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Reference ballistic imaging database performance

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Abstract

Ballistic imaging databases allow law enforcement to link recovered cartridge cases to other crime scenes and to firearms. The success of these databases has led many to propose that all firearms in circulation be entered into a reference ballistic image database (RBID). To assess the performance of an RBID, we fired 4200 cartridge cases from 600 9 mm Para Sig Sauer model P226 series pistols. Each pistol fired two Remington cartridges, one of which was imaged in the RBID, and five additional cartridges, consisting of Federal, Speer, Winchester, Wolf, and CCI brands. Randomly selected samples from the second series of Remington cartridge cases and from the five additional brands were then correlated against the RBID. Of the 32 cartridges of the same make correlated against the RBID, 72% ranked in the top 10 positions. Likewise, of the 160 cartridges of the five different brands correlated against the database, 21% ranked in the top 10 positions. Generally, the ranking position increased as the size of the RBID increased. We obtained similar results when we expanded the RBID to include firearms with the same class characteristics for breech face marks, firing pin impressions, and extractor marks. The results of our six queries against the RBID indicate that a reference ballistics image database of new guns is currently fraught with too many difficulties to be an effective and efficient law enforcement tool.

Keywords: Forensics; Firearms identification; Ballistic fingerprinting; Imaging; Automated comparisons

1. Introduction

Fired cartridge cases and bullets bear characteristic marks, which enable firearm examiners to identify the firearm that fired them. When firearms are seized in connection with a crime, they can be test-fired and the bullets or cartridges cases compared to the bullets and cartridge cases from other crime scenes. Unidentified cartridge cases and bullets are retained in a database of evidence material, often called the open case file. When new evidence material is received, it is usually compared to this open case file to link different crimes. As the open case files grow larger with the addition of new evidence, the comparisons become very time-consuming. These open case files, which number in the thousands for larger agencies, are moreover located over a broad geographical area, making microscopic comparisons tedious and difficult. Thus, the advent of the digital imaging comparison system has given forensic firearms examiners a welcome tool for reducing the number of microscopic comparisons they must perform.

The number of success stories resulting from these systems has led to the idea of establishing a reference ballistic imaging database (RBID). Such a database would contain images of characteristic marks left by all firearms in circulation as well as information about these firearms. Law enforcement agencies would then be able to compare firearm-related evidence from the crime scenes to the images in the RBID. Using such a system would enable the forensic laboratory to identify a firearm which is not yet seized and available for examination. A successful match would lead to the identification of a firearm and possibly to the owner.

Several difficulties regarding the use of such databases were identified in [1]. These difficulties have prevented most of the states in the United States from developing and using

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an RBID. However, two states, Maryland and New York, have implemented statewide ballistics imaging databases for new handguns sold in those states. Article [1] evaluates the current New York state legislation in light of forensic and practical needs.

For an RBID to be useful and thus successful, it must reduce the rankings that must be optically compared. Such success depends on two criteria—(1) the efficiency of the algorithm and (2) the reproducibility of the striae and impressions on the cartridge components. Satisfying these criteria decreases the number of manual comparisons that the firearms examiners have to perform to verify results with acceptable certainty. In 2000, the Legislature in the State of California ordered a study on the feasibility and the potential benefits to law enforcement of an RBID. The subsequent report [2], currently known as the AB1717 report, describes the result of a study using 792 Smith & Wesson Model 4006 pistols, each chambered for the 0.40 S & W cartridge. This study raises some difficulties involving the use of large RBIDs. In this article, we will discuss the results of a similar study using a different type of firearm. This subsequent study was conducted to add to the statistical relevance of the AB1717 results.

2. Design of the study

Currently, no technology has been perfected to deal specifically with very large databases of images of marks made by firearms. In this study, we applied a current technology from integrated ballistic identification system (IBIS™), manufactured by Forensic Technology Inc. (FTI), which appears to be dealing with a similar type of problem. We are trying to assess whether or not this current technology used in local and regional databases can be applied and effectively used on the more complex problem of very large databases of images of marks made by firearms. IBIS™ is used with the much smaller open case files (those consisting of multiple guns of different makes, models, and calibers). It performs automated comparisons of fired bullets and cartridge cases from different crime scenes. IBIS™ is the cornerstone of the National Integrated Ballistics Information Network (NIBIN), deployed by the Bureau of Alcohol, Tobacco and Firearms [3]. Currently, FTI is also developing a Virtual Serial Number (VSN) machine for the collection of reference images at the gun manufacturers' premises. The physical collection and selection of the fired cartridge cases will be automated. The subsequent entry of the relevant image data will then pass through a simplified system based on IBIS™ technology.

To test the performance of an RBID, examiners would have to enter into the system a large number of firearms having the same distribution as the actual new gun sales. This task would be large and time-consuming. The comparison of a cartridge case to an RBID is limited to only those cartridge cases which possess the same class characteristics; [4] hence, only cartridges of the same caliber need to be compared. If we assume an ideal situation in which all firearm models possess different class characteristics, only comparisons to cartridge cases fired by firearms of the same make and model need to be performed.

In this study, we used a large number of similar pistols (make, model, and caliber) to simulate a large database. This selection process corresponds to the best-case scenario, one based on the assumption that all models of firearms have different class characteristics. As this scenario does not represent a real situation, actual RBID databases will have a lower performance. A total of 600 9 mm Para pistols were used for test firing. While very unlikely that this large number will ever be found in a criminal database, it is quite likely to be far exceeded in a civilian database of new handguns sales.

To test this RBID, we randomly selected cartridge cases fired from the 600 pistols. We then performed queries with ammunition of the same and of different makes. In addition, we used portions of the RBID to evaluate the change in correlation position in an increasing database size. These results can be used to predict larger database performance.

The RBID was also embedded in a larger database to verify if the assumption of distinct class characteristics for every firearm applies. This larger database consisted of the cartridge cases test-fired with criminal firearms and those from the open case file.

3. Experimental setup

Approximately 600 Sig Sauer model P226 series pistols[1] of caliber 9 mm Para, used by the Sacramento and Modesto police departments, were used to fire a set of the cartridges selected for this study. A criminalist loaded the specified cartridges into a magazine. An individual officer, to whom the firearm was assigned, fired the pistol in a designated cleared area. The fired cartridges cases were collected and placed into a sealed envelope onto which were recorded the date, initials of the collector, model number and serial number of the pistol.

The cartridges used for our study are listed in Table 1. One of the two Remington (RP) cartridge cases fired in each pistol was used to create the reference database. An example of the marks left on the cartridge case is given in Fig. 1. As can be seen, the headstamp ''R-P 9 mm LUGER'' is spread across the cartridge case in large letters, meaning that the

[1] Of the 600 9 mm Sig Arms (Sig Sauer) pistols used in this study, 554 were model P226, 15 were model P225, 29 were model P228, and two were model P229. The P226 is a full size pistol with a double column magazine; the P225 is a full size pistol with a single column magazine; the models P228 and P229 are compact size pistols with double column magazines. The general breech face, firing pin aperture, and extractor configurations are essentially the same.

Table 1
List of ammunition used for the test firing

Quantity	Brand of ammunition	Bullet
2	Remington	115 grain FMJ
1	Winchester	147 grain JHP
1	Speer	115 grain FMJ
1	Wolf	115 grain FMJ
1	Federal	147 grain FMJ
1	CCI	115 grain FMJ

headstamp will very likely interfere with an ejector mark. During our study, we observed a substantial variation in the ejector marks, which indicates the potential usefulness of this mark. The areas of interest are the breech face marks and firing pin impressions. This information is the same as that captured by the previously mentioned VSN system.

An IBIS™ composed of a data acquisition station (DAS) and signature analysis station (SAS) unit version 3.4.167 was used to enter the data in accordance with the procedures from FTI's manual. [5] The breech face and firing pin image, as illustrated in Fig. 1, was entered by experienced operators, trained by FTI. With a VSN, the image entry can be automated. In our study, the automatic data entry was manually adjusted for corrections to obtain optimal images. These corrections involved the amount of light, the size of the region of interest, and the positioning of the region of interest for both the breech face and the firing pin marks. The occurrence of these corrections is given in Table 2. These corrections, along with the administrative difficulties and need to determine the orientation of the cartridges, increased

Table 2
Frequency of the manual corrections applied to correct the automatic imaging of the breech face and the firing pin of the cartridge cases. These corrections are in accordance with the IBIS™ instruction manual

Correction	Frequency (%)
Breech face positioning	18.5
Breech face lighting	37.2
Firing pin position	15.8
Firing pin lighting	25.7
Breech face size	6.5
Firing pin size	14.7

the total input time up to 5 min for a single cartridge case. All the fired cartridge cases were entered into the database in the same orientation, as determined by the position of the ejector and the extractor marks.

The database searches, conducted as required in FTI's manual, [5] looked at the correlation of the fired cartridge cases by gap separation, looking at all candidates above the gap or in the top 10 positions of either breech face or firing pin correlation. A candidate-hit cartridge case can be identified based on its separation, or correlation score according to the FTI protocols. Experienced IBIS™ staff performed the subsequent correlations as a ‘‘blind’’ study, not knowing the actual identity of the unknown test specimens. They generated records for the top 30 cartridges of each correlation. The analysis of the correlations is based on both the firing pin and the breech face correlation. For certain analyses presented in this paper, the results for the breech face

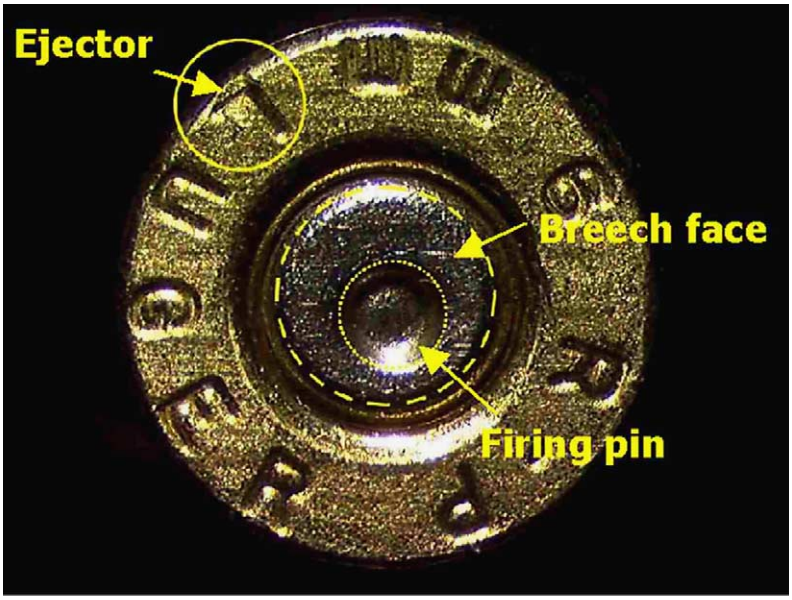

Fig. 1. Typical marks left by a Sig Sauer pistol on a Remington cartridge case. The mark left by the ejector is indicated by a solid line, the firing pin by a dotted line, and the breech face by a dashed line.

and firing pin correlations are combined retaining only the best-ranking result.

4. Results

4.1. Queries with ammunition of the same manufacturer

We selected 32 Remington test specimens from the second set of test fires to correlate to the 600-gun RBID,using random numbers [6,7] generated by a Microsoft Excel™ spreadsheet function. The resulting histogram of the ranking order is presented in Fig. 2. The histogram shows that 23 out of 32 cartridge cases (71.8%) were found by the IBIS™-algorithm within the first 10 positions of the ranking. The separate ranking for the firing pin impression and breech face mark of all samples is given in Table 3.

4.2. Queries to the RBID with ammunition of a different manufacture

For this query, 160 test specimens, equally dispersed among five different ammunition types, were selected for comparison to the 600-gun RBID, using random numbers [6,7] generated by the Microsoft Excel™ spreadsheet function.

The results of the ranking are presented in Figs. 3–7. These results are significantly different for each type of ammunition. When different ammunition is used, the top-10 ranking ranges between 2 and 12 out of 32 cartridges (6–37.5%). The separate ranking for both firing pin impression and breech face mark of all samples is given in Table 3.

Table 3
Summary of the ranking order results for each type of ammunition

Brand of ammunition	Number within the first 10 positions of ranking		
	Breech face	Firing pin	Both
Remington	17	14	23
Winchester	4	4	7
Speer	7	8	12
Wolf	3	3	5
Federal	0	2	2
CCI	2	6	8

Separate data is given for the breech face and the firing pin correlation results. The best ranking order is retained in the last column.

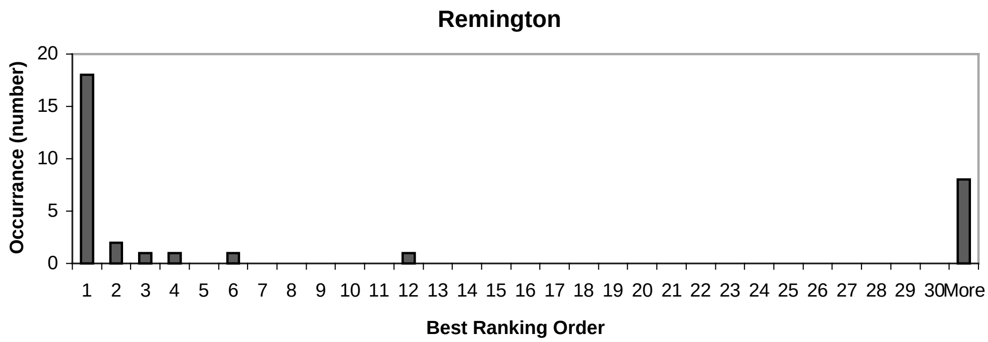

Fig. 2. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. Both cartridge cases were of the same make.

Fig. 3. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. The RBID was queried by cartridge cases made by Winchester.

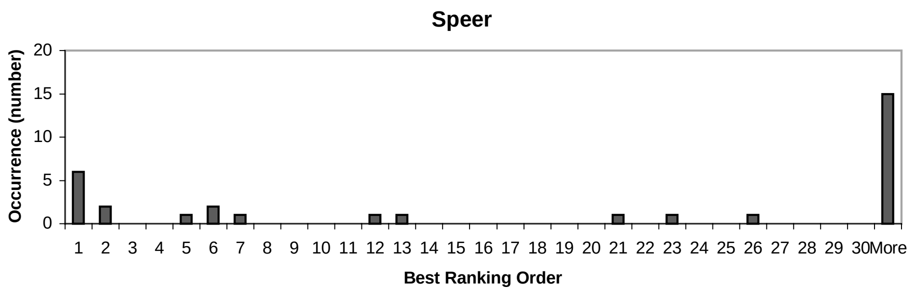

Fig. 4. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. The RBID was queried by cartridge cases made by Speer.

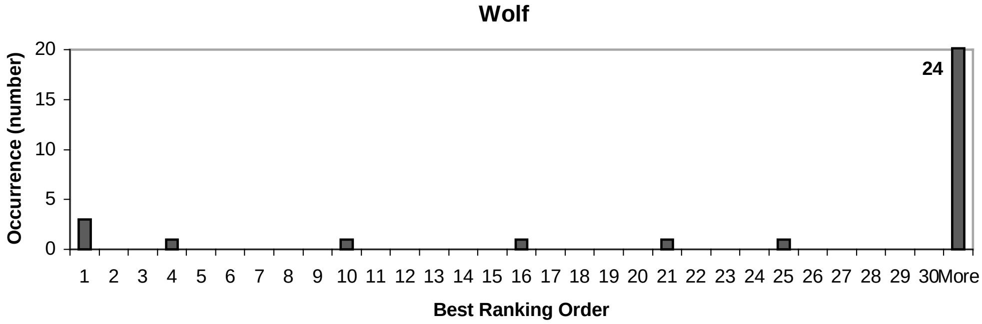

Fig. 5. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. The RBID was queried by cartridge cases made by Wolf.

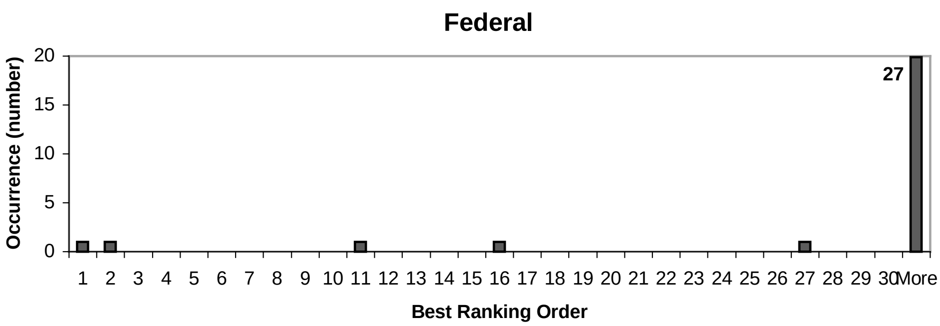

Fig. 6. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. The RBID was queried by cartridge cases made by Federal.

The composite results for all the different ammunition are grouped together in Table 4.

4.3. Queries to the RBID by sequential increase of its size

This study investigated the ranking of a breech face and a firing pin image in a database that was gradually extended by increments of 50 units (firearms). The test images were selected on the basis of their ranking in a 600 RBID. The result of the correlation ranking as a function of RBID size is illustrated in Fig. 8. It can be seen that the dependence is close to linear. Our data does not allow us to predict an eventual deviation from this linear behavior for larger databases. The same linear behavior can be seen for other test queries.

In a couple of specimens, the ranking improved for a few incremental steps and then it continued its ranking degradation (see the two circled points in Fig. 8). This possible nonlinear behavior (and in some cases the slight improve-

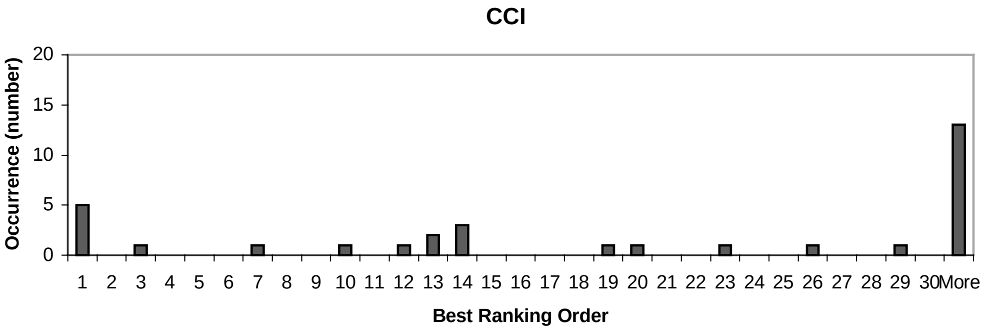

Fig. 7. Histogram representing the best ranking order for either firing pin or breech face correlations, as provided by IBIS™ for a 600-gun RBID. The RBID was queried by cartridge cases made by CCI.

Table 4
Comparison of the performance as a percentage of the specimens found in the top 10 positions

Performance	Same ammunition (%)	Different ammunition (%)
9 mm Para–600 Sig Sauer pistols	72	21
0.40 S & W–792 S & W pistols	62	38

The 9 mm Para RBID used Remington cartridges, while the 0.40 S & W RBID used Federal cartridges.

ment in ranking) during the course of this test cannot be satisfactorily explained.

The data shows that the range of rankings is determined by the size of the database; thus, the range increases with a larger database. This functional dependence on database size is a complex problem. Resolving the problem requires grappling with a number of factors which have not been closely researched at this time.

4.4. Queries to the RBID embedded in a larger database

To make a larger database, we combined the RBID with the actual criminal open case file of caliber 9 mm Para, as well as with the test-fires of investigated pistols. The purpose of this expansion was to verify if our assumption of distinct class characteristics for every firearm applies. The larger database did not include any criminal test-fired cartridge

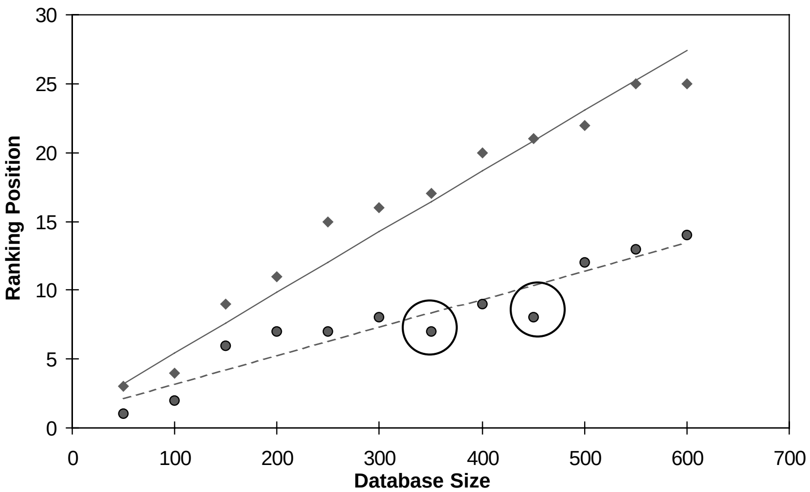

Fig. 8. Figure representing the best ranking order for either firing pin (circles) and breech face (diamonds) correlations, provided by IBIS™ for an RBID of varying size between 50 and 600 firearms. The RBID was queried by cartridge cases manufactured by Remington. The two circles indicate an anomalous behavior of the RBID, providing improvement in ranking for a larger database.

cases from 9 mm model P226 Sig Sauer pistols. The open case file could theoretically include such firearms; however their appearance is very unlikely because of their substantial price and low circulation in Belgium.

This new database contained a total of 1394 fired cartridge case images, a relatively small number for testing our assumption. An increased ranking range was observed in eight of 32 comparisons for either breech face marks or firing pin impressions. This range increase indicates that there is an overlap in class characteristics of the firearms from different manufacturers in contradiction to our assumption. As an example, a correct reference case which ranked in the first breech face position dropped to the second position, replaced instead by a 9 mm FN Browning pistol.

The increased range resulting from an expanded database creates inaccuracies not seen in the smaller databases.

4.5. Correlation time queries to the RBID as a function of size

The correlation time of a single cartridge case to a database varying in size between 25 and 1394 specimens was measured. We obtained the results from an RBID using a Silicon Graphics Origin 200 computer. These results, illustrated in Fig. 9, show that the time required to correlate a specimen behaves as a linear function. Using this data, we are able to extrapolate that it would take 45.9 min to correlate a 10,000-specimen database.

4.6. Results of blind evaluations and selections

For each of the specimens, we asked the IBIS™ operators to evaluate either the top 10 specimens with similar scores or the specimens with a scoring break for subsequent optical comparison microscopy. In an actual database, this microscopic examination would be the subsequent and most time-consuming step. An optical comparison and its ancillary tasks usually takes between 4 to 6 h. The 4–6 h estimate includes transfer of evidence between agencies, chain of custody protocols, and detailed examination of the evidence cartridge case for marks on the firing pin, breech face, ejector, extractor, chamber, and ejector part.

We conducted these blind tests to determine how many specimens listed in the high-confidence ranking (top 10 ranks) were erroneously selected for optical comparison and how many corresponding cartridge cases were erroneously excluded. Of course, the number of erroneous selections for microscopy is highly dependent on the operator's judgment and experience. For this database about 10% of the samples were erroneously excluded and 4% were erroneously included. These exclusion figures are a low estimate, as a result of the poor ranking order for the ammunition from different manufacturers.

5. Discussion and comparison with the AB1717 study

We compared the results in this study to the data reported in the AB1717 study [2] and found strong similarities. That study used 792 0.40 S & W Federal cartridges fired by Smith & Wesson model 4006 pistols as the reference RBID. For both studies, Table 4 contains the percentages in the top 10 ranks for the same and different ammunition brands used as the reference ammunition for setting up the RBID. Fig. 10 depicts similar information for each particular ammunition brand.

If one considers the queries with the same ammunition as the reference ammunition, Table 4 shows that a higher percentage of top 10 ranked cartridge cases was obtained for the 600 RBID than for the 792 RBID of the AB1717. A probable explanation for this increase is the 24% difference in size between both databases. A similar effect can be seen in Fig. 8 for an increasing database size. However, an opposite behavior occurred when different ammunition was used, with a substantially lower percentage of matches (about half of the value) (Table 4). These low results defy the expectation of higher ranking ranges in the smaller database. A possible explanation for these unexpected results rests in the use of a different set of ammunition brands for performing the queries. However, lower ranking percentages were

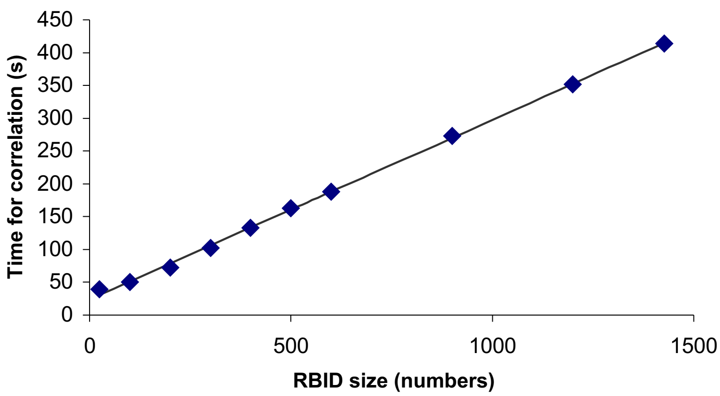

Fig. 9. Time necessary to perform the correlations for an increasing RBID size. The straight line is the linear regression of the data.

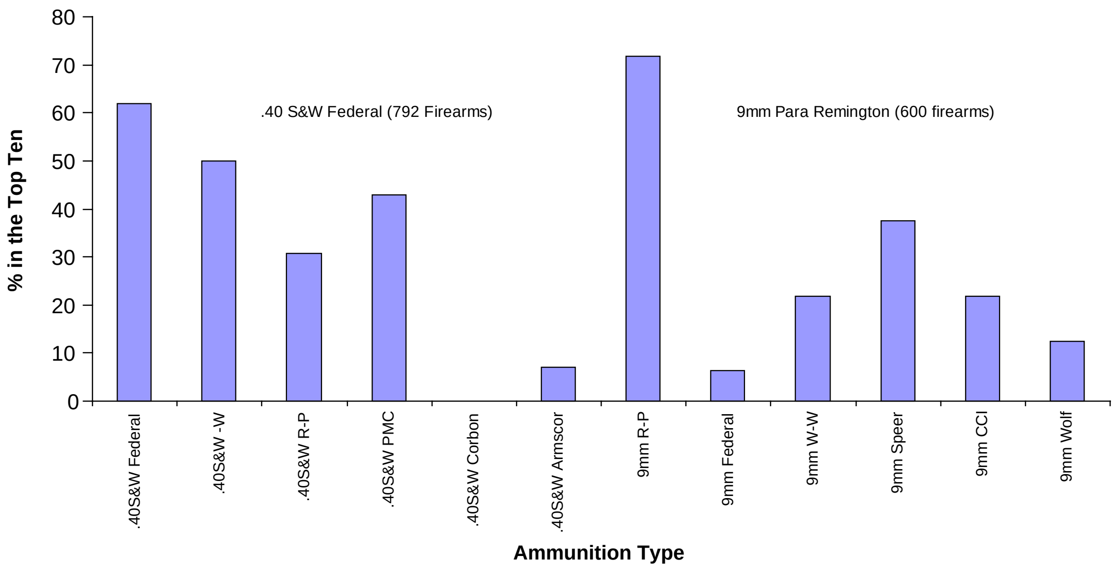

Fig. 10. A comparison of the percentage of fired cartridges in the top 10 ranks (best ranking in breech face or firing pin) in both RBIDs, based on reference ammunition of different caliber and manufacture (W-W stands for Winchester, PMC for Eldorado, and R-P stands for Remington).

obtained even when using the same type of query ammunition (see Fig. 10). Thus, we can conclude that the lower performance in this study is due to the brand of reference ammunition used in the RBID.

From Table 4, we see that the performance of IBIS™ is about 72% for our study and 62% for the 0.40 caliber AB1717 study when we used the same ammunition for the RBID as for the queries. This performance is acceptable. However, the IBIS™ performance is dramatically impaired when different ammunition is used. We may improve this performance by correctly selecting the reference ammunition for RBID after considering several factors, such as the primer seating, chamber pressure, and primer hardness. An extended study needs to be performed that compares the ranking of the marks left on different types of ammunition. Such a study will yield the most suitable reference ammunition for setting an RBID.

If one type of ammunition can cover the whole range of currently available brands, it should be selected to testfire the firearms. If one type of ammunition does not provide sufficiently good correlation results, multiple types of ammunitions may have to be selected. The selection of multiple types allows us to account for a variation in the marks left on different makes of cartridge cases. The disadvantage of using multiple reference cartridges is the increase in input time and database size: selecting two cartridges, one with a hard primer and one with a soft primer, results in an RBID that is twice the size.

Furthermore, using ammunition without a headstamp should be considered if the ejector mark is to become an additional screening criterion. In our study, a substantial (and hence useful) variation in the ejector marks could be observed.

6. Conclusion on the suitability of large databases

Ballistics imaging databases have proved useful to law enforcement for retaining and comparing fired cartridge case evidence from crime scenes and possible crime weapons. For large metropolitan areas, these databases have demonstrated their success with a series of cold (previously unknown) hits, linking shooting scenes and firearms. At first, it seems logical to extend the imaging concept to all available firearms in the hope of achieving similar success.

However, a closer look shows otherwise. Current open case databases are composed of images of numerous cartridge cases fired by firearms of assorted calibers from many different manufacturers, making the database useful to law enforcement in ranking possible matches. It would be extremely unusual to have 600 pistols, comprising one caliber, model, and make, in such a database. In contrast, if one were to set up an RBID for all firearms in circulation, such a possibility would become a reality, with the number of entries likely to surpass the 600 pistols. Typical law enforcement agencies currently have databases numbering in the thousands. An RBID would number in the millions because of the need to retain all images for an extended period. This requirement does not extend to the open case database, which is periodically purged by law enforcement agencies.

The results of our study illustrate that an RBID cannot adequately and efficiently compare specimens, leading us to conclude that such a database is unsuitable for law enforcement work. The current miss rate identified in this study is unacceptable for an RBID. Adding to its inherent failings are significant difficulties in computer capabilities, evidence protocols, and the storage of the test-fired components. Much more effort needs to be devoted to the problems raised in this paper before all firearms in circulation should be entered into a comprehensive RBID.

Other options to the RBID need to be considered. One alternative solution to achieve the same results is to design a firearm that imparts its serial number on the cartridge case by means of a micro-engraved [8] number on the firing pin tip or other suitable area of the pistol. Currently, several law enforcement agencies and private companies are pursuing this idea. Should this approach be successful, it would greatly reduce the need for complex, unsatisfactory, and expensive RBIDs.

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