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An Examination Of A Three-Dimensional Automated Firearms Evidence Comparison System

Natalie G. Carpenter
University of South Florida

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by

Natalie G. Carpenter

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Major Professor: Tom Mieczkowski, Ph.D
Kim M. Lersch, Ph.D
M. Dwayne Smith, Ph.D

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ABSTRACT

This thesis is an examination of a firearm identification system that creates a three-dimensional image of a bullet in order to record the depth and length of striations occurring along the bullet's surface. Ballistics evidence is an area of forensics in great need of further development. The advent of more sophisticated firearms such as semi-automatic and automatic weapons has increased the need for a matching system that connects bullets found at crime scenes with suspect guns. In the past, control bullets matching ones found at the crime scene have been test fired and then examined by a comparison microscope for similarities with the evidence bullet.

The purpose of this thesis is to examine data collected by an emerging system that uses three-dimensional technology by way of a laser and convex mirrors to create a digitized representation of the lands and grooves of a bullet. This representation is a measure of the depth of striations or markings created on the bullet's surface during the firing event. The objective of this thesis is to statistically examine the data collected by this system, which consists of bullets produced by eight different manufacturers.

The data for this thesis comes from a pilot study conducted by the creators of a three-dimensional system called SCICLOPS. Variables examined include the maximum and minimum number of striations recorded, the relative position of the bullet (as determined by the six lands and grooves measured by the system), and the manufacturer type. It is hypothesized that there will be differences in the number of striations measured across

manufacturer types. Results indicate that manufacturer type may play an important role in how bullets “take” striations or markings during the firing event. Implications for the SCICLOPS system and future research are discussed.

Chapter One

Introduction

The term “ballistics” refers to the study of the motion of a projectile. There are three types of ballistics that are usually studied - internal, external, and terminal. Internal ballistics involves the study of the projectile within the firearm and includes the areas of chamber configuration, chamber pressure, and rifling. Exterior ballistics concerns the projectile after it leaves the firearm, i.e. velocity and trajectory. Finally, terminal ballistics concerns the study of the effects of the projectile on a target. In the *Handbook of Forensic Science*, the Federal Bureau of Investigation (1981) defines firearms identification as “the study by which a bullet, cartridge case, or shotshell casing may be identified as having been fired by a particular weapon to the exclusion of all other weapons”(p.52). Firearms themselves have had a long, illustrious, and documented history, while the first written reference to the subject of firearms identification has been recorded as occurring in 1900 with Hall’s “The Missile and the Weapon” in the *Buffalo Medical Journal*. It was not until the 1920’s, however, that the topic gained attention. Calvin Goddard, often credited as the “father” of firearms identification, was responsible for much of the early work on the subject during his examination of the various kinds of firearms and bullets at his Scientific Crime Detection Laboratory in Chicago.

Today, the area of firearm identification contains within itself a huge quantity of information. The advent of semiautomatic and automatic weapons calls for a new technology in identification. One system to emerge has been a three- dimensional automated firearm identification system. This and other identification systems will be explored in this thesis, along with the history of firearm identification and a breakdown of the parts and manufacturing of firearms.

Firearms Identification

Firearms identification requires knowledge of weapons and ammunition. Giannelli (1991) lists rifles, handguns, and shotguns as the three types of firearms typically used for examination. Firearms can be divided further into smooth bores and rifled arms. Smooth bores are firearms in which the bore (inside of the barrel) is perfectly smooth from end to end. A rifled arm has a longitudinal cut with a number of parallel spiral grooves. The surfaces between the grooves are called lands. The lands and grooves twist in either a right-hand or left-hand direction. Manufacturers specify the number of lands and grooves, the direction of twist, the angle of twist (pitch), the depth of the grooves, and the width of the lands and grooves. Shotguns fall under the smooth bores category, while handguns and rifles are considered rifled arms.

Some common firearm terms include bore and caliber. Bore can be used to describe the “diameter of the interior of a weapon’s barrel” (Territo, 2000, p.106). In a handgun or rifle, the bore is usually measured between two opposing lands (ridges). Caliber refers to the diameter of the bullet intended for use in the firearm and is usually expressed in either hundredths or thousandths of an inch (.22, .45 caliber) or millimeters (7.62 mm). The bullet is usually larger than the diameter of the bore, so that the lands grip it as it passes through the barrel. This causes the bullet to rotate, usually in a right-hand direction. This movement creates highly individualized striations on the bullet as well as increasing the accuracy. Because the lands “bite” into the bullet surface, the land and groove impressions are imprinted on the bullet and play an important role in firearms identification. Firearms identification is concerned with two types of characteristics of a firearm: class and individual. Table 1 lists examples of each type of characteristic.

Table 1. Characteristics of a Firearm

Characteristic	Definition	Examples
Class	Characteristics dealing with type and manufacturer	Caliber, number of lands and grooves
Individual	Characteristics dealing with actual firearm itself	Barrel deformities, number of striations created during firing

Class Characteristics

The class characteristics of a firearm include its caliber and rifling specifications: (1) the land and groove diameters; (2) the direction of rifling (right or left twist); (3) the number of lands and grooves; (4) the width of the lands and grooves; (5) the degree of the rifling twist; and (6) the depth of the grooves. In firearm identification, if the class characteristics do not match, the firearm could not have fired the bullet. Also, if the bullet is recovered before the firearm, the class characteristics could provide information about the type of firearm that could have fired the bullet. Thus, identifying the class characteristics of a firearm is useful in matching a gun to a bullet. However, the class characteristics, while useful in determining what brand of gun was used, are not helpful in identifying a specific gun. No manufacturing process produces one hundred percent identical guns one after another. The rifling process causes unique striations or markings on each gun produced. This can be due to several reasons, but no matter the reason, class characteristics cannot focus attention on one specific gun. The individual characteristics of the gun are the most important when matching a bullet to a gun.

Individual Characteristics

Once a firearm and an evidence bullet have been matched on class characteristics, a positive identification can be made as to what type of gun a bullet was fired from. But it takes matching the individual characteristics of a gun to a bullet to really be positive that one certain gun was the only gun that could have fired that bullet.

Barrels are machined during the manufacturing process, and any imperfections in the machine are imprinted on the bore. Subsequent use of a firearm adds more individual markings, such as erosion caused by the friction of the bullets passing through the bore or corrosion caused by moisture (rust). As stated previously, these individual markings can distinguish one gun and maybe even one bullet of the same type from another. The ability to perform bullet-to-bullet comparisons based on microscopic surface features is therefore at the core of forensic firearms identification. The ability to say something such as, “Of all of the 9mm revolvers in the world, this is the only one that could have fired this specific bullet” would allow for stronger evidence in shooting cases. The question surrounding the issue of identification is whether it is even possible to distinguish two guns or two bullets based on the microscopic features.

Types of Handguns

Most handguns can be divided into two types, revolvers and semiautomatic pistols. One major difference between the two is that the cartridge case is automatically ejected when a semiautomatic pistol is fired. Revolvers have a cylindrical magazine that rotates behind the barrel, with the cylinder holding around five to nine cartridges, each within a separate chamber. Semiautomatic pistols do not have cylinders; instead, the cartridges are contained within a vertical magazine, which is typically loaded into the grip of the pistol. Rifle and handgun cartridges (also known as ammunition) consist of the projectile (bullet), case, propellant (powder), and primer. The primer contains a small amount of explosive mixture that detonates when struck by the firing pin. This detonation incites the ignition of the propellant. Modern propellant is smokeless powder, either single-base (nitrocellulose) or double-base (nitrocellulose and nitroglycerin). Bullets are generally composed of lead and small amounts of other elements, known as hardeners. These bullets may be completely covered with another metal ("jacketed,") or only partially covered ("semi-jacketed"). Bullets may also have different shapes, such as flat base, hollow base, round nose, flat nose, or hollow point.

Shotguns, as previously mentioned, do not have lands and grooves. Their shells consist of a case, primer, propellant, projectiles, and wadding. Wadding keeps the powder and the pellets in position inside the shell and may be paper or plastic material. The projectiles are generally spherical balls (pellets).

Firearm Manufacturing Techniques

There are several different methods of manufacturing firearms. The methods presented here include hook cutting, broaching, buttoning, mandrel, and drilling. Each of these methods involves a rifling process, in which the barrel's inner surface is impressed with spiral grooves. The spiral grooves are important during the firing process, because they guide the bullet through the barrel, giving it a rapid spin and, by that, a straight trajectory.

The hook cutting method was prevalent prior to 1940. In this method, barrels are rifled by having one or two grooves at a time cut into the surface with steel hook cutters. The cutting tool is rotated as it passes down the barrel to give the grooves direction (to the left or right).

The broach cutting method involves a series of concentric steel rings (known as a "broach"), with the size of the ring increasing slightly down the line. The broach simultaneously cuts all of the grooves into the barrel at the required depth as it passes through the barrel. As in the hook cutting method, the rotation of the broach in the barrel gives a direction and rate of twist to the grooves.

In the button process, a steel plug or "button" impressed with the desired number of grooves is forced under extremely high pressures through the barrel. Only a single pass is necessary to compress the metal and create lands and grooves on the barrel walls. The rotation of the button, as with the other methods, gives the grooves a direction and rate of twist.

In the mandrel rifling process, a rod of hardened steel is molded and formed so that the shape is the reverse impression of the rifling it is intended to produce. This rod is inserted into a slightly oversized bore, and the barrel is compressed with hammering or heavy rollers into the mandrel's form. The rod is then removed, leaving the finished product with impressions on the inside of the barrel.

Lastly, the drilling process involves a barrel being produced from a solid bar of steel that has been hollowed out by drilling. This drilling leaves microscopic marks on the barrel's inner surface. The drilling process is a more modern technique, but imperfections in the manufacturing equipment are still a cause of microscopic marks on the inside of the barrel.

These manufacturing processes determine the class characteristics of firearms. Since no two manufacturers use exactly the same method or equipment, firearms can be distinguished by the manufacturing process used to create the barrel. One can tell a Luger from a Sig because of the class characteristics associated with each firearm type. This has become important in the area of firearm identification due to the number of manufacturers and the large number of firearms in use. A preliminary step in matching a suspect bullet to a suspect firearm is checking the suspect gun for the class characteristics that could distinguish that gun as a certain make.

Bullet Manufacturing

Similar to firearms, bullet manufacturing has a myriad of types and methods. Williams (1980), in his book *Practical Handgun Ballistics*, tries to break down the major categories of bullets. He categorizes bullets into three types – soft lead bullets, hard lead bullets, and jacketed bullets. Williams describes two processes for manufacturing bullets – the cast lead process and the commercial swaged lead process. For a cast lead bullet, manufacturing is simply a process of melting lead and pouring a small amount into a mold, allowing it to cool and harden, and then removing that small amount from the mold. If done correctly, the bullet resembles its final shape. But it must be noted that this is not the final bullet, as the product formed from the mold is somewhat deformed. It takes the lubricating and shaping process to create the final product. This process involves running the bullet through a sizing die that is precisely the same size as the barrel the bullet is intended for (i.e., .357 Magnum). This die is involved in the final forming of the bullet. Lubrication involves a sort-of cleaning of the bullet in which the surface of the bullet is made smooth. If lubricating is not done, lead scrapings from the bullet would coat the barrel and clog it. Lubricating helps prevent lead buildup on the barrel of the gun and helps to lengthen the life of the barrel. A special aspect of cast lead bullet manufacturing to consider is the nose type.

Williams (1980) lists four types of cast lead bullet noses: wadcutter, hollow-point, round nose, and Keith type. The nose of the bullet is important, as it is the first part of the bullet to come into contact with the target. Older bullet nose types, such as the wadcutter and round-nose, were found to either not work in high velocity barrels (wadcutter) or to have such problems as excessive penetration and deflection upon hitting hard surfaces (round-nose). The hollow-point bullet nose was an improvement, as it expanded shortly after impact (causing more damage to the target). The Keith type was formulated to bring together the best aspects of the hollow point and the round nose. When the bullet strikes, the nose would expand like the hollow point, but the heavy, solid middle part of the bullet would push forward and penetrate the target with greater force (like the round nose). The problem with lead cast bullets was found to be that they did not stand up to the high temperatures created in a high-velocity barrel (most modern guns). Thus came the advent of the jacketed bullet.

The premise behind the creation of the jacketed bullet is that encasing the lead bullet within a gliding metal cover or "jacket" would allow the bullet to be fired through high-velocity gun barrels without melting or deforming. A long, lengthy process ensued the advent of the jacketed bullet, due to the question of how to keep the jacket on the bullet during the firing process, as it was known to blow off when leaving the barrel. It was found that crimping (pressing with a machine) very long jackets over the bullet kept the jacket stable so it would not fall off.

Summary of Bullet Identification

The procedure normally used in bullet identification involves a comparison of the evidence bullet and a test bullet fired from the weapon. The test bullets are usually obtained by firing a firearm into a recovery box, a bullet trap (filled with cotton), or a recovery tank (filled with water). The two bullets are then compared by means of a comparison microscope, which permits a split-screen view. This allows for visual identification of striations and other marks. The firing of a bullet through a barrel is thought to create unique markings on the bullet's surface. The question then evolves as to whether it is then possible to identify a bullet by its unique characteristics as coming from a specific gun. As stated before, it is thought that the unique characteristics of a bullet's surface come into play during the manufacturing process. Therefore, researchers have examined bullets and firearms created by different manufacturers in order to find similarities or differences in striations created during the firing event.

Several studies have been conducted on this question starting back in the early years of firearm manufacturing, and they have emerged with mixed results.

Purpose

The purpose of this thesis is to examine the next step in firearm identification- a three-dimensional imaging system that digitizes the ridges and grooves created on a bullet's surface during the firing mechanism. The research questions surrounding this issue include the following:

- whether bullets can be differentiated by manufacturer;
- whether all bullets of a single manufacturer will match each other;
- whether the imaging system reads differences in bullets.

Chapter Two

Literature Review

The ability to compare bullets by examining microscopic striations on each bullet's surface is at the heart of ballistics assessment. As stated before, microscopic striations are formed on a bullet's surface during the firing sequence. Some causes of this include structural imperfections of the firearm or pressure created during the firing sequence. It has therefore been thought possible to "match" one bullet to another by firing both bullets from the same firearm. Studies investigating this possibility have emerged with mixed results.

Review of Previous Studies

Nichols (1997), in his exhaustive review of firearm and toolmark identification literature, examined thirty-four articles dating from 1949 to the present. Empirical studies conducted on bullets and casings fired through the same weapons have made up the majority of research. Nichols reports the earliest empirical study on firearm identification to have been conducted by Churchman in 1949.

Empirical Studies

Churchman (1949) analyzed characteristics typical of the Cooey .22 caliber rifle barrel. He emphasized the importance of knowing the origin of markings on bullets before one could utilize them for the purposes of unequivocal identification. The Cooey rifle was manufactured using the broaching technique, which Churchman believed was responsible for producing sub-class characteristics on the bullets (striations at the edges of the land impressions). He examined test-fired bullets from three consecutively broached rifle barrels. He found that the broach characteristics persisted from barrel to barrel. However, he also found individual characteristics of each rifle that did not carry over to the other two.

Using Statistics to Test Matching

Biasotti (1959) conducted a statistical evaluation of the individuality of bullets fired from different firearms. Using a total of twenty-four .38 SPL Smith & Wesson revolvers in the comparison, Biasotti gathered different combinations of bullets, land impressions, and groove impressions. Sixteen of the revolvers had previously been fired, while the last eight were new. The sixteen used revolvers were grouped together, and the test bullets fired from these revolvers were compared amongst the other bullets fired by the same revolver and the test bullets fired by the other fifteen. Groups II and III consisted of the eight new revolvers. Group II contained the same bullet types as Group I (158 grain solid lead bullets) while Group III fired 158 grain jacketed bullets. Biasotti then evaluated the different impression combinations for percentage of matching striations and consecutiveness. In order to do the analysis, Biasotti developed terms for the striations. A "line" was defined as "an engraving or striation appearing on a bullet as a result of being engraved by the individual irregularities of characteristics of the barrel, plus any foreign material present in the barrel capable of engraving the bullet" (p. 36). So each line was an individual characteristic. "Consecutiveness" was defined as "the compounding of a number of individual characteristics" (p. 36). This would be defined as class characteristics, in that Biasotti wanted to see if individual characteristics carried over to the other guns of the same type and manufacture. Any consecutiveness would mean that individual characteristics were not actually unique. Biasotti thus evaluated both quantity (objective feature) and quality (subjective feature). He found that the average percentage of matching lines in jacketed bullets fired from the same gun was 21-24%, and 15-20% matching striations on land or groove impressions between bullets fired from different weapons. For consecutiveness, Biasotti found no more than three consecutive matching striations for lead bullets fired from different weapons and no more than four for the jacketed bullets.

Testing Consecutively Manufactured Barrels

Lutz (1970) published one of the first studies on the correspondence of markings on bullets test fired from consecutively rifled barrels, meaning that the barrels were manufactured one right after the other. Lutz fired a series of jacketed and lead bullets through each of two unused .38 SPL barrels. He then fired a second set of bullets through each barrel and had them coded. Firearms examiners were then asked to compare the first set of bullets (test set) to the second, coded set. The results indicated that the examiners were able to "easily identify the barrel of origin for each of the bullets" and that there were many "dissimilarities" of land impressions from each barrel.

Skolrood (1975) conducted a study similar to that of Churchman. He performed a series of comparisons on bullets fired from three new, consecutively broached, .22 caliber Winchester rifle barrels. He found that comparisons of bullets fired from the same rifle yielded more persistent characteristics than comparisons on bullets fired from different rifles. Thus, bullets fired from a specific gun had a higher matching rate than bullets fired from other guns of the same type and manufacturer.

Freeman (1978) conducted a study on three consecutively rifled, Heckler & Koch, 9-mm Luger caliber, polygonally rifled barrels. He found that each barrel was distinctly individual, and that, although the first two barrels could be easily inter-compared, the third barrel yielded poorly marked test bullets. Thus, even consecutively rifled barrels contained individual characteristics, even though they were manufactured one after the other.

Murdock (1981) empirically assessed the individuality of button-rifled barrels. In this study, he discussed the various forms of early cut-rifling methods and the idea that these methods left sub-class features on barrels. He also discussed the newer methods of rifling that did not involve the removal of any metal, which is the opposite of the earlier methods. Assessing the individuality of .22 caliber barrels, he found no continuity of sub-class characteristics in the bullets fired from each of the three barrels. In a similar study conducted in four Shilen DGA barrels, Hall (1983) found that test-fired shots closer in firing sequence showed more similarity than test-fired shots further apart in the sequence. He was able to conclude that, "with bullets closely related in the firing sequence the dissimilarity of marks created by any two different barrels is significantly greater than the dissimilarity seen on bullet pairs that are from the same barrel" (p. 45).

In contrast to the previous studies, Matty (1985) conducted comparisons on three revolver barrels all cut from the same section of rifled tube. He had observed that the buttons used to rifle the barrels did acquire "some damage" and wanted to see if the damage was transferred to the bore surface. Matty did observe longitudinal striations on the groove impressions caused by button imperfections, of which a few persisted along the length of all three barrels. He found that there was a settling-in period during which test fired bullets from the same barrel could not be identified to each other. This was important because of the question of how similarity between bullets could be proven with newly manufactured guns. Matty also found that, after the settling-in period, comparisons of bullets fired from different barrels proved inconclusive for groove impressions and showed no consistency for land impressions.

Improvements on Previous Studies

Brundage (1992) conducted a replication of Lutz's (1970) study, with some significant improvements. He provided a pair of test-fired bullets from ten consecutively rifled Ruger barrels to 30 laboratories across the country, along with fifteen unknowns. All of the laboratories properly associated the unknowns with the barrel from which they were fired. This was an improvement over Lutz's study in that the examiners were not provided any information regarding barrel or test manufacture.

Lastly, Brown and Bryant (1995) compared barrels from multi-barreled derringers in an attempt to determine whether the barrels in these weapons may have been consecutively manufactured. Brown and Bryant indicated that, "a major contributor to the individual bullet striation from the button rifled barrels is certainly the compressed reamer marks that appear very prominently in the casts of the lands and grooves" (p. 256). This meant that the marks transferred as individual markings to the surface of the bullets and would not be considered class characteristics but individual characteristics that could show consecutiveness among bullets fired from a single gun.

Summary

As stated previously, the literature has shown mixed results for the comparison of bullets fired by identical or dissimilar firearms. The lack of consistent methodology and scientific experimentation in these studies has shown the need for more advanced analyses of firearms and bullets. The importance of this experimentation lies in the area of forensics. The question of whether a single bullet could be matched to a single gun, if answered, could provide a new direction in shooting cases. Suspects could be tied to a shooting by evidence concerning whether their gun is the only one that could have fired a certain bullet and created the unique individual characteristics found on the bullet. Creating such a system is only one step in the process. Another important area of firearms identification lies in the legal usefulness of this kind of information. A policeman may be able to match a bullet to a gun and therefore a suspect, but the courts must decide the admissibility of this sort of evidence.

Legality of Firearms Evidence

Since the beginning of firearms identification, the courts have had to make decisions of the permissibility of this sort of information as evidence.

Court Decisions on Firearm Identification Evidence

Inbau (1999) conducted a review of important court decisions regarding firearms identification. *Dean v. Commonwealth* (1879) was found to be the first case in which an appellate court approved of testimony regarding the similarity between test bullets and bullets used in a crime. In the 1881 case of *State v. Smith,* the court refused the defendant’s request to permit an expert to examine and experiment with the evidence pistols to determine which was possibly the one to have fired the suspect bullet. Inbau (1999) stated that this decision was important only for the reason that “it apparently represents an early attempt at judicial recognition of the science of firearms identification.” The matching of suspect and test bullets was first approved by an appellate court in the 1902 decision of *Commonwealth v. Best.* The evidence presented included photographs of a test bullet having been “pushed” through the defendant’s rifle barrel. The court agreed with the evidence, stating that the information provided by the expert witness concerning how a test bullet would be marked during firing was a question of “much importance” to the case. *Laney v. United States* (1923) was a federal case that involved firearm identification in its decision, in which it was considered admissible for an expert to testify on the matching between a bullet and a pistol. Within the next two decades, the cases of *State v. Boccadoro* (1929), *Galenis v. State* (1929), and *People v. Beitzel* (1929) all affirmed the admissibility of firearm identification testimony. *Evans v. Commonwealth* (1929) was considered to give the first exhaustive opinion on firearms identification as a science. *People v. Fiorita* (1930) included in its opinion a guideline against incompetent firearms expert testimony, stating that “while the science of ballistics is now a well-recognized science both in this country and abroad, testimony based upon it should be admitted with the greatest care. No witness should be permitted to testify regarding the identification of firearms and bullets by the use if this science unless the witness has clearly shown that he is qualified to give such testimony.”

Meaning of “Expert” Testimony

Inbau (1999) described the kinds of expert testimony required in court outside of bullet/gun matching. He listed the distance and direction at which a shot is fired, similarity in the size and weight of bullets, proof that a bullet was fired from a weapon of a certain caliber, proof that wounds were caused by a specific type of firearm, and to prove that a suspected gun was recently fired as others of interest to courts in the area of firearms identification. More recent cases have reaffirmed the precedents set by the former courts in admitting evidence of bullet, cartridge case, and even shot shell identifications. It seems that the admissibility of firearms identification evidence has been well-established by the court system. Yet it still remains to be seen as to how far in the future this admissibility will last, for as manufacturing techniques become more sophisticated, differentiation between bullet types may not be possible. Let us hope that as manufacturing techniques become more sophisticated, so too will identification systems. As can be seen below, this may indeed be the future trend.

Introduction to Previous Identification Systems

The need for a standardized, highly accurate firearms identification system has been shown throughout the history of firearms identification. During the early parts of the twentieth century, a magnifying glass was the tool most often used in the examination of firearms and bullets. Police or other firearm experts would make the decision of whether a bullet and gun matched by visually examining the two. This method did not last long, for the advent of the comparison microscope made possible photographs of two bullets showing similarities and differences.

Comparison Microscope

Inbau (1999) detailed the workings of this system of identification. The comparison microscope consists of two ordinary microscopes arranged in a way that images passing through both are brought together in one eye-piece midway between them. Each bullet (a test bullet and the suspect bullet) is placed under each lens, and, by properly focusing the instrument and placing the bullets in the same orientation, the microscope transmits the fused picture of the two bullets. The two pictures were merged together as one. If the two bullets were fired from the same weapon, there would be very little difference between them in the way of markings and striations. This was an innovative technique in its day, as it was possible to make a visual inspection of two bullets at the same time.

Unfortunately, this system contained flaws in the accuracy of the picture projected and the ability of an "expert" to make a decision concerning the matching of a gun and bullet. More sophisticated and faster paced techniques were needed to accumulate the ever-growing number of comparisons to make. The laser topography system is one such innovative technique.

Laser Topography System

A study published by De Kinder, Prevot, Pirlot, and Nys (1998) introduced a new technology for firearms identification – laser topography. The authors stated the problems with the previous system of comparison microscopy to be differences in light intensity (global or for different regions of the object under study), the surface material (nickel or copper), type of light used (temperature of the light source), and angle of incidence of the light (how light hit an object in order to be reflected back). Laser topography was an improvement over comparison microscopy because it accurately measured the topography of the surface. It did this by focusing an infrared laser on the object's surface. The reflected light was collected by the same lens and detected by a diode array, which means that light was reflected onto a surface, and a laser keep track of where the light went and what part of the surface the light was measuring. This signal was used to correct the position of the focusing lens in such a way as to keep the focus of the laser spot on the surface; thereby keeping the position of the lens corresponding to the distance to the surface relative to a common reference plane. This compensated for any sliding or movement on the part of the bullet. The range was 1 micrometer to 0.1micrometers, the highest difference in height that could be measured by the apparatus.

System Testing

The equipment was tested in the following areas: static noise, positioning accuracy, reproducibility, and correctness of the measurement. The testing of static noise resulted in the detection of a substantial backlash, leading to the development that surfaces had to be measured while scanning in the same direction. This meant that the data received by the laser was not being sent, because there was too much for the laser to filter through to find the signal. This doubled the measurement time. The positioning accuracy of the rotational stage was verified, as well as the reproducibility and correctness of the measurement. This showed where to place the bullet so that it would be scanned correctly. Optimal scanning speed was found to be 0.5 – 1 mm/s.

As for the testing of how the system actually measured bullets, tests were also conducted on striation marks on 9 mm Para bullets to indicate whether the topography system could compete with the comparison microscope. Only one striation mark on the bullets was the focus, in order to verify the origin of the striation. This was thought to lessen any chance of comparing bullets on different sides from each other. The following bullets were studied: an unused bullet (for reloading purposes), a bullet originating from an unfired round, fired bullets of different type (lead or jacketed), and fired bullets caught by different traps (water or cotton wool). This would enable the experimenters to differentiate between fabrication marks, striations made by the barrel, and marks left during the bullet recovery process. The bullets were fired with a Fabrique Nationale High Power pistol, resulting in six grooves with a right-hand twist. The measurements were then made by the topography system on one striation mark. A correction for the curvature of the surface had to be performed. Results showed that the jacketed bullets bore no characteristic marks from the fabrication process apart from the normal circle created during the firing process. However, lead bullets were found to have fabrication marks. There was no evident difference between bullets recovered in the water tank and in cotton wool. The topography measurement of the one striation in the bullets was thought to be indicative of the system's success in measuring the same phenomena as the comparison microscope and proof that the grazing angle illumination (laser making slow passes across whole object) had a very high sensitivity for detecting small topographical differences. In scanning the surfaces of bullets, the laser topography system was forced to superimpose the obtained profile on a slowly varying sinusoid. The experimenters found it evident that the striation marks found carried characteristic information; however, they took this to mean that less measurements were necessary to extract the characteristic information. Not all lands and grooves were measured, and yet the recording time was still higher than the comparison microscope method. Although laser topography was a step in the right direction, further advancements were necessary, especially in the areas of scanning and measuring the entire bullet.

Automated Systems

The continuous evolution of smaller, more powerful computers since the 1990s has heralded the arrival of a powerful screening tool for firearm identification experts. Automated "search and retrieval" systems have the objective of enabling the comparison of evidence and control bullets, therefore "transforming forensic ballistic analysis from an evidence verification tool into a crime-fighting tool" (Bachrach, 2002, p. 1).

Basic Components of an Automated System

The two basic components of an automated system are the acquisition and the correlation components. The acquisition component involves the capturing of data and encoding it in order to make it analyzable. Data that has been encoded and processed is referred to as "normalized data". The correlation component, however, is responsible for making sense of the normalized data, through comparing the sets of data and organizing the results for the user's inspection. Bachrach (2002) specifies the correlation component as including all the software elements necessary to:

a.) Evaluate the degree of similarity between two sets of normalized data b.) If more than two bullets are involved in a comparison, to organize the results of a set of comparisons in some convenient way, and

c.) To provide the user with tools to verify the results obtained by the correlation algorithms.

Examples of Automated Systems

Two major automated systems have already been developed: the Integrated Ballistics Identification System (IBIS) and DRUGFIRE. These two systems have many points in common, such as the capability of acquiring data from bullets and cartridge cases, storing this data in a database, and using the database to perform comparisons on a given bullet. The most important area of comparison between the two systems is the use of a two-dimensional representation of the surface of the specimen. IBIS processes digital microscopic images of identifying features found on both expended (already fired) bullets and cartridge casings. DRUGFIRE emphasizes the examination of unique markings on the cartridge cases expended by the weapon. The data capture processes in both systems use a source of light directed at the bullet or cartridge casing's surface to reflect striations, land impressions, and groove impressions for a camera to record. Bachrach (2002) notes that, when using light as a source, the incident light angle and the camera view angle cannot be the same in order to obtain a pattern of dark-and-bright reflections of the bullet's surface. This accounts for the method of side lighting in two-dimensional imaging, and thereby makes this method an indirect measurement of the bullet's surface. Bachrach introduces a three-dimensional process believed to improve upon the two-dimensional systems.

A Three-Dimensional Automated System

The SCICLOPS system, based on the use of a three-dimensional characterization of the bullet's surface, has as its source confocal sensors, which operate by projecting a laser beam through a lens onto the surface of the object and detecting the reflection of the laser with the same lens. This is an improvement over the laser topography technique proposed by De Kinder et al. (1998) in that the sensor continuously displaces the lens in order to maintain the laser and allow for an accurate imaging of the entire bullet. Unlike the IBIS and DRUGFIRE programs, the angle of incidence and the angle of reflection of the laser beam are the same, so there is no side-lighting. The data acquired is therefore the distance between the surface features and an imaginary plane, as the measurement is made along a direction perpendicular to the surface.

Advantages and Disadvantages of 2D and 3D Systems

Some disadvantages of the two-dimensional system include the robustness and discontinuity of the data. Bachrach (2002) states a significant problem associated with 2D data capture to be the fact that the "transformation relating the light incident on the bullets surface and the light reflected by it depends not only on the striations found on the bullet's surface, but also on a number of independent parameters such as the light incident angle, the camera view angle, variations on the reflectivity of the bullet surface, light intensity, accurate bullet orientation, etc…implying that the captured data are also dependent on these parameters" (p. 3).

Another problem is the phenomenon of shadowing, in which some of the smaller features can be "shadowed" by larger features. This shadowing could cause inaccurate reflections of the captured data. This problem is not unique to two-dimensional systems, as the SCICLOPS system's laser beam requires an unobstructed conical region to properly operate. This limits the steepness that the confocal sensors can measure. The acquisition speed of two-dimensional systems is significantly faster than the three-dimensional SCICLOPS system, allowing examiners to make decisions more quickly. In comparing the DRUGFIRE system with SCICLOPS, Bachrach found that the SCICLOPS system created a clear definition of the transitions between land and groove impressions, whereas the same boundary was not as well-defined by the DRUGFIRE system.

Components of the SCICLOPS System

As with the study by De Kinder et al. (1998), the SCICLOPS system has a measurement resolution of 0.1 micrometers in depth and 1 micrometer in lateral resolution, thought to be significant enough to capture the most significant elements of the surface data. Experimentation showed the final configuration of the acquisition unit to be on the order of 1 micrometer, as it was limited by sensor and mechanical vibration noise. The digitization process involves taking cross-sections of the bullet and measuring land and groove impressions, with a sufficient number of cross-sections giving a complete description of the bullet as a three-dimensional object. The geometric region defined by the cross section is approximately an elliptical, because of tilt. The data normalization process of SCICLOPS then conceptually consists of two steps: estimation of the ellipse defined by the geometric location of the land impressions (the cross-section) identified in the acquired data and the projection of the acquired data onto the estimated ellipse. The second step corrects for any deformation of the bullet whether in the structure or the acquisition process. For the correlation component, SCICLOPS receives as an input the normalized data of two bullets for matching purposes. The output returns the following information: relative orientation at which the two bullets are most similar and a similarity measure (0 = no similarity up to 1 = identical). The similarity measure used is the correlation function. This is a normalized (maximum value is 1) quantification of the degree of similarity between two bullets. A macro and micro correlation are computed while comparing the two bullets in different relative orientations. The macro correlation is obtained at the orientation in which the two bullets are most similar, while the micro correlation is taken at the most dissimilar orientation. The Composite Correlation is the geometric average of the macro and micro correlations and an overall measure of similarity.

A preliminary evaluation conducted by the researchers showed the system to produce reliable characterizations of a bullet surface and to successfully identify similarities between bullets fired by the same gun. Problems of the SCICLOPS system as noted by the researchers include the use of only pristine bullets in the creation and evaluation of the SCICLOPS system creating a need for acquisition and correlation algorithms for damaged bullets, statistical methodologies to quantify the performance of automated systems, the need for determining how likely it is that the said bullet was fired by the same gun as the evidence bullet, and a consensus on which is the best location on the bullet’s surface to acquire the data.

Summary

The SCICLOPS system is thought to represent the next generation in firearm identification with the creation of a three-dimensional image of a bullet that would accurately represent all striations and impressions on the bullet’s surface. The history of forensics and firearm identification in particular has shown the need for a comprehensive system of comparing evidence bullets with test bullets in order to match a suspect gun to a shooting. The creation of striations and impressions on a bullet’s surface during the firing process allows for an examination of whether the striations and impressions are consistent among bullets fired by the same gun. The advent of computers has allowed for faster, more comprehensive processing of striations and impressions on a bullet’s surface than the original comparison microscope did. The large quantity of guns being used in the United States and in shootings shows the need for a database of firearm and bullet characteristics. The SCICLOPS system allows for a three-dimensional image of a bullet created by taking cross-sections of the bullet’s surface and representing them on a plane in space. This system allows for the comparison of two bullets, just as the comparison microscope, but the SCICLOPS system computes a correlation function detailing how the two bullets compare mathematically. This thesis focuses on the SCICLOPS system and the correlation functions computed by the imaging process. When bullets are matched perfectly, there will be a correlation of 1.0. As there are many types and manufacturers of bullets, it remains to be seen whether bullet types are affected by or themselves affect the striations and impressions created on bullets during the firing process.

Hypotheses

Based on the existing literature and description of the SCICLOPS system, two hypotheses about ballistics matching can be drawn. However, this project focuses on one area of ballistics - ammunition. Given that there are many manufacturers of bullets, it seems appropriate to hypothesize that there will be differences in the amount and quality of striations and impressions made during the firing event. The reason behind this concerns the differences in the quality and manufacturing processes of ammunition today. Some manufacturers have sophisticated high-tech processes that create identical bullets, while other manufacturers may not have such high standards. In other words, bullet manufacturers will make a difference in the ability of a bullet to acquire striations during the firing event. The SCICLOPS system should be able to measure all bullets no matter the manufacturer.

Therefore, the first hypotheses proposed are:

H_0: *There will be no differences in the ability of a bullet to acquire striations based on manufacturer.*

H_1: *There will be differences in the ability of a bullet to acquire striations based on manufacturer.*

The second hypotheses deal with the bullets as grouped by manufacturer. All bullets produced by the same manufacturer should be more similar to each other than to bullets of other manufacturers. This also deals with the SCICLOPS system, because if the bullets of one manufacturer do not match to others of the same type, then the SCICLOPS system will not show the class characteristics that could differentiate bullets of different manufacturers. The system would only show individual characteristics, which is good for matching a bullet to a gun. However, there could be a problem when the gun is not present to make a determination of what kind of gun could have fired the bullet. Therefore, the second hypotheses proposed are:

$H_{0:}$ *There will be no differences in the means of measured striations for all bullets of the same manufacturer.*

H_1: *There will be differences in the means of measured striations for all bullets of the same manufacturer.*

Chapter Three

Methodology and Data

Methodology

A secondary data analysis methodology was selected for this project. Secondary data analysis is a research methodology that involves using data collected by other researchers to answer new research questions (Maxfield and Babbie, 2001). Although secondary data analysis has several drawbacks, including availability, completeness, and validity, this type of methodology is cost-effective and timely, involving only willingness on the part of the original researcher to allow access to the data. This design allows for further exploration of data already collected, which fits the purpose of this project in assisting in the validation of the SCICLOPS system. Hopefully, this project will allow other researchers to gain access to this valuable data set and allow for more statistically advanced evaluations of the SCICLOPS system.

Data

The data for this study comes from the engineering firm of Intelligent Automation, Inc., the creator of the SCICLOPS system. This data was collected for use in testing the SCICLOPS system in the area of gun identifiability. Gun identifiability deals with whether the impressions produced by a gun's barrel reproduce the same on every bullet fired by it. The data set collected by Intelligent Automation Inc. included nine types of bullets in the testing, all of which were lead core jacketed bullets. A listing and description of all bullet types is given below.

Table 2. Descriptions of Bullets Used in Analysis

Manufacturer	Caliber	Weight	Model
Magtech	9mm luger	115 Gr.	FMC (9A)
PMC	9mm luger	115 Gr.	FMJ (9A)
Remington UMC	9mm luger	115 Gr.	Metal case (L9MM3)
Winchester	9mm luger	115 Gr.	FMJ (Q4172)
CCI Blazer	9mm luger	115 Gr.	TMJ (3509)
Norinco (LY)	9mm luger	124 Gr.	China (Ball)
Federal American Eagle	9mm luger	124 Gr.	Metal Case (AE9DP)
Lellier & Bellot	9mm luger	115 Gr.	Czech

These bullet types were chosen by the researchers as being of the same type – lead core jacketed bullets. The firearm used in the analysis was a Ruger P89, whose manufacturing technique was gang broaching. An initial test was completed in which twelve bullets of three different manufacturers (CCI, Remington, and Winchester) were fired by the Ruger into a water tank and retrieved for analysis, which was a verification that the gun did produce clear and reproducible impressions. After this was verified, ten samples of each type of ammunition were fired. The order of firing was interlaced to prevent bias due to the firing order; thus, the ammunition was fired following an alternating sequence of types. Therefore, a Magtech bullet was fired first, followed by a PMC, all the way down to LB.

Variables

Table 3 presents a summary of the variables used in this study. *Bullet1* lists the number assigned to the bullet during the test firings. Magtech comprises bullets #2 – 11 (only 10 bullets were tested for Magtech, which is one less than all other bullet types), PMC comprises 12 through 21, and so on. *Wtavgstr* lists the average weighted value for all comparable striations found on the bullet. The average value was weighted in order to compensate for the number of measurement pulses taken during the acquisition phase. For whichever reason, during measurement, some of the stria may not have received the same number of measurement pulses from the laser. Weighting the average value allowed for a composite number that took into account the integrity of the measure. This put all of the six measured lands and grooves into equal standing. *Relpos* indicates the relative position of the bullet on the stage, with 1 being the first land or groove measured and 6 being the last. *Opticorr* indicates the maximum position, which is considered the right orientation of the six lands and grooves measured. This variable was used as a comparison point for later significance testing but has no bearing on the project.

Table 3. Summary of Variable Definitions and Coding

Variable	Definition	Coding
Bullet1	ID number assigned to bullet	10 consecutive numbers, starting with 2 and ending with 172 (LB type did not follow exact pattern but consisted of #73 – 81 and 172
Wtavgstr	Weighted mean of the striations measured	Any number between 0 and 1, with up to six decimal places
Relpos	The relative position of the bullet on the analysis stage	1 –6, with 1 being the first land or groove measured and 6 being the last
Opticorr	The marking of relative positions to show the highest number of striations found between two bullets	0 or 1, with 0 being the incorrect positions and 1 being the highest correlation position (used as a dividing point for significance testing)

Analysis Strategy

The following analyses were performed on the data set to address the previously stated hypotheses.

Descriptive Statistics

The first type of analysis presents descriptive statistics on the weighted average number of striations found on the bullet. These statistics include the number of bullets fired, the number of striations measured, the minimum and maximum number of striations found, the average number of striations found, and the standard deviation.

Normality Testing

The second type of analysis presents tables for the assessment of normality in the distributions of each bullet manufacturer. Normality testing concerns the examination of each of the distributions (correct vs. incorrect orientation) to see whether it violates the assumptions of parametric testing. It is proposed that distributions concerning incorrect orientations will be normal or close to normal, if there is nothing operating except random error. The incorrect orientation should not deviate from normality, as the manufacturer type should have no effect on that distribution. The correct orientation, on the other hand, is proposed to be leptokurtic, as the weighted number of striations should be highest in this distribution. Manufacturer type may have an effect here, if there are differences in how high the numbers are by manufacturer type. This may show that some bullets "take" striations better than others. This could have an effect on the ability of the SCICLOPS system to measure the striations and make a determination of class and individual characteristics.

Significance Testing

The third and final type of analysis presents an ANOVA table for each bullet type. As each type contained several bullets, ANOVA was conducted to assess the individuality of the bullet and its manufacturer; that is, whether the bullets of a certain type showed consistency in the number of striations measured by the SCICLOPS system. This created eight different groups for the eight manufacturers to test for similarity in the means against other manufacturers and within each manufacturer. Post hoc Tukey tests and homogenous subset tests were performed to examine where any differences existed.

Chapter Four

Results

Descriptive Statistics for Weighted Average Striations by Bullet Type

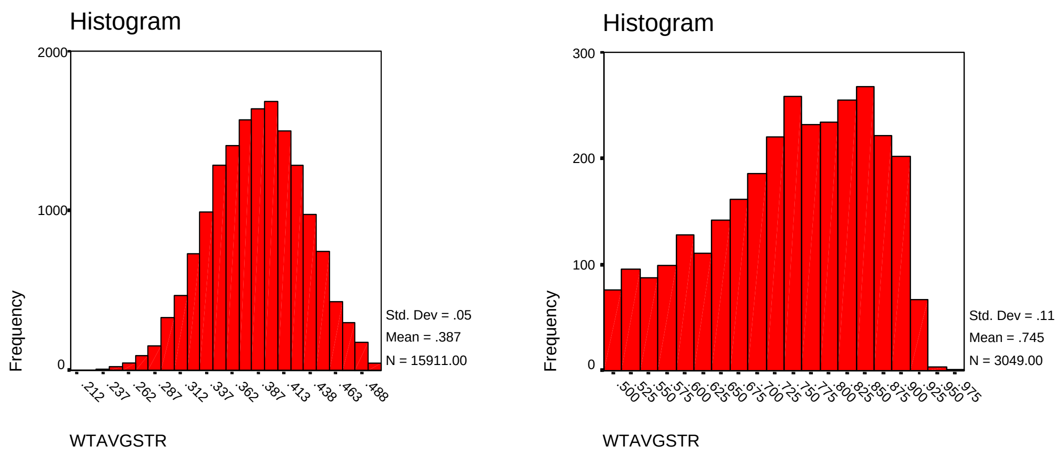
The descriptive statistics for average weighted striations by bullet type are presented in Table 4. Minimum and maximum values, as well as the mean and standard deviation, are included. It should be noted that the number of test firings are not equal. The number of striations measured is larger than the number of bullet firings, due to the measurements of 6 orientations of the bullet by the SCICLOPS system.

Table 4. Descriptive Statistics for Average Weighted Striations

Bullet Type	Number of bullets test fired	Number of striations measured (N)	Minimum	Maximum	Mean	Standard Deviation
MAG	730	4470	.240815	.925541	.45244033	.159813317
PMC	629	3870	.246069	.923105	.4469079	.155101147
RUMC	558	3270	.212806	.904019	.43961947	.130965913
WIN	424	2670	.241248	.937230	.45247036	.149304754
CCI	288	2070	.221234	.877064	.41355351	.115519092
NOR	225	1470	.237090	.865893	.44045690	.124976656
FAE	148	870	.288131	.954995	.46271168	.148342660
LB	47	270	.286378	.966533	.44350814	.127912088
All types	3049	18960	.212806	.966533	.44418845	.145197155

Normality Tests

The distributions of average weighted striations showed bi-modality, with a mean of around 0.4 to 0.5, and large amounts of numbers on either side. Therefore, the distribution was split in half to show the distribution of incorrect orientations, which were proposed to have significantly lower numbers than the correct orientation, which would approach 1. A cut-off point of 0.5 was used to separate the distributions into incorrect and correct orientations. As each bullet was measured using six orientations, only one orientation, with the highest number of striations, was deemed the correct orientation; the other five orientations were deemed incorrect and were therefore expected to have lower numbers than the correct orientation. Analyses therefore concentrated on examining differences among bullet types of the normality or non-normality of their distributions for both correct and incorrect orientations. The incorrect orientation distributions were proposed to approach a normal distribution for every bullet type, due to the low number of striations measured and the occurrence of measurement and random error. The correct orientations would be positively skewed, as they were expected to hover near 1. These distributions were used to show the consistency of measurement by the SCICLOPS system. The correct orientation distribution would be positively skewed if the SCICLOPS system was measuring what it intended, to show that all of the bullets by the same manufacturer were statistically similar in the number of average weighted striations. Examples of these distributions are shown in Figures 1 and 2.



Figures 1 and 2. Histograms of Incorrect and Correct Orientations for all Bullet Types.

As can be seen, the distribution on the left represents the incorrect orientations. A bell-shaped curve can be seen that almost straddles the middle of the graph. The histogram on the right, however, shows a correct orientation distribution. This histogram does not follow a curve, but does look leptokurtic. This is expected due to the higher numbers of striations for the orientation.

The analyses conducted were normality tests as well as histograms and Q-Q plots for each manufacturing type of bullet (see Appendix A). The normality test conducted was the Kolmogorov- Smirnov test with a Lilliefors Significance Correlation. As predicted, most of the bullet type distributions, both correct and incorrect orientations, followed the hypothesized pathway. Tables 5 and 6 show the normality tests by bullet type and orientation.

Table 5. Normality Tests by Bullet Type for Incorrect Orientation

Bullet Types	Kolmogorov-Smirnov		
	Statistic	Degrees of Freedom	Significance
MAG	.015	3740	.054
PMC	.026	3241	.000*
RUMC	.011	2712	.200
WIN	.024	2246	.003*
CCI	.020	1782	.096
NOR	.021	1245	.200
FAE	.025	722	.200
LB	.047	223	.200

* significant at the .01 level

The Kolmogorov- Smirnov test shows that WIN bullets and PMC bullets measured in incorrect orientations do not follow a normal distribution, while the MAG, RUMC, CCI, NOR, FAE, and LB bullets do. Thus, six of the eight manufacturers follow the predicted pattern, while two do not.

Table 6. Normality Tests by Bullet Type for Correct Orientations

Bullet Types	Kolmogorov-Smirnov		
	Statistic	Degrees of Freedom	Significance
MAG	.124	730	.000*
PMC	.090	629	.000*
RUMC	.054	558	.000*
WIN	.088	424	.000*
CCI	.049	288	.098
NOR	.107	225	.000*
FAE	.073	148	.050
LB	.150	47	.009*

*significant at the .01 level

The results for the Kolmogorov-Smirnov test show all but CCI and FAE to be non-normal distributions, with LB near the cut-off point of .01. Thus, five of the manufacturing types followed the predicted pattern, while three did not. It is interesting to note that the manufacturing types with distributions differing from the expected path for correct orientations were not the same as those differing for the incorrect orientations. Implications of this will be discussed in the next chapter.

Analysis of Variance

Analysis of Variance tests were performed on each bullet manufacturer, testing across manufacturers as well as within all of the bullets of each manufacturer. The ANOVAs tested differences across the means of each manufacturer for the average weighted number of striations. Forty-five cases from each manufacturer were used, at forty-five was the lowest common amount (equal to the smallest group, LB). This was done to allow for further significance testing.

The ANOVAs for both the correct and incorrect orientations were significant at the .01 level, $F(7, 352) = 50.798$, $p < .01$ and $F(7, 352) = 17.620$, $p < .01$, respectively. These showed that significant differences existed across manufacturers for both orientations.

Post hoc Tukey and Homogenous Subsets Tests

Post hoc Tukey tests were then done to examine which manufacturers, if any, had significantly different means from the other manufacturers. Tables 7 and 8 show that there are significant differences across almost all of the manufacturers at the .01 level.

Table 7. Tukey Test Between Manufacturers for Correct Orientations

	MAG	PMC	RUMC	WIN	CCI	NOR	FAE	LB
MAG		.682	.000*	.953	.000*	.000*	.702	.000*
PMC	.682		.000*	.999	.000*	.000*	1.000	.000*
RUMC	.000*	.000*		.000*	.000*	.362	.000*	.388
WIN	.953	.999	.000*		.000*	.000*	.999	.000*
CCI	.000*	.000*	.000*	.000*		.275	.000*	.254
NOR	.000*	.000*	.362	.000*	.275		.000*	1.000
FAE	.702	1.000	.000*	.999	.000*	.000*		.000*
LB	.000*	.000*	.388	.000*	.254	1.000	.000*	

* significant at the .01 level

Table 8. Tukey Test Between Manufacturers For Incorrect Orientation

	MAG	PMC	RUMC	WIN	CCI	NOR	FAE	LB
MAG		1.000	.999	.000*	.120	.031	.000*	.003*
PMC	1.000		.999	.000*	.124	.030	.000*	.003*
RUMC	.999	.999		.000*	.409	.004*	.000*	.000*
WIN	.000*	.000*	.000*		.000*	.617	1.000	.951
CCI	.120	.124	.409	.000*		.000*	.000*	.000*
NOR	.031	.030	.004*	.617	.000*		.418	.998
FAE	.000*	.000*	.000*	1.000	.000*	.418		.848
LB	.003*	.003*	.000*	.951	.000*	.998	.848	

*significant at the .01 level

As can be seen by these results, significant differences exist across manufacturers. No two manufacturers were alike for both the correct and incorrect orientations. This was expected for correct orientations, as each manufacturer should have bullets that are not identifiable with other manufacturers. The weighted means should be significantly different, to show that the SCICLOPS system does not read every bullet as the same. For the incorrect orientations, however, there were some surprising findings. Although all of the manufacturers had one or more other manufacturers to whom they were similar, there were many more significant differences than expected. If the incorrect orientation numbers were due to chance, then there should not be significant differences across manufacturers.

The surprising lack of significant differences between manufacturers was also shown when conducting a Homogenous Subsets test, which examines the means for similarity and groups any similar bullet types together. These results are presented in Tables 9 and 10.

Table 9. Homogenous Subsets for All Manufacturer Types in Incorrect Orientation

mincorr

Tukey HSD[a]

Bullet 1 Manufacturer	N	Subset for alpha = .05	
		1	2
CCLid	45	.30844982	
RUMCid	45	.32125491	
PMCid	45	.32486969	
MAGid	45	.32494656	
NORid	45		.34438696
LBid	45		.34850109
WINid	45		.35533316
FAEid	45		.35710813
Sig.		.120	.418

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 45.000.

Table 10. Homogenous Subsets for All Manufacturers in Correct Orientation

maxcorr

Tukey HSD[a]

Bullet 1 Manufacturer	N	Subset for alpha = .05		
		1	2	3
CCLid	45	.64241969		
NORid	45	.68938278	.68938278	
LBid	45	.69022482	.69022482	
RUMCid	45		.73327211	
PMCid	45			.85978349
FAEid	45			.86040164
WINid	45			.87165400
MAGid	45			.89407044
Sig.		.254	.362	.682

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 45.000.

These findings show further that there is some homogeneity (similarity) amongst the bullet types. For the correct orientation, there seem to be three groupings, with two groups overlapping and then the three group (consisting of PMC, FAE, WIN, and MAG) having higher and non-overlapping means. For the incorrect orientation, there are two groups that do not overlap. None of the subset groups for either orientation are significantly different from others within their group though. These results will be discussed further in the next section.

As a whole, these findings support the idea that manufacturers may have an effect on the number of striations measured by the SCICLOPS system. There does seem to be mostly normal distribution for incorrectly oriented bullets no matter the type (with exceptions) as well as non-normal distributions for correctly oriented bullets (again with exceptions). There were significant differences when comparing the average weighted mean number of striations for correct orientations across manufacturers, which was to be expected.

Differences in Means Within Each Manufacturer

Also tested was the hypothesis that there would be no differences in the mean average weighted striations for all bullets of the same manufacturer. Only the correct orientations were tested, due to the proposed leptokurtic distributions. If the mean average weighted striations for all bullets of the same type are similar (as they should be), then the ANOVA should not be significant. Table 11 presents these results.

Table 11. ANOVA Test for Differences Within Manufacturers

Manufacturer	N	Degrees of Freedom	F	Significance
MAG	746	9, 737	1.381	.193
PMC	646	9, 637	2.683	.005*
RUMC	544	9, 535	14.816	.000*
WIN	444	9, 435	1.995	.038
CCI	344	9, 335	54.288	.000*
NOR	244	9, 235	36.806	.000*
FAE	144	9, 135	1.198	.301
LB	44	8, 36	1.761	.118

* significant at the .01 level

These results show that the PMC, RUMC, CCI, and NOR types have significant differences in the mean weighted average striations within each of their bullet types, while the bullets of MAG, WIN, FAE, and LB types do not differ significantly from others within their respective types.

Chapter Five

Discussion

After having examined the results from the data, it is now important to discuss these findings and their implications to the proposed hypotheses.

Differences in Striations Measured by Bullet Type

The results from the ANOVA show support for both alternate hypotheses, which was that differences exist by bullet manufacturer in the amount of striation measured by the SCICLOPS system and in the differences in means. This can be seen through the ANOVA and even the normality tests. As discussed before, the ideal distribution for each bullet type would show a statistically discernable bimodal pattern, with incorrect orientations having a normal distribution and correct orientations having a negatively skewed distribution. The normal distribution of the incorrect orientations would be the result of random error, while the skewed distributions of the correct orientations would be the result of the clustering of numbers closer to 1. This was not always the case for the eight bullet types tested.

When examining the descriptive statistics for average number of striations, one can see some differences, but the numbers look pretty close together. The highest maximum number of striations was .966533 (LB type), while the lowest was .865893 (Norinco type). The minimum number of striations, mean number, and standard deviations followed the same pattern, with not much visually discernable differences to be found. It is only when examining the histograms and normality tests that the big picture emerges.

The histograms of the incorrect orientations by bullet type showed that visually, all of the bullet types followed the predicted pattern. The histograms of the correct orientation by bullet type showed differences. The Magtech type showed a leptokurtic skewed distribution, as did the PMC type, Win type, and FAE type. Distributions not fitting this pattern included the Remington (RUMC) type, CCI type, Norinco type, and LB type. The LB type had the lowest number of observations to measure (N = 47), which may have affected the tests conducted. Therefore, the LB type will not be discussed in this section.

As the histograms were only a visual aid, tests of normality were conducted on both sets of distributions. The results were quite different from what was expected, especially considering the two tests performed. The Kolmogorov- Smirnov test examines how closely the sample distribution is to normal. When examining normality by bullet type, one can see that the Magtech bullets followed the predicted pattern in both cases, with the incorrect orientation distribution having a normal distribution, while the correct orientation did not. This test does not look at why the distribution is non-normal (which way it is skewed), just that it does not follow a normal distribution. The PMC bullet type, on the other hand, had statistically discernable departures from normality in both cases. This was unexpected, especially as the histogram showed no discernable departure from normality. The Remington (RUMC) bullet type, showed a normal distribution for incorrect orientations, and a non-normal distribution for the correct orientations.

Winchester (WIN) type showed departures from normality for both distributions. CCI showed normal distributions for both orientation types. Norinco (NOR) type showed the expected pattern, with normal distribution for incorrect orientation and a non-normal distribution for correct orientation. FAE showed normal distributions for both as well. Again, the LB type had much fewer cases than any other type, and is therefore being omitted from analysis.

The pattern that emerged from the results shows that there are differences in bullet type, just not in the predicted direction. Some bullet types were very reliable in the amount of striation measured by the SCICLOPS system, while others were not. Some suggested differences would be in manufacturing techniques and materials used in the construction of that particular type of bullet. Although all of the bullets were of the cast lead jacketed type, manufacturing processes and type of material used may have differed. The CCI and Norinco types especially should be examined for differences in manufacturing techniques. Norinco is a Chinese ammunition, and perhaps the processes are very different from U.S. manufacturing companies. The CCI type showed very low numbers, but this can be due to the fact that the jacketing material is of thicker quality. More information on manufacturing techniques is needed to conduct further analyses.

The ANOVA tests showed further that differences exist across manufacturers. In testing all eight of the bullet manufacturers against each other, the ANOVA showed significant differences, thereby rejecting the null hypothesis in favor of the alternate hypothesis. In breaking down these differences by manufacturer, there seems to be no discernible pattern as to why this is so. Further testing is needed to draw out the differences, for the ANOVA only shows that differences do exist, not really why they exist. It may be manufacturing techniques, jacket types used, the order of firing, or some hitherto unknown explanation. This is also seen in the post hoc Tukey and Homogenous subsets tests. Both tests show where exactly the differences and similarities amongst bullet manufacturing types exist. The Tukey tests show that each of the bullet types is similar to at least one another type, but not to all other types. The Homogenous subsets show that the mean average weighted striations of each bullet type are comparable to several others. When comparing the manufacturer types in the incorrect orientation, two distinct groups emerge that do not overlap. Only one group would be expected if the numbers recorded were due to random error. For the correct orientation, three groups emerge when eight separate groups were expected. Two of the groups overlap, leading to a conclusion that the CCI, NOR, and LB types are very similar to each other, somewhat similar to the RUMC type, and very different from the MAG, PMC, FAE, and WIN types. The MAG, PMC, FAE, and WIN types all have notably higher values than the other types. This could also be due to manufacturing processes or what type of alloy is used to create the bullet jacket. Whichever the case, the CCI, NOR, and LB types seem to be read completely differently by the SCICLOPS system. Further testing is needed to figure out why this is so.

Differences Within Manufacturer

This is also evident in the within manufacturer testing. Four of the eight types had significant differences about their means, while the other four did not. PMC, RUMC, CCI, and NOR all had differences within their own bullets. These differences show that these bullet types have less identifiability as being of a certain type than do MAG, WIN, FAE, and LB. This could be a problem when trying to match a bullet to a gun by scanning the bullet with the SCICLOPS system.

In looking at these results, one comes up with mixed support for the SCICLOPS system. In a perfect world, each bullet manufacturing type would have two distinct distributions comprised of the two orientations and be significantly different from other bullet manufacturing types. Since some of the manufacturing types are not significantly different from each other, it remains a question as to whether class characteristics such as the manufacturing type can be read by the SCICLOPS system or whether only individual differences can be seen. Finding a system that connects already known class characteristics to individual characteristics should be a major goal in firearm identification. The implications of the ANOVA and Tukey tests are that, although some significant differences could be read by the SCICLOPS system, there were still others that remained similar, and that some of the manufacturer types are identifiable as that type while others are not. More testing in this area should be done with the SCICLOPS system to see if improvements could be made that would increase the number of significant differences found. The goal of identification would be that each manufacturer is significantly different from the rest, making bullets of that manufacturing type easy to distinguish from others. Identifying class characteristics such as that would make identifying individual differences easier, thereby allowing more confident matches between bullets and guns.

The question of bullet identifiability has long been of concern in the area of firearms investigation and will continue to be so until a solution is found. Is it that the system cannot measure differences, or does the problem lie with the bullets themselves? Future studies should be done with a greater range of bullet types, including not only different manufacturers but also different kinds of bullets (hard nose, jacketed, etc.). This would further test the SCICLOPS system as an accurate identifier of bullets and firearms and allow for a more widespread comparison of how bullets perform against others of the same and different types.

Limitations

One major limitation of this study is the unequal number of cases for each bullet type. Future testing should comprise equal numbers of bullets, to allow for a more accurate determination of normality and deviation from the mean. Another limitation is the study design. As this is a secondary analysis, there may be unknown problems with data collection procedures or data quality and validity. This may also limit the generalizability of the results and conclusions. The study design included the use of a sequential firing order in which one bullet from each manufacturer was fired in a row before repeating the order. This may have biased the resulting number of striations found on the bullets. Test firing ten bullets in a row for each manufacturer before going on to the next may produce different results, which might prove useful in determining the identifiability of a certain bullet manufacturing type. Test firing more than one bullet at a time for a manufacturer may allow striations to appear more uniformly than firing one bullet of each manufacturer at a time, and thus allow for greater identifiability.

Conclusion

In conclusion, this study does find some support for the use of the SCICLOPS system as a technique for firearm identification. Several of the bullet types proved identifiable as a group (of test firings). Uncertainty remains about whether the lack of identifiability of the other bullet types is due to the identification system or the manufacturing of the bullet.

The results suggest that there are two distributions to examine when using the SCICLOPS system- the incorrect orientations and correct orientations. As these are determined by the orientation having the highest striation number, there may exist a need to find a more sophisticated technique to ensure accuracy. The SCICLOPS system does in fact represent the next generation of firearm identification. This system allows for depth analysis that did not previously exist with the comparison microscope. Firearms identification is still a large part of forensics and criminal investigations, and continuous improvements in the SCICLOPS system will show it to be a useful and accurate tool for aiding law enforcement and other firearm experts.

Future Areas of Study

More research in this area is needed to complete the development of an automated firearms identification system such as SCICLOPS. Data sets and tests involving various types of firearms, bullets, and even cartridge cases could strengthen the confidence behind the SCICLOPS system as a useable tool. An area in special need of research is in bullet manufacturing practices. As can be seen in this project, not all bullets are reliable in their matching to others of the same type. Exploration of why this could be is necessary as a backup to further explorations of what SCICLOPS is capable of. If differences between bullet types can be quantified, then the SCICLOPS system stands a chance at showing identifiability for all types, no matter the manufacturing process of the bullet.

Another area of future study involves a direct comparison of the SCICLOPS system to the comparison microscope and any other emerging identification systems. A comparison such as this could prove the improvement of using SCICLOPS over the more traditional method of the comparison microscope.

Again, this project concerned only an exploratory analysis of data created by the SCICLOPS system. More advanced statistical analyses should be conducted to further test the reliability, consistency, accuracy, and validity of the SCICLOPS system.

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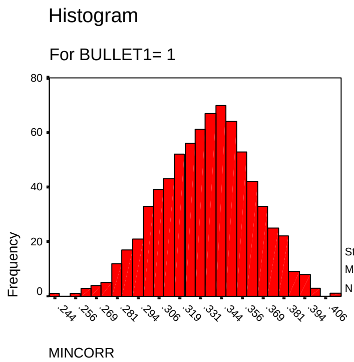
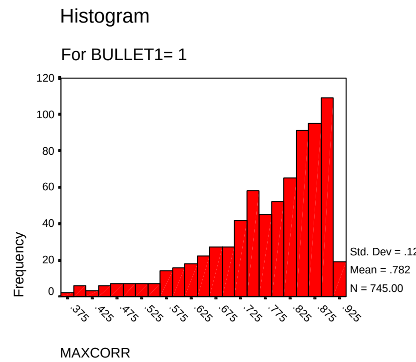
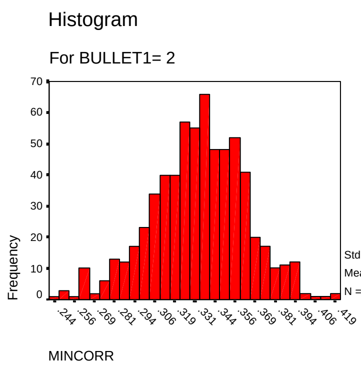
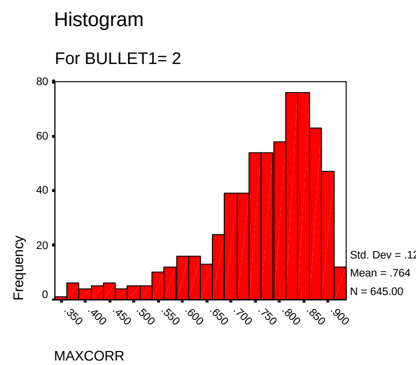
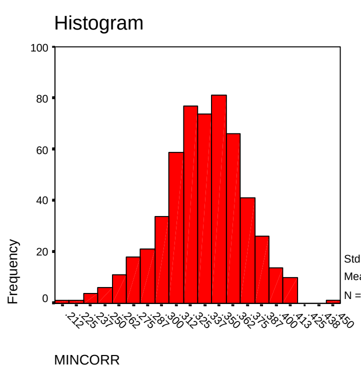
Appendix A: Histograms and Boxplots by Orientation and Manufacturer

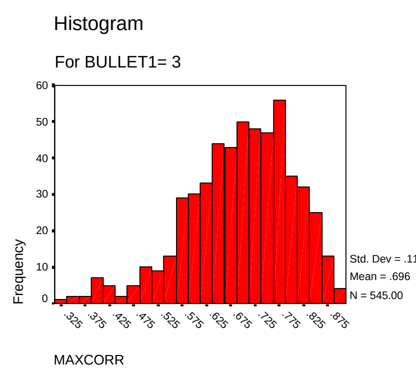


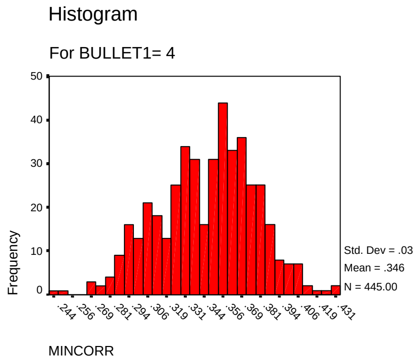


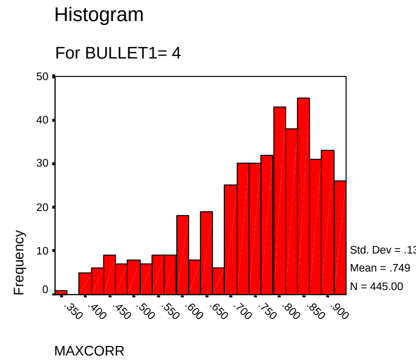









Histogram
For BULLET1= 4
Frequency
Std. Dev = .03
Mean = .346
N = 445.00
MINCORR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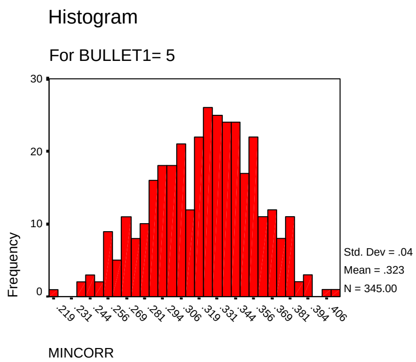
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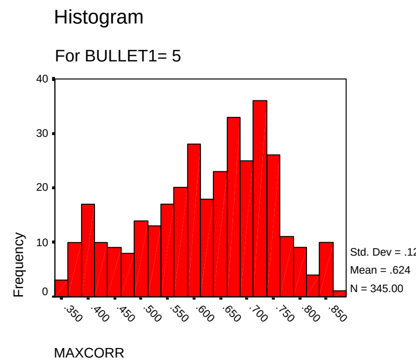
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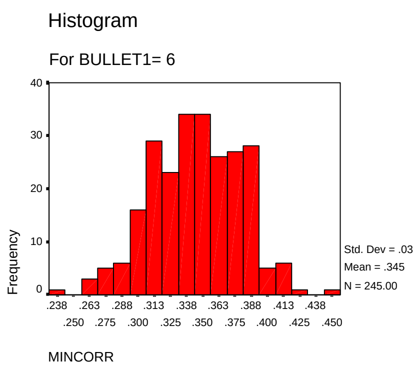
N = 345.00
MAXCORR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Frequency
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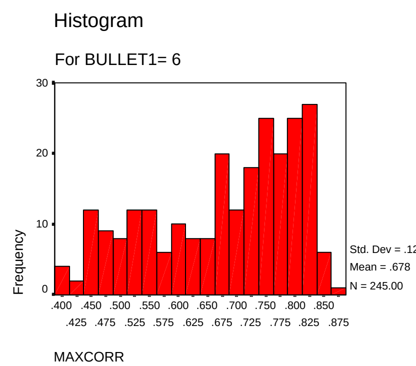
N = 245.00
MINCORR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For BULLET1= 6
Frequency
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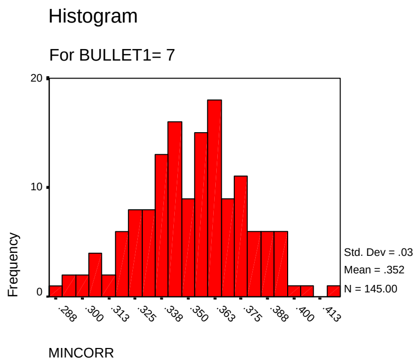
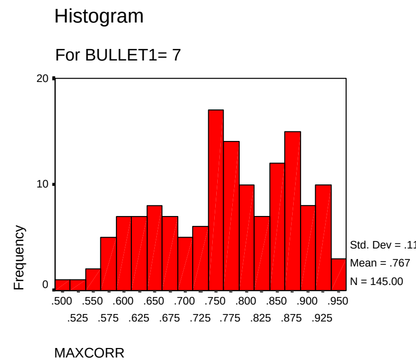
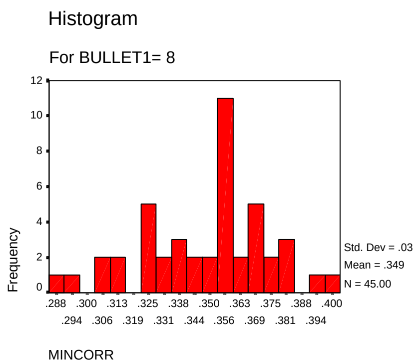
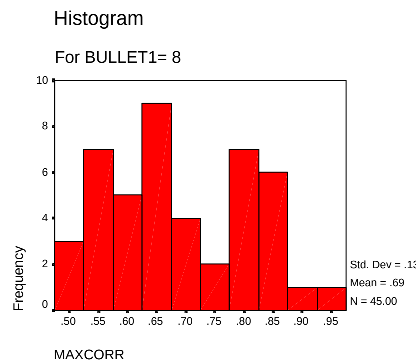
Mean = .678
N = 245.00
MAXCORR









Boxplots for all manufacturing types