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Abstract

Wear is defined as the erosion of a shoe's outsole or the loss of tread pattern, and it happens gradually over time with use. After a shoeprint is collected from a crime scene, it is questioned whether an individualization can be made if an exemplar is created after additional use of the shoe. The shoes of ten volunteers at San Jose State University were analyzed over a period of 40-45 days. Wear and Randomly Acquired Characteristics (RACs) were analyzed over time to determine if there were any observable changes or additions to the already present wear. It was hypothesized that initial wear and RACs would persist over time. The present wear retained over time throughout the study. Sixty-five percent of the shoes showed no additional wear or RACs. The remaining 35% showed at most 1 cm of additional loss of tread pattern. Therefore, it is possible for an individualization after 40-45 days between evidence collections. This study was limited by the time allotted. Future studies will need to investigate wear over many months of use.

Keywords

footwear evidence, forensic science, wear characteristics, randomly acquired characteristics, pattern analysis

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Wear is defined as the erosion of a shoe's outsole or the loss of tread pattern, and it happens gradually over time with use. After a shoeprint is collected from a crime scene, it is questioned whether an individualization can be made if an exemplar is created after additional use of the shoe. The shoes of ten volunteers at San Jose State University were analyzed over a period of 40-45 days. Wear and Randomly Acquired Characteristics (RACs) were analyzed over time to determine if there were any observable changes or additions to the already present wear. It was hypothesized that initial wear and RACs would persist over time. The present wear retained over time throughout the study. Sixty-five percent of the shoes showed no additional wear or RACs. The remaining 35% showed at most 1 cm of additional loss of tread pattern. Therefore, it is possible for an individualization after 40-45 days between evidence collections. This study was limited by the time allotted. Future studies will need to investigate wear over many months of use.

Introduction

Footwear imprints are a type of pattern evidence that can be valuable in a criminal investigation. Much like fingerprints, shoes leave behind unique imprints or impressions that can be examined by investigators. They can be found on a variety of surfaces including glass, wood, concrete, tile, mud, sand, and snow. Footwear imprints can be collected for analysis and compared to an exemplar shoe to determine if the shoe is the source of the imprint.

A footwear analyst considers three types of characteristics. The first is class, in which a characteristic is shared by two or more shoes. This includes brand, model, and size that will have corresponding tread designs and dimensions. Examiners can identify the type of shoe that left an imprint by searching tread patterns in databases created by manufacturers, the FBI, and other agencies. Class characteristics reduce the possible number of shoes that could have made an imprint, but alone they are not a basis for an individualization. Nonetheless, it is still powerful for eliminating shoes as the source.

Individual characteristics are the second type and include features on footwear outsoles that are not shared by any other shoe, commonly referred by experts as Randomly Acquired Characteristics (RACs). These characteristics on the outsoles are unique, accidental, and include random damage such as tears, nicks, holes, and cuts that are the result of its use. The changes to an outsole are evident on the footwear and sometimes the footwear imprint. More importantly, these characteristics accumulate over time, making footwear outsoles increasingly distinguishable.

Wear is the third characteristic examiners use to analyze footwear evidence. Wear is the result from the natural erosion of a shoe's sole resulting from its use. The position, condition,

amount, location, and pattern are specific characteristics that are considered while examining wear damage. Wear, like RACs, is commonly reflected in footwear imprints and is helpful for comparisons to include or exclude a potential source of an imprint.

These features continue to change as they are worn, so it is questioned if there are observable differences of wear or RACs between an imprint collected at a crime scene and an imprint created weeks later by an exemplar shoe. This study analyzed imprints of shoe soles containing variable amounts of wear damage and compared them to imprints made after 40-45 days of consistent use. It was hypothesized that footwear imprints with sufficiently distinctive patterns of wear or RACs can be observed to persist over time with little or no change. The results of this study validate previous research and address issues with pattern evidence raised by the National Academy of Sciences (NAS) report and the Scientific Working Group for Shoeprint and Tire Tread Evidence (SWGTTREAD).

Literature Review

Footwear pattern research in the area of wear damage and RACs progresses in a way that reflects development in information and consideration of these characteristics. Recent studies have examined the discriminatory power of RACs and concluded these features should be considered as individualizing, since the randomness and uniqueness of these patterns are persistent with continued wear (Adair, Lemay, McDonald, Shaw, & Tewes, 2007; Cassidy, 1980; Sheets, Gross, Langenburg, Bush, & Bush, 2013; Wilson, 2012). Previous studies also consider general wear patterns as class characteristics and are proven effective and valid for excluding shoes as a source of an impression (Bodziak, Hammer, Johnson, & Schenck, 2012;

Cassidy, 1980; Gross, Jeppesen, & Neumann, 2013; Hancock, Morgan-Smith, & Buckleton, 2012).

Accidental Damage

The Mount Bierstadt Study supports the hypothesis that accidental characteristics acquired on the outsoles of shoes are rare and can be used to individualize a shoe (Adair et al., 2007). The study utilized 12 pairs of unused boots worn by six participants. Each participant wore two pairs: one while hiking up Mount Bierstadt and the other pair while hiking down. The length of the hike is approximately 3.5 miles in each direction, and the elevation of Mount Bierstadt is 14,065 feet. After the hike, the authors examined the boots and determined there were enough observable RACs to individualize each boot. Each participant wore two pairs of the same type of footwear and, under the same conditions of activity, still resulted in creating individual characteristics in each boot. Although the authors studied a small sample, the results demonstrated that RACs found on footwear outsoles are randomly produced and may be created by a single step.

A similar study confirms the random formation of RACs and supports the use of RACs for individualization (Wilson, 2012). This study examined 39 pairs of shoes and controlled major variables such as using the same type of shoe, one wearer, and the amount of wear (Wilson, 2012). Wilson (2012) counted RACs for comparison between shoes. Even though shoe soles contained a comparable number of features, they were easily distinguished by differences in size, location, and shape of the RACs present. The authors concluded RACs have sufficient discriminatory power to be considered individual characteristics.

General Wear

Bodziak and colleagues (2012) evaluated the comparative value of general wear and more advanced damage such as nicks and holes. The authors analyzed the hypothesis that more than one shoe will contain similar general wear. There is considerable empirical evidence and overall acceptance that RACs, such as nicks and tears, provide a basis for individualization, but the same cannot be stated for general wear. The authors conducted a survey among the international community of footwear pattern analysts. The results of the survey indicate a consensus that general wear reduces the number of shoes that could have made the given impression, but it is not used for sole individualization. Therefore, this study concluded that general wear is a class characteristic. The authors reported that

Shoes in the closet of an individual, assuming they have many varied types of footwear and wear them for a range of purposes, will have general wear that appears similar when compared to some shoes and different from other shoes. For example, wear may appear similar on shoes of the same design belonging to the same person if the shoes have been used for a similar purpose. (Bodziak et al., 2012, p. 258).

Two important questions must be asked when formulating a conclusion regarding wear between impressions: Is there an agreement between the position and degree of general wear, or lack thereof, in both the questioned and known impressions, and what is the relative value of the wear present? (Bodziak et al., 2012). These questions aid in determining the significance of wear in a given impression. The authors also note three important factors to consider during an evaluation of wear: time interval between impressions, clarity and distortion of an

impression, and manufacturing characteristics that can be mistaken for wear.

Assessing class characteristics is still essential in narrowing down the number of possible shoes that made an impression. Hancock et al. (2012) collected 500 footwear impressions from student volunteers in New Zealand. These impressions were compared against each other for corresponding class characteristics. In addition, partial prints were created from a subset of impressions to simulate the type of footwear pattern evidence typically found at crime scenes. Roughly 97% of the patterns was represented only once in the sample. Only 3 of the 500 observations had corresponding patterns for the most common shoe brand, Converse Chuck Taylor All Star. For the partial prints, roughly 94% of the sample was considered unique. A similar study analyzed 402 impressions retrieved from casework of the Minnesota Bureau of Criminal Apprehension for comparison of class characteristics (Gross et al., 2013). Of the 80,601 comparisons, only one comparison required an analysis of wear to be distinguished. These studies support both the fundamental value and effectiveness of using class characteristics, including general wear damage, in excluding possible sources of imprints.

Discrimination Power Over Time

Sheets et al. (2013) conducted a study on retention rates of artificial cut-marks on 11 pairs of athletic shoes. The examiners created these marks in the same location and size on each shoe. They then monitored loss of the cut-marks due to erosion and acquisition of new wear damage and RACs over a period of seven weeks. They analyzed their data using principal component analysis (PCA), a feature vector method commonly utilized for facial recognition. The authors noticed intra-shoe variation was

considerably less than inter-shoe variation. In other words, each shoe matched itself better in comparison to all the other shoes despite any accumulated wear.

Cassidy (1980) established some idea of how long cuts and abrasions might last by making impressions of a new pair of boots made with rubber soles. The author identified and recorded the duration of 36 characteristics by noting the time they first appeared and then again upon their disappearance. The study found 33% of characteristics persisted over 59-68 days, and more than 50% of characteristics persisted for at least 48 days. Cassidy (1980) concluded that an identification could possibly be made after many weeks; therefore, footwear evidence should not be discarded.

Methodology

Materials

Ten volunteer students from San Jose State University were selected for analysis of their personal footwear. The shoes initially had variable amounts of wear depending on the volunteer. A Steel-Grip® Fingerprint Ink Roller was used to coat Grade “A” Fingerprint Slab Ink on volunteers’ shoes. White printer paper was used to collect the imprints and was subsequently scanned electronically with an iPad Pro for analysis. The software Notability was used to compare the wear over time with the scanned ink imprints.

Method

The volunteers were accepted for this study without consideration of the brand, amount of wear, size, age, or other class characteristics that describe their personal shoes. Volunteers were asked to wear their shoes as they normally would for six weeks. A record was kept by each volunteer of the amount of use each pair of shoes received by providing the number of days worn

during the study. The personal accounts reflected an average use with all but one volunteer wearing their shoes at least 50% of the total days allotted for the study; the exception wore their shoes 30% of the total days. A list of variables in this study are identified in Table 1.

Independent	Dependent	Control	Background
Time	Wear on shoe sole	Same wearer	Gait
		Regular use for 6 wks	Level of activity
		Gait while imprinting	Type of use
		Same imprinting method	Sole material
		Same time interval	Terrain

Table 1. A list of independent, dependent, control, and background variables.

Each volunteer's shoes were inked on three occasions in three-week intervals. Before imprinting, shoes were cleaned of loose debris with a lint roller, and a photo was taken of the outsole. The ink was applied on flattened cardboard and rolled out with the ink roller for coating. The shoes were then coated by the ink roller. Volunteers were instructed to step onto white paper by planting their foot from heel to toe to ensure a complete imprint. Each imprint was assigned a code for record keeping, and the size and model of the shoe were also recorded.

The prints were scanned electronically with an iPad Pro and uploaded to Notability, an application software used for PDF

annotation. Qualitative observations of any wear damage on the outsoles and its appearance in the imprint were recorded. Each print was compared to itself to determine if there were any change or accumulation of wear reflected in the imprint over time. Characteristics were not rated on their significance. Only general observations were recorded.

Data and Discussion

Accumulation of Wear

Nicks, scratches, and holes found on the sole of the shoe were not reflected in most of the imprints. This could be due to many factors, including the amount of pressure the volunteer used when making the imprint, causing a heavier or lighter ink transference. No shoes acquired new RACs (tears, holes, nicks, etc.) that were detectable in the imprints during the study. Every shoe that originally contained RACs and general wear retained these characteristics over time. One shoe (Volunteer 8's right shoe, 8R) showed an increase of damage to a tear, but this change was not reflected in the imprints (Figure 1).





Figure 1. A tear increased in damage between the 2nd and 3rd imprints, but it is not easily distinguished in the imprints.

Sixty-five percent of the imprints showed no evidence of accumulated wear. The other thirty-five percent of the shoes showed less than 1 cm of additional pattern loss in one or two areas of wear. Much of the shoes' tread pattern, wear, and imprint otherwise appeared consistent throughout the study. For example, Figure 2 shows the letter "K" slowly disappearing from Volunteer 2's left shoe, but the other areas of wear persisted in appearance.



Figure 2. The disappearance of the letter “K” over six weeks in three-week intervals. Note the persistence of other areas of wear. (Volunteer 2’s left shoe).

The volunteer (Volunteer 9’s left & right shoe, 9L & 9R) that showed the most accumulation of wear in their shoes reported they wore their shoes for a high level of activity at a music festival

(Figure 3). However, a volunteer (Volunteer 10's left & right shoe, 10L & 10R) that wore their shoes 87.5% of the days allotted for the study showed no evidence of increased wear (Figure 4). The brand Volunteer 10 used, Vans, was also the most common brand of shoe in this study and reflected the least amount of wear for other volunteers that also wore them. This demonstrates the material and the level of activity can have an influence on the accumulation of wear.



Figure 3. Pattern disappears and emboldens with ink over time, showing an accumulation of wear in the identified areas. (Volunteer 9's right shoe. From left to right: First, second, and third imprints.)

Ink Transference

It is important to note how wear transfers in an ink imprint because there are factors that can affect an examiners ability to evaluate wear characteristics. First, it was impossible to create identical imprints. The pressure in which the volunteer steps, the amount of ink coating the shoe, and the volunteer's gait can vary between imprints and can therefore affect the appearance of an imprint. Secondly, wear was observed as smears and loss of pattern in an imprint. If there is distortion during ink transference, it could be mistaken as wear. For example, without photo documentation or an examination of the actual shoe, the thick pattern transference identified in the first imprint in Figure 4 could be mistaken as wear during an evaluation. Experience and training are required to differentiate between poor ink transference and characteristics of wear.

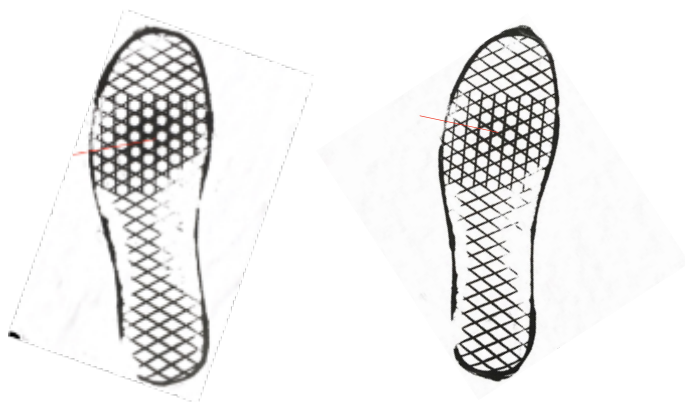




Figure 4. From left to right: First, second, and third imprints of Volunteer 10's left Vans shoe over six weeks. Wear is not observed to accumulate, but the ink distortion in the first imprint could be mistaken as wear. Gait features are observed in areas showing a lack of ink transference and persist over time.

Gait Features

Ink imprints also showed evidence of a person's gait. Like wear characteristics, gait features persist in imprints made later in the study (Figure 4). Areas where there is a lack of ink transference indicates where the shoe does not touch the paper. This can be due to the shoe conforming to the volunteer's foot shape, or the way they step onto the paper. Even if there is no evidence of wear in an imprint, imprints with the same tread pattern can be distinguished with observable gait features. For example, Figure 5 shows two shoes of the same tread pattern but are differentiated due to patterns of gait reflected in the loss of ink transference. It is important to note, however, that many shoes showed a loss of ink transference in the foot arch area. Therefore, an occurrence of a gait feature should be considered a class characteristic because it can appear similarly in more than one

person's imprint. Multiple areas of gait feature, however, are collectively powerful in differentiating between shoes.



Figure 5. Two shoes with the same tread pattern and general wear are differentiated by examining patterns of gait features. (Left photo: Volunteer 4's right shoe. Right photo: Volunteer 10's right shoe.)

Limitations

This study was limited by time. For future research, many months should be allotted to determine the rate in which wear accumulates and how long an accidental characteristic or general wear might be present. Future research should also explore

different methods of documenting wear as gait could be mistaken for wear in ink imprints. The ink imprints also did not clearly show RACs and wear that were observed in photographs. Taking a mold of the outsole, for example, can better show the appearance of wear and any additional wear over time.

Conclusion

The results of this study demonstrate the unlikelihood of observing an accumulation of additional wear in a six-week period with used shoes. These findings support the hypothesis and the literature that wear patterns persist for at least 40-45 days. Therefore, it is possible to individuate shoes collected weeks later. Less than half of the sample showed marginal (<1 cm of additional loss of pattern) change in one or two areas of wear, but it was not enough to misconstrue a match, especially if the examiner is aware of the time interval between the two imprints. The level of activity, the volunteer's gait, the footwear material, and the initial amount of wear seemed to affect how and the rate in which wear accumulates; therefore, minor inconsistencies of wear between imprints should not be the basis for a non-match.

Gait in footwear evidence is also helpful when comparing imprints as these features were shown to persist throughout the study. It should be included as a class characteristic during footwear evidence examinations. However, this would require the same person to produce both imprints that are to be compared to make any conclusion based on gait features.

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