

Question 1: (Has been broken down into three parts)

Part 1: What studies have been published in the past 5 years RE. FW/TT?

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Cohen, A., et al. (2011). A New Method for Casting Three-Dimensional Shoeprints and Tire Marks with Dental Stone. *Journal of Forensic Sciences*. 56(S1), pp. S210-S213.

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Farrugia, K., et al. (2010). Chemical enhancement of footwear impressions in blood deposited on fabric – Evaluating the use of alginate casting materials followed by chemical enhancement. *Science and Justice*. 50(4), pp. 200-204.

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Hammer, L., et al. (2013). A Study of the Variability in Footwear Impression Comparison Conclusions. *Journal of Forensic Identification*. 63 (2), pp. 205-218.

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Koehler, J. (2011). If the Shoe Fits They Might Acquit: The Value of Forensic Science Testimony. *Journal of Empirical Legal Studies*. 8(S1), pp. 21-28.

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Luostarinen, T. and A. Lehmussola. Measuring the Accuracy of Automatic Shoeprint Recognition Methods. *Journal of Forensic Sciences*. 59(6), pp. 1627-1634.

Patil, P., and J. Kulkarni. (2009). Rotation and intensity invariant shoeprint matching using Gabor transform with application to forensic science. *Pattern Recognition*. 42(7), pp. 1308-1317.

Petraco, N., et al. (2010). Statistical Discrimination of Footwear: A Method for the Comparison of Accidentals on Shoe Outsoles Inspired by Facial Recognition Techniques. *Journal of Forensic Sciences*. 55(1), pp. 34-41.

Rathinavel, S. and Arumugam S. (2011). Full Shoe Print Recognition based on Pass Band DCT and Partial Shoe Print Identification using Overlapped Block Method for Degraded Images. *International Journal of Computer Applications*. 26(8), pp. 16-21.

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Question 1 Cont'd:

Part 2: What studies have been published in the past 5 years that support the foundational aspects of each of the pattern-based forensic science methods, including (but not limited to) FW/TT?

Hancock et. al. (2012) collected 500 footwear impressions from participants at the University of Auckland, New Zealand. Every print was compared to all others in order to determine associations of class characteristics within the dataset, for a total of 124,750 pairwise comparisons. In addition, a subset of impressions was selected to be used as partial prints in order to mimic the types of evidence typically encountered at a crime scene. Of the 500 prints collected, approximately 97% of the outsole patterns were only encountered once in the dataset and the maximum number of repeated patterns was just 3 [1]. For the partial prints, approximately 94% of the dataset was considered unique, with no duplicate manufacturing patterns [1]. The results from this study suggest that an assessment of class characteristics is integral to narrowing down the possible suspect shoes which could have created an impression.

Likewise, Gross et. al. (2013) analyzed a set of 402 impressions, obtained from the casework of the Minnesota Bureau of Criminal Apprehension, for class correspondences. Similar to Hancock et. al. (2012), pairwise comparisons were conducted for a total of 80,601 possible pairs. Comparisons were conducted using the following four-tiered hierarchy of analysis [2]:

1. Examine outsoles for the presence of nine outsole elements.
2. Evaluate pairs for consistency in general outsole design.
3. Assess the correspondence of design element shape, size, number, and position.
4. Compare wear patterns on outsoles.

This methodology was used in a stepwise manner. More specifically, if outsoles exhibited discordancy at any point in this chain, the impressions were distinguished and examination was concluded without any further comparison. Based on the results of this study, 99% of all impressions were distinguishable without considering wear on the outsole; only two impressions required an analysis of erosion in order to be differentiated [2]. The findings from this study are consistent with previous findings that manufacturing characteristics are extremely effective at minimizing the number of possible source shoes.

Though class and subclass characteristics are immensely useful for discriminating purposes, these features cannot be used to reach an identification. Rather, an analysis of randomly acquired characteristics (RACs) is necessary in order to determine whether a given shoe was the source of a crime scene print. In recent years, several studies have examined the discriminating power of RACs and determined that these features are, in fact, random and unique enough to be considered identifying and that this discrimination potential is persistent even with continued wear [4, 5, 6].

Wilson (2012) examined the outsoles of 39 pairs of the same shoe which were worn by the same person over a comparable number of miles. This scenario, in theory, maximizes the potential for random co-

occurrence of features on different outsoles because conditions (type of shoe, wearer, and degree of wear) were kept as constant as possible. Randomly acquired characteristics on each outsole were identified, marked, and counted. After comparison between shoes, even in outsoles that exhibited a comparable *number* of features, the two were easily distinguished based on a visual assessment of the location, size, and shape of RACs present [4]. Therefore, these results indicate that accidental characteristics are random and can provide sufficient discrimination potential to be used for an identification of source.

While Wilson (2012) offers evidence that accidental characteristics are highly discriminating and can be utilized for footwear identification, a major challenge with footwear impression evidence is continued wear after the commission of a crime. Just as RACs are acquired by wear, they can likewise be worn away over time due to continued wear of the outsoles. Therefore, a major factor contributing to the weight of this evidence is the timeline; however, research suggests that even with additional wear an identification of source can still be accurately made. Petraco et. al. (2010) examined footwear impressions using principal component analysis (PCA), a technique commonly utilized for facial recognition. Assuming that variance captures the information of the dataset, PCA can ideally be used to reduce the data by minimizing the number of correlated features while still capturing the variability of the original dataset [7]. Therefore, a dataset is represented as a number of principal components, which comprise the minimum number of features required to retain much of the original information contained in a dataset. For this study, five pairs of the same type of shoe, each worn by the same individual, were examined. More specifically, the RACs present in the ball of the outsole were identified and analyzed based on position, using an Abbott Grid locator. After localization, PCA was completed on the dataset. Similarity between the resulting principal components was computed and the results indicated that the correct identification rate of the five pairs of shoes was approximately 92% [5]. These results indicate that with wear, even when the shoes are worn by the same person and exhibit the same manufacturing characteristics, shoe impressions are still statistically separable and the RACs provide enough information to be used for identification.

Furthermore, Sheets et. al. (2013) utilized PCA to determine the rate at which wear affects the persistence of acquired characteristics. A set of "accidentals", each of relatively the same size and location, was cut into each shoe in a set of eleven pairs. Participants then wore each pair for a period of seven weeks and the outsoles were examined several times throughout the period of wear [6]. By overlaying a square grid onto each outsole, the size of each accidental, based upon percentage of the grid occupied, was recorded; location and shape of features were ignored for these analyses. Throughout the study, intra-shoe variation was much lower than inter-shoe variation; thus, even with additional wear, each shoe better matched itself than any other shoe to which it was compared [6].

Therefore, recent research provides support for the utility and discriminating potential of footwear impression evidence through analysis of both manufacturing and acquired characteristics and provides evidence, both empirical and theoretical, for the identification of source based upon an analysis of randomly acquired characteristics on shoe outsoles [1, 2, 4-6]. Furthermore, some of these studies propose mathematical methods for comparison of RACs [5, 6]. The results from these studies further

support the foundational assertion that features on outsoles can be used to greatly reduce a suspect pool of shoes and even further, that accidental characteristics can be used for identification of footwear.

Works Cited

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Question #1 Cont'd:

Part 3: What studies are needed to demonstrate the reliability and validity of these methods?

Question 2:

Have studies been conducted to establish baseline frequencies of characteristics or features used in these pattern-based matching techniques? If not, how might such studies be conducted? What publicly accessible databases exist that could support such studies? What closed databases exist? Where such databases exist, how are they controlled and curated? If studies have not been conducted, what conclusions can and cannot be stated about the relationship between the crime scene evidence and a known suspect or tool (e.g., firearm)?

Currently, a limited number of databases exist which can be used for classification of footwear outsole patterns. However, no study has been conducted on the frequency of outsole pattern designs or manufacturing characteristics. This is due in large part to the number of factors that must be accounted for in order to complete such a study. For example, shoe manufacturers do not provide details on how many shoes of a specific design are made or where they are sold. In addition, there are a number of counterfeit shoes on the market which copy the outsole design of popular shoes. Furthermore, once shoes are bought, it is unknown how long each person keeps a single pair of shoes, so it is near impossible to estimate how many shoes of a given make/model are in the population at a given time.

Existing Pattern Databases?

- Raven Technology/National Footwear Reference Collection – UK (30,000 patterns)
- Everspry – China (now USA – EVIDENT sells a database with 20,000 patterns)
- SoleMate – SICAR (Foster & Freeman – 33,000+ patterns)

Existing Private Databases?

- **Girod, A., (1996) Computerized classification of the shoeprints of burglar's soles. Forensic Sci. Intl., 82(1)** Forensic Technical Laboratory in Neuchâtel, Switzerland – 1500+ reference files.
- **Belser, Ch., Ineichen, M., Pfefferli, P. (1996) Evaluation of the ISAS system after two years of practical experience in forensic police work Forensic Science International, Volume 82, Issue 1, 53-58** Zurich Cantonal Police - 10,000+ images.
- **Mikkonen, S., Astikainen, T. (1994) Databased classification system for shoe sole patterns: Identification of partial footwear impression found at a scene of crime Journal of Forensic Sciences, Volume: 39 Issue:5, 1227-1236** Finland in-house database.

To date, there have been two major studies which have assessed the baseline frequencies, and potential co-occurrence, of RACs found in footwear impressions [1, 2], in addition to several smaller studies. The first large empirical study was conducted by Cassidy in 1995, and the results provide a baseline numerical estimate for the probability of repeated RACs based on a dataset of boots worn by police recruits. Given that all shoes were worn for the same time span and while traversing the same terrain, conditions favored the chance reproduction of features [1]. Two impressions from each of 97 shoes were recorded and the shoes were broken into two groups A (59 shoes) and B (38 shoes) based on the presence of a heel on the boot. From each impression, three accidentals were selected and compared against all other shoes for duplication in position, ignoring shape and complexity. Results indicated that for minute characteristics,

the greatest potential for random co-occurrence was about 1 in 6. Furthermore, the results for moderately sized characteristics indicate that these features are less likely to be duplicated (probability ranged from 1:20 to 1:38) [1]. The author concluded that quality of features greatly affects the chance of encountering a duplicate accidental. More specifically, features which are small or of poor quality require a larger number of features to reach identification while large and more complex features are more individualizing.

Similarly, in an effort to characterize the chance for random duplication of accidentals, Stone (2006) utilized theoretical probabilities. More specifically, the hypothetical probability of encountering two RACs on different shoes with the same position, shape, and orientation was computed. To arrive at the computed probabilities, a hypothetical 16,000 square millimeter grid was superimposed on a theoretical shoeprint. For a point characteristic, the probability of random co-occurrence was modeled as 1 in 16,000. For a line, the length, orientation, and position were combined to obtain a potential for duplication of 1 in 384,000. Furthermore, when considering the position, length, orientation, direction of curvature, degree of curvature, and apex location, curves were computed to possess a 1 in 19,200,000 probability of finding a given curve characteristic on another shoe. Therefore, as characteristics become larger and more complex, the chance for random duplication greatly decreases [2].

Existing RAC Databases?

- Israeli Police Suspect Database – 400+ shoes with 13,000+ RACs
(http://www.samsi.info/sites/default/files/Yekutieli_august2015.pdf)
- WVU HQ Database – 1,000 shoes, 57,000+ RACs

Currently, there are two major conclusions scales that are used for footwear comparison results. In the United States, the SWGTREAD conclusion scale is utilized by many forensic laboratories [3]:

1. Lacks sufficient detail
2. Exclusion
3. Limited associated of class characteristics
4. Association of class characteristics
5. High degree of association
6. Identification

Conversely, in Europe, the conclusion scale developed by the ENSFI Marks subcommittee is a common standard for footwear comparisons [3]:

1. Elimination
2. Likely not the source of the impression
3. Inconclusive
4. Probably the source of the impression
5. Very probably the source of the impression
6. Identification

Works Cited

- [1] M. J. Cassidy, *Footwear Identification*, Lightning Powder Company, Inc., 1995.
- [2] R. S. Stone, "Footwear examinations: Mathematical probabilities of theoretical individual characteristics," *Journal of Forensic Identification*, vol. 56, pp. 577-599, 2006.
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Question 3:

How is performance testing (testing designed to determine the frequency with which individual examiners obtain correct answers) currently used in forensic laboratories? Are performance tests conducted in a blind manner? How could well-designed performance testing be used more systematically for the above pattern-based techniques to establish baseline error rates for individual examiners? What are the opportunities and challenges for developing and employing blind performance testing? What studies have been published in this area?

Response:

How is performance testing (testing designed to determine the frequency with which individual examiners obtain correct answers) currently used in forensic laboratories?

There are several Proficiency Test providers who are approved by the American Society of Crime Laboratory Directors/Laboratory Accreditation Board such as Collaborative Testing Services, Inc., Forensic Assurance, Forensic Testing Services and Ron Smith and Associates who provide proficiency testing in Footwear and/or Tire Tread analysis. Additionally, Forensic ITC Services, although not listed with ASCLD/LAB is also a proficiency test provider. These tests are prepared to simulate case work that laboratories and examiners would receive. Proficiency tests are designed to assess the performance of the footwear and tire tread examiners. They can be used as a training tool, to demonstrate competency of a newly trained examiner and to demonstrate the ongoing proficiency of the experienced examiner. If the test is used as performance testing the individual examiner results are reported to the test provider who compiles the results and issues a report to the participants. The report includes the frequency of the conclusions for each of the questioned impressions as reported by the participants.

Are performance tests conducted in a blind manner?

There are no requirements through the test provider or through ASCLD/LAB to conduct the examination or verification in a blind manner. The original examiner does not know the results or ground truth of the comparisons. A verifier may know the conclusions of the original examiner; but neither is aware of the conclusions specified by the provider.

How could well-designed performance testing be used more systematically for the above pattern-based techniques to establish baseline error rates for individual examiners?

Forensic Assurance states that “the proficiency test answer sheet, when combined with participant information, can be used to calculate statistics relevant to the forensic science and legal communities. Forensic Assurance collaborated with statisticians from the University of Michigan to develop statistical models to calculate false positive and false negative error rates, as well as sensitivity and specificity. This statistical information will be available for practitioners to use in admissibility hearings”. Some test providers, such as Collaborative Testing Services, Inc. had not intended for the test results to be used to estimate baseline error rates of footwear examiners. Collaborative Testing Services, Inc. places the following statement on their website to address using information compiled from the

completed proficiency tests: “all information presented in this site is intended for the non-commercial use of CTS’ Interlaboratory Program participants. The use of information obtained through this site to establish independent data files or compendiums of statistical information is prohibited.” The proficiency tests can be purchased by any lab and does not require that the examiner have specified training to take the test. Collaborative Testing Services, Inc. does not collect information regarding the individual examiners who complete the test nor consider why the tests are being purchased. “Using CTS proficiency test results to determine an error rate would therefore not necessarily reflect the standards of examinations used in casework since the results do not consider the participant-directed employment of the testing and examiner demographics.” Considering this, proficiency test should not be used to establish baseline error rates for examiners as a whole.

In order to incorporate the results of proficiency testing to establish baseline error rates for individual examiners more information would need to be provided regarding the use of the test, the level of training and experience of the examiner completing the test and the test would need to be reviewed by trained examiners to compensate for the variability in stating results. Impression evidence results are not always clear cut in actual casework but must be supported through documentation.

What are the opportunities and challenges for developing and employing blind performance testing?

Challenges of incorporating blind verification would be the impact of casework and the limited number of examiners per agency who are trained in footwear and tire track examinations. The examiner conducting a blind verification would essentially “rework” the case of the initial examiner. This work is time consuming and an agency would need to be properly staffed to complete blind-verifications.

What studies have been published in this area?

Some studies have been done to assess between-examiner variability in footwear examinations (Majamaa & Ytti, 1996, Hammer et al., 2012, Kerstholt et al., 2006); even in these studies, the examiners were aware that their performance was being observed. As such, neither the results from the proficiency tests nor the research studies should be taken as representatives of actual error rates of examiners.

Since there is no ground truth in actual casework, it would not be feasible to correlate or make inferences regarding the significance of the proficiency testing data and apply it to real-world cases. In this regard, it may be useful to adopt data mining techniques for characterizing and analyzing the decision making process and outcomes, which are already in use in other fields such as airline customer relationship management (Liou, 2008), fault diagnosis in engineering (Yam et al., 2001), bankruptcy risk assessment, etc. (Greco et al., 2002; McKee and Lensberg, 2002).

NEW TECHNOLOGY Question 4:

What are the most promising new scientific techniques that are currently under development or could be developed in the next decade that would be most useful for forensic applications? Examples could include hair analysis by mass spectrometry, advances in digital forensics, and phenotypic DNA profiling.

Imaging:

1. Hyperspectral imaging (HSI) is a technique that combines spectral and spatial information regarding an item of interest (Edelman et al. 2012). It is a non-destructive method that has extraordinary potential for the detection and recognition of footwear impressions deposited on a variety of substrates (Miskelly & Wagner 2005).
2. High dynamic range (HDR) photography is a method that can maximize shadows, mid-tones, and highlights to produce a single image with a demonstrably wider tonal range. Not exactly “new” or novel anymore though.
3. For shoeprint impressions with well-observed depth, three-dimensional scanning techniques are likely to become more commonplace. If validated, reasonably priced, and of sufficient resolution, 3D scanning could even replace or compliment traditional casting or lifting techniques (Gamage et al. 2013).

Works Cited:

Edelman, G. J., Gaston, E., Van Leeuwen, T. G., Cullen, P. J., & Aalders, M. C. G. (2012). Hyperspectral imaging for non-contact analysis of forensic traces. *Forensic Science International*, 223(1), pp. 28-39.

Gamage, R. E., Joshi, A., Zheng, J. Y., & Tuceryan, M. (2013, January). A high resolution 3D tire and footprint impression acquisition for forensics applications. In *Applications of Computer Vision (WACV), 2013 IEEE Workshop on*, pp. 317-322.

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Question 5:

What standards of validity and reliability should new forensic methods be required to meet before they are introduced in court?

Generally validity is synonymous with accuracy and reliability is akin to precision. As such, accuracy refers to the closeness of a measured value to a standard or known value. Conversely, precision is a description of the consistency of the measured values.

Standards of validity (accuracy):

- Suitability – the method should test what it is expected to test; in other words, it should fit the purpose for which it was intended.
 - In examination, this would probably mean that the expert should not base their interpretation process on improper data. Relates to training, testing, proficiency, etc.
 - If a numerical method, it must be fully vetted. For example, if a circle has more degrees of freedom than a line (e.g., you can rotate a circle and it still looks like the same circle, but if you rotate a line, it has a different orientation) does your numerical metric capture this? Do you want your numerical metric to capture this?
 - If using pixel-based RAC images, is your numerical metric sensitive to pixel differences? Is this acceptable? Should you treat your RACs as vectors instead of pixels? How does this impact the results?
- Availability of independent verification – there is independent evidence to show that the method works or is reporting as close to the true value as possible.
 - This may take into account the variability among different examiners.
- Justifiable variability – the range in variation/difference should be substantiated/expected and demonstrated. When variation falls within the expected or accepted range, it is considered reasonable. Variation outside of this range must be approached with caution since it falls outside the common confidence interval.
 - What range in loss RAC can be expected based on transfer mechanisms?
 - What range in loss of RAC complexity and quality can be expected based on transfer mechanisms?
 - How does size impact RAC loss in transfer mechanism?
 - How does RAC shape impact RAC loss in transfer mechanism?
 - How does substrate impact RAC loss?
 - How does media impact RAC loss?

Standards of reliability (precision):

- Identified sources of error – in addition to establishing error rates, what are the sources of error? Factors contributing to differences in reported values should be identified, and if possible, quantified in order to provide a frame of reference when assessing the reliability of the method.
- Measures to mitigate sources of error – after identification, there should be steps to increase consistency in measurement. These steps should be effective in ensuring the precision of the reported values.
- Recognition of constraints – the limitations and range of a particular method should be determined. This can be obtained through control tests or via extraction from routine applications.

References

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Ermer, J., & Ploss, H. J. (2005). Validation in pharmaceutical analysis: Part II: central importance of precision to establish acceptance criteria and for verifying and improving the quality of analytical data. *Journal of pharmaceutical and biomedical analysis*, 37(5), 859-870.

Morrison, G. S. (2011). Measuring the validity and reliability of forensic likelihood-ratio systems. *Science & Justice*, 51(3), 91-98.

Question 6:

Are there scientific and technology disciplines other than the traditional forensic science disciplines that could usefully contribute to and/or enhance the scientific, technical and/or societal aspects of forensic science? What mechanisms could be employed to encourage further collaboration between these disciplines and the forensic science community?

Technology

Footwear examination relies heavily on traditional side-by-side comparison methods. One scientific technology that can be efficiently used to enhance footwear comparisons is the use of an eye-tracker. For example, an eye tracker would allow the examiner to track his or her gaze behavior while evaluating footwear evidence and looking for similarities in known and questioned impressions. To illustrate, fixations on both known and questioned impression can be recorded separately, and then later merged and analyzed to construct a heat map that allows the examiner to see areas of emphasis (Busey et al., 2011).

T. Busey, C. Yu, D. Wyatte, J.R. Vanderkolk, F.J. Parada, R. Akavipat. Consistency and variability among latent print examiners as revealed by eye tracking methodologies *Journal of Forensic Ident.*, 61 (1) (2011), pp. 60–91.

Collaboration

Universities?

Conferences?