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PAPER

CRIMINALISTICS

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Comparison of GSR Composition Occurring at Different Locations Around the Firing Position

ABSTRACT: Variations in gunshot residue (GSR) compositions are used in the reconstruction of shooting incidents. In this study, GSR samples taken from seven different locations around and in the firearm were collected and analyzed using scanning electron microscopy/energy dispersive X-ray analysis. Four different types of ammunition were applied. Very low correlations were found when different ammunition were used. This clearly shows that it is possible to differentiate between ammunition types. When the same ammunition was used, high correlations were found between samples taken from external positions (such as hands of shooter, bullet-entrance holes) but poor correlation was found between internal samples (such as firearm barrel, cartridge case) and external samples. A high degree of association was found between samples that simulated victim and shooter. These findings clearly demonstrate that GSR comparison studies are meaningful but care needs to be taken when choosing suitable exhibits. External samples (such as hands of shooter, bullet-entrance holes) are more suitable candidates than internal samples (barrel of the firearm, cartridge case).

KEYWORDS: forensic science, gunshot residue, firearm, scanning electron microscopy, composition comparison, association, correlation

When a firearm is fired, a cloud consisting of gases and particles is released into the environment. The particle ensemble consists mainly of (un)burnt remains of the propellant and primer particles. The particles deposit on a variety of surfaces in the close vicinity of the firearm, such as the shooter's hand. Collectively, they are termed gunshot residue (GSR).

Because of the large diversity in arms and ammunition designs (1,2), and the complexity of the firing process, the amount and composition of GSR vary. Each shot is different from the next.

Even when using the same type of ammunition with the same firearm, slight variations in GSR composition will occur because of variations in usage history, variation in the primer/gunpowder load of the shell, and variation in the physical conditions (e.g., temperature and pressure) during the shot. Because of all these variations, it is expected that each shot will expel gunsmoke with a GSR composition profile that is different than the following shot. Measuring and comparing these profiles may be of use in forensic casework.

The ideal GSR composition profile needs to include reliable information on the GSR particle size distribution, GSR elemental composition distribution, amount of GSR and morphological characteristics. Collection of the relevant information into databases has been performed by several investigators. In a pioneering work (3), Wrobel et al. have defined a set of differentiating properties for 22 ammunition that together form a database. This database was used for comparison purposes or to identify the ammunition. Another attempt to provide a GSR database was made by Pun and Gallusser (4) by using gunpowder characteristics, i.e., the organic GSR. In Europe, a GSR database is being developed within the European "AGIS" framework (5).

A number of earlier studies have recognized the feasibility of associating GSR samples from a crime scene with the type of ammunition used by analysis of the GSR X-ray spectra, notably the work of Brożek-Mucha et al. (6–8) and Steffen (9). Those works were also supported by the AGIS program (10). Brożek et al. and Steffen also attempted particle shape analysis as an added value to the composition analysis (9,11). These authors were able to differentiate, to a certain extent, between primers based on cluster analysis of a (large) number of samples.

In the reconstruction of shooting incidents, especially when multiple firearms and multiple ammunition have been used, questions concerning the chain of events need to be answered. One of the more interesting questions is, Can GSR samples from a single incident, taken at different locations, be associated (for example being identified as having the same source)? For example, is there a "positive association" between GSR found on the victim's clothing and the GSR found on the shooter's hand? Or between GSR from the cartridge case and the suspect's hand? And how specific is this positive association? The latter question remains unanswered by lack of a comprehensive database. As we shall see, however, some types of ammunition may be excluded as a source. Samples were taken at seven different locations around the firearm (Fig. 1) and analyzed by scanning electron microscopy/energy dispersive X-ray analysis (SEM/EDX) and then compared.

We take a different approach to comparing GSR samples than the mentioned researchers. It is shown that by a simple correlation calculation, GSR samples taken from the hand of the shooter and GSR taken from the victim correlate well. However, it is also shown that GSR sampled from cartridge cases do not always correlate well with the other GSR samples from the same shot.

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*The proficiency test 2005 is a standard test sample with Pb-, Sb-, and Ba-containing particles of known size and position.

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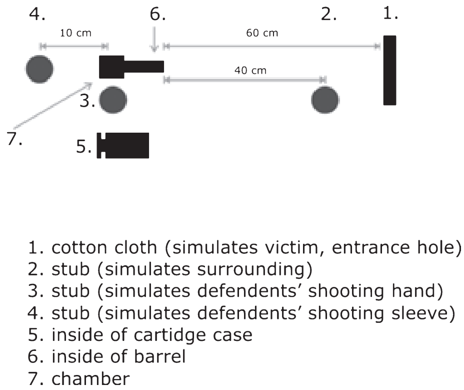

FIG. 1—*Schematic of experimental setup.*

Materials and Methods

All test firings were carried out at an indoor range. A single semi-automatic pistol (Sig Sauer P228; caliber 9 mm) was used in all test firings. Four types of 9 mm × 19 mm full metal jacket (FMJ) ammunition were chosen according to the characteristics of their primer compositions (Table 1). Seven sample locations were identified (Table 2, Fig. 1) as representative for possible real case sample locations.

Barrel and chamber of the gun were first cleaned by standard practice, i.e., wiping the interior with felt pads drenched in ballistol®. Then, they were ultrasonically cleaned in 2-propanol for 10 min. The outside of the weapon was wiped with paper towel drenched in ethanol. To finally clean the barrel, five rounds of ammunition were fired 10 min before setting up the experiment.

The pistol was mounted in a stationary adjustable shooting rig, allowing fixed positions for the collection of GSR, and operated by remote control. Aluminum stubs with a diameter of 12.5 mm coated with double-sided adhesive carbon tabs and a stand with the cotton cloth were placed and uncovered at the predetermined positions. A single test shot was fired through the cotton cloth. After a 10-min waiting period, the stubs, cotton cloth, and cartridge case were collected. The 10-min wait is considered sufficient for settling of the GSR cloud (13). Barrel and chamber were sampled for GSR (for sampling details, see next section). Then, a second test shot was fired using the same experimental setup, with another 10-min wait before collecting the items. Different ammunition were used on different days.

Sampling

The stubs at positions 2, 3, and 4 are passive samplers, i.e., GSR particles were allowed to deposit onto them for 10 min. Then, they were covered with a plastic cover until further analysis. The other four positions were actively sampled. The cotton cloth was sampled by dabbing an area (about 5 cm in diameter) around the bullet hole 50 times with a carbon tab-coated stub. Barrel, chamber, and cartridge case were sampled by rubbing a wooden stick along their inside. The wooden stick was then rolled onto a carbon tab-coated stub, transferring the GSR. The cartridge case was also put upside down onto the stub and lightly tapped. All stubs were kept in standard containers.

TABLE 1—*Characteristics of ammunition used in experiments.*

Brand or Manufacturer	Type	Main Primer Elements	Other Charact. Elements
Sellier & Bellot	RN FMJ	Pb, Sb, Ba	Sn*
Geco	Sintox FMJ	Ti, Zn	Sn*
Fiocchi	RN FMJ	Pb, Sb, Ba	
RUAG Ammotec	Action Effect	Ti, Zn	Gd†

RN, round nose; FMJ, full metal jacket.
*Bullet jackets are plated with Sn.
†The Action Effect ammunition is the standard ammunition of the Dutch police force. Gd is added to the lead-free primer as a marker (12).

TABLE 2—*Sample types and locations.*

Pos. #	Sample Type*	Sample Location	Simulates
1	Cotton cloth	60 cm from muzzle	Clothing of victim
2	Stub	40 cm, slightly right from muzzle	Surrounding objects
3	Stub	5 cm right from breech	Hands of shooter
4	Stub	10 cm behind gun	Clothing of shooter
5	Cartridge case	Inside of case	
6	Mouth of barrel		
7	Chamber		

*Sample types that are not stubs were sampled afterward to produce stubs containing gunshot residue.

Analysis

For each type of ammunition, two sets of seven stubs were obtained. Each set was analyzed in a standard manner for GSR using an automated SEM/EDX system, which detects, analyzes, and classifies particles into a predetermined classification scheme (Table 4). The SEM used was a FEI Quanta 400 model equipped with an Oxford Instruments INCAx-sight EDX detector (Tubney Woods, Abingdon, Oxfordshire, UK). The software used for GSR analysis and microscope control was Oxford Instruments INCAFeature, revision 4.07 (2006). Details on the measurement parameters are given in Table 3.

Brightness and contrast of the BE image were calibrated using a submicron GSR particle on the proficiency test 2005*. The video threshold was set to a fixed value of 160.

Classification Scheme

To quantitatively describe the overall composition of GSR, a tentative classification scheme is proposed that covers particle compositions representative of GSR, both from conventional and lead-free ammunition. Also, a class is added that is specific to the Action Effect ammunition (TiZnGd). A total of 16 classes were defined (Table 4). Class frequency is calculated by dividing the number of particles counted in a class by the total number of particles counted in the 16 defined classes. The class frequency or percentage is referred to as the "GSR composition" or "GSR profile" in the following.

Results and Discussion

For each ammunition type, two (three in the case of Action Effect) sets of seven stubs (seven locations for each shot) were

TABLE 3—*Operating conditions of the SEM.*

Parameter	Value
Accelerating voltage	25 kV
Working distance	10 mm
Magnification	250×
Beam current	1.0–1.1 nA

TABLE 4—*Classification list of (potential) gunshot residue particles used in the current study.*

(semi-)Ternary	(semi-)Binary	(semi-)Unary
PbBaSb	PbBa	Pb
PbBaSb(Sn)	PbSb	Ba
TiZnGd	BaSb	Sb
	PbBa(Sn)	Ba(Sn)
	PbSb(Sn)	Sb(Sn)
	BaSb(Sn)	
	TiZn	
	CuSn	

analyzed, a total of 63 stubs. If applicable, particles were classified into one of the 16 classes, and class frequencies were calculated. As an example, data on the GSR composition found on the cotton cloth are given in Table 5. Ammunition are identified by the first number (1,2 = Sellier & Bellot [S&B], 3,4 = Geco, etc.), and the location by the second number (1 = cotton cloth, etc., Table 2). For each sampling location, a similar table can be constructed. From these tables, it is evident that large differences exist in GSR composition when different ammunition is used. GSR compositions resulting from different shots but with the same ammunition and at the same location are similar to each other. This can be seen more easily when the data are presented in bar graphs, as in Fig. 2. Qualitatively, the differences between the ammunition are immediately apparent. It is also apparent that we find differences between two shots with the same ammunition.

Blanks

Immediately prior to a test-firing, two blanks were exposed to the atmosphere of the shooting range for 10 min. The exposure time is equal to that of the experiments. The stubs were placed at sampling locations 2 and 4 (Fig. 1). Those locations represent areas where, respectively, most (position 2) and least (position 4) GSR deposition is expected (14). A total of two and three particles, respectively, were detected on the blanks. None of those particles showed properties that were specific to GSR. This result means that GSR particles found on the stubs after a shooting experiment all pertain to that particular experiment and do not originate from previous shooting events.

TABLE 5—*Example of experimental data: numbers are percentages of the total of classified particles; sampling location is the cotton cloth.*

	P1-1	P2-1*	P3-1	P4-1	P5-1	P6-1	P7-1	P8-1	P8bis-1
PbBaSbSn	31.4	37.1	0	1.1	0.2	1.2	0	0.3	0.5
PbBaSb	2.7	1.1	0	0	46.7	39.2	0	0.3	0.7
PbBaSn	0.5	0.6	0	0	0.2	0	0	0	0.2
PbSbSn	12.4	17.8	0	0.2	0	0	0	0	0.3
BaSbSn	8.4	13.9	0	0	0	0	0	0.6	0
PbBa	0.7	0.5	0	0	2.6	2.7	0	0.3	1.4
PbSb	7.5	4.5	0	0	10.9	20.8	0	0.3	0.8
BaSb	3.1	1.1	0	0	15.9	10.3	0	0	0
BaSn	1.2	2.0	0	0	0	0	0	0.3	0
SbSn	0	0	0	0	0	0	0	0	0
Pb	20.9	13.9	0.3	0	9.5	7.6	13.3	10.0	17.4
Ba	4.3	2.3	0	0	5.0	2.1	21.1	2.7	2.3
Sb	5.3	3.3	0	0	7.8	15.7	0	0	0
TiZn	0.1	0.1	8.6	10.4	1.2	0.4	8.9	8.8	10.5
TiZnGd	0	0	0	0	0	0	56.7	75.8	65.8
CuSn	1.5	1.9	91.0	88.3	0	0	0	0.6	0.2

*Average of three independent measurements.

Comparing the Data: A Quantitative Measure

To find out whether two classified measurements are alike or unlike, a simple correlation calculation between all samples was performed:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\left\{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2\right\}}} \qquad (1)$$

The square of this Pearson r-value (also known as *correlation coefficient*) was taken as a measure for the similarity, with $r^2 = 1$ meaning that the samples are identical, and $r^2 = 0$ meaning that there is no similarity at all between the samples. The calculation leads to a 56×56 matrix of r^2-values, with 14×14 matrices per ammunition type on the diagonal. Some extra measurements were also taken into account. The total number of calculated r^2-values is 1540. Figure 3 presents an overview of calculated r^2-values grouped together by value. The bulk (76%) of observations is between 0 and 0.1, indicating uncorrelated results.

The amount of GSR particles released and present in gunsmoke varies from shot to shot (15,16), and the amount deposited at a specific location also depends on the position relative to the firearm (14). The number of GSR characteristic particles detected on the passive samples is given in Table 6. In some cases, the number of particles deposited is very low, even as low as five (mainly at the "sleeve" position). Obviously, no reliable profile could be drawn in these cases. Samples that had less than 50 classified particles were excluded from further analysis. This was the case for S&B at the "hand" position (both samples), Sintox at the "sleeve" position (one sample), Fiocchi at the "sleeve" position (both samples), and Action Effect at the "sleeve" position (two out of three samples).

Reproducibility of Measurements

Any stub containing particles that is measured twice or more under nominally the same conditions, will show variation. Both the total number of particles and the number of particles for each class detected will differ more or less. To account for this variation, we have repeatedly measured and analyzed one of the experimental samples (P6-3, ammunition Fiocchi, hand position): six automated results were obtained, and from those, five manually corrected samples were taken. Pearson r correlations were calculated for all combinations of the measurements. Assuming a t-distribution for the measurements, it was established that in 95% of the cases the true r^2-value would be contained within the 0.95–0.99 interval. This finding is equivalent to stating that when two samples are found to have an r^2-value >0.95, they must be considered as being indistinguishable by the current method. It is the case in 6% of the observed values (Fig. 3). The manual correction gave only minor improvement in the variability; therefore, the results of the automated measurements were used *as is*. The latter finding is consistent with (7).

Within Ammunition, Within Location Reproducibility

As from each type of ammunition two samples per location were obtained, a quantitative comparison between the two can be made for each of the seven different locations. In Fig. 4, it is shown that 88% of the r^2-values is higher than 0.8 (31 out of a total of 35 observations). Fifty-four percent of the observed values

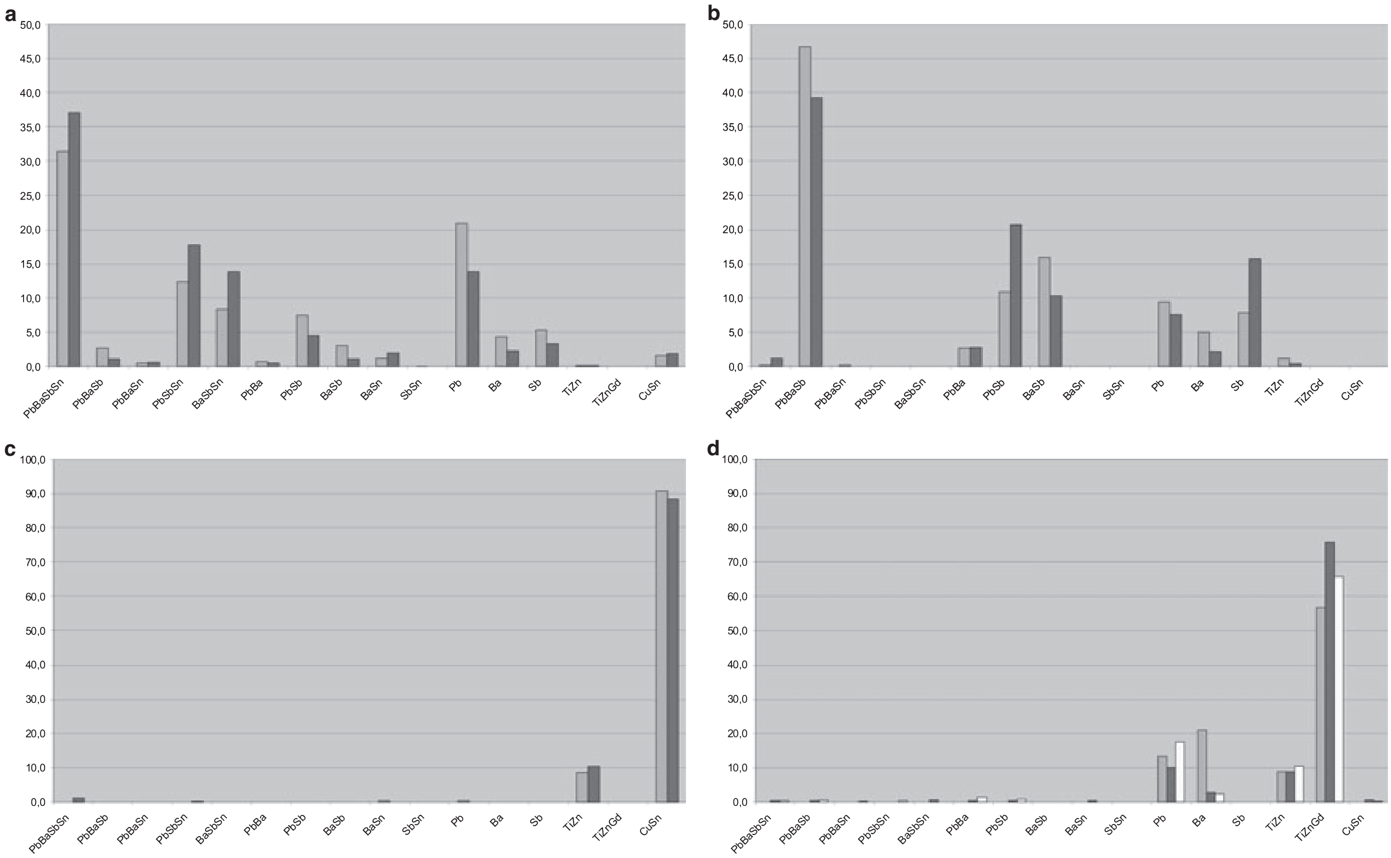

FIG. 2—*Data from Table 5 presented as bar charts to illustrate differences and similarities in the profiles. (a) Sellier & Bellot profile at cotton cloth. (b) Fiocchi profile at cotton cloth. (c) Geco Sintox profile at cotton cloth. (d) Action Effect profile at cotton cloth.*

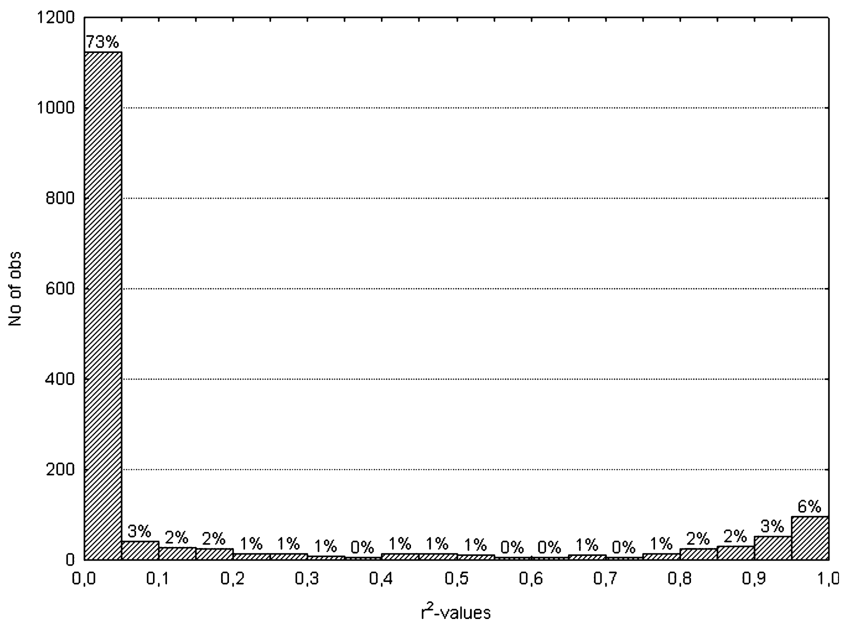

FIG. 3—*Histogram of all observed* r^2*-values (1540 observations).*

is higher than 0.95, somewhat less than with the reproducibility measurements. This means that the variability between two shots is somewhat higher than the measurement variability. Thus, two different samples of the same ammunition at the same location show high correlations. On the other hand, when different primers from our set are compared at the same location, they generally show very low r^2-values. Of the 173 observations, 170 were below 0.1 (98%) and the remaining three observations were

TABLE 6—*Number of gunshot residue characteristic particles detected on the "passive" samples for S&B: PbBaSb(Sn); for Fiocchi: PbBaSb(Sn); for Sintox: TiZn+CuSn; for AE: TiZnGd.*

	S&B		Sintox		Fiocchi		AE		
	1	2	3	4	5	6	7	8	8bis
Surroundings	174	394	460	494	302	113	77	259	894
"Hand" position	14	5	128	306	53	56	95	82	90
"Sleeve" position	32	58	28	115	7	7	7	57	5

below 0.5, (the *between* ammunition, within location, values are very low).

Within Ammunition Correlation Versus Between Ammunition Correlation

Between different ammunition, no r^2-value higher than 0.53 was found at any location, meaning that whenever a value of r^2 higher than 0.53 is found between two samples, the samples *must* have originated from the same primer *within the chosen set of ammunition*. However, within ammunition, sometimes values lower than 0.53 were found. So, with a value lower than 0.53, samples *may* have originated from the same primer, although the samples seem to be qualitatively very different.

Figure 5 shows the frequency of r^2-values calculated *within* all primers taken together (381 observations). The majority of values is higher than 0.8 (52%), but there is a considerable spread caused by differing results by ammunition type. For example, one S&B sample showed strong deviation in the "within" group, having r^2-values not higher than 0.44 for any location. This sample was compromised because it dropped on the floor of the range.

Fiocchi ammunition showed the highest internal consistency, with 92% of the r^2-values higher than 0.8, and no r^2-value lower than 0.68 (all samples from all locations can be positively associated).

Figure 6 shows the distribution of r^2-values *between* ammunition. It is shown that virtually all values are below 0.3, with 96% of the values under 0.1.

Within Ammunition, Between Location Correlations

How do samples from different locations compare within a single type of ammunition? Table 7 summarizes the average r^2-values obtained from those cases. The table presents somewhat of a mixed image, i.e., observed trends are always countered by exceptions.

High correlations ($r^2 > 0.8$) are found between samples from positions 1, 2, 3, and 4 (the external deposits), *within* the same ammunition. Remember that cross-values (*inter*-ammunition) on the other hand show values much lower than 0.1 (Fig. 6). Especially noteworthy are the correlations between samples from the cotton cloth (victim simulation) and the hand position (perpetrator simulation): in the available cases, r^2-values were all higher than 0.9. This result indicates that it is possible to associate GSR found on a victim with GSR found on a shooter's hand.

In casework, samples from spent cartridges found at the crime scene are sometimes investigated. From Table 7, it may be seen that in the majority of cases, there is poor correlation between samples from the cartridge and other locations (especially with S&B and Sintox ammunition). This may be caused by the GSR from a case being relatively "pure." Hardly any deposits from the inside of the gun will be mixed into it (see discussion of the memory effect below).

Chamber and barrel samples (internal deposits) show low correlation with all other locations in general, except when using Fiocchi ammunition.

Explanation for poor correlations, i.e., samples being "unlike" although originating from the same shot, must be sought in the admixing of "foreign" GSR particles into the "native" GSR mixture, a phenomenon sometimes referred to as the "memory effect" (17–22). With each shot, a certain amount of GSR is deposited on the interior surfaces of the firearm. At the same time, deposits from previous shots will get loose and leave the barrel together with GSR from the current shot. In the current study, PbBaSb particles were found at several locations outside the firearm after shooting with ammunition having lead-free primers (Sintox and Action Effect). Many of such particles were found in samples from the barrel and chamber after shooting with lead-free

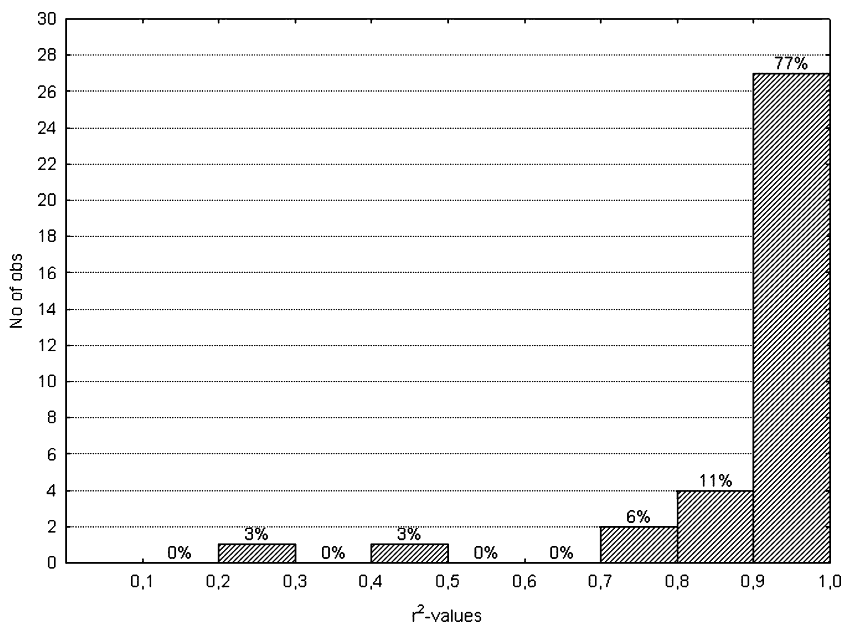

FIG. 4—*All correlations from within ammunition, within location (35 observations).*

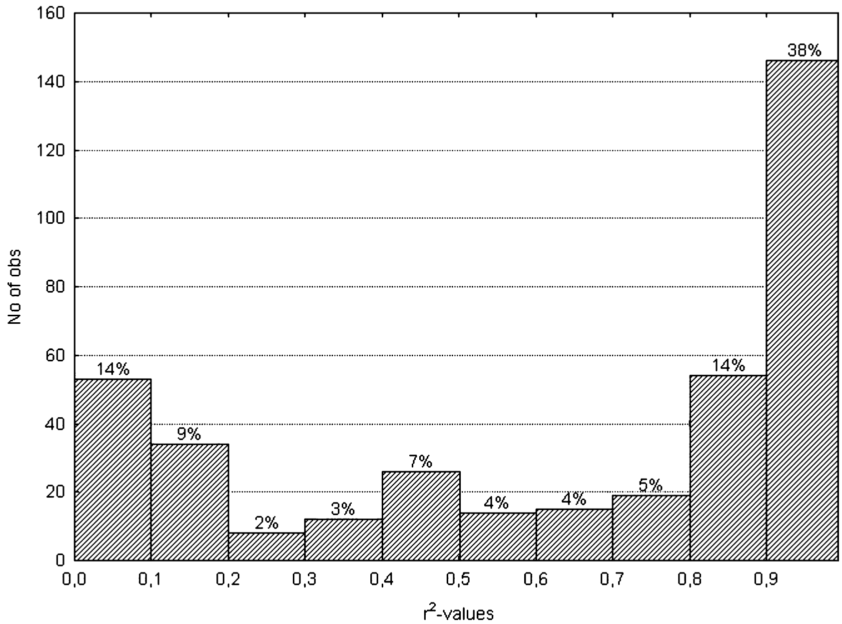

FIG. 5—*Distribution of r^2-values within ammunition, all ammunition and locations taken together (381 observations).*

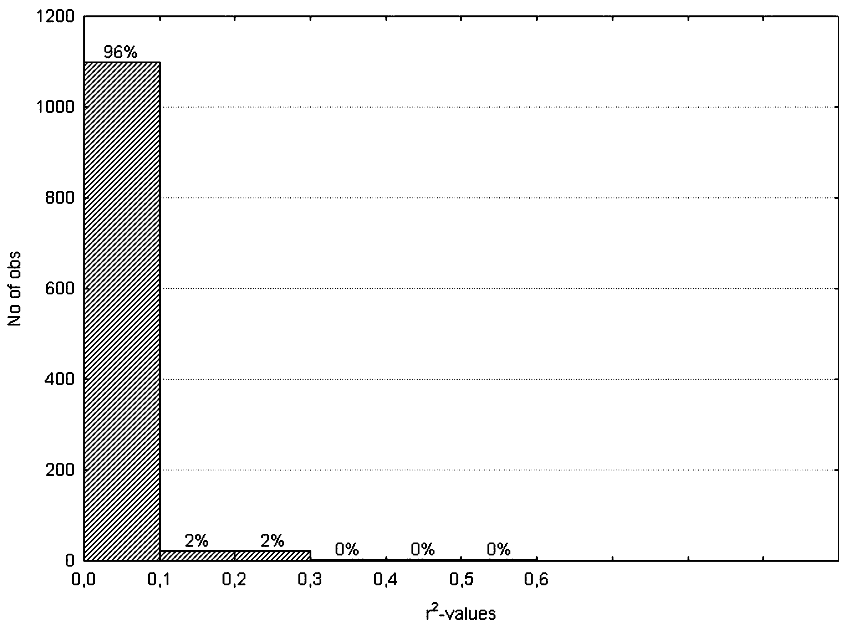

FIG. 6—*Distribution of r^2-values between ammunition, all ammunition and locations taken together (1147 observations).*

ammunition. As a comparison, in Table 8, the percentage of PbBaSb(Sn) particles found after shooting with a conventional primer (S&B) are also given. The memory effect is relatively weak for the external samples where the number of PbBaSb(Sn) particles is a factor 30–40 lower when lead-free ammunition is fired. The effect is stronger for the internal samples: especially, in the chamber samples, high concentrations of PbBaSb(Sn) particles may be found.

Conclusions

When ammunition is fired, different GSR composition profiles are created in and around the firearm. In this study, experiments were performed in which GSR was collected from seven different locations in and around the firearm. The samples were analyzed by scanning electron microscopy, using a specially designed classification schedule. Comparison was carried out by calculating squared correlation coefficients.

Positive (having the same source) and negative (having a different source) associations turned out to be possible within the chosen set of ammunition. This verifies that GSR comparisons are possible and meaningful. In this study, it was shown that the location of GSR collection (hands of shooter, firearm, cartridge case, etc.) is an important variable in comparison studies.

When *different types of ammunition* were used, very low correlations were found. In other words, it could be concluded that, within

TABLE 7—*Average r^2-values between different locations by ammunition type.*

	S&B	Sintox	Fiocchi	Action Effect
Cloth-Surroundings	0.9093	0.9521	0.9185	0.8608
Cloth-Hand	id	0.9386	0.9018	0.9270
Cloth-Sleeve	0.7965	0.9042	id	0.9492
Cloth-Cartridge case	0.6978	0.0106	0.7884	0.9158
Cloth-Barrel	0.7860	0.9702	0.8431	0.0970
Cloth-Chamber	0.7237	0.0165	0.8040	0.4364
Surroundings-Cloth	0.9093	0.9521	0.9185	0.8608
Surroundings-Hand	id	0.9961	0.9667	0.9406
Surroundings-Sleeve	0.8067	0.9851	id	0.9185
Surroundings-Cartridge	0.6718	0.0989	0.9200	0.7697
Surroundings-Barrel	0.7793	0.9760	0.9372	0.3068
Surroundings-Chamber	0.7055	0.1100	0.9322	0.3325
Hand-Cloth	id	0.9386	0.9018	0.9270
Hand-Surroundings	id	0.9961	0.9667	0.9406
Hand-Sleeve	id	0.9935	id	0.9769
Hand-Cartridge case	id	0.1181	0.8971	0.8842
Hand-Barrel	id	0.9722	0.9548	0.1871
Hand-Chamber	id	0.1304	0.9323	0.4196
Sleeve-Cloth	0.7965	0.9042	id	0.9492
Sleeve-Surroundings	0.8067	0.9851	id	0.9185
Sleeve-Hand	id	0.9935	id	0.9769
Sleeve-Cartridge	0.3374	0.1581	id	0.9455
Sleeve-Barrel	0.6353	0.9567	id	0.1159
Sleeve-Chamber	0.3626	0.1733	id	0.4308
Cartridge-Cloth	0.6978	0.0106	0.7884	0.9158
Cartridge-Surroundings	0.6718	0.0989	0.9200	0.7697
Cartridge-Hand	id	0.1181	0.8971	0.8842
Cartridge-Sleeve	0.3374	0.1581	id	0.9455
Cartridge-Barrel	0.6989	0.0531	0.8972	0.0212
Cartridge-Chamber	0.9807	0.9735	0.9446	0.5131
Barrel-Cloth	0.7860	0.9702	0.8431	0.0970
Barrel-Surroundings	0.7793	0.9760	0.9372	0.3068
Barrel-Hand	id	0.9722	0.9548	0.1871
Barrel-Sleeve	0.6353	0.9567	id	0.1159
Barrel-Cartridge	0.6989	0.0531	0.8972	0.0212
Barrel-Chamber	0.7378	0.0619	0.9615	0.0107
Chamber-Cloth	0.7237	0.0165	0.8040	0.4364
Chamber-Surroundings	0.7055	0.1100	0.9322	0.3325
Chamber-Hand	id	0.1304	0.9323	0.4196
Chamber-Sleeve	0.3626	0.1733	id	0.4308
Chamber-Cartridge	0.9807	0.9735	0.9446	0.5131
Chamber-Barrel	0.7378	0.0619	0.9615	0.0107

id, insufficient data; dark green, samples are indistinguishable (= very strong correlation); light green, strong correlation; pink, (very) weak correlation; red, (almost) no correlation.

TABLE 8—*Percentage of PbBaSb(Sn) particles as a percentage of the total of classified particles, illustrating the memory effect.*

Pos		P1 (S&B)	P2 (S&B)	P3 (Geco)	P4 (Geco)	P7 (AE)	P8 (AE)	P8bis (AE)
1	Cloth	34.1	38.2	0.0	1.1	0.0	0.6	1.2
2	Surroundings	46.6	31.0	0.4	0.2	0.8	0.9	2.3
3	Hand	id	id	1.5	0.3	1.6	3.7	2.2
4	Sleeve	32.4	23.3	id	3.8	id	0.0	id
5	Shell	66.9	78.1	0.0	0.4	0.4	0.0	1.0
6	Barrel	50.7	43.7	2.4	4.1	19.8	8.9	6.4
7	Chamber	69.0	78.8	11.8	12.6	34.4	10.2	36.3

id, insufficient data.

the chosen set of ammunition, the GSR samples did not have the same type of ammunition as a source.

On the other hand, when the *same type of ammunition* was used, GSR samples collected from different locations around the firearm (external samples) were found to be having high correlations, implying a high probability that the GSR samples had the same source.

The compositions of samples from the chamber and barrel (interior of firearm) in most cases could not be associated with samples from other locations. GSR samples taken from inside the cartridge case were in most cases poorly correlated with the other samples, especially when lead-free ammunition was used. This finding indicates that care must be taken when comparison studies are made between GSR collected from hands of persons and GSR collected from cartridge cases.

In this study, the amount of GSR at the hand or sleeve position sometimes was insufficient to make meaningful comparisons.

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