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Shape measurement tools in footwear analysis: A statistical investigation of accidental characteristics over time

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ABSTRACT

Presence of accidental characteristics on footwear strengthens the linkage of a given piece of footwear to a footwear impression left at a crime-scene. Thus an understanding of rate of appearance and disappearance of these characteristics is of importance. Artificial cut-marks, 1–3 mm in depth, were cut into outsoles of 11 pairs of athletic shoes. Loss of these cut-marks and acquisition of new accidental characteristics/wear patterns were monitored over a seven-week time-span. Feature-vector methods were used to acquire multivariate data on wear/acquisition rates. A repeatability study indicated the feature vector method could detect small differences among shoes relative to measurement uncertainty. The shoes displayed a strong retention of artificial cut-marks over the study interval. Net rate of wear was 0.1% of the textured area of the shoe per week, predominantly in the heel and ball area. Results indicate accidental characteristics can reasonably be expected to persist over time.

1. Introduction

Footwear impression evidence has a long history in both the investigation and prosecution of criminal activity [1,2]. The typical use is to link a given individual to a crime scene; like all evidence, the strength of that connection may vary tremendously. While the concept of "individualization" or "uniqueness" in forensic science may be under debate [3–7], it is clear that some types of evidence (fingerprints and DNA) can reach high enough levels of confidence in the association of evidence to an individual so as to constitute a substantial linkage between the crime scene evidence and a considered individual source. Understanding how to accurately estimate and state strength of forensic evidence appears to be of substantial concern at present [8–10].

In footwear impression evidence, class characteristics of a shoe do not uniquely identify a shoe, but have the potential to provide useful and informative information about the association between a suspect and a crime-scene [1]. Such data might, for example, exclude some members of a suspect population. In some cases, class characteristics might provide some degree of association of an individual shoe to a scene. Accidental characteristics would provide additional evidence that is typically thought of as being "unique" to a given shoe, and thus provides an exceptional strong connection of an individual shoe to a scene [1,2,7,11]. To evaluate the strength of accidental characteristics and/or wear as evidence however, requires some background information about the rate of acquisition of accidental characteristics, the extent to which these characteristics are retained on the shoe, and the rate at which wear occurs on shoes [11].

Despite the importance of accidental characteristics on shoes, there have been relatively few systematic studies on rate of appearance of accidental characteristics on shoes [1,2,12–15], or on the persistence of those characteristics over time as the shoes are worn. This study aimed to contribute to the basic scientific background of footwear impression analysis by analyzing the rate at which wear occurred in a particular model of Nike athletic footwear, using numerical approaches to quantifying both the location and magnitude of wear. In addition to a detailed study of wear (interpreted here as the removal of the original texture on the outsole of the shoe) over time, the rate of loss of artificially created individualizing characteristics (cuts and holes in the tread pattern) was recorded, as was the rate of appearance of new, accidental characteristics. The results of this study may help complement previous work on these questions, addressing basic background issues as raised by the NAS report [8] and SWGTREAD [16]. The study used a measurement approach known as feature vector analysis, verifying the utility of this approach as applied to the study of footwear [13] impression evidence.

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2. Methodology

2.1. Materials

Eleven pairs of the same style and size (men's size 10) Nike Air Force 1 shoes with the common Air Force 1 tread pattern of concentric circles and parallel lines were purchased from a local shoe store. On the outsole of each shoe, a set of purposely-produced cut-marks was made, attempting to mimic randomly acquired accidental characteristics. A dental handpiece (drill) was used to make the artificial cut-marks. Cuts of 2–3 mm depth were made in several locations on the shoe using a circular cutting blade and holes or dimples of a depth of 1 mm were made with a dental round bur (Fig. 1). These cuts were made in a fixed set of locations on the outsoles by two different operators. A template or cutting guide was not used and thus the "accidental characteristics" created were highly similar but not identical.

All necessary Institutional Review Board approvals were obtained for volunteer participation in the study. The volunteer shoe-wearers consisted of male students from the SUNY at Buffalo Dental program. All shoes were scanned prior to wear on a HP optical computer scanner prior to distribution to the volunteers, recording an image of the bottom of the shoe at 300 dpi. Since our experimental procedure relies on the analysis of digital images, we scanned the shoes directly, rather than obtaining an inkless or inked impression and then digitizing the impression. An ABFO #2 scale was also visible in each image allowing for scaling of the image.

The volunteers were asked to simply wear the shoes in their daily lives in a manner "similar" to their normal use of shoes. No attempt was made to record the amount of use each shoe received, or to standardize the use, so this study reflects average usage, much as in the studies by Cassidy [2] or Fruchtenicht et al. [15].

The shoes were scanned again at 300 dpi (same scanner used) after 2, 4 and 7 weeks of use by the students. The seven-week interval occurred (rather than 6) due to the timing of the University's spring break vacation relative to the study interval.

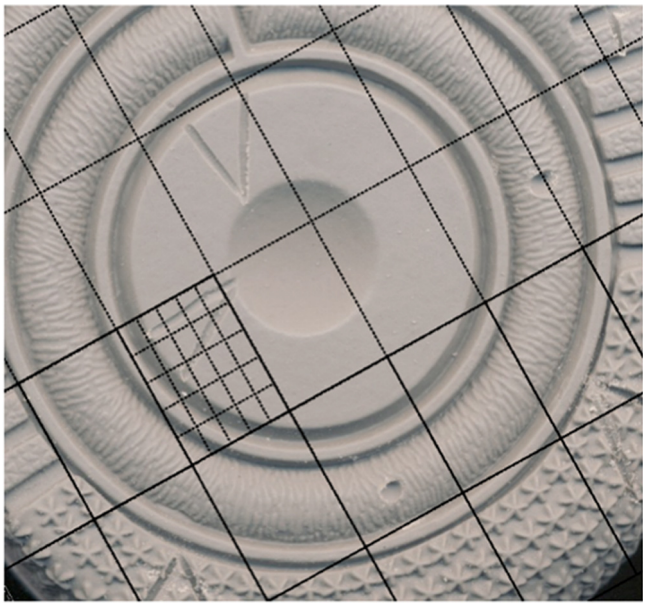

Fig. 2. The grid and subgrid system superimposed on the center heel region of a scanned shoe. Note the level of detail on the edges of the cut-marks.

2.2. Methods: feature vectors of shoes

To capture information about both accidental characteristics and wear patterns on the outsoles of the shoes, a feature vector approach was used. This is similar to that used by Petraco et al. [13] to study footwear impressions. This approach to recording both accidental characteristics and wear allows for both multivariate statistical analysis of the location and size of characteristics as well as the wear. It also allows for simple univariate measurements of net accidental characteristics on the shoes. Unlike Petraco et al. [13] a rectangular grid was used that covered the entire outsole of the shoe, rather than the more complex curved grid system covering only the ball of the foot as adapted from the work of Kennedy et al. [17,18] on barefoot impressions. While the square grid system does not conform to the outline of the sole of these shoes, it is an approach that may be readily adapted to a wide range of sole shapes.

Computer software was written in Matlab (version 2012a) [19], making use of the image processing toolbox, to record the feature vectors describing wear and accidental characteristics (software available by request from the authors). For this study, a rectangular grid of 20 cells along the long axis of the shoe was used, with 10 cells across the width of the shoe. The grid was aligned along the left side of the shoe, with the horizontal axis intersecting the rearmost point of the heel, perpendicular to the left side of the shoe. This mimics the alignment one would get by placing the shoe in a cardboard box, and aligning the left side of the shoe with the left side of the box, and sliding the shoe along the side of the box until the heel hit the edge of the box. This approach appears to produce consistent alignment of the shoe with the grid in a repeatable and straightforward manner.

Once the grid was in place, a human operator recorded the percentage of each grid cell covered by accidental characteristics and by wear. The operator examined each grid cell with the aid of a superimposed square "subgrid" of 25 boxes within each individual cell to aid in the estimation of the percentage of the cell covered by an accidental characteristics or wear pattern (Fig. 2). The area of the cell covered by accidental characteristics and wear was then recorded based on visual inspection of these subgrid boxes, in increments of 1/4 of the each subgrid. Since each of the subgrid boxes was 4% of the total area of a cell, a resolution of roughly 1% of the area of each cell was achieved. Not all of the 200 cells in the 20 × 10 grid were occupied

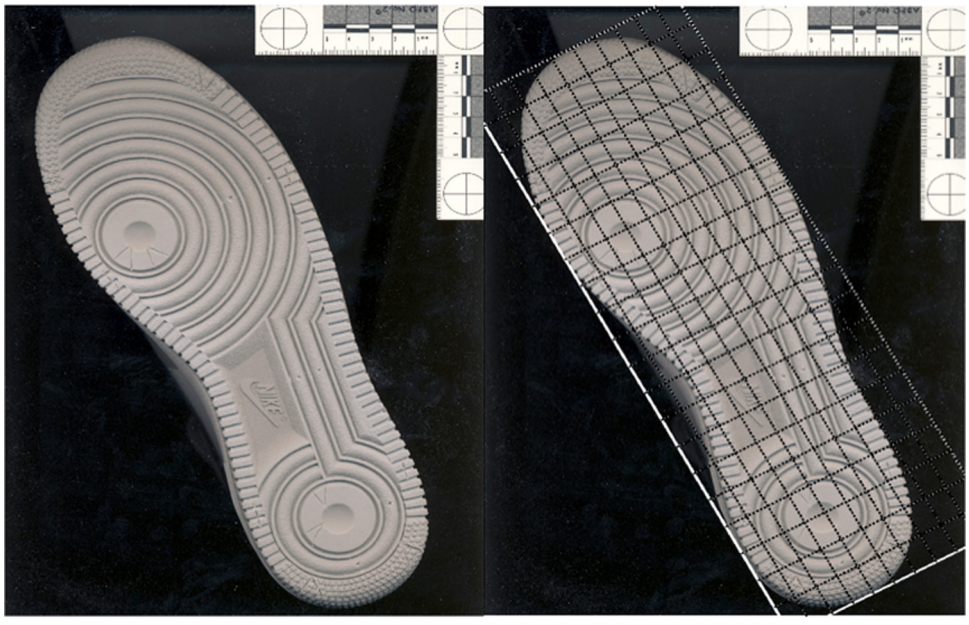

Fig. 1. (Left): Sole of the shoe used in the study showing artificial cut-marks cut into the sole using a dental drill, prior to any use of the shoe. (Right): The same image with the 200 cell grid superimposed on it.