

## **FOUNDATIONAL STUDIES RELATED TO FOOTWEAR IMPRESSION EVIDENCE**

### **Introduction**

The following is a list of research that has been conducted in the forensic footwear discipline, divided into particular topics.

For a list of active research being conducted in the field of footwear and tire impression evidence, please refer to the [active research and development projects](#) at TreadForensics.com.

Please note, there are currently two on-going decision analysis studies to test the accuracy of examiner opinions (i.e. black box) being conducted at West Virginia University and the Federal Bureau of Investigation Forensic Laboratory. These types of studies were singled out by PCAST as needed to establish the scientific validity and degree of reliability of footwear impressions evidence.

As this is a “living” document, it will be updated as new research is released. However, should you have any references you feel need to be added or have any comments regarding the list, please [email the chair](#) of the IAI Footwear & Tire Track Examination Sub-Committee.

### **STUDIES THAT RELATE TO THE RELIABILITY AND EXAMINATION OF CLASS (MANUFACTURED) CHARACTERISTICS**

Benedict, I. et. al. (2014), Geographical Variation of Shoeprint Comparison Class Correspondence, *Science and Justice*, 54(5): P. 335-337.

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

Bodziak, W. J. (1986), Manufacturing Processes for Athletic Shoe Outsoles and Their Significance in the Examination of Footwear Impression Evidence, *Journal of Forensic Sciences*, 31(1): P. 153-176.

Champod, C., Voisard, R., Girod, A. (2000), A Statistical Study of Air Bubbles on Athletic Shoe Soles, *Forensic Science International*, 109(2): P. 105-123.

Davis, R. et. al. (1977), A Survey of Men’s Footwear, *Journal of the Forensic Society*, 17(4): P. 271-285.

Gross, S. et al. (2013), The Variability and Significance of Class Characteristics in Footwear Impressions, *Journal of Forensic Identification*, 63(3): P. 332-351.

Hamm, E.D. (1989), The Individuality of Class Characteristics in Converse All-Star Footwear, *Journal of Forensic Identification*, 39(5): P. 277-292.

Hancock, S. et. al. (2012), The Interpretation of Shoeprint Comparison Class Correspondence, *Science and Justice*, 52(4): P. 243-248.

Kainuma, A. (2005), Manufacturing Variations in a Die-Cut Footwear Model, *Journal of Forensic Identification*, 55(4): P. 503-517.

## Foundational Studies Related to Footwear Impression Evidence

Jay, C.B. and Grub, M.J. (1985), Defects in Polyurethane-soled Athletic Shoes – Their Importance to the Shoeprint Examiner, *Journal of the Forensic Science Society*, 25: P. 233-238.

Keijzer, J. (1990), Identification Value of Imperfections in Shoe with Polyurethane Soles in Comparative Shoeprint Examination, *Journal of Forensic Identification*, 40(4): P. 217-223.

Music, D.K., Bodziak, W.J. (1988), Evaluation of the air bubbles present in polyurethane shoe outsoles as applicable in footwear impression comparisons, *Journal of Forensic Sciences*, 33(5): P. 1185-1197.

Nisida, T., Suemoto, A. (2008), A Study of a Production Characteristic Caused by the Footwear Sole, *Japanese Journal of Forensic Science and Technology*, Vol. 13(1): P. 101-106.

Parent, S. (2010), The Significance of Class Associations of Footwear Evidence, Unpublished, Presented at the 2010 Impression and Pattern Evidence Symposium, Clearwater Beach, Florida.

Zmuda, C.W. (1953), Identification of Crepe-Sole Shoes, *Journal of Criminology, Criminal Law and Police Science*, 44(3): P. 374-378.

### **STUDIES THAT RELATE TO THE RELIABILITY AND EXAMINATION OF WEAR AND RANDOMLY ACQUIRED CHARACTERISTICS**

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): P. 199-205.

Banks, R. et. al. (2010), Evaluation of the Random Nature of Acquired Marks on Footwear Outsoles, Presented at the 2010 Impression and Pattern Evidence Symposium, Clearwater Beach, Florida.

Bodziak, W. et. al. (2012), Determining the Significance of Outsole Wear Characteristics During Forensic Examination of Footwear Impression Evidence, *Journal of Forensic Identification*, 62(3): P. 254-276.

Chen, J., Donovan, J.A. (1994), The Relation of Schallamach Pattern to Rubber Properties and Wear Conditions, *Rubber World*, 211(2) P. 23-27.

Davis, R.J, Keeley, A. (2000), Feathering of Footwear, *Science and Justice*, 40(4): P. 273-276.

DeHaan, J. D. (1987), Wear Characteristics of Men's Footwear, Presented at the International Association of Forensic Science meeting, Vancouver, B.C.

Deskiewicz, Kevin J., (2000), Schallamach Pattern on Shoe Outsole Acknowledged by Court in Footwear Identification, *Journal of Forensic Identification*, 50(1): P. 1-4.

Facey, O.E., Hannah, I.D., Rosen, D. (1992), Shoe Wear Patterns and Pressure Distribution Under Feet and Shoes Determined by Image Analysis, *Journal of Forensic Science Society*, 32(1): P. 15–25.

Fruchtenicht, T.L., Herzig, W.P., Blackledge, R.D. (2002), The Discrimination of Two-Dimensional Military

## Foundational Studies Related to Footwear Impression Evidence

Boot Impressions Based on Wear Patterns, *Science & Justice*, 42(2): P. 97-104.

Hamburg, C. & Banks, R. (2010), Evaluation of the Random Nature of Acquired Marks on Footwear Outsoles, Presented at the 2010 Impression and Pattern Evidence Symposium, Clearwater Beach, Florida.

Hara, T. (2004), Qualitative Evaluation of the Distinguishing Characteristics in Footprints Identification and Their Evidential Values, *Japanese Journal of Science and Technology for Identification*, 9(1): P. 59-63.

Hayes, A. J. (1994), Factors that influence wear on shoes, Presented at the International Symposium on the Forensic Aspects of Footwear and Tire Impression Evidence, FBI Academy, Quantico, VA.

LeMay, J. (2013), Accidental Characteristics in a Footwear Outsole Caused by Incomplete Blending of Fillers in the Outsole Rubber, *Journal of Forensic Identification*, 63(5): P. 525-530.

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

Sheets, H. et. al. (2013), Shape Measurement Tools in Footwear Analysis: A Statistical Investigation of Accidental Characteristics Over Time, *Forensic Science International*, 232(1-3): P. 84-91.

Speir, J.A., Richetelli, N., Fagert, M., Hite, M., Bodziak W. J. (2016), Quantifying Randomly Acquired Characteristics on Outsoles in Terms of Shape and Position, *Forensic Science International*, 266: P. 399-411.

Speir, J.A., Richetelli, N., Nobel, M., Bodziak, W. (2017), Quantitative Assessment of Similarity Between Randomly Acquired Characteristics on High Quality Exemplars and Crime Scene Impressions via Analysis of Feature Size and Shape, *Forensic Science International*, 270: P. 211–222.

Speller, H. C. (1949), The Identification of Crepe Rubber Sole Impressions, *The Police Journal*, 22: P. 269-274.

Stone, R.S., (2006), Footwear Examinations: Mathematical Probabilities of Theoretical Individual Characteristics, *Journal of Forensic Identification*, 56 (4): P. 577-599.

Tart, M.S., Downey, A.J, Goodyear, J.G., Adams, J. (1996), The Appearance and Duration of Feathering as a Feature of Wear, *The Forensic Science Service, FSS Report No. RR 786*.

Tart, M.S., Adams, J., Ohene, A. (1999), Wear Patterns: Location and Rate of Advancement, *The Forensic Science Service, FSS Report No. RR 801*.

Tart, M.S., Downey, A.J, Goodyear, J.G., Adams, J., Ohene, A. (1998), Feathering, Transient Wear Features and Wear Pattern Analysis: A Study of the Progressive Wear of Training Shoe Outsoles, *Information Bulletin for Shoeprint and Toolmark Examiners*, 41(1): P. 51-68.

Toso, B. & Girod A. (1997), Evolution of Random Characteristics (Appearance and Disappearance, Presentation conducted at the First European Meeting of Forensic Science, Lausanne, Switzerland.

## Foundational Studies Related to Footwear Impression Evidence

Wilson, H. (2012), Comparison of the Individual Characteristics in the Outsoles of Thirty-Nine Pairs of Adidas Supernova Classic Shoes, *Journal of Forensic Identification*, 62(3): P. 194-203.

Wyatt, J. M., Duncan, K., Trimpe, M. A. (2005), Aging of Shoes and its Effect on Shoeprint Impressions, *Journal of Forensic Identification*, 55(2): P. 181-188.

Yekutieli, Y., Shor, Y., Wiesner, S., Tsach, T. (2016), Expert Assisting Computerized System for Evaluating the Degree of Certainty in 2D Shoeprints, <https://www.ncjrs.gov/pdffiles1/nij/grants/250336.pdf>

### **STUDIES THAT RELATE TO EXAMINER CONCLUSIONS**

Bodziak, W.J. (2012), Traditional Conclusions in Footwear Examinations vs. the Use of the Bayesian Approach and Likelihood Ratio: a Review of a Recent UK Appellate Court Decision, *Law, Probability and Risk*, 11(4): 279-287.

Collaborative Testing Services Inc., (2010), CTS Statement on the Use of Proficiency Testing Data for Error rate Determination, [www.collaborativetesting.com](http://www.collaborativetesting.com).

Duffy, K., Hammer, L., Daeid, N., Fraser, J., (2013), A Study of the Variability in Footwear Impression Comparison Conclusions, *Journal of Forensic Identification*, 63(2): P. 205-218.

Evet, I.W., Lambert, J.A., Buckleton, J.S., (1998), A Bayesian Approach to Interpreting Footwear Marks in Forensic Casework, *Science & Justice*, 38: P. 241-247.

Kerstholt J.H., Paashuis R., Sjerps, M. (2007), Shoe Print Examinations: Effects of Expectation, Complexity and Experience, *Forensic Science International*, 165(1): P. 30-34.

Majamaa, H., Ytti, A. (1996), Survey of Conclusions Drawn of Similar Footwear Cases in Various Crime Laboratories, *Forensic Science International*, 82(1): P. 109-120.

Peterson, J.L., Markham, P. (1995), Crime Lab Proficiency Testing Results, 1978-1991, II: Resolving Questions of Common Origin, *Journal of Forensic Sciences*, 40(6), 1009-1029.

Raymond, J., Sheldon, P., (2015), Standardizing Shoe Mark Evidence- An Australian and New Zealand Collaborative Trial, *Journal of Forensic Identification*, 65(5): 868-883.

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): P. 380-384.

Skerrett, et al., (2011), A Bayesian Approach for Interpreting Shoemark Evidence in Forensic Casework: Accounting for Wear Features, *Forensic Science International*, 210(1-3): P. 26-30.

Ytti, A., Majamaa, H., Virtanen, J. (1998), Survey of the Conclusions Drawn of Similar Shoeprint Cases, Part II, *Information Bulletin for Shoeprint and Toolmark Examiners*, 4(10): P. 157-169.

**STUDIES THAT RELATE TO  
AUTOMATED CLASSIFICATION OF FOOTWEAR, DATABASE CREATION AND INTELLIGENCE**

AlGarni, G., Hamiane, M., (2008), A Novel Technique for Automatic Shoeprint Image Retrieval, *Forensic Science International*, 181(1-3): P. 10-14.

Ashley, W. (1996), What Shoe Was That? The Use of Computerised Image Database to Assist in Identification, *Forensic Science International*, 82(1): P. 7-20.

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*, 82(1): P. 53-58.

Bowen, R., Schneider, J. (2007), *Forensic Databases: Paint, Shoe Prints, and Beyond*, *National Institute of Justice Journal*, 58: P. 34-38.

Dardi, F., Cervelli, F., Carrato, S. (2009), An Automatic Footwear Retrieval System for Shoe Marks from Real Crime Scenes, *Proceedings of the 6th International Symposium on Image and Signal Processing and Analysis*, P. 668-672.

David, R. (1981), An Intelligence Approach to Footwear and Toolmarks, *Journal of the Forensic Science Society*, 21: P. 183–193.

Gao, B., Allinson, N.M. (2009), A Novel Model-Based Approach for 3D Footwear Outsole Feature Extraction, *Proceedings of the 6th International Symposium on Image and Signal Processing and Analysis*, P. 673-677.

Geradts, Z., Keijzer, J. (1996), The Image-Database REBEZO for Shoeprints with Developments on Automatic Classification of Shoe Outsole Designs, *Forensic Science International*, 82(1): P. 21-31.

Girod, A. (1996), Computerized Classification of the Shoeprints of Burglar's Soles, *Forensic Science International*, 82(1): P. 59-65.

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*, 46(2): P. 79-89.

Hire, V.R., Shaikh, F.I., Jadhav, J.B., Joshi, M.V. (2012), A Novel Automated Shoeprint Matching Technique for use as Forensic Evidence in Criminal Investigation, *International Journal of Computer Applications*, 48(4): P. 25-31.

Jing, M.Q., Ho, W., Chen, L.H. (2009), A Novel Method for Shoeprints Recognition and Classification, *International Conference on Machine Learning and Cybernetics*, P. 2846-2851.

Keijzer, J., Geradts, Z., Keereweer, I. (1995), Nationwide Classification System for Shoe Outsoles Designs, *Journal of Forensic Identification*, 45(1): P. 30-37.

Lai, M.Y., Wang, L.L. (2008), Automatic Shoe-Pattern Boundary Extraction by Image-Processing Techniques, *Robotics and Computer-Integrated Manufacturing*, 24: P. 217-227.

## Foundational Studies Related to Footwear Impression Evidence

Lin, G., Elmes, G., Walnoha, M., Chen, X. (2009), Developing a Spatial-Temporal Method for the Geographic Investigation of Shoeprint Evidence, *Journal of Forensic Sciences*, 54(1): P. 152–158.

Luostarinen, T., Lehmuusola, A. (2014), Measuring the Accuracy of Automatic Shoeprint Recognition Methods, *Journal of Forensic Sciences*, 59(6): P. 1627-1634.

Majamaa, H. (2000), Footwear Databases Used in Police and Forensic Laboratories, *Information Bulletin for Shoeprint/Toolmark Examiners*, 6: P. 133–157.

Mikkonen, S., Suominen, V., Heinonen, P. (1996). Use of Footwear Impressions in Crime Scene Investigations Assisted by Computerised Footwear Collection System, *Forensic Science International*, 82(1): P. 67-79.

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*, 39(5): P. 1227-1236.

Milne, B. (2013), *Forensic Intelligence*, CRC Press.

Milne, R. (2001), Operation Bigfoot, a Volume Crime Database Project, *Science & Justice*, 41: P. 215-217.

Napier, T.J. (2002). Scene Linking using Footwear Mark Databases, *Science & Justice*, 42 (1): P. 39-43.

Natarajan, N., Ranjit, G., M. (2005), Computer Assisted Analysis of Footprint Geometry, *Journal of Forensic Identification*, 55(4): P. 489-498.

Patil, P.,M., Kulkarni, J.V. (2009), Rotation and Intensity Invariant Shoeprint Matching using Gabor Transform with Application to Forensic Science, *Pattern Recognition*, 42(7): P. 1308-1317.

Pavlou, M., Allinson, N., M. (2009), Automated Encoding of Footwear Patterns for Fast Indexing, *Image and Vision Computing*, 27(4): P. 402–409.

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

Saxena, A., Khosla, N., Venkataraman, V. (2013), Building an Image-Based Shoe Recommendation System, Stanford University.

Tang, Y., Kasiviswanathan, H., Srihari, S. (2012), An Efficient Clustering-Based Retrieval Framework for Real Crime Scene Footwear Marks, *International Journal of Granular Computing, Rough Sets and Intelligent Systems*, 2(4): P. 327-360.

Tang, Y., Srihari, S. N., Kasiviswanathan, H. (2010), Similarity and Clustering of Footwear Prints, *IEEE International Conference on Granular Computing*, P. 459-464.

## Foundational Studies Related to Footwear Impression Evidence

Wei, Chia-Hung. (2013), The Use of Scale-Invariance Feature Transform Approach to Recognize and Retrieve Incomplete Shoeprints, *Journal of Forensic Sciences*, 58(3): P. 625-630.

### **TERMINOLOGY AND TEXTS RELATED TO THE EXAMINATION OF FOOTWEAR EVIDENCE**

Abbot, J. (1964), *Footwear Evidence*, Charles C. Thomas.

Bodziak, W. (2000), *Footwear Impression Evidence* 2<sup>nd</sup> Ed., CRC Press.

Bodziak, W. (2016), *Forensic Footwear Evidence*, CRC Press.

Cassidy, M. (1980), *Footwear Identification*, Canadian Government Publishing Centre.

Girod, A., Champod, C., Ribaux, O. (2008), *Traces de Souliers*, Presses Polytechniques et Universitaires Romandes.

Hilderbrand, D. (1999), *Footwear, the Missed Evidence*, Staggs Publishing Company.

Sharma, B. (1980), *Footprints- Tracks and Trails in Criminal Investigation and Trials*, Central Law Agency.

Scientific Working Group for Shoeprint and Tire Tread Evidence (SWGTHREAD)

Standard for Terminology Used for Forensic Footwear and Tire Impression Evidence

[http://www.swgtread.org/images/documents/standards/published/swgtread\\_15\\_terminology\\_evidence\\_201303.pdf](http://www.swgtread.org/images/documents/standards/published/swgtread_15_terminology_evidence_201303.pdf)