
4' - 8'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	10 16.67 100.00 25.00	10 16.67
4' -10'	1 1.67 100.00 11.11	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 1.67
6' - 10'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	6 10.00 100.00 15.00	6 10.00
6' - 9'	0 0.00 0.00 0.00	1 1.67 100.00 9.09	0 0.00 0.00 0.00	1 1.67
8' - 11'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	9 15.00 100.00 22.50	9 15.00
8' 3" -	0 0.00 0.00 0.00	0 0.00 0.00 0.00	5 8.33 100.00 12.50	5 8.33
8' 5" -	0 0.00 0.00 0.00	3 5.00 100.00 27.27	0 0.00 0.00 0.00	3 5.00
9' - 13'	0 0.00 0.00 0.00	4 6.67 100.00 36.36	0 0.00 0.00 0.00	4 6.67
Total	9 15.00	11 18.33	40 66.67	60 100.00

Statistic	DF	Value	Prob
Chi-Square	28	113.4667	<.0001
Likelihood Ratio Chi-Square	28	98.9032	<.0001
Mantel-Haenszel Chi-Square	1	2.3235	0.1274
Phi Coefficient		1.3752	
Contingency Coefficient		0.8088	
Cramer's V		0.9724	
WARNING: 96% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 15 ***(Correlation Results 3 Conditions in relation to Distance)***

Table of MLSD by HoleSize

MLSD Frequency Percent Row Pct Col Pct	HoleSize 10mm	11mm	9mm	Total
0 - 1'	0 0.00 0.00 0.00	5 8.33 100.00 23.81	0 0.00 0.00 0.00	5 8.33
0 - 2'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	2 3.33 100.00 7.14	2 3.33
1' - 3'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	3 5.00 100.00 10.71	3 5.00
2' - 5'	0 0.00 0.00 0.00	6 10.00 100.00 28.57	0 0.00 0.00 0.00	6 10.00
4' - 10'	1 1.67 33.33 9.09	2 3.33 66.67 9.52	0 0.00 0.00 0.00	3 5.00
4' - 6'	1 1.67 100.00 9.09	0 0.00 0.00 0.00	0 0.00 0.00 0.00	1 1.67
4' - 7'	0 0.00 0.00 0.00	1 1.67 100.00 4.76	0 0.00 0.00 0.00	1 1.67
4' - 8'	5 8.33 50.00 45.45	0 0.00 0.00 0.00	5 8.33 50.00 17.86	10 16.67
4' -10'	0 0.00 0.00 0.00	1 1.67 100.00 4.76	0 0.00 0.00 0.00	1 1.67
6' - 10'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	6 10.00 100.00 21.43	6 10.00
6' - 9'	0 0.00 0.00 0.00	1 1.67 100.00 4.76	0 0.00 0.00 0.00	1 1.67
8' - 11'	0 0.00 0.00 0.00	3 5.00 33.33 14.29	6 10.00 66.67 21.43	9 15.00
8' 3" -	1 1.67 20.00 9.09	2 3.33 40.00 9.52	2 3.33 40.00 7.14	5 8.33
8' 5" -	3 5.00 100.00 27.27	0 0.00 0.00 0.00	0 0.00 0.00 0.00	3 5.00
9' - 13'	0 0.00 0.00 0.00	0 0.00 0.00 0.00	4 6.67 100.00 14.29	4 6.67
Total	11 18.33	21 35.00	28 46.67	60 100.00

Statistic	DF	Value	Prob
Chi-Square	28	75.1017	<.0001
Likelihood Ratio Chi-Square	28	84.4058	<.0001
Mantel-Haenszel Chi-Square	1	0.7425	0.3889
Phi Coefficient		1.1188	
Contingency Coefficient		0.7456	
Cramer's V		0.7911	
WARNING: 100% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Figure 16 ***(Correlation Results Ammunition in Relation to Distance)***

Figures 15 and 16 documents the results of the chi-square test between the correlation of the furniture conditions and ammunition as they relate to distance. Both of the above results show there is a significant p-value, both tests were less than .0001, meaning there is a correlation between the configuration of the furniture and distance, as well as, the caliber of the bullet and distance. For clarification purposes, the remaining test results of the above two figures are outlined below:

1. Likelihood Ratio Chi-Squared: statistical test of association or goodness of fit
2. Mantel-Haensznel Chi-Squared: test the alternate hypothesis that there is a linear association between the row variable and the column variable.
3. Phi-Coefficient: is a measure of association derived from the Pearson Chi-Square
4. Contingency Coefficient: this is a measure of the association derived from the Pearson Chi-Square
5. Cramer's V: this is a measure of association calculated from the Pearson Chi-Square

What is most important for the outcome of the initial analysis was the p-value of less than .05. With the other results confirming the p-value and the goodness of fit for the ammunition and furniture configuration. Goodness of fit is defined as how well the input data will fit into a model of prediction reference the dependent variable. Therefore the research could conclude there is a relationship between the three separate conditions and the three types of bullets as it relates to the distances[5].

Figure 17 depicts all of the correlation with bootstrapping results for all independent variables. A review of the data shows there are correlations between distance and all of the independent variables input. This result is known for two reasons, the first being the Sig (2-tailed) results are less than .05. Additionally, when examining the Pearson Correlation, most of

[5] The ammunition was not analyzed any further. This research focused on the limited distance of fire, which, according to Noedel (2009), at 15' the drop is only marginal. All shots for this research were conducted within 12 feet. Because of this, it is only relevant to note, caliber does correlate with distance, but additional research will be required to determine how ammunition as an independent variable may assist with refining the techniques outlined here.

the independent variable results are negative, but this becomes statistically valid when looking at the Bias Corrected and Accelerated (BCa), in conjunction with the Pearson Correlation. If the independent variable Pearson Correlation, upper, and lower BCa are all on the same side of zero, the inference is there is a correlation between the factors.

Correlation can be both + or – and the assumption of no relationship given the negative numbers is rejected here. If for, example, a further review of the GSR result is conducted, the Pearson Correlation for the dependent variable is one, and the three previously mentioned numbers for the independent variable (GSR) are negative. This result means that as distance increases, GSR decreases. This is an expected result, given the information outlined in this research. The same is true when examining the results of the other five independent variables. These correlations confirm the variables have significance in the goodness of fitness test, predictive models, and overall distribution amongst distance.

Correlations[b]

					Y=Distance	X1=GSR
Y=Distance	Pearson Correlation				1	-.733**
	Sig. (2-tailed)					.000
	Sum of Squares and Cross-products				73768.850	-495.350
	Covariance				1250.319	-8.396
	Bootstrap[anx]	Bias			0	.012
		Std. Error			0	.081
		BCa 95% Confidence Interval	Lower		.	-.866
			Upper		.	-.478
X1=GSR	Pearson Correlation				-.733**	1
	Sig. (2-tailed)				.000	
	Sum of Squares and Cross-products				-495.350	6.183
	Covariance				-8.396	.105
	Bootstrap[anx]	Bias			.012	0
		Std. Error			.081	0
		BCa 95% Confidence Interval	Lower		-.866	.
			Upper		-.478	.

**. Correlation is significant at the 0.01 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

anx. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Correlations[b]

				Y=Distance	X2=Obj Back Wall
Y=Distance	Pearson Correlation			1	-.372**
	Sig. (2-tailed)				.003
	Sum of Squares and Cross-products			73768.850	-291.500
	Covariance			1250.319	-4.941
	Bootstrap[anx]	Bias		0	.003
		Std. Error		0	.113
		BCa 95% Confidence Interval	Lower	.	-.608
			Upper	.	-.136
X2=Obj Back Wall	Pearson Correlation			-.372**	1
	Sig. (2-tailed)			.003	
	Sum of Squares and Cross-products			-291.500	8.333
	Covariance			-4.941	.141
	Bootstrap[anx]	Bias		.003	0
		Std. Error		.113	0
		BCa 95% Confidence Interval	Lower	-.608	.
			Upper	-.136	.

**. Correlation is significant at the 0.01 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

anx. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Correlations[b]

				Y=Distance	X3= Obj Front Wall
Y=Distance	Pearson Correlation			1	-.294*
	Sig. (2-tailed)				.023
	Sum of Squares and Cross-products			73768.850	-308.400
	Covariance			1250.319	-5.227
	Bootstrap[anx]	Bias		0	.004
		Std. Error		0	.120
		BCa 95% Confidence Interval	Lower	.	-.539
			Upper	.	-.041
X3= Obj Front Wall	Pearson Correlation			-.294*	1
	Sig. (2-tailed)			.023	
	Sum of Squares and Cross-products			-308.400	14.933
	Covariance			-5.227	.253
	Bootstrap[anx]	Bias		.004	0
		Std. Error		.120	0
		BCa 95% Confidence Interval	Lower	-.539	.
			Upper	-.041	.

*. Correlation is significant at the 0.05 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

anx. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Correlations[b]

				Y=Distance	X4=U/D
Y=Distance	Pearson Correlation			1	-.341**
	Sig. (2-tailed)				.008
	Sum of Squares and Cross-products			73768.850	-156.150
	Covariance			1250.319	-2.647
	Bootstrap[any]	Bias		0	.011[anz]
		Std. Error		0	.140[anz]
		BCa 95% Confidence Interval	Lower	.	-.629[anz]
			Upper	.	-.017[anz]
X4=U/D	Pearson Correlation			-.341**	1
	Sig. (2-tailed)			.008	
	Sum of Squares and Cross-products			-156.150	2.850
	Covariance			-2.647	.048
	Bootstrap[any]	Bias		.011[anz]	0[anz]
		Std. Error		.140[anz]	0[anz]
		BCa 95% Confidence Interval	Lower	-.629[anz]	.[anz]
			Upper	-.017[anz]	.[anz]

**. Correlation is significant at the 0.01 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

any. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

anz. Based on 947 samples

Correlations[b]

				Y=Distance	X5=L/S Wall
Y=Distance	Pearson Correlation			1	.612**
	Sig. (2-tailed)				.000
	Sum of Squares and Cross-products			73768.850	642.400
	Covariance			1250.319	10.888
	Bootstrap[anx]	Bias		0	.005
		Std. Error		0	.084
		BCa 95% Confidence Interval	Lower	.	.432
			Upper	.	.783
X5=L/S Wall	Pearson Correlation			.612**	1
	Sig. (2-tailed)			.000	
	Sum of Squares and Cross-products			642.400	14.933
	Covariance			10.888	.253
	Bootstrap[anx]	Bias		.005	0
		Std. Error		.084	0
		BCa 95% Confidence Interval	Lower	.432	.
			Upper	.783	.

**. Correlation is significant at the 0.01 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

anx. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Correlations[b]

				Y=Distance	X6=Max Distance
Y=Distance	Pearson Correlation			1	.612**
	Sig. (2-tailed)				.000
	Sum of Squares and Cross-products			73768.850	642.400
	Covariance			1250.319	10.888
	Bootstrap[anx]	Bias		0	.002
		Std. Error		0	.088
		BCa 95% Confidence Interval	Lower	.	.402
			Upper	.	.768
X6=Max Distance	Pearson Correlation			.612**	1
	Sig. (2-tailed)			.000	
	Sum of Squares and Cross-products			642.400	14.933
	Covariance			10.888	.253
	Bootstrap[anx]	Bias		.002	0
		Std. Error		.088	0
		BCa 95% Confidence Interval	Lower	.402	.
			Upper	.768	.

**. Correlation is significant at the 0.01 level (2-tailed).

b. $bootstrap_split=0,:Listwise N=60

anx. Unless otherwise noted, bootstrap results are based on 1000 bootstrap samples

Figure 17 ***(Correlation with Bootstrapping Results)***

The Linear Regression model results below were analyzed using IBM SPSS modeler. Figure 18 is the R-squared and the Adjusted R-squared and the Parameter Estimates. The R-squared and the Adjusted R-squared are a measure of the goodness of fit for the independent variables and their importance of predicting the dependent variable. These results are based on a 0-1 scale, with the closer the output is to 1, the better fit the data is for the model. The Parameter Estimates depict significant p-values <.05 for all variations ran except (GSR (yes) and Object on the Back wall (otherwise) and U/D (D) and Max Distance (10’) not proving significant. There are several blank spaces on the charts, due to the program deeming the configurations redundant and removing the configurations from the model.

Figure 19 depicts the importance of the independent variables based on their impact predicting the dependent variable. The scale is on a 0-1 with overall distance, and GSR being the top three important factors. Figure 20 depicts the goodness of fit for the independent variables in a table form. In a 100% model, all of the represented dots would be precisely along the 45-degree line; however, as previously stated, the independent variables here were not at 1, so this outcome was expected.

Linear Regression

Model Information

Target Field	Y=Distance
Model Building Method	Forward Stepwise
Forward Stepwise Criterion	Adjusted R-Squared
Forward Stepwise Rule	Single Factor
Number of Predictors Input	6
Number of Predictors in Final Model	6
Corrected Akaike Information Criterion (AICc)	293.045

Records Summary

Records	Number	Percent
Included	60	100.00
Excluded	0	0.00
Total	60	100.00

Tests of Model Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Error	5,532.716	51	108.485		
Corrected Total	73,768.850	59			

Dependent Variable: Y=Distance

R-Squared = 0.925 (Adjusted R-Squared= 0.913)

[X1=GSR=0.0] * [X2=Obj Back Wall=0.0]	55.652	17.153	3.244	0.002	21.216	90.087
[X1=GSR=0.0] * [X2=Obj Back Wall=1.0]	53.750	9.020	5.959	0.000	35.641	71.859
[X1=GSR=1.0] * [X2=Obj Back Wall=0.0]	-11.524	16.241	-0.710	0.481	-44.129	21.081
[X1=GSR=1.0] * [X2=Obj Back Wall=1.0]	0[b]					
[X4=U/D=0.0] * [X6=Max Distance=0.0]	-34.000	12.027	-2.827	0.007	-58.145	-9.855
[X4=U/D=0.0] * [X6=Max Distance=1.0]	-0.250	11.645	-0.021	0.983	-23.628	23.128
[X4=U/D=1.0] * [X6=Max Distance=0.0]	0[b]					

Dependent Variable: Y=Distance[a]
a. Computed using alpha = .05
b. This parameter is set to zero because it is redundant.

Parameter Estimates[a]

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Intercept	38.932	14.896	2.614	0.012	9.026	68.837
X3= Obj Front Wall=0.0	-22.682	5.661	-4.006	0.000	-34.048	-11.316
X3= Obj Front Wall=1.0	0[b]					
[X2=Obj Back Wall=0.0] * [X4=U/D=0.0]	33.667	15.331	2.196	0.033	2.888	64.446
[X2=Obj Back Wall=0.0] * [X4=U/D=1.0]	0[b]					
[X2=Obj Back Wall=1.0] * [X4=U/D=0.0]	0[b]					
[X2=Obj Back Wall=1.0] * [X4=U/D=1.0]	0[b]					
[X2=Obj Back Wall=0.0] * [X5=L/S Wall=0.0]	-23.408	9.804	-2.388	0.021	-43.090	-3.726
[X2=Obj Back Wall=0.0] * [X5=L/S Wall=1.0]	0[b]					
[X2=Obj Back Wall=1.0] * [X5=L/S Wall=0.0]	0[b]					
[X2=Obj Back Wall=1.0] * [X5=L/S Wall=1.0]	0[b]					

Figure 18 ***(Linear Regression Model Results)***

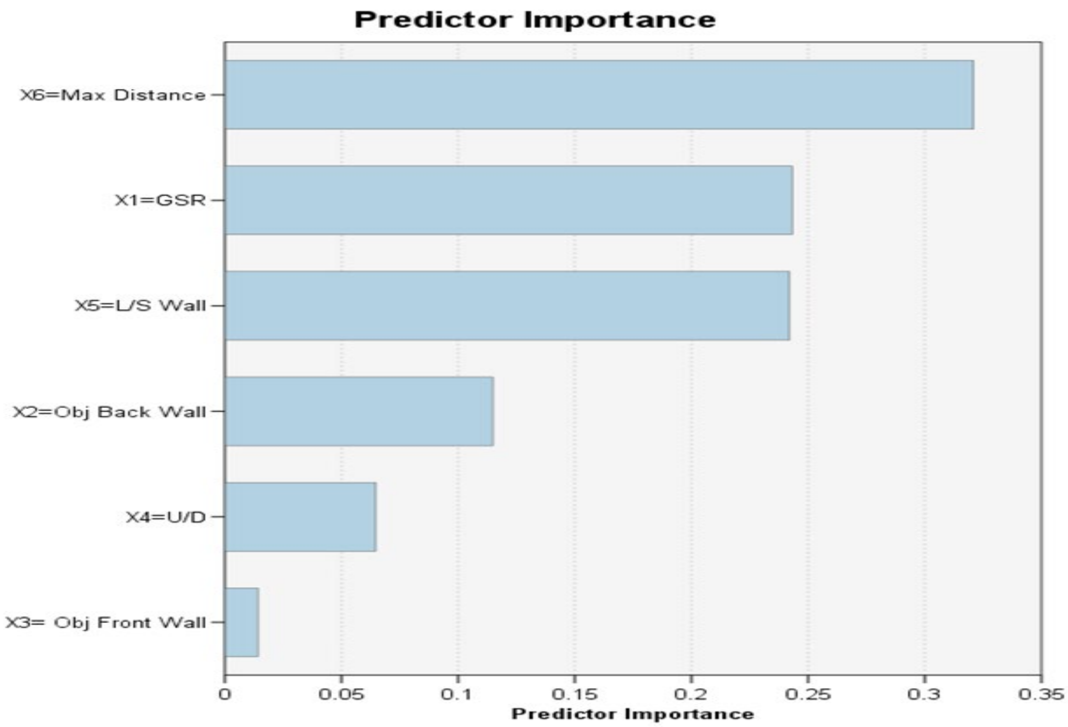

Figure 19 ***(Independent Variable by Level of Importance)***[6]

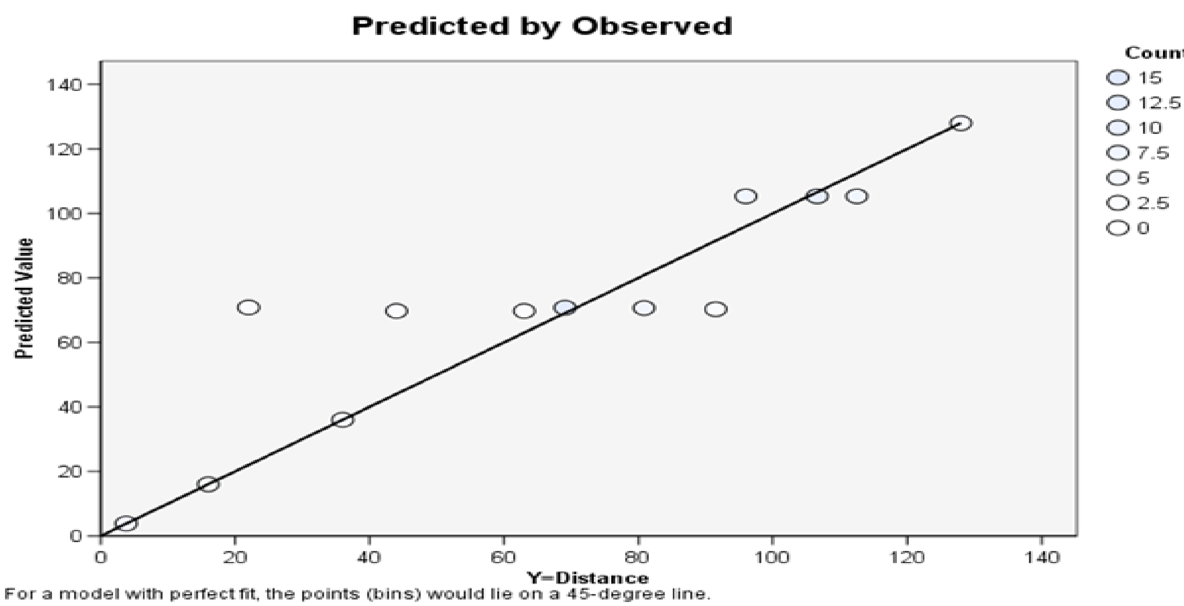

Figure 20 ***(Goodness of Fit)***

[6] **Max Distance=.32, GSR=.24, L/S=.24, Back Wall=.11, U/D=.06, and Front Wall=.01**

The last test was a Neural Network 1, which was run via IBM SPSS Modeler. Figure 21 depicts the summary of the test run, as well as the accuracy of the test 92.2%. This accuracy is based on the independent variables ability to predict the dependent variable. Figure 22 depicts the same 0-1 scale of ranking the independent variables in their strengths at predicting the dependent variables. There is some deviation in the ranking of the independent variables, but what is clear is that GSR, furniture, and minimum and maximum distance are all influential independent variables when predicting the dependent variable. This may be attributed to the different methods used to predict distance. With the Neural Network model learning from mistakes and then correcting the algorithm. Figure 23 depicts the goodness of fit in a chart form. This model does not provide the same 45-degree line as the Linear Regression model, but most of the dots are still generally along the 45-degree angle.

Model Summary

Target	Y=Distance
Model	Multilayer Perceptron
Stopping Rule Used	Error cannot be further decreased
Hidden Layer 1 Neurons	5

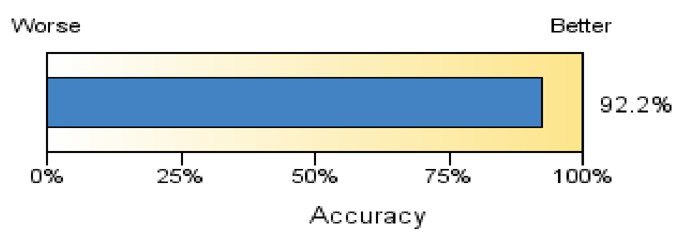

Figure 21 ***(Neural-Net Results)***

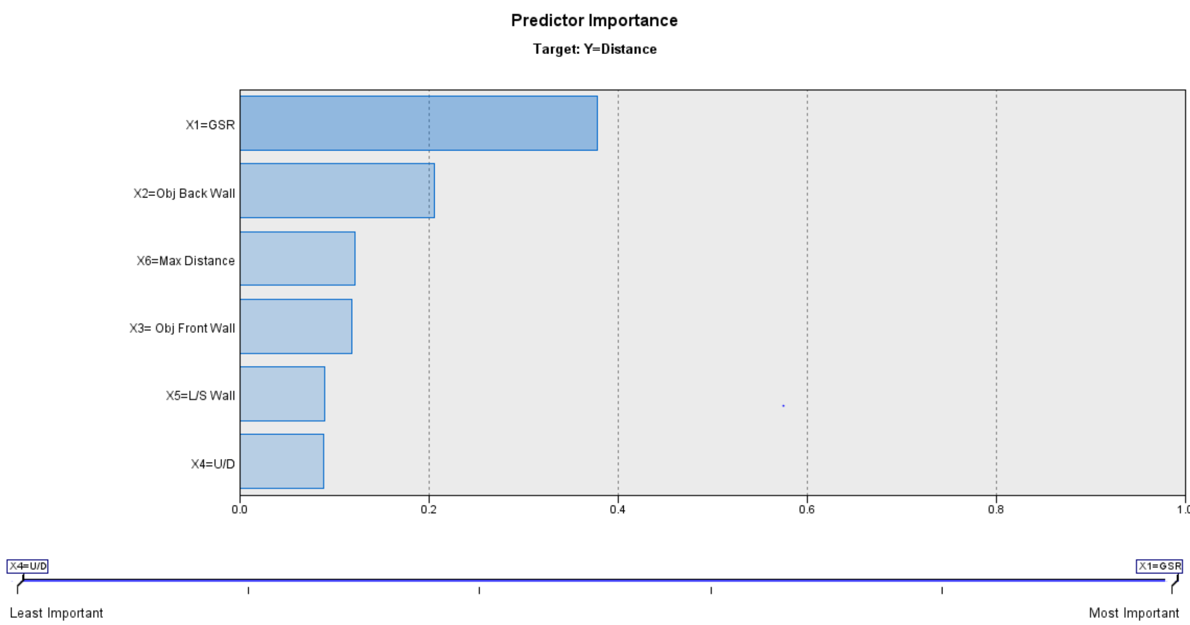

Figure 22 ***(Independent Variable Level of Importance)***[7]

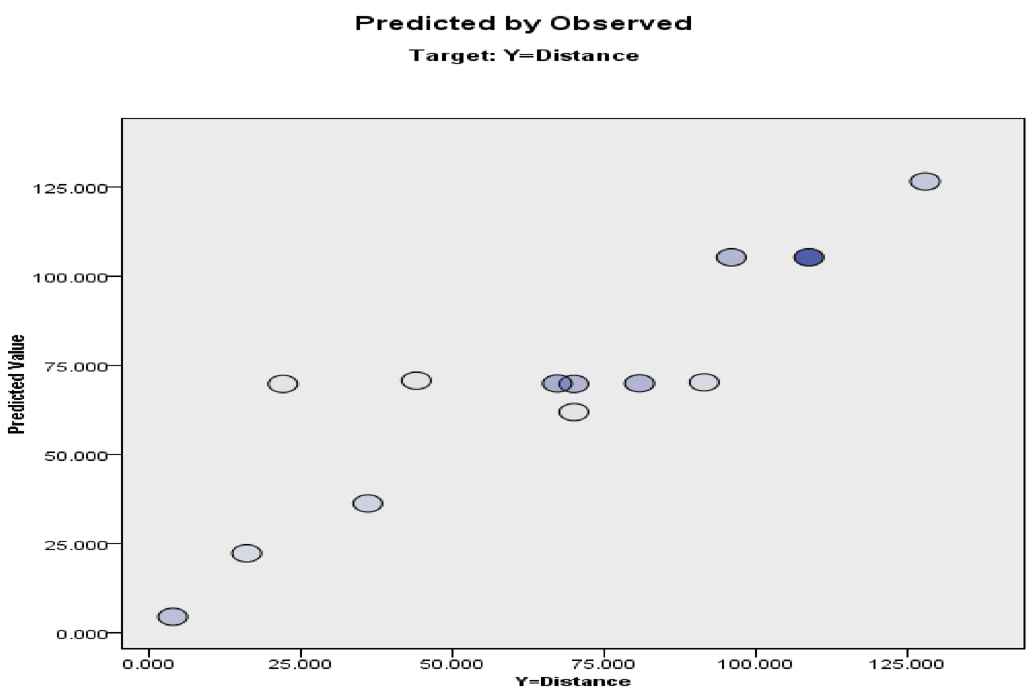

Figure 23 ***(Goodness of Fit)***

[7] **GSR=.38, Back Wall=.21, Max Distance=.12, Front Wall=.12, L/S=.09, and U/D=.09**

Discussion:

Based on the given statistical analysis, it appears there is evidence to support the original hypothesis; if bullet hole characteristics, GSR, and limiting factors are accounted for, a shooter can be placed within +/- three through five feet of their location at the time the weapon was fired. From the results, the conclusion can be made an object on the same wall as the bullet hole, and the up and down angles are less important in conducting the predictions. While no statistical analysis was done, the presence of bullet wipe for this research was significant. Bullet wipe will be present in most instances and may be useful in identifying defects as a bullet holes; this could be another factor to aide in the reconstruction. The use of actual furniture and a larger space to create more room configurations could prove valuable to improving the predictive models. The bullet could pass through the furniture, and the furniture could be moved around the scene to a greater extent providing additional quantification of these variables.

Lastly, the use of predictive models and incorporation of the critical/limiting factors discussed herein are intended to guide crime scene investigators. Much more research will be required to refine the model as a whole further. Other factors may prove to be more important, which would replace the less significant factors in the models put forth by this research. In hopes of getting to a point where there will be key elements, investigators can collect and use to render their opinions. Ultimately, using prediction models to determine the statistical validity and accuracy of the CSI's opinion, thus moving away from subjective interpretations and into scientifically valid ones.

Future Research:

Some areas of future research may include examining how different types/size of bullet grains effects visible GSR. Notably, gunpowder comes in a host of different load configurations.

Gun manufacturers routinely change the configuration of the load. This change may have a direct impact on the ability of GSR to travel, such as throwing a baseball through the air will travel further, versus if a Frisbee is thrown end over end through the air. Incorporating larger spaces and more limiting factors to assess if their incorporation into predictive models can improve overall accuracy. Through this research, some data was not recorded, specifically, furniture distance to the actual bullet hole. This may be another avenue, which can refine the original formula put forth in this research.

Determining to what extent GSR reagents may be able to identify a trail of GSR over distance. Specifically, if a shooter is outside of the accepted 3' window, with the proper trajectory analysis and distance determination identifying if a path of GSR can be visualized, is another factor that may place a shooter in a room. Additionally, incorporating the presence of a bullet wipe into the formula may be another useful factor in placing a shooter. An example would be if there is a bullet wipe on the couch, and an impact in the wall and the CSI determines the angles align, then it is reasonable to assume the shooter was behind the couch.

The conditions outlined in this research merely included the configuration of the room. Future research may consist of expanding these conditions, to include all of the independent variables. Then correlation could be run against whole groups of independent variables, thus allowing the research to focus on those conditions most important and then further analyze them using predictive modeling.

Conclusion:

Putting more science into forensic science is a must. There may be occasions, when a CSI is unable to determine, at the time of their scene examination, the shooter's location; however, when the above factors are available, they should attempt to collect them, and to every extent possible, provide a scientifically valid range of where the shooter was positioned. Trajectory analysis should focus on developing testable hypotheses, creating and refining scientifically accurate formulas, and collecting critical data points, to ensure the science of the discipline. This research is a small first step to try and develop critical pieces of information that should be collected from shooting scenes when applicable. More data points are needed to determine if predictive modeling is a plausible tool for trajectory analysis. All of the independent variables outlined in this research may not be applicable in some cases, and there may be other factors far more important that could replace some of the variables described above. This research intends to start a discussion and eventually determine if there is a set of variables that could improve the predictive model accuracy to 100%.

This research will only strengthen the investigations being conducted and could prove scientifically, the actions that took place at a shooting scene. With a goal in mind of being able to present facts as the science says they are. What must be remembered is the act of conducting these exams should not become so complicated that the average analyst can't explain them. It does no good if scientifically valid interpretations are provided, but they are so convoluted and confusing to understand, only mathematicians can do so.

References:

Bell, S. (2012). stippling. In A Dictionary of Forensic Science. Retrieved from http://www.oxfordreference.com/view/10.1093/acref/9780199594009.001.0001/acref-9780199594009-e-1184

Biedermann, A., & Taroni, F. (2006). A probabilistic approach to the joint evaluation of firearm evidence and gunshot residues. *Forensic Science International*, *163*(1), 18–33. https://doi.org/10.1016/ j.forsciint.2005.11.001

Carlucci, Donald E., and Jacobson, Sidney S. Ballistics theory and design of guns and ammunition. 2nd ed. Boca Raton [Fla: Taylor & Francis Group, 2014. Print.

Digital photography & imaging. (2003). *Forensic Science International*, *136*, 24–31. https:// doi.org/10.1016/S0379-0738(03)90007-7

Braswell, M. Fish, J., Miller, L. & Wallace, E. (2014). Crime scene investigation (3rd ed.). Oxfordshire, England ;:Routledge.

Galligan, A., Fries, C., & Melinek, J. (2017). Gunshot wound trajectory analysis using forensic animation to establish relative positions of shooter and victim. *Forensic Science International*, *271*, e8–e13. https://doi.org/10.1016/j.forsciint.2016.12.039

Gardner, R. (2005). Practical crime scene processing and investigation . Boca Raton, Fla: CRC Press.

Gardner, R., & Bevel, T. (2009). Practical crime scene analysis and reconstruction. Boca Raton: CRC Press.

Gardner, R., & Krouskup, D. (2019). Practical crime scene processing and investigation (Third edition.). Boca Raton, FL: CRC Press.

Große Perdekamp, M., Nadjem, H., Merkel, J., Braunwarth, R., Pollak, S., & Thierauf, A.

(2011). Two-gun suicide by simultaneous shots to the head: interdisciplinary reconstruction on the basis of scene investigation, autopsy findings, GSR analysis and examination of firearms, bullets and cartridge cases. International Journal of Legal Medicine, 125(4), 479–485. https://doi.org/10.1007/s00414-010-0517-6

Gramlich, J. (2019, August 16). What the data says about gun deaths in the u.s. Retrieved from https://www.pewresearch.org/fact-tank/2019/08/16/what-the-data-says-about-gun-deaths-in-the-u-s/

Haag, L. (2005). Physical forms of contemporary small-arms propellants and their forensic value. The American Journal of Forensic Medicine and Pathology, 26(1), 5–10. https://doi.org/10.1097/01.paf.0000154117.60171.52

Haag, Lucien C. and Haag, Michael G., Shooting incident reconstruction. 2nd ed. San Diego, CA: Academic Press, 2011. Print.

Heard, B. (2008). Handbook of firearms and ballistics : examining and interpreting forensic evidence . Oxford ;: Wiley-Blackwell.

Hueske, Edward E. Practical analysis and reconstruction of shooting incidents. Boca Raton, FL: CRC/Taylor & Francis, 2006. Print.

Kochanek, K., Murphy, S., Xu, J., & Arias, E. (2019, June 24). Deaths: final data for 2017. National Vital Statistics Report, 68(9), 1–77. doi: https://www.cdc.gov/nchs/data/nvsr/nvsr68/nvsr68_09-508.pdf

Kerkhoff, Wim, Alberink, Ivo, and Mattijssen, Erwin J. A. T. “An Empirical study on the relation between the critical angle for bullet ricochet and the properties of wood.”

Journal of Forensic Sciences 60.3 (2015): 605–610. Web.

Mattijssen, Erwin J. A. T., Kerkhoff, Wim, and Bestebreurtje, Marlies E. “Bullet trajectory after impact on laminated particle board.” Journal of Forensic Sciences 63.5 (2018): 1374–1382. Web.

Mattijssen, E., & Kerkhoff, W. (2016). Bullet trajectory reconstruction – methods, accuracy and precision. *Forensic Science International*, *262*, 204–211. https://doi.org/10.1016/j.forsciint.2016.03.039https://doi.org/10.17226/12589

National Research Council, Division on Engineering and Physical Sciences, Committee on Applied and Theoretical Statistics, Policy and Global Affairs, Committee on Science, T., & Committee on Identifying the Needs of the Forensic Sciences Community. (2012). Strengthening Forensic Science in the United States: A Path Forward (pp. 1–328). https://doi.org/10.17226/12589

Robinson, E. (2016). Crime scene photography (3rd edition.). London: Academic Press.

Shooting Reconstruction, 1912 Waihi Strike. N.p. Print.

SPSS Statistics - Overview. (n.d.). Retrieved March 1, 2020, from https://www.ibm.com/products/spss-statistics