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Shooting Distance Determination: Identifying Variables Affecting Lead Density on a Target.

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2016-DN-BX-0184

Final Summary Overview

Purpose

The purpose of this project is to develop a statistical foundation to support the established methods for determining the muzzle-to-target distance that are based on empirical research. The goal is to demonstrate, quantitatively, that the lead distribution on a target is directly related to the firing distance. If this can be established, the lead distribution can be measured by any method, AAS, ICP, mass spectroscopy, or by colorimetric methods. The proposed experiments are to determine if the density of lead on a target can be used to determine shooting distance at a 95% confidence level with an error rate acceptable for forensic science. Two potential calibration curves will be tested:

1. The natural log of the lead density on the area surrounding the bullet hole.
2. The *ratio* of the mass of lead of an inner ring, 1.5-5 cm from the bullet hole, and an outer ring, 5-10 cm from the bullet hole.

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Objectives

1. Validate an AAS method for the concentrations of lead found in a ring with an internal diameter of 2.5 cm and an external diameter of 7 cm around a bullet hole.
2. Determine the spread of values for *d*Pb deposited on a target by a 9mm Smith & Wesson handgun.
3. Develop a method for determining muzzle-to-target distance using the lead density on the target.
    a. The number of test fires will be determined from the data in Objective 2.
    b. Compare the reliability of calibration curves generated by plotting the *d*Pb in a ring of 10 cm in diameter around the bullet hole and a *ratio* of *d*Pb from inner and outer rings within a 10 cm diameter.
1. Test the reliability of the linear regression of the *d*Pb over distances from 15-75 cm (5.9-29.5 inches) with test fires from known distances.

Project Design and Methods

In this project, the following issues were investigated:

1. Neither the lead extraction method nor the linear regression calibration model has been validated for muzzle-to-target distance determinations.
2. The spread of the data for GSR from shots fired at a single distance is unknown.
3. Distance affects the distribution on a target in two ways. Not only does less lead reach the target as the distance increases, but also the radial distribution of the lead around the target increases. In the context of the *d*Pb measurements, the *ratio* of lead from a ring

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close to and a ring further from the bullet hole may be a better indicator of firing distance than simply the lead density around the target.

Step 1. Lead extraction, percent recovery, and reproducibility

The objective of Step 1 was to optimize the extraction and document the percent recovery reproducibility. Several acids were tested for the extraction. Nitric acid has the best reproducibility of the Pb recovery with spiked target material. However, the lead extraction method was tested using lead nitrate AAS standards. To ensure that the extraction method is would also work with the elemental lead produced in GSR lead powder (particle size ≤ 74 µm. for an average mass of 4.5 µg/particle) was applied to the target material.

The AAS reports the concentration of lead in the extract. The concentration times the volume of extract gives the mass of lead extracted from the target material. The *d*Pb is given by the mass of lead divided by the area fabric extracted, grams of $Pb/2\pi r^2$.

Step 2. Determining the spread of dPb for distance standards

For this project, a Smith & Wesson 9mm handgun was be purchased and used solely for this and future research. As all firearms are test fired by the manufacturer, the possibility of purchasing a new barrel was considered, but rejected as introducing a variable not commonly encountered with seized handguns. A by-product of the project will be the continued documentation the aging of the firearm in future research projects.

The intention was to use only ammunition from the same manufacturer and type of ammunition, however, the amount of lead extracted from targets shot with Hornady 9mm ammunition was below the limit of detection for the AAS. The brand of ammunition was changed to Tulammo, a Russian made ammunition, known for being ‘dirty.’

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One hundred cartridges, were fired at 15, 30, 45, and 60 cm. A set of 32 test fires were shot at 75 cm and 5 cm. Several sets of test fires were fired from different distances for comparison with the sets of 100, to examine variation in the results for shots fired on different dates and from different ammunition lot numbers. Some of the test fires were at the same distances as the calibration distances (15, 30, 45, 60, 75) and some were at random distances, 33, 42, 49, and 64 cm. The standard deviation of the 100 test fires will be used to calculate the sample size (X) required for a 95% confidence level in the calibration curve and the variation compared to that of the lead density data.

A random collection of six cartridges was selected to disassemble and the mass of the bullet and powder recorded.

Step 3. Calibration curves for distance determination

Calibration curves were generated from random data points and compared. It was determined that the analysis by different analysts was a factor in the data. This is currently being analyzed and will be reported in future publications on the project.

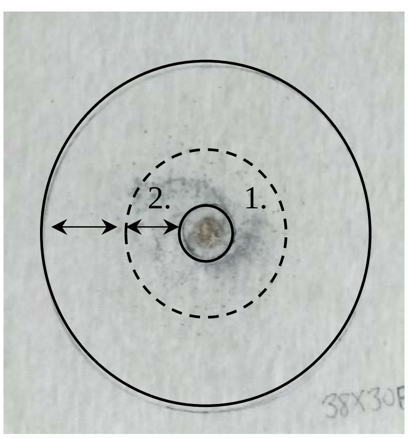

Figure 1. Proposed concentric rings drawn around bullet

The *d*Pb was determined for set of 3 test fires at 15, 30, 60, and 75 cm. Curves were plotted for both the total and ratio of lead densities. As previously stated, not only does the amount of lead diminish with distance, the radial spread increases as well. We proposed that the variables affecting the amount of lead that reaches the target (small variations in the cartridge, the barrel temperature, defects in the barrel or rifling, temperature, humidity, evidence handling, etc.) would have a lesser effect on

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the spread of the GSR on the target. In effect, measuring the ratio of lead near the bullet hole to that further out will cancel out small variations in the total lead content. However, this did not prove to be accurate.

The residuals were be plotted to evaluate the validity of the linear. Finally, the reliability of the calibration curves were tested with the known test fires. A set of the known test fires will be randomly selected for each calibration curve. The purpose was to test the calibration curve with known test fires shot at different dates, not just the same date as the calibration test fires. In casework, the test fires are not shot on the same day as the evidence, so it is important to show that the correct distance can be calculated for a casework sample shot on a different day.

The sodium m rhodizonate colorimetric test was on 36 test fires shot at 30 cm, followed by lead extraction. Using both the *d*Pb and colorimetric tests could serve as an experimental control. If both tests fail, then there may be another factor affecting the analysis, possibly indicating a lead free ammunition. Second, variations in the visual images of the colorimetric tests at each distance can be compared to the spread of the numerical values obtained from the lead extraction. Finally, the photos of the colorimetric distance standards will serve as a large population for future research.

The data from Step 3 will be used for:

1. Determination of distances with no overlap for the two quantitative methods
2. Document the reliability of *d*Pb for distance determinations.
3. Document the reliability of the ratio of *d*Pb on inner and outer rings centered on a bullet hole

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4. Provide data for comparing conclusions from colorimetric and quantitative distance determinations.

Step 4. Evaluation of distance determinations in a blind test

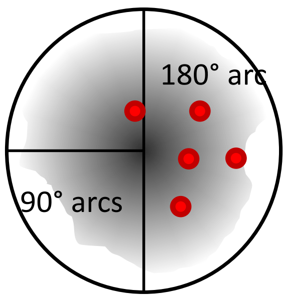

Figure 2. Schematic of 90 and 180° arcs to be analyzed for

The final evaluation of the quantitative and colorimetric was be with a blind test, where the researchers do not know the firing distance of the blind test fires.

The data from Step 4 will enable the researchers to make a final evaluation of the utility of *d*Pb as an indicator of firing distance under the conditions of the analysis.

Future work will include developing method for the lead extraction for bloodstained garments, determining if the Pb can be extracted after the colorimetric tests have been used on a GSR pattern, and determining if accurate data can be collected from a fraction of the pattern as illustrated in Figure 6.

Step 5. Dissemination

The results of this project have been presented at several conferences and universities:

Oral Presentations

"Lead Density on a Target, A Significant Indicator of Firing Distance, but is it Reliable?", Elizabeth A. Gardner, 2018 Annual Meeting of the Alabama State Association of Forensic Sciences, Destin FL, May 31, 2018.

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“Lead Density on a Target, A Significant Indicator of Firing Distance, but is it Reliable?”, Elizabeth A. Gardner, Alabama State University 2018 Annual Research Symposium, Montgomery, AL March 14, 2018.

Poster Presentations

“Sodium Rhodizonate Color Test Limit of Detection” Tyler Shelton and Elizabeth Gardner, 2018 Annual Meeting of the Alabama State Association of Forensic Sciences, Destin FL, May 31, 2018.

“Sodium Rhodizonate Color Test Limit of Detection” Tyler Shelton and Elizabeth Gardner, UAB 2018 Spring Expo, University of Alabama at Birmingham, April 13, 2018.

“Firing Distance Determination using atomic absorption spectroscopy and sodium rhodizonate”, Matthew Grbac, Elizabeth Gardner. Annual meeting of the Alabama State Association of Forensic Sciences, Sandestin, FL, June 1, 2017.

In addition, two manuscripts will be submitted to peer-reviewed journal, one focusing on the results of the sodium rhodizonate tests, both the limit of detection for lead and its effect on the subsequent lead extraction for AAS analysis for submission by July 31, 2091. The second manuscript will focus on the statistical analysis of the 100 test fires at 15, 30, 45, and 60 cm, and will be submitted in August, 2019.

Research Methods

Test fires were made in the indoor range at Security Engineers, Inc., Birmingham, AL. The indoor range has clean air ventilation that will provide a constant airflow and prevent accumulation of GSR in the air as multiple test fires are shot. The firearm was a Smith &

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Wesson 9mm handgun and the ammunition was Tulammo 9 mm cartridges. Targets were constructed from white cotton twill fabric stapled to a cardboard backing and set at the specified distance from the handgun, which rested on a pistol stand.

Data Analysis

The lead density has been entered into an Excel spreadsheet for analysis of the median, mean, standard deviation, and smallest representative samples size at the 95% confidence level, and calculation of residuals

Findings

The principle findings include:

- The lead extraction method with nitric acid is effective in extracting the elemental lead from the target, as well as lead salts.
- The limit of detection for lead by AAS is lower than the LOD for the sodium rhodizonate test.

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- The ratio of lead density of the inner (1.0 cm-5 cm) to the outer (5 cm-10 cm) rings of the target does not give better distance determinations than the sum of the lead from 1.0 cm-7.5 cm
    - Analysis indicated that while the amount of lead decreased with distance for both rings
    - The contribution of the outer ring was an order of magnitude smaller at 15-30 cm, but was equal to the inner ring at distance greater than 45 cm, consequently, the method was adapted to only extract lead from a ring 1.0 to 7.5 cm.
        1. This also reduce error during the ring extraction.
- The differences in the data between analysts varies to a greater extent than the data collected by one analyst.
    - In this study, there were three scenarios
        1. Shots were fired and analyzed by graduate student 1
        2. Shots were fired by graduate student 1 and extracted by graduate student 2
        3. Shots were fired and analyzed by graduate student 2.
    - Data analysis is still being run on these factors

Implications for Criminal Justice Policy and Practice

The results of this project have shown that the limit of detection for lead by AAS is lower than that for the sodium rhodizonate color test. This has implications at both lead free and total metal jacket bullets. Even hollow points often have an aerodynamic polymer plug covering the point of the bullet. If these trends continue, chemical analysis of targets may become more important in GSR analysis for shooting distance determinations. While this project has not fully untangled the factors affecting the lead deposition, the greater lead sensitivity of the AAS is

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sufficient motivation to continue looking at analytical methods for determining shooting distances.

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