November 16, 2011
SWGTREAD response to questions submitted from the NSTC Subcommittee on Forensic Science Research Testing Development and Evaluation Interagency Working Group.

QUESTION 1
What literature exist that addresses the number of characteristics/identifying marks required to render a conclusion?

No literature/studies could be found which specifically addresses the number of characteristics and/or identifying marks necessary to render a conclusion relating to footwear and/or tire track evidence.

Impressions evidence practitioners agree that rendering opinions relative to footwear and/or tire track examinations must be based upon a combination of both class and individual characteristics.

"Class characteristics of footwear and tires result from repetitive, controlled processes that are typically mechanical, such as those used to manufacture items in quantity".[1] Although defined similarly by various authors, Bodziak describes footwear class characteristics as "an intentional or unavoidable characteristic that repeats during the manufacturing process and is shared by one or more other shoes."[2]

Individual characteristics are defined by Bodziak as "individual identifying characteristics that result when something is randomly added to or taken away from a shoe outsole that either causes or contributes to making that shoe outsole unique."[3] Often referred to as accidental characteristics, they can include cuts, scratches, gouges, holes, cracks, tears caused by extreme wear, or random inclusions that may result from manufacturing, such as bubbles, and other items or substances subsequently introduced to the outsole or tread, such as rocks, chewing gum, nails, tacks or small twigs.

Footwear and tire tread examination practitioners agree that a specific number of individual or random characteristics are not necessarily needed to render an opinion.

It is generally accepted that the specific number of characteristics needed to assign a definite positive identification depends on the quality and quantity of these accidental

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[1] Committee on Identifying the Needs of the Forensic Sciences Community, 2009, *"Strengthening Forensic Science in the United States – A Path Forward"*, National Research Council, p. 146,

[2] W.J. Bodziak. 1999. *Footwear Impression Evidence–Detection, Recovery, and Examination,*. Boca Raton, FL: CRC Press, 2nd ed., p. 329.

[3] Ibid, pg 335,

characteristics and the criteria established by individual laboratories.[4] According to Cassidy, many factors and accidental characteristics are required before a positive

identification can be established; however, the most important are the examiner's experience, the clarity of the impression, and the uniqueness of the characteristic.[5]

Identifications are largely subjective and are based on the examiner's experience and on the number of individual, identifying characteristics in common with a known standard.[6]

Nause best answers the question "How many accidental characteristics are required?" by saying "No particular set number of accidental characteristics are required to make a positive identification"[7] He describes several factors which must be considered before an opinion is reached and further states "Each case must be judged on its own merits"[8]

[4]K. Inman and N. Rudin. 2001. *Principles and Practice of Criminalistics*. Boca Raton, FL: CRC Press, p. 129.

[5] M.J. Cassidy, 1980, *"Footwear Identification",* Ottawa, Ontario, Canada, Lightning Powder, Co.. Inc (reprint).

[6] Committee on Identifying the Needs of the Forensic Sciences Community, 2009, *"Strengthening Forensic Science in the United States – A Path Forward"*, National Research Council, p. 146,

[7] L.S. Nause, Forensic Tire Impression Identification, 2001, Canadian Police Research Centre, pg. 223

[8] Ibid., pg 223

QUESTION 2
What is the literature that discusses the use of statistics to support an examiner's conclusion?

The majority of published material that discusses the use of statistics to support footwear examiner's conclusions relates to the application of "Bayes" factor in European countries. The Bayesian approach is not practiced in the United States.

The following paper presents a theoretical model to give probability estimates for the occurrence of individual characteristics on a shoe outsole/ shoe print. The model is not intended for application to casework, but it demonstrates in theory how unlikely it would be to duplicate the occurrence of a pattern of individual characteristics.

Stone, R.S., Footwear Examinations: Mathematical Probabilities of Theoretical Individual Characteristics, *Journal of Forensic Identification*, 2006, 56 (4), 577-599
Abstract: The trend in the forensic sciences favors objectivity over subjectivity. Courts in the United States are becoming increasingly hesitant to accept the opinion of an examiner who states, "It's a 'match' because I *say* it's a 'match'". Objectivity, in most cases, is reinforced by quantification. The individual characteristics that appear on a shoe print or shoe impression can be quantified using two primary variables. Their location on the print and their configuration and orientation yield measurable, discriminating data values. Theoretical types of individual characteristics that are found on shoe prints are described and discussed, and a hypothetical model is presented with probability estimates applied to quantify the likelihood of occurrence of the characteristics. With marks or combinations of marks of reasonable complexity, the magnitudes of the resultant numbers, though entirely abstract and based upon conservative assumptions, are remarkable.

This paper provides actual casework examples of the application of the likelihood ratio in New Zealand and the United Kingdom.
Evett, IW, Lambert, JA, Buckleton, JS, A Bayesian approach to interpreting footwear marks in forensic casework, *Science & Justice* , 1998, 38, 241-247
Abstract: This paper describes an attempt to formalize the interpretation of footwear marks. First, the definitions of *identification* and *individualization* which were given by Kirk are discussed and formalized, then a Bayesian analysis is presented in which the assumptions made are clarified. The analysis is broken down into components which reflect different interpretative issues. Application of a formal expression for the likelihood ratio is then illustrated by means of examples from casework in New Zealand and the United Kingdom.

This paper expands on the paper mentioned directly above and outlines a more detailed Bayesian approach that has the intent of making a more structured and transparent evaluation of footwear impression evidence.

J. Skerrett, et al., A Bayesian approach for interpreting shoemark evidence in forensic casework: Accounting for wear features, *Forensic Sci. Int.* (2011), doi:10.1016/j.forsciint.2011.01.030

Abstract: Shoemark evidence remains a cornerstone of forensic crime investigation. Shoemarks can be used at a crime scene to reconstruct the course of events; they can be used as forensic intelligence tool to establish links between crime scenes; and when control material is available, used to help infer the participation of given individuals to the commission of a crime. Nevertheless, as for most other impression evidence, the current process used to evaluate and report the weight of shoemark evidence is under extreme scrutiny. Building on previous research, this paper proposes a model to evaluate shoemark evidence in a more transparent manner. The model is currently limited to sole pattern and wear characteristics. It does not account formally for cuts and other accidental damages. Furthermore, it requires the acquisition of relevant shoemark datasets and the development of automated comparison algorithms to deploy its full benefits. These are not currently available. Instead, we demonstrate, using casework examples, that a pragmatic consideration of the various variables of the model allows us to already evaluate shoemark evidence in a more transparent way and therefore begin to address the current scientific and legal concerns.

This paper is not specific to footwear comparisons, but it presents currently used applications of Baye's theorem and proposes a new approach based on an extended likelihood ratio.

Buckleton J.S., Triggs, C.M., Champod, C., An extended likelihood ratio framework for interpreting evidence, *Science & Justice* 2006 46 69-78

Abstract: This paper reviews some current methods, the likelihood ratio based approach and the full Bayesian approach for the interpretation of evidence and discusses previously identified shortcomings in them. It suggests an approach based on a compromise-based on an extended likelihood ratio - that may combine the merits of logic without overstepping acceptable bounds for the forensic scientist in the presentation of evidence. The approach is exposed formally and takes advantage of inferential networks called Bayesian networks.

While not specifically addressing the use of statistics to support an examiner's conclusion, this article describes an initial study to build statistical models to evaluate the uniqueness and evolution of the pattern of accidental features occurring on shoe outsoles.

Petraco, N. D. K., et. al., Statistical Discrimination of Footwear: A Method for the Comparison of Accidentals on Shoe Outsoles Inspired by Facial Recognition Techniques, J. Forensic Sci. 2010; 55(1), 34-41

Abstract: In the field of forensic footwear examination, it is a widely held belief that patterns of accidental marks found on footwear and footwear impressions possess a high degree of ‘‘uniqueness.’’ This belief, however, has not been thoroughly studied in a numerical way using controlled experiments. As a result, this form of valuable physical evidence has been the subject of admissibility challenges. In this study, we apply statistical techniques used in facial pattern recognition, to a minimal set of information gleaned from accidental patterns. That is, in order to maximize the amount of potential similarity between patterns, we only use the coordinate locations of accidental marks (on the top portion of a footwear impression) to characterize the entire pattern. This allows us to numerically gauge how similar two patterns are to one another in a worst-case scenario, i.e., in the absence of a tremendous amount of information normally available to the footwear examiner such as accidental mark size and shape. The patterns were recorded from the top portion of the shoe soles (i.e., not the heel) of five shoe pairs. All shoes were the same make and model and all were worn by the same person for a period of 30 days. We found that in 20–30 dimensional principal component (PC) space (99.5% variance retained), patterns from the same shoe, even at different points in time, tended to cluster closer to each other than patterns from different shoes. Correct shoe identification rates using maximum likelihood linear classification analysis and the hold-one-out procedure ranged from 81% to 100%. Although low in variance, three dimensional PC plots were made and generally corroborated the findings in the much higher dimensional PC-space. This study is intended to be a starting point for future research to build statistical models on the formation and evolution of accidental patterns.

The following two papers are related to barefoot impressions. However, the statistical methods used to estimate chance match probabilities can potentially be adapted to footwear impression problems.

Kennedy, R. B., Pressmann I. S., Chen S., Petersen P.H., Pressman A.E., Statistical analysis of barefoot impressions, *J Forensic Sci.* 2003;48(1):55–63.

Abstract: Comparison of the shapes of barefoot impressions from an individual with footprints or shoes linked to a crime may be useful as a means of including or excluding that individual as possibly being at the scene of a crime. The question of the distinguishability of a person’s bare footprint arises frequently. This study indicates that measurements taken from the outlines of inked footprint impressions show a great degree of variability between donors and a great degree of similarity for multiple impressions taken from the same donor. The normality of the set of measurements on footprint outlines that we have selected for this study is confirmed. A statistical justification for the use of the product rule on individual statistical precisions is developed.

Kennedy, R.B., Chen, S., Pressmann, I.S., Yamashita, A.B., Pressman, A.E., A large-scale statistical analysis of barefoot impressions, *J Forensic Sci.* 2005;50(5):1071–9.

Abstract: In an earlier paper, outlines of footprints of persons walking normally were studied to determine whether different people make verifiably distinct footprints. Our

basic null hypothesis is: given a footprint outline trace made by Subject A (Alice), then Subject B (Bob), a distinct person, cannot produce a footprint outline trace indistinguishable from that of Alice. We showed in the previous work that the probability of a chance match is less than 10−8. In this paper we report two new advances in our research. First, we establish a rigorous mathematical framework for calculating worst case and average chance-match probabilities. Second, we repeat the previous experiment to substantiate the earlier results, but with an expanded population sample size and a more representative and significantly bigger repeated sample. These improvements and a new automated tracing procedure for extracting all numerical measures lead to a sharpened accuracy with average chance match probabilities of 7.88×10−10 for a general population. In other words, the odds of a chance match are one in 1.27 billion.

QUESTION 3

What literature exists that measures the consistency of examiner conclusions, incorporating multiple examiners, with various training and experience, given the same sample set of known "matches" and known "non-matches" of varying quality?

Shor, Y. & Weisner, S. (1999). A survey on the conclusions drawn on the same footwear marks obtained in actual cases by several experts throughout the world. Journal of Forensic Sciences, 44 (2), 380-384.

A survey was conducted with two sets of shoeprints from actual crime scenes and the corresponding suspect's shoes. Experts from seven countries were asked to give their opinion on the probability that the suspect's shoe made the shoeprint impression at the crime scene. Each expert gave his/her opinion based on the scale used in his/her country. The distribution of the answers is discussed in this paper.

Majamaa, H. & Ytti, A. (1996). Survey of conclusions drawn of similar footwear cases in various crime laboratories. Forensic Science International, 82 (1), 109-120.

This study focuses on the reporting of shoeprint cases concerning the possibility of various laboratories drawing different conclusions from similar cases. For this purpose, six sets of photographs — six fictitious crime cases — were prepared. The six cases were distributed to the 34 crime laboratories having registered for the European Meeting for Shoeprint and Toolmark Examiners. The examiners in different laboratories were asked to examine the cases and to draw their conclusions from each of them based on pattern, shape, size and the accidental characteristics marked on the photos. The expressions for the conclusions were selected as degrees of probability. The examiners were asked to follow the expressions given, even if they were not using the same wording in their own reports. Based on the survey, there seem to be remarkable variations in the conclusions of shoeprint reports drawn from identical cases in different crime laboratories.

Note: this study is presently unpublished, has been presented as a poster at the International Identification Association Educational Conference 2010 and **a**t the National Institute of Justice Impression and Pattern Evidence Symposium 2010.

A study of the variability in footwear impression comparison conclusions

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2Hammer Forensics, Anchorage, Alaska.

Six footwear case examples were prepared and footwear examiners were asked to assess each comparison based solely on the observations that were clearly identified for each impression. By requesting that the examiners base their conclusions on the Scientific Working Group on Shoe Print and Tire Track Evidence (SWGTREAD) guidelines it was discovered that the use of standardized terminology significantly decreased the variations seen within thoe results reported by certified examiners. Furthermore, it was determined that experienced examiners are able to interpret the findings of footwear comparisons more accurately than individuals with an education in forensic science, but limited knowledge, training or experience in this particular field. Conclusions were; it is advantageous for footwear examiners to interpret their findings by using a standardized conclusions scale, as by doing so, the variation between the conclusions drawn for identical cases fell within a justifiable range. The variations in the conclusions of trained, certified footwear examiners were smaller than those of individuals with less training than certified footwear examiners. This finding confirms that examiners performing impression evidence comparisons must be knowledgeable and adequately educated in this field to accurately interpret footwear impression evidence. Even when a standardized scale of conclusions is used when interpreting the findings of a footwear impression comparison, some variability in the reported conclusions still exist. Reasons for this inconsistency may include the experience of the examiner with this type of comparison or the fact that the amount of corresponding individualizing characteristics that constitutes a positive identification is unknown.

QUESTION 4

What is the literature that addresses the effects of examiner experience/training/caseload in shoeprint/tire tread examinations?

Little research exists in this area, the study below addresses the question of training and experience, but none were found related to caseload.

Note: this study is presently unpublished, has been presented as a poster at the International Identification Association Educational Conference 2010 and **a**t the National Institute of Justice Impression and Pattern Evidence Symposium 2010.

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QUESTION 5

What is the literature on the potential and actual cognitive bias in shoeprint and tire tread examinations?

The following literature is a partial list of articles and research on the relationship of cognitive bias and forensic science. The question specifically calls out shoeprint and tire tread examinations; however, it is our contention that the relative research pertaining to all physical match comparisons in forensic science is applicable and relative. Many of the papers focus their attention on fingerprint comparisons; this is primarily due to the dynamics of the volume of forensic comparisons conducted and the large numbers of test subjects available to researchers.

On the subject of cognitive bias as it relates to footwear and tire tread examinations, we recognize that it exists as an avoidable and controllable facet of comparison work. There are two primary ways of dealing with cognitive bias as a forensic community; first is the robust development of standards within the community that are well supported with scientific research, and second is training of examiners with emphasis focused on

defining and understanding cognitive bias and the implementation of methods and procedures to make forensic examinations as objective as possible.

Budowle, B. et al., A Perspective on Errors, Bias, and Interpretation in the Forensic Sciences and Direction for Continuing Advancement. *J Forensic Sci*, 54(4), 2009.
Abstract: The forensic sciences are under review more so than ever before. Such review is necessary and healthy and should be a continuous process. It identifies areas for improvement in quality practices and services. The issues surrounding error, i.e., measurement error, human error, contextual bias, and confirmatory bias, and interpretation are discussed. Infrastructure is already in place to support reliability. However, more definition and clarity of terms and interpretation would facilitate communication and understanding. Material improvement across the disciplines should be sought through national programs in education and training, focused on science, the scientific method, statistics, and ethics. To provide direction for advancing the forensic sciences a list of recommendations ranging from further documentation to new research and validation to education and to accreditation is provided for consideration. The list is a starting point for discussion that could foster further thought and input in developing an overarching strategic plan for enhancing the forensic sciences.

Busey, T. & Dror, I.E. Special abilities and vulnerabilities in forensic expertise. In A. McRoberts (Ed.) *Friction Ridge Sourcebook*. Washington DC, USA: NIJ Press. March, 2011
Abstract: Latent print examinations are complex perceptual and cognitive tasks. Examiners rely on their visual systems to find similarities in pairs of prints. They then must compare the degree of perceived similarity against others found in previous examinations, and ultimately must decide whether the commonalities found between the prints (as well as regions of unexplainable disagreement) merit the conclusion that the prints either did or did not come from the same source. This process involves perception, similarity judgments, memory and decision making. These abilities vary among people, and can be improved with training and experience. They are also subject to potential biases and external influences. In this chapter, we draw from our expertise in the visual and cognitive sciences to illustrate how an understanding of the human mind is relevant and critical to the fingerprint domain. Such an understanding clearly shows the unique cognitive processes and special abilities of experts, and that these also entail vulnerabilities. We begin with a quick overview of what we consider to be foundational findings in cognitive science, and then discuss how these research areas have been extended to latent print examiners, both in our labs and in others.

Byrd, J.S., Confirmation bias, ethics, and mistakes in forensics. J Forensic Identification, 2006, 56, 511–525

Charlton, D., Fraser-Mackenzie, P., & Dror, I. E., Emotional experiences and motivating factors associated with fingerprint analysis. *J Forensic Sci*, 55 (3) March, 2010. In this study, we investigated the emotional and motivational factors involved in fingerprint

analysis in day-to-day routine case work and in significant and harrowing criminal investigations. Thematic analysis was performed on interviews with 13 experienced fingerprint examiners from a variety of law enforcement agencies. The data revealed factors relating to job satisfaction and the use of skill. Individual satisfaction related to catching criminals was observed; this was most notable in solving high profile, serious, or long-running cases. There were positive emotional effects associated with matching fingerprints and apparent fear of making errors. Finally, we found evidence for a need of cognitive closure in fingerprint examiner decision-making.

Cooley, C.M., Psychological influences and the state employed forensic examiner: How to elicit evidence concerning observer effect errors through cross-examination and discovery. *Illinois Association of Criminal Defense Lawyers Newsletter Summer*, 2003.
http://www.law-forensic.com/iacdl_newsletter_summer_2003.htm

Dror, I. E. Perceptual, Cognitive, and Psychological Elements Involved in Expert Identification, *Friction Ridge Sourcebook*, SWGFAST, NIJ, In Press.
http://www.ojp.usdoj.gov/nij/pubs-sum/225320.htm

Dror, I.E. et al., Decision making under time pressure: An independent test of sequential sampling models. *Memory & Cognition 1999, 27 (4), 713-725*
Abstract: Choice probability and choice response time data from a risk-taking decision-making task were compared with predictions made by a sequential sampling model. The behavioral data, consistent with the model, showed that participants were less likely to take an action as risk levels increased, and that time pressure did not have a uniform effect on choice probability. Under time pressure, participants were more conservative at the lower risk levels but were more prone to take risks at the higher levels of risk. This crossover interaction reflected a reduction of the threshold within a single decision strategy rather than a switching of decision strategies. Response time data, as predicted by the model, showed that participants took more time to make decisions at the moderate risk levels and that time pressure reduced response time across all risk levels, but particularly at the those risk levels that took longer time with no pressure. Finally, response time data were used to rule out the hypothesis that time pressure effects could be explained by a fast-guess strategy.

Dror, I.E. et al. Contextual information renders experts vulnerable to making erroneous identifications. *Forensic Science International* 156 (2006) 74–78
Abstract: We investigated whether experts can objectively focus on feature information in fingerprints without being misled by extraneous information, such as context. We took fingerprints that have previously been examined and assessed by latent print experts to make positive identification of suspects. Then we presented these same fingerprints again, to the same experts, but gave a context that suggested that they were a no-match, and hence the suspects could not be identified. Within this new context, most of the fingerprint experts made different judgments, thus contradicting their own previous identification decisions. Cognitive aspects involved in biometric identification can explain why experts are vulnerable to make erroneous identifications.

Dror, I. E. & Mnookin, J. The use of technology in human expert domains: Challenges and risks arising from the use of automated fingerprint identification systems in forensics. *Law, Probability and Risk*. (in press).

Dror, I.E. et al., Cognitive issues in fingerprint analysis: Inter- and intra-expert consistency and the effect of a 'target' comparison, Forensic Sci. Int. (2010), doi:10.1016/j.forsciint.2010.10.013

Abstract: Deciding whether two fingerprint marks originate from the same source requires examination and comparison of their features. Many cognitive factors play a major role in such information processing. In this paper we examined the consistency (both between-and within-experts) in the analysis of latent marks, and whether the presence of a 'target' comparison print affects this analysis. Our findings showed that the context of a comparison print affected analysis of the latent mark, possibly influencing allocation of attention, visual search, and threshold for determining a 'signal'. We also found that even without the context of the comparison print there was still a lack of consistency in analyzing latent marks. Not only was this reflected by inconsistency between different experts, but the same experts at different times were inconsistent with their own analysis. However, the characterization of these inconsistencies depends on the standard and definition of what constitutes inconsistent. Furthermore, these effects were not uniform; the lack of consistency varied across fingerprints and experts. We propose solutions to mediate variability in the analysis of friction ridge skin.

Dror, I.E. and Fraser-Mackenzie, P.A.F., Cognitive Biases in Human Perception, Judgment, and Decision Making: Bridging Theory and the Real World *in Criminal Investigative Failures*, Ed. Rossmo, K., Taylor & Francis, 2008.

Dror, I.E. How can Francis Bacon help forensic science? The four idols of human biases. *Jurimetrics: The Journal of Law, Science, and Technology* (in press).

Abstract: In this paper, I try to find ways to improve forensic science by identifying potential vulnerabilities. To this end, I use Francis Bacon's doctrine of idols, which distinguishes between different types of human biases that may prevent scientific and objective inquiry. Bacon's doctrine contains four sources for such biases: *idola tribus* (idols of the tribe), *idola specus* (idols of the den or cave), *idola fori* (idols of the market), and *idola theatri* (idols of the theatre). While his 400-year-old doctrine does not, of course, perfectly match up with our current world view, it still provides a productive framework for examining and cataloguing some of the potential weaknesses and limitations in our current approach to forensic science.

Dror, I.E. Paradoxical functional degradation in human expertise. In N. Kapur, Pascual-Leone, & V. S. Ramachandran (Eds.) *The Paradoxical Brain*. Cambridge, UK: Cambridge University Press. (in press).

Dror, I.E., and Cole, S.A., The vision in 'blind' Justice: Expert perception, judgment and visual cognition in forensic pattern recognition, *Psychonomic Bulletin & Review*, in press.

Abstract: Many forensic disciplines require experts to judge whether two complex patterns are sufficiently similar to conclude that both originate from the same source. Studies in this area have revealed that there are a number of factors that affect perception and judgment and that decisions are subjective and susceptible to

extraneous influences (such as emotional context, expectation, and motivation). Some studies have shown that the same expert examiner, examining the same prints but within different contexts, may reach different and contradictory decisions. However, such effects are not always present; some examiners seem more susceptible to such influences than do others—especially when the pattern matching is "hard to call" and when the forensic experts are not aware that they are being observed in an experimental study. Studying forensic examiners can contribute to our understanding of expertise and decision making, as well as have implications for forensic science and other areas of expertise.

Dror, I.E., Charlton, D., Peron, A., Contextual information renders experts vulnerable to making erroneous identification, *Forensic Science International*, 156, 2006.

Dror, I.E., Charlton, D., Why experts make errors. Journal of Forensic identification 56(4), 2006.

Abstract: Expert latent fingerprint examiners were presented with fingerprints taken from real criminal cases. Half of the prints had been previously judged as individualizations and the other half as exclusions. We re-presented the same prints to the same experts who had judged them previously, but provided biasing contextual information in both the individualizations and exclusions. A control set of individualizations and exclusions was also re-presented as part of the study. The control set had no biasing contextual information associated with it. Each expert examined a total of eight past decisions. Two-thirds of the experts made inconsistent decisions. The findings are discussed in terms of psychological and cognitive vulnerabilities.

Dror, I.E., Peron, A.E., Hind, S-L., Charlton, D., When emotions get the better of us: The effect of contextual top-down processing on matching fingerprints. *Applied Cognitive Psychology*, 19, 2005.

Summary: Twenty-seven participants made a total of 2,484 judgments whether a pair of fingerprints matched or not. A quarter of the trials acted as a control condition. The rest of the trials included top-down influences aimed at biasing the participants to find a match. These manipulations included emotional background stories of crimes and explicitly disturbing photographs from crime scenes, as well as subliminal messages. The data revealed that participants were affected by the top-down manipulations and as a result were more likely to make match judgments. However, the increased likelihood of making match judgments was limited to ambiguous fingerprints. The top-down manipulations were not able to contradict clear non-matching fingerprints. Hence, such contextual information actively biases the ways gaps are filled, but was not sufficient to override clear bottom-up information.

Dror, I.E., Rosenthal, R., Meta-analytically quantifying the reliability and biasability of forensic experts. *J Forensic Sci*, 53(4), 2008.

Abstract: In this paper we employ meta-analytic procedures and estimate effect sizes indexing the degree of reliability and biasability of forensic experts. The data are based on within-expert comparisons, whereby the same expert unknowingly makes judgments on the same data at different times. This allows us to take robust measurements and conduct analyses that compare variances within the same experts, and thus to carefully quantify the degree of consistency and objectivity that underlie expert performance and

decision making. To achieve consistency, experts must be reliable, at least in the very basic sense that an expert makes the same decision when the same data are presented in the same circumstances, and thus be consistent with themselves. To achieve objectivity, experts must focus only on the data and ignore irrelevant information, and thus be unbiasable by extraneous context. The analyses show that experts are not totally reliable nor are they unbiasable. These findings are based on fingerprint experts decision making, but because this domain is so well established, they apply equally well (if not more) to all other less established forensic domains.

Evett, I., Evaluation and professionalism. *Science and Justice* 49, 2009.

Forrest, R., Context-free forensic science. *Science and Justice* 44(2), 2004.

Giannelli, P.C., Confirmation Bias, *Criminal Justice*, 22(3), 2007.

Hall, L.J. and Player, E., Will the introduction of an emotional context affect fingerprint analysis and decision-making? *Forensic Science International*, 181, 2008.

Dror, I.E. On proper research and understanding of the interplay between bias and decision outcomes, *Forensic Science International*, 191, 2009.

Hall, L.J. and Player, E., The value of practitioner research in the field of fingerprint analysis, *Forensic Science International*, 191, 2009.

Saks, M.J. Concerning L.J. Hall, E. Player, ''Will the introduction of an emotional context affect fingerprint analysis and decision making?'' *Forensic Science International*, 191, 2009.

Hall, L.J. Player, E. The value of practitioner research in the field of fingerprint analysis (2). *Forensic Sci. Int.* 191, 2009.

Hartl, D.L., and Fairbanks, D.J., Mud Sticks: On the Alleged Falsification of Mendel's Data in Perspectives *in Anecdotal, Historical and Critical Commentaries on Genetics* Eds. Crow, J.F. and Dove, W.F., Genetics Society of America, 2007.

Hasel, S, Kassin, L., On the presumption of evidentiary independence Psychological Science; Can Confessions Corrupt Eyewitness Identifications? 20(1), 2009

Kerstholt J.H., Paashuis R., Sjerps, M. Shoe print examinations: Effects of expectation, complexity and experience, *Forensic Science International*, 165, 2006.

Abstract: Even though trace evidence is becoming more and more important in legal cases, only little is known about the influence of task and context factors on comparative judgments. In the present study we investigated how expectations and complexity affect shoe print examinations and to what extent differences exist between beginners and experienced examiners. Twelve examiners assessed similarity between a shoe print and a shoe for eight different cases. For half the cases expectation was induced by providing additional incriminating evidence. A complex case meant that the print was relatively noisy, for example because the perpetrator rotated his foot. A simple case meant that the print was clear. The results showed that there was no effect of expectation and no effect of experience. Only complexity affected the examiners' assessments: when the background was noisy, the acquired features received a lower evidential value than when the background was clear. Apparently, examiners compensated for the quality of the print and were more cautious in drawing conclusions when prints were less clear. Even though the results allow for some optimism with

regard to the influence of expectations on shoe print examinations, it has to be taken into account that the Dutch procedure is supported by a formal guideline, which may (partly) explain the present findings.

Krane, D.E., Ford, F., Gilder, J.R., Inman, K., Jamieson, A., Koppl, R., Kornfield, I.L., Risinger, D.M., Rudin, N., Taylor, M.C., Thompson W.C., Sequential Unmasking: A Means of Minimizing Observer Effects in Forensic DNA Interpretation, *J Forensic Sci* 53(4), 2008.

Wells J.D. Commentary on: Sequential unmasking: a means of minimizing observer effects in forensic DNA interpretation. *J Forensic Sci*, 54(2) 2009.

Krane, D.E., Ford, F., Gilder, J.R., Inman, K., Jamieson, A., Koppl, R., Kornfield, I.L., Risinger, D.M., Rudin, N., Taylor, M.C., Thompson W.C., Authors' Response, *J Forensic Sci*, 54(2) 2009.

Ostrum B. Commentary on: Sequential unmasking: a means of minimizing observer effects in forensic DNA interpretation. *J Forensic Sci*, 54(6), 2009.

Krane, D.E., Ford, F., Gilder, J.R., Inman, K., Jamieson, A., Koppl, R., Kornfield, I.L., Risinger, D.M., Rudin, N., Taylor, M.C., Thompson W.C., Authors' Response, *J Forensic Sci*, 54(6), 2009.

Langenburg, G., Champod, C., and Wertheim, P., Testing for potential contextual bias effects during the verification stage of the ACE-V Methodology when conducting fingerprint comparisons *J Forensic Sci*, 54(3) 2009.

Abstract: This study was conducted to assess if fingerprint specialists could be influenced by extraneous contextual information during a verification process. Prior to the experiment, participants were separated into three groups: a control group (no contextual information was given), a low bias group (minimal contextual information was given in the form of a latent print examination report prompting conclusions from an anonymous, but qualified, specialist), and a high bias group (an internationally recognized fingerprint expert provided conclusions and case information to deceive this group into believing that it was his case and conclusions). A similar experiment was later conducted with novices (laypersons with no experience in conducting fingerprint comparisons). Participants were aware that they were being tested and participants may not have de facto conducted examinations in a manner consistent with their normal work habits. Given these limitations, the results still showed that fingerprint experts are influenced by contextual information during fingerprint comparisons, but not towards making errors. Instead, fingerprint experts under the biasing conditions provided significantly fewer definitive and erroneous conclusions than the control group. They tended to provide opinions that were inconclusive. In contrast, the novice participants were more influenced by the bias conditions and did tend to make incorrect judgments, especially when prompted towards an incorrect response by the bias prompt. This was not the case with the fingerprint experts. Experience (in terms of years of experience in fingerprint examination) was not shown to be a significant factor for specialists when assessing images from the same source, but was a factor when assessing images from different sources. Finally significant variation was observed for fingerprint experts when asked to count the number of minutiae in agreement for trials

where the images originated from the same source. The number of minutiae in agreement as reported by the specialist was a significant factor in whether the specialist claimed the images to be a definitive match.

Mankevich, A. Blind verification; Does it compromise the conformance of ACE-V methodology to the scientific method? Chesapeake Examiner 45(2), 2007.

Miller, Larry S., Bias among forensic document examiners: A need for procedural changes. J Police Science and Administration, 12(4), 1984.

Miller, Larry S., Procedural bias in forensic science examinations of human hair. *Law and Human Behavior* 11(2) 157, 1987.

Phillips V.L., Saks M.J., Peterson J.L., The application of signal detection theory to decision-making in forensic science. *J Forensic Sci*; 46(2) 2001.
Abstract: Signal Detection Theory (SDT) has come to be used in a wide variety of fields where noise and imperfect signals present challenges to the task of separating hits and correct rejections from misses and false alarms. The application of SDT helps illuminate and improve the quality of decision-making in those fields in a number of ways. The present article is designed to make SDT more accessible to forensic scientists by: (a) explaining what SDT is and how it works, (b) explicating the potential usefulness of SDT to forensic science, (c) illustrating SDT analysis using forensic science data, and (d) suggesting ways to gain the benefits of SDT analyses in the course of carrying out existing programs of quality assessment and other research on forensic science examinations.

Risinger, D.M., Saks, M.J. Thompson, W.C., Rosenthal, R., The Daubert/Kumho implications of observer effects in forensic science: Hidden problems of expectation and suggestion. *California Law Review*, 90(1) 2002.

Abstract: After the Supreme Court's decision in Kumho Tire v. Carmichael and the recent amendment of Federal Rule of Evidence 702, proffers of expert testimony will have to be found reliable for the particular application of the asserted expertise to the "task at hand." That is, expertise which is reliable in some global sense, which might apply to other cases but not to the particular application before the court, does not satisfy the requirements for admission. With that in mind, this article examines the phenomenon of "observer effects" and the vulnerability of forensic science examinations to such observer effects. Observer effects occur when the results of an examination are distorted by the context and state of the observer, including the observer's expectations and desires. The article reviews the findings and practices of a range of scientific fields concerning such observer effects and their control, with special attention to the relevant research and theory from cognitive and social psychology. This literature establishes that in virtually every area of human judgment, such observer effects have a relentless and sometimes dramatic effect on the accuracy of results. The article then examines current forensic science practice in light of that research, concluding that forensic science practice is far behind most scientific fields in controlling for such effects, leaving the reliability and accuracy of many forensic science results in doubt. The article then suggests practical ways in which forensic science practice can be changed to reduce

such problems, such as the adoption of blind testing regimes. Finally, the article analyzes the current state of the law under Kumho Tire and Rule 702, concluding that the results of forensic science examinations are in danger of being excluded if their reliability continues to be undermined by the failure to control observer effects.

Saks, M.J., Risinger, D.M., Rosenthal, R., Thompson, W.C., Context effects in forensic science: A review and application of the science of science to crime laboratory practice in the United States. Science & Justice, 43(2), 2003.

Schiffer B., Champod C., The potential (negative) influence of observational biases at the analysis stage of fingermark individualization. *Forensic Sci Int*,167, 2007.

Stacey, R.M., A report on the erroneous fingerprint individualization in the Madrid train bombing case. Journal of Forensic Identification, 54, 2004.

Thompson WC. A sociological perspective on the science of forensic DNA testing. *UC Davis Law Rev*, 30(4), 1997.

Thompson, W.C. and Cole, S.A., Psychological aspects of forensic identification evidence. In M. Costanzo, D. Krauss & K. Pezdek (Eds.) *Expert Psychological Testimony for the Courts*. New York: Lawrence Erlbaum & Associates. 2007.

Thompson, W.C. and Ford, S., The meaning of a match: Sources of ambiguity in the interpretation of DNA prints. In J. Farley & J. Harrington (Eds.) *Forensic DNA Technology*. New York: CRC Press, Inc., 1991.

Thompson, W.C., Accepting Lower Standards: The National Research Council's Second Report on Forensic DNA Evidence. *Jurimetrics* 37(4), 1997.

Thompson, W.C., Observer Effects, Context Effects and Confirmation Bias in Forensic Science in *Wiley Encyclopedia of Forensic Science*, Eds. Jamieson, A., and Moenssens, A., John Wiley & Sons, 2009.

Thompson, W.C., Painting the target around the matching profile: the Texas sharpshooter fallacy in forensic DNA interpretation, Law Probability and Risk, 2009

Thompson, W.C., Subjective interpretation, laboratory error and the value of DNA evidence: Three case studies. *Genetica* 96, 1995.

Thomson M.A., Bias and quality control in forensic science; a cause for concern. *J Forensic Sci*, 10(3), 1974.

USDOJ OIJ, A review of the FBI's handling of the Brandon Mayfield Case, 2006.

Vokey, J., Tangen, J., & Cole, S., On the preliminary psychophysics of fingerprint identification. *Quarterly Journal of Experimental Psychology*, 62(5), 2009

Whitman, G., Koppl, R., Institutional Bias in Forensic Science. In Press??

QUESTION 6

What literature exists that investigates the effects of environmental conditions on shoeprint/tire treads?

No citations are available that specifically answer this question.

What is the literature that documents the formation of individual characteristics amongst a group of people wearing the same shoe for the same period of time?

Hamburg, C. & Banks, R. (2010, August). Evaluation of the random nature of acquired marks on footwear outsoles [PowerPoint slides]. Presentation conducted at the Impression and Pattern Evidence Symposium, Clearwater Beach, FL. Retrieved from http://projects.nfstc.org/ipes/presentations/Hamburg_random-acquired-marks.pdf

The individualization of a footwear impression is based on the postulate that "accidental" marks on outsoles acquired through wear are random. This project tests that assumption by evaluating the marks acquired on multiple pairs of shoes during normal wear while attempting to control certain variables that include outsole design, wearer, travel paths, and length of wear. This project is a long-term evaluation of an entire outsole of modern material and design typically seen in casework. Travel paths were essentially reproduced for each pair of shoes by careful documentation of the participants' daily activities along with the use of a pedometer to attempt to duplicate the number of steps taken. Test impressions were taken from each pair of shoes prior to the start of the project and at each predetermined interval. Four pairs of shoes were worn, 2 for each participant. All right shoes and all left shoes were compared to each other. No acquired marks were found to repeat.

Adair, T. W., Lemay, J., McDonald, A., Shaw, R. & Tewes, R. (2007). The Mount Bierstadt study: An experiment in unique damage formation in footwear. Journal of Forensic Identification, 57 (2), 199-205.

Randomly formed damage on footwear outsoles has appropriately been used to compare crime scene impressions to the known shoes of suspects, witnesses, and victims. In this study, the authors wore new, identical boots (two pairs) during a seven-mile hike. The authors attempted to control the major variables except the manner in which the outsole of the boot made contact with the ground. The results of this experiment support the use of these marks for the individualization of footwear and confirm their random formation through the use of the shoe by the wearer.

Wyatt, J. M., Duncan, K., Trimpe, M. A. (2005). Aging of shoes and its effect on shoeprint impressions. Journal of Forensic Identification, 55(2), 181-188.

This research studied the change in the outsole patterns over a given amount of time in order to investigate what is to be expected in a two-month delay in the collection of known samples from a suspect. The study compared the class characteristics, wear patterns and individual characteristics of 54 different shoe outsoles before and after a two-month time lapse. The research concluded that an identification is still possible even if a known shoe is collected two months after the crime occurred.

Fruchtenicht , T.L., Herzig, W.P., 2 & Blackledge, R.D. (2002). The discrimination of two-dimensional military boot impressions based on wear patterns. Science & Justice, 42 (2), 97-104.

A study was undertaken to determine the discrimination value of wear patterns in the comparison of two-dimensional footwear impressions with questioned shoes. In order to isolate the influence on wear caused by individual differences in weight, bone structure, and walking styles, only right foot, size 10, military combat boots worn by US marines were studied. A commercial footwear impression kit featuring a chemically infused pad and sensitized paper was used for boot impression acquisition. Feature measurement was accomplished with an image analysis system to acquire the two-dimensional impressions as files, and then using a commercial marker-measurement system. A total of 127 different right boot impressions were acquired, scanned, measured, and measurement values entered into the database. The power of the developed metrics to discriminate between outsole impression patterns was evaluated in a blind challenge experiment. The system analyst was provided with 26 coded outsole impression sheets as "unknowns", of these, 22 had been previously entered in the database and four were outside samples. No false matches were made, and of all the non-matching images in only one instance did all of measurements fall within the 0.10 cm match criteria selected by the system operator.

Toso, B. & Girod A. (1997, September). Evolution of random characteristics (appearance and disappearance). Presentation conducted at the First European Meeting of Forensic Science, Lausanne, Switzerland.

This research was conducted to analyze the appearance and disappearance of random characteristics with respect to size and location on twelve pairs of shoe soles. These shoes were worn for a period of fifty days. Test impressions were made from each shoe at ten-day intervals to track the appearance and disappearance of the random characteristics observed on the shoes. The following conclusions were reached at the end of this study regarding random characteristics: (1) those characteristics which appear frequently on the sole tend to disappear rapidly, (2) the appearance and disappearance of these characteristics is gradual with time, (3) these characteristics are more likely to appear than to disappear, (4) small characteristics disappear more frequently and faster than large random characteristics, and (5) the majority of the characteristics that were present at ten days were still present at 50 days and their location and size were recognizable.

QUESTION 7

What is the literature that investigates the transfer of identifying features from sole or tread to impression medium across differing substrates?

Bodziak, W. J. (2008). Tire tread and tire track evidence: Recovery and forensic examination. Documenting and recovering tire impression evidence (pp. 45-48). Boca Raton, FL: CRC Press.

Bodziak, W. J. (2000). Footwear impression evidence: Detection, recovery and examination, 2nd edition. Awareness, detection, and treatment of footwear impression evidence (pp. 7-24). Boca Raton, FL: CRC Press.

QUESTION 8
What is the literature that investigates the development of defects/individualizing characteristics on different sole or tread materials?

Bodziak, W. J. (2000). Footwear impression evidence: Detection, recovery and examination, 2nd edition. Awareness, detection, and treatment of footwear impression evidence (pp. 7-24). Boca Raton, FL: CRC Press.

Toso, B. & Girod A. (1997, September). Evolution of random characteristics (appearance and disappearance). Presentation conducted at the First European Meeting of Forensic Science, Lausanne, Switzerland.

This research was conducted to analyze the appearance and disappearance of random characteristics with respect to size and location on twelve pairs of shoe soles. These shoes were worn for a period of fifty days. Test impressions were made from each shoe at ten-day intervals to track the appearance and disappearance of the random characteristics observed on the shoes. The following conclusions were reached at the end of this study regarding random characteristics: (1) those characteristics which appear frequently on the sole tend to disappear rapidly, (2) the appearance and disappearance of these characteristics is gradual with time, (3) these characteristics are more likely to appear than to disappear, (4) small characteristics disappear more frequently and faster than large random characteristics, and (5) the majority of the characteristics that were present at ten days were still present at 50 days and their location and size were recognizable.

QUESTION 9
What literature exists that describes the automated systems in shoeprint/tire tread examinations?

What literature exists that addresses the accuracy and validity of automated systems in shoeprint/tire tread examinations?

What literature exists that addresses the effectiveness of human examiners and automated systems used in conjunction to render a conclusion in shoeprint/tire tread examinations?

Note:

Automated systems used by footwear and tire track analysts are utilized for the

collection of information that may lead to a make and model determination.

Automated systems are not currently utilized to compare the unique features of a questioned impression from a scene to the unique features of a suspect's shoe or tire.

All currently available databases for shoes or tires require the manual input of information (shape codes or measurements) by the examiner, and manual inspection of the results for an identification of make and model to occur.

Various forensic laboratories (FBI, other countries) may have their own collection of known shoes or tires in a database, which they use for searches. These databases may also include collections of scene impressions which can be searched.

Footwear

A commercially available footwear database is available for use by forensic laboratories. Questioned tread designs can be searched in an attempt to determine the make and model of footwear that made the impression. The results of a make and model search are provided to an agency as an investigative lead. Shoeprint Image Capture and Retrieval (SICAR) is sold by the company Foster & Freeman is a computer software program that can be used to perform searches of a database of known footwear (SOLEMATE) and other outsoles input by laboratory personnel. This database is not a comprehensive database of all footwear sold, and only represents a fraction of those sold worldwide. Searches are performed by the manual "coding" of a questioned impression utilizing its apparent tread design shapes and orientations. A list of "hits" will result, however a manual comparison is necessary before any correlation can be made.

Crimeshoe.com is an internet service of Foster & Freeman where you pay for them to search your questioned impression and provide the possible results.

TreadMark is another commercially available footwear database by the company CSI Equipment Ltd. (United Kingdom). It reportedly provides for a central database of footmarks left at crime scenes, and images of footwear taken from prisoners. The database is accessible to all those who have an interest in footwear evidence from their own personal computer. Calibrated images of footmarks can be entered by crime scene investigators. According to the manufacturer, the custody officers have an easy means of taking images of the soles of the shoes taken from suspects. Footwear expert examiners can process the images – identifying the pattern code, marking up damage and searching the database to make scene to scene and scene to suspect links. Using the TreadMark interface these links are added to a 'Crime Series' which in turn form the basis of intelligence reports.

Tire

Foster & Freeman also sells TreadMate. This is a reference collection containing details of over 8,500 vehicle tires (not a comprehensive collection). It may be used as a stand-alone system or with SICAR, the company's shoe print and tire mark evidence management system

Tread Assistant was a searchable database containing images of tire tread designs - This database was discontinued in 2010.

Tire Stance:

There was previously a database available for searching vehicle tire stance measurements. Jato Dynamics developed a web-based search program which provided web access to vehicle stance data which was periodically updated. Jato released TirePrint.com in 2003 and sold subscriptions until 2009 when they discontinued the service. Now, there is at least one online resource, Canadian Transport's Canadian Vehicle Specification Program, that has vehicle stance measurements as a content of a database. The program is free and updated at least twice a year. The program has the three most used measurements, front track, rear track and wheelbase. The current version contains vehicle data from 1971 to 2011.

Literature:

What literature exists that describes the automated systems in shoeprint/tire tread examinations?

Bodziak, William J. (2000) Footwear Impression Evidence Detection, Recovery and Examination, pg 284

The author describes some databases that have been utilized by forensic examiners for footwear evidence.

Bodziak, William J. (2008) Tire Tread and Tire Track Evidence Recovery and Forensic Examination, 270-286

The author describes the databases that have been utilized by forensic examiners for tire tread and tire track evidence.

Robin Bowen; Jessica Schneider (2007) Forensic Databases: Paint, Shoe Prints, and Beyond. National Institute of Justice Journal Issue: 58, 34-38
Contains information about available databases: "… TreadMark is a commercial product

that uses four parameters--pattern, size, damage, and wear--in order to identify individual outsole impressions. These are then compared with shoe-print data from suspects in custody and crime scenes. The SoleMate database contains information on over 12,000 sports, work, and casual shoes (manufacturer, date of market release, an image or offset print of the sole, and pictorial images of the uppers). TreadMate contains information on more than 5,000 vehicle tires and tire tread patterns." Information is provided on how each of the forensic databases work and the organization that manages it.

Keijzer, J.; Geradts, Z. ; Keereweer, I. (1995) Nationwide Classification System for Shoe Outsoles Designs Journal of Forensic Identification, Volume: 45 Issue:1, 30-37
In the Netherlands, a project was been initiated to develop a nationwide classification system in which data on footwear outsole designs and footwear impressions can be stored. When completed, the database was to be made available to police districts who can communicate with each other by a wide area network called PODACS (Police Data Communication System). The database consists of three parts: (1) outsole shoe designs which can be purchased in shops in the Netherlands; (2) shoe outsole designs from suspects; and (3) images of footwear impressions found at crime scenes. Shoe classification systems in other countries are also noted.

Bolhouse, R.J. (1984) The identification of vehicles from wheelbase and tire stance measurements. Identification News, 34 (6), 5 - 6
and
Bolhouse R.J., and Nause, L.A., (1990) Tires and computers, R.C.M.P. Gazette (Cand.), 52:1, 1 - 11.
The authors describe a searchable database containing tire track (stance) measurements that was a collaboration of the Michigan State Police and the RCMP. (Note: This type of information was more recently available using TirePrint.com, however that has been discontinued)

Mikkonen, S., Suominen, V., Heinonen, P. (1996) Use of footwear impressions in crime scene investigations assisted by computerised footwear collection system, Forensic Sci. Intl, Volume 82, Issue 1, 67-79
(Finland) Crime scene footwear classification systems utilized to look for possible suspects, to get models and brand names for crime scene impressions and to link crime scenes. In this work a computerized footwear classification system was presented. The classification coding of the system was been designed especially for partial footwear impressions which are the most typical in crime scenes. The system is flexible because it is possible to agree within a crime scene investigation unit the way in which the system is to be applied. The accurate classification coding is propounded by the fact that only a few experienced users are needed to perform the classification and data storage and all police officers returning from crime scenes are able to perform searches very easily. The crime scene investigation unit of the Turku police tested the system for a period of 1.5 years. The system has proved to be of valuable assistance in investigation when several

of the hints lead to early solving of a crime. Practical experiences are described.

AlGarni, G., Hamiane, M., (2008) A novel technique for automatic shoeprint image retrieval Forensic Science International, Volume 181, Issues 1-3, 10-14
(Saudi Arabia) Recent developments in forensic science have resulted in large numbers of scene of crime images being collected for recording and analysis. Shoeprint images are no exception. In fact, these have recently been of great interest to police and forensic scientists as footwear evidence is now treated in the same manner as fingerprint and DNA evidence. Traditional approaches to shoeprint representations attempt to classify shoeprint images based on a number of possible patterns. Such approaches are difficult to implement in an automatic fashion without the intervention of a forensic specialist. This paper presents a robust algorithm for shoeprint matching based on Hu's moment invariants. It is shown that decreasing the resolution of images does not have a significant effect on the performance of the algorithm. It is also shown that the optimal performance of the proposed system is attained for images rotated by any angle.

Geradts, Z., Keijzer, J. (1996) The image-database REBEZO for shoeprints with developments on automatic classification of shoe outsole designs
Forensic Science International, Volume 82, Issue 1, 21-31
(Netherlands) A database for footwear outsole designs developed on a PC. The database consists of three files: shoes of suspects, shoeprints from the scene of crime and shoes available from the shops. For REBEZO an algorithm is implemented for the automatic classification of outsole patterns. The algorithm first segments the shoe profiles in different profiles. The Fourier-features are calculated for those profiles. The best Fourier features are selected and are classified with a neural network. By using this algorithm many different shapes can be recognized. Integrating the results of the invariant moments in the neural network will give better results.

Natarajan, N., Ranjit, G.M., (2005) Computer assisted analysis of footprint geometry, Journal of Forensic Identification, Volume: 55, Issue: 4, 489-498
The authors describe the mechanics of using each of the following geometric tools: straight line/slanting line tools, the rectangle/square tool, and the ellipse/circle tool. The use of the software to superimpose two footprints for comparison is also described. Various measurements of two-dimensional footprints (foot length, ball width, intertoe separation, angles subtended by the center of the toes to the axis, etc.) can be calculated faster and more accurately with appropriate computer software than with the tools of manual measurement (ruler, protractor, etc.). Although not tested in the current study, other software similar to Adobe Pagemaker, such as QuarkXpress and CorelDraw, can also be used to calculate and compare footprint dimensions
What literature exists that addresses the accuracy and validity of automated systems in shoeprint/tire tread examinations?

What literature exists that addresses the accuracy and validity of automated systems

in shoeprint/tire tread examinations?

Bodziak, William J. (2008) Tire Tread and Tire Track Evidence Recovery and Forensic Examination, 270-286
The author describes the databases that have been utilized by forensic examiners for tire tread and tire track evidence, and describes the use and variability that can be obtained depending on how the data entry is performed.

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 – An evaluation of a database made in-house. Sole designs are stored with shoe information (brand name, size, style, material, etc.), pattern types, and certain features on shoe soles or in footwear impressions, and they are used as searching criteria. There are two different classification code systems in the database. Preliminary classification is a very broad classification, and it is meant for shoe-sole pattern designs and full shoe-sole impressions; its classification codes are based on defined basic shapes and certain principles that facilitate storing partial footwear impressions, shoe-sole designs that identify partial impressions, and the elimination of interpretation error while classifying. They determined that the user-friendly software made the classification easy and searches rapid and effective. Until now the system has been tested in laboratory conditions. It has recently been installed in a local police unit for pilot testing. According to the experiences collected, the feature classification seems to be flexible, because it permits a feature to be composed of the defined basic shapes and certain definitions. The user must only follow the simple principles and order of the coding while classifying. The classification could also be used both at a very accurate level and a lower level. Because the coding is started from the center of the feature outward, it was determined to be easy to find an agreement at the local level with sufficient accuracy.

Lin, G., Elmes, G., Walnoha, M., and Chen, X. (2009) Developing a spatial-temporal method for the geographic investigation of shoeprint evidence Journal of Forensic Sciences Volume 54, Issue 1, 152–158
This article examines the potential of a spatial-temporal method for analysis of forensic shoeprint data. The large volume of shoeprint evidence recovered at crime scenes results in varied success in matching a print to a known shoe type and subsequently linking sets of matched prints to suspected offenders. Unlike DNA and fingerprint data, a major challenge is to reduce the uncertainty in linking sets of matched shoeprints to a suspected serial offender. Shoeprint data for 2004 were imported from the Greater London Metropolitan Area Bigfoot database into a geographic information system, and a spatial-temporal algorithm developed for this project. The results show that by using distance and time constraints interactively, the number of candidate shoeprints that can implicate one or few suspects can be substantially reduced. It concludes that the use of space-time and other ancillary information within a geographic information system can

be quite helpful for forensic investigation.

Hannigan, T.J., Fleury, L.M., Reilly, R.B., O'Mullane, ., B.A. deChazal P., (2006) Survey of 1276 shoeprint impressions and development of an automatic shoeprint pattern matching facility Science & Justice, Volume 46, Issue 2, 79-89
The study included an effort to make the use of databases for assessing the strength of matching pattern evidence easier and more widespread by developing a fully automatic shoeprint processing system using scanned images. The test impressions were made on paper under ideal conditions. The result was that the system could sort images, but did not sort database images as successfully in response to partial prints as when processing full prints. They concluded that to have practical application, a system must be able to deal with photographs of crime scene impressions and further work would need to be done to accomplish that.

T.J. Napier (2002) Scene linking using footwear mark databases Science & Justice, Volume 42, Issue 1, 39-43
Analysis of crime scene data which includes footwear pattern, time and place was evaluated as to its usefulness in linking crime scenes. They determined that for footwear databases to provide useful intelligence in that regard, they need to contain very precise pattern coding to be highly discriminating. They also need to be able to analyze incidents from a geographical and time perspective in relation to footwear patterns.

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
(Switzerland) ISAS is an intelligent system for the administration of footwear impressions and reference-shoesoles, which had been in practical use with the Forensic Science Division of the Zurich Cantonal Police for two years at the time of writing. It is a powerful, efficient and user-friendly system, developed in co-operation with an external picture processing specialist, that can comfortably handle a database of 10,000 and plus images. Even inexperienced users are able to find a reference-sole in a short time. The system has proved to be an efficient tool in investigation assistance and crime scene linking.

What literature exists that addresses the effectiveness of human examiners and automated systems used in conjunction to render a conclusion in shoeprint/tire tread examinations?

Geradts, Z., Bijhold, J. (2002) Content based information retrieval in forensic image databases Journal of Forensic Sciences Volume: 47 Issue:2, 285-292
This research assesses how the various algorithms for correlation and image matching are applicable in forensic science. First, an overview is provided of current research and applications, followed by an application of these methods to several forensic databases,

each focusing on a different method of matching images. These databases are tool marks, shoeprints, cartridge cases, and drugs/pills. In the literature, databases are divided into different generations. This research focuses on second generation visual information systems. In these systems, there are different ways of searching in the database . The user can search in the database on features such as texture, shapes, and color distribution. The features can be combined with text strings in the database. With this method, the user can search for a certain group of cases in a forensic database and compare the images with features of the images. Most current research focuses on finding features in images, indexing a database in an efficient manner, and the man-machine interface. A sketch generated by the user will be compared with a database of images. Whether this framework will actually be used very much will depend on the market. In future databases, more powerful methods that require parallel processing can be used. The authors concluded that it may be possible to automate the classification of the outsole design as long as the classification matrix is not too complicated. They also conclude that searching in the databases on content is still a difficult task, since shoeprints are often blurred. This requires the examiner to do much of this work manually.

Ashley, W. (1996) What shoe was that? The use of computerised image database to assist in identification, Forensic Science International, Volume 82, Issue 1, 7-20
(Australia) The use of a computerized (digital image-based) reference system for the capture, storage and retrieval of shoe soles and uppers with the ability to give information to the investigator in relation to the brand and model of shoe responsible for impressions located at crime scenes. The success of the system described was due to the diversity and simplicity of the classification codes, coupled with the ability to search part or all of a shoe sole area. Determined to have discriminating power with the use of icons and 'click on' features, making the system useful when classifying and searching for shoes, thus reducing the possibility of interpretation error.
Other:

Girod, A., (1996) Computerized classification of the shoeprints of burglar's soles. Forensic Sci. Intl., 82(1)
Description of the system created at the forensic technical laboratory in Neuchâtel, Switzerland, offering a means of classification concerning the standards of the shoeprints of burglars' soles. This classification system was created using the data processing program FileMaker Pro 2.1 of Macintosh. It had been established in Neuchâtel for 4 years and contains over 1500 reference files. During this period of time it has been possible to identify four times as many burglars through shoeprints than with fingerprints.

Smith, J., (2007) Image enhancement and Adobe Photoshop: Using calculations to extract image detail, Journal of Forensic Identification Volume: 57 Issue: 4, 493 to 505
This article presents step-by-step instructions, along with a case example, of how to use Adobe Photoshop to clarify image details while reducing distracting background

patterns during forensic print analysis.

Napier, T.J. (2002) Scene linking using footwear mark databases. Science & Justice, 42 (1), 39 - 43.
(United Kingdom) Scene linking using footwear mark databases.

QUESTION 10
What is the literature on error rates in shoeprint/tire tread examinations?

Peterson, J. L., Markham, P, "Crime Lab Proficiency Testing Results, 1978-1991, II: Resolving Questions of Common Origin," *Journal of Forensic Sciences*, JFSCA, Vol. 40, No. 6, November 1995, pp. 1009-1029.
Proficiency tests have been used by crime laboratories since the mid-1970s as a quality control mechanism to measure and monitor the proficiency of their examiners. These proficiency tests are created by an outside entity and purchased by crime laboratories. This research examined proficiency test results from the period of 1978-1991 in order to study the proficiency of laboratories in determining common origin of various physical evidence samples. Proficiency tests for footwear were started in 1985 therefore this study looked at the seven test results from 1985-1991. From a total of 1745 comparisons, 87% of the comparisons agreed with target values and only 0.7% did not while 12% were inconclusive. Overall, the study reported that footwear impression comparisons were one area in which laboratories performed the best. The article stated that while the rates of successful responses were lower than some of the other disciplines it had the second lowest rate of improper responses.

Collaborative Testing Services Inc., CTS Statement on the Use of Proficiency Testing Data for Error rate Determination, March 30, 2010, www.collaborativetesting.com.
Collaborative Testing Services, Inc. (CTS) provides proficiency tests to crime laboratories on a fee for test basis. In a statement released in March 2010, CTS acknowledges the attempt by some to use their proficiency tests as a mechanism to calculate error rates but states that its tests can not and should not be used for such purposes. In this statement CTS explains that demographic information about the participants is not routinely gathered and that the participants include a wide margin of experience. CTS also states that they have no control over how an agency might use one of its tests. An agency could be using the test as a proficiency test for accreditation requirements or for training new examiners. Also, CTS points out that they do not record "correct" and "incorrect" responses, only whether the response agrees or disagrees with the consensus of the conclusions received. Also, the tests are designed to meet accreditation requirements and are not intended to simulate a real-world environment. For all of these reasons CTS claims that its proficiency tests can not be used as a true indication of the error rates in each discipline tested.

H. Majamaa, Y. Anja, "Survey of the Conclusions Drawn of Similar Footwear Cases in Various Crime Laboratories," *Forensic Science International*, 1995, 82: 109-120.
This study examined the conclusions drawn between various footwear examiners in a variety of laboratories in 20 European counties. The study provided 6 tests to 34 laboratories in which they received 33 responses. The objective of the study was to examine any variability between conclusions between examiners. The study found wide variations in the conclusions drawn by different examiners. The major limitation of this study were differences in reporting styles and reporting criteria of different laboratories. *Caution should be exercised when trying to use this study to gather information about the conclusions drawn by footwear examiners in the United States. European examiners use different wording in their conclusions than those in the United States. An additional study was performed in the United States by Duffy, K. et. al., that found conclusions to have very little variability. This study has not yet been published.

QUESTION 11
What is the literature that addresses the feasibility and reliability of partial print comparisons (i.e. situations where some of the sole pattern may be present with individual detail, but there is insufficient detail to compare class characteristics)?

Impression evidence, is by it's nature almost exclusively only a partial print of the item that was impressed on the surface. A footwear or tire impression which exhibits sufficient clarity that individual detail is visible will have some degree of class characteristic also visible, or be so minute as to preclude a comparison from being made or a conclusion reached. The main factor that must be considered when doing a comparison of any evidence is clarity. There is a direct inverse relationship between quality (clarity) and quantity , in that if clarity is low, a greater quantity of detail is necessary to reach a conclusion than if clarity is high.

Petraco, Nicholas.et al., Statistical Discrimination of Footwear: A Method for the Comparison of Accidentals on Shoe Outsoles Inspired by Facial Recognition Techniques Journal of Forensic Sciences, Vol. 55, No. 1(Jan 2010), p. 34-41.
Authors applied statistical techniques used in facial pattern recognition to a minimal set of information gleaned from accidental patterns , using only the coordinate location of accidental marks to characterize the entire pattern. They numerically gauged the similarity of the two patterns one to another in a worst-case scenario. They used only a partial portion of the shoes studied, all of the same make, model, and worn by the same person for the same amount of time. Out of the 135 accidental patterns recorded for nine shoes , 116 contained at least one accidental mark. This study used only a tiny amount of the information typically available to a footwear examiner , and yet using PCA it was found that of the 32 PC's described 99.5 % of the total variance of the data set.

Adair, T. W., Lemay, J., McDonald, A.,Shaw, R., Tewes,R. The Mount Bierstadt Study: An Experiment in Unique Damage Formation in Footwear. Journal of Forensic Identification 57,2 (Mar/Apr 2007) 199-205
The authors obtained new boots, made test impressions of them, then wore the boots over the same path at the same time on a hike, with each person wearing two pairs of boots during the experiment. The of the 38 elements of the boots were given specific address locations and individual characteristics in each location were recorded. Comparisons conducted between all of the outsoles at each of these address locations, found that there were no corresponding marks at any locations, supporting the reliability of partial impression comparisons.

Cassidy, Michael J., Footwear Identification Government of Canada Press, 1987
The author conducted a research project involving 194 boots, specifically the heels only. The boots were worn in the same geographical area (RCMP Training Academy) examining wear and accidental (individual) characteristics, to determine the possibility of accidental characteristics reoccurring in the same place on other shoes, and the incidence of general wear being repeated.
Approximately 10,000 examinations were conducted. The author concluded that each characteristic must be weighed on its own individual merits, and that how the characteristic is individually shaped and how accurately they are recorded is more important than the size of the characteristic.

QUESTION 12

What is the literature that describes the rarity of class characteristics and uniqueness of individual characteristics in shoeprints/tire treads?

What published databases exist that describe the frequency statistics of various shoeprint/tire tread patterns?

Existing literature describing the rarity of class characteristics and uniqueness of individual characteristics is described below. It should be noted that the term class characteristics encompasses a group of characteristics that includes but is not limited to shoe outsole/tire tread design.

Numerous attempts have been made at producing databases of shoe outsole and tire tread patterns. These databases have not attempted to catalogue the frequency of occurrence of each pattern in the population; rather, they have attempted to represent examples of as many patterns as possible to assist the examiner when determining the makes and models that could have created an unknown impression.

There are no known databases that describe the frequency of occurrence for shoe outsole/tire tread patterns. A database project of this type would present significant challenges in terms of characterizing the entire shoe/tire population. At present, there is

no reasonable means of tracking ongoing production statistics for every manufacturer, make, and model of shoe/tire. In addition, because the length of time shoes and tires are retained and used is highly variable and because these items are often transported over long distances, it is difficult to determine how long a particular shoe/tire might be in circulation in a given population. Once the manufacturer of a particular shoe or tire is known, it is sometimes possible to obtain information on the production and distribution of a specific type of item by contacting the manufacturer.

Adair, T.W., Lemay, J., McDonald, A., Shaw, R., Tewes, R.; The Mount Bierstadt Study: An Experiment in Unique Damage Formation in Footwear, Journal of Forensic Identification, 57(2), 199-205

In this study 12 pairs of boots were worn (2 pairs by each of 6 participants) while engaging in common activity. Variables contributing to the formation of marks such as the style and condition of the boots, the walking path, environmental conditions, and duration of use were controlled. Following this activity each of the outsoles had acquired sufficient characteristics to be identified supporting the hypothesis that damage to outsoles is randomly acquired and provides for the possibility of individualization.

Bessman, C.W., Schmeiser, A. Survey of Tire Tread Design and Tire Size as Mounted on Vehicles in Central Iowa, Journal of Forensic Identification, 51(6), 2001, 587-596

The authors surveyed the tires of 1250 vehicles and determined that most (slightly more than 70%) of the vehicles had four tires with matching tread designs. The next most likely combination is two pairs of matching tires. A small percentage of vehicles were found to have tires of four different tread designs.

Birkett, J. Variations in Adidas "Kick" and Related Soles, MPFSL Report Number 34, Metropolitan Police Forensic Science Laboratory, London, 1983

Impressions from 78 sole units of the same type were evaluated and compared. The soles were produced by cutting from calendared rubber material. It was determined that 77 of the soles were clearly distinguishable based on manufacturing characteristics. The remaining pair was also distinguishable, however, the distinguishing features were more subtle and may not be clear in casework type impressions were smudging is present.

Bodziak, William J., Footwear Impression Evidence: Detection, Recovery, and Examination, 2nd edition, Chapter 10, Class and Identifying Characteristics, pp. 329-356, CRC Press, Boca Raton, Florida, 2000

The author discusses both class and identifying characteristics and gives theoretical and actual examples of their use and significance.

Bodziak, William J., Manufacturing Processes for Athletic Shoe Outsoles and Their Significance in the Examination of Footwear Impression Evidence, Journal of Forensic Sciences, 31(1), 153-176
This article explains how each of the most common manufacturing process creates features that may be useful in the examination of impressions. The article presents the specific type of class and or individual characteristics created as part of each manufacturing process, the relative uniqueness of these characteristics, and their significance in drawing conclusions regarding impressions made by the shoes.

Bodziak, William J., Tire Tread and Tire Track Evidence: Recovery and Forensic Examination, Chapter 9, Individual Characteristics, pp. 209-221, CRC Press, Boca Raton, Florida, 2008

Cassidy, Michael J., Footwear Identification, Government of Canada Press, 1987
The author conducted research involving the examination of wear and individual characteristics produced in 194 impressions from the heels of boots worn in the same geographic area. With regard to individual characteristics, the author concluded that size of the individual characteristic is not the most important factor in examination and each individual characteristic must be evaluated on its own merit taking into account the shape and the quality of recording of the impression.

Champod, C., Voisard, R., Girod, A., A statistical study of air bubbles on athletic shoesoles, Forensic Science International, 109, 105-123
An area on the outsole of 71 pairs of shoes (142 shoes) of common outsole pattern, size, and manufacturer was evaluated with the goal of assessing the statistical variability and independence of air bubbles created during the manufacturing by the injecting molding process. The authors found air bubble configurations in this sample set were highly variable in this sample set; however, the adoption of a simple statistical model to predict the probability of a given configuration was not possible. Further, the authors found that the data generated in this study could only be applied to assess the specificity of air bubble configurations on shoes from this particular production line. In short, the variables involved in the production of air bubbles following the injection process make every situation very specific in terms of the probability of the random occurrence of a given configuration even if the variables of general pattern, manufacturer, and size are controlled.

Davis, R.J and Keeley, A. Feathering of Footwear, Science and Justice, 40(4), 2000, 273-276.
Feathering was produced on outsole test samples in the laboratory and the no significant matches were found between the samples, even those taken from the same area of different outsoles produced in the same mold. No matches were found between training shoes produced in the same mold and worn for the same length of time by the same person.

Hamburg, C. and Banks, R. Evaluation of the Random Nature of Acquired Marks on Footwear Outsoles, unpublished, presented at the 2010 Impression and Pattern Evidence Symposium, Clearwater Beach, Florida, August 2010.
This project evaluated the marks acquired on four pairs of shoes (two subjects each wearing two pairs of shoes). Variables including outsole design, wearer, travel paths, and length of wear were controlled. All right shoes and all left shoes were compared to each other. No acquired marks were found to repeat.

Hamm, E.D. The Individuality of Class Characteristics in Converse All-Star Footwear, Journal of Forensic Identification, 39(5), 1989, 277-292
The author discusses the manufacturing process for Converse All-Star shoes and demonstrates how each step of the process has the potential to impart certain features. When the combination of features is considered, the population of shoes that share the same combination of characteristics can be significantly narrowed even when the shoes are of the same general design and size.

Hanningan, T.J., Fleury, L.M., Reilly, R.B., O'Mullane, B.A., deChazal, P. Survey of 1276 sheoprint impressions and development of an automatic shoeprint pattern matching facility, Science and Justice, 46(2), 2006, 79-89
1276 outsole pattern impressions were obtained from male attendees at a scientific exhibition. The patterns were sorted and it was determined that the largest group of outsoles sharing a common overall design represented only 1% of the sample set. Each of the other outsole designs represented a significantly smaller proportion of the sample set. 773 outsole designs occurred only one time. The authors conclude that even a correlation in outsole design can be potentially significant evidence.

Kainuma, A. Manufacturing Variations in a Die-Cut Footwear Model, Journal of Forensic Identification, 55(4), 2005, 503-517
100 pairs of shoes produced using the die-cut manufacturing process were evaluated for variations imparted during the manufacturing process. No two pairs shared identical class features.

Jay, C.B. and Grub, M.J. Defects in Polyurethane-soled Athletic Shoes – Their Importance to the Shoeprint Examiner, Journal of the Forensic Science Society, 25: 233-238
The authors examine the occurrence of bubbles in polyurethane soles and conclude that within a given shoe sole design there will be some similarity in pattern of bubbles.

Keijzer, J. Identification Value of Imperfections in Shoe with Polyurethane Soles in Comparative Shoeprint Examination, Journal of Forensic Identification, 40(4), 1990, 217-223
Twenty-two shoe soles (fourteen left and eight right) of the same make and model were evaluated for similar imperfections. Air bubbles were often found to occur in the same places on the sole surfaces and were sometimes similar in shape and size. Factors

affecting the location, size, and shaped appeared to be the form of the sole surface and the high degree of accuracy of the manufacturing process.

Music, D.K., Bodziak, W.J., Evaluation of the air bubbles present in polyurethane shoe outsoles as applicable in footwear impression comparisons, Journal of Forensic Sciences, 33(5), 1988, 1185-1197
The chemical, physical, and mechanical factors influencing the formation of air bubbles in polyurethane shoe outsoles are discussed with regard to the various manufacturing techniques. The authors present factors for consideration in interpreting the relative uniqueness of air bubbles encountered in casework.

Parent, S. The Significance of Class Associations of Footwear Evidence, unpublished, poster presented at the 2010 Impression and Pattern Evidence Symposium, Clearwater Beach, Florida, August 2010.
1607 shoeprints (1,290,421 possible pairs) were collected from the general public in various cities in the state of Texas. The shoeprints were compared with regard to tread design, size, and general wear condition and no two shoeprints were found to be the same. Shoeprint comparisons involving both the two and heel of the shoe proved to be more discriminating than partial prints involving only the toe.

Petraco, N.D., Gambino, C., Thomas, K.A., Oivio, D., Petraco, N. Statistical Discrimination of Footwear: A Method for the Comparison of Accidentals on Shoe Outsoles Inspired by Facial Recognition Techniques. Journal of Forensic Sciences 2010; 55(1) In this study a statistical technique used in facial pattern recognition (maximum likelihood Gaussian linear classification) was applied to evaluate acquired marks on five pairs of shoes worn by the same individual for a period of thirty days. In order to maximize potential similarity, only the location of the marks was evaluated. Factors such as size, shape, and orientation were not considered and only a portion of the sole was evaluated. Despite the fact that only a small amount of the information typically available to an impressions examiner was utilized, this method was usually able to identify which shoe generated a particular pattern. According to the authors, “The high correct classification rates from our minimally detailed data lend a great deal of credence to the proposition postulated by imprint examiners of the “uniqueness” of accidental patterns. If data are also recorded for the physical characteristics of each accidental, the above results indicate that this method would be even more successful in identifying a shoe from one or more related accidental patterns.”

Stone, R.S., Footwear Examinations: Mathematical Probabilities of Theoretical Individual Characteristics, Journal of Forensic Identification, 56(4), 2006, 577-599
Theoretical types of individual characteristics are discussed and a statistical model for the evaluation of the probability of occurrence of each type of mark and of combinations of marks is presented.

Tart, M.S., Downey, A.J, Goodyear, J.G., Adams, J. The Appearance of Feathering as a Feature of Wear, The Forensic Science Service, (FSS Report No. RR 786) 1-11
Twenty-seven pairs of shoes were assessed to determine the frequency and earliest time of occurrence of feathering, the stability of the pattern, and the similarity of pattern between outsoles. The authors conclude that feathering occurs commonly with minimal wear, the patterns commonly change over relatively short periods of time, and the patterns can be distinguished between soles with similar states of wear. The findings indicate that feathering patterns can be used as highly distinguishing characteristics.

Zmuda, C.W. Identification of Crepe-Sole Shoes, Journal of Criminology, Criminal Law and Police Science, 44 (3): 374-378
Nearly 200 crepe soles shoes, over 100 consecutively cut soles and nearly 50 sole assemblies were examined. No two soles were found to be exactly alike.

QUESTION 13

What is the literature on quantification; measurement precision and uncertainty in shoeprint/tire tread examinations? For example, are there studies that would help describe "small" and "large" scratches in terms of measurement uncertainty? For example, is > 1.0 cm plus/minus 0.1cm big and how jagged does a scratch need to be before it is unique?

Individual characteristics have a location and orientation on the known item, and may range from minute to various measurements. However, when the item impresses on a surface, the measurement of a cut, scratch or gouge can be different based on a number of variables including the type, flexibility or degree of hardness of the surface they are impressed upon or the amount of weight or pressure placed on the item when it made the impression. Precise measurement of the characteristic is therefore not as significant as the clarity of the feature, its specific location and orientation on the item, and whether it corresponds to the impression left behind.

Stone, Rocky S. Footwear Examinations: Mathematical Probabilities of Theoretical Individual Characteristics. Journal of Forensic Identification 56, 4 (Jul/ Aug 2006) 577-599.
The author quantifies individual characteristics that appear on a shoe impression using two primary variables: their location and their configuration . Theoretical types of individual characteristics that are found on shoe prints are described and a hypothetical model is presented with probability estimates applied to quantify the likelihood of occurrence of the characteristics.
The author also discusses combinations of characteristics where more than one individual characteristic exists, and the application of this research to partial footwear impressions and tire impressions.

Adair, T. W., Lemay, J., McDonald, A.,Shaw, R., Tewes,R. The Mount Bierstadt Study: An Experiment in Unique Damage Formation in Footwear. Journal of Forensic Identification 57,2 (Mar/Apr 2007) 199-205

The authors obtained new boots, made test impressions of them, then wore the boots over the same path at the same time on a hike, with each person wearing two pairs of boots during the experiment. The of the 38 elements of the boots were given specific address locations and individual characteristics in each location were recorded. Comparisons conducted between all of the outsoles at each of these address locations, found that there were no corresponding marks at any locations, supporting the reliability of partial impression comparisons.

Bodziak, W.J. Footwear Impression Evidence Detection , Recovery and Examination 2nd Edition, CRC Press, 2000

The author describes individual characteristics, and the random nature of the size, shape, orientation and/or position, and indicates that they can range from the tiniest, almost obscure pinpoint sized characteristic to one having tremendous distinctness. Considerations must include clarity, reproducibility and repeatability and confirmation of random occurrence, as well as degree of uniqueness based on size, shape, position and orientation. Clarity plays an important role, and the association of the characteristic between the known item and the questioned impression must be demonstrable.

He also discusses the value of one confirmable random characteristic based simply on the random placement/location on the item and the concept that one single characteristic can have multiple features within it.

Cassidy, Michael J., Footwear Identification Government of Canada Press, 1987

The author conducted a research project involving 194 heel impressions of boots worn in the same geographical area (RCMP Training Academy) examining wear and accidental (individual) characteristics to determine the possibility of accidental characteristics reoccurring in the same place on other shoes, and the incidence of general wear being repeated.

Approximately 10,000 examinations were conducted. The author concluded that each characteristic must be weighed on its own individual merits and that how the characteristic is individually shaped and how accurately they are recorded is more important than the size of the characteristic.

QUESTION 14

What is the literature on population-based studies that describe variation (e.g. due to gender, pathologies, height/weight, running vs. walking, stride, etc)?

Barton, C. J., Bonanno, D., & Menz, H. B. (2009). Development and evaluation of a tool for the assessment of footwear characteristics. Journal of Foot and Ankle Research, 2:10.

This article discusses footwear characteristics that have been linked to falls in older adults and children and how they may have an effect on the development of many musculoskeletal conditions due to the relationship between footwear and pathology. The goal was to develop a simple, efficient, and reliable footwear assessment tool potentially suitable for use in a range of patient populations that would allow for an accurate and efficient critique on an individual's footwear. The study resulted in the development of a comprehensive footwear assessment tool to assist with future research and clinical footwear assessment. The tool has good reliability and can be used with confidence in research and clinical settings, but further research is needed to determine the clinical validity of each item in various patient populations.

Whittle, M. W. (1996). Gait analysis: An introduction, Second edition. Oxford, England: Butterworth-Heinemann.

Ostrosky, K. M., VanSwearingen, J. M., Burdett, R. G. & Gee, Z. A comparison of gait characteristics in young and old subjects. (1994). Physical Therapy, 74(7), 637-644.
The purpose of this study was to describe and compare active range of motion during free-speed gait in younger and older people. Sixty volunteers in good health were studied. Thirty subjects (15 male, 15 female) were between 20 and 40 years of age, and 30 subjects (15 male, 15 female) were between 60 and 80 years of age. Methods. Subjects were videotaped walking down a 6-m walkway with reflective markers at six locations along their right side. The videotape was analyzed for nine gait characteristics using a two-dimensional video motion analysis system. Differences in gait characteristics between the two groups were examined using a multivariate analysis of variance, followed by univariate F tests. Results. Two gait variables—knee extension and stride length—were significantly different between groups, and differences in velocity approached significance. For individuals in good health, the gait of older people differs from the walking pattern of young people for selected variables. Older people demonstrate less knee extension and a shorter stride length compared with younger people. Differences in self-paced walking velocity between old and young people may have influenced the gait characteristics measured.

Cassidy, M. J. (1980). Footwear identification. Identification of footwear evidence (pp. 98-108). Quebec, Canada: Canadian Government Printing Centre.

Murray, M.P., Kory, C., Clarkson, B. H., & Sepic, S. B. (1966). Comparison of the free and fast speed walking patterns of normal men. American Journal of Physical Medicine & Rehabilitation, 45 (1), 8-24.

Murray, M. P., Drought, A. B., & Kory, R. C. (1964). Walking patterns of normal men. The Journal of Bone and Joint Surgery, 46 (2), 335-360.
A simple and inexpensive photographic method has been developed whereby many kinematic components of the walking act in the sagittal, frontal, and transverse planes can be measured and related temporally. A factorial design was used to study the

displacement patterns of sixty normal men who ranged in age from twenty to sixty-five years and in height from sixty-one to seventy-four inches. Each subject's weight was within normal limits for his height and frame size. There was striking similarity in the duration of successive phases of stance, swing, and double-limb support during the same walking trial and during repeated trials of the same subject. Step and stride length and stride width showed the same striking similarity. Foot angles, however, showed greater individual variability. The differences in timing and stride dimensions did not relate systematically with age. However, the subjects sixty to sixty-five years old differed from younger subjects in that they took shorter steps and strides and showed a greater degree of out-toeing. The only variables which related systematically with height were the step and stride lengths, with the tall subjects taking the longest steps and strides and the short subjects, the shortest. Seven displacement patterns of free-cadence walking were analyzed for sixty normal men from twenty to sixty-five years old and from sixty-one to seventy-four inches tall. These displacement patterns include sagittal rotation of the pelvis, hip, knee, and ankle and vertical, lateral, and forward movement of the trunk. Each movement pattern was strikingly similar for repeated trials of the same subject and for subjects in the various age and height groups. Slight differences in the magnitude of hip flexion excursion occurred, which showed a low positive correlation with age and a similarly low but negative correlation with height. There was no evidence of presenile changes in these excursions among our oldest subjects, except for some decrease in the magnitude of ankle extension at the end of the stance phase. The serial transverse rotations of the pelvis and thorax have been analyzed in free-cadence walking of sixty normal men. Although there was striking similarity in these excursions for repeated trials of the same subject, there was wide variation in these excursions among the subjects in similar age and height categories. These variations suggest that pelvic and thoracic rotation are not obligatory elements of normal gait. The decreased pelvic rotation in the group sixty to sixty-five years old may possibly represent another aspect of the presenile pattern of walking.

Drillis, R. J. (1958). Objective recording and biomechanics of pathological gait. Annals of the New York Academy of Sciences, 74, 86-109.