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Research article

Anthropological identification of a suspect based on traces of footprints: A case study

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Abstract

In the field of forensics, one of the most crucial tasks for a criminal investigator is suspect identification. Among various anthropometric features, the dimensions of the foot, particularly its length and width, hold significant value in establishing a person's identity. This paper aims to introduce a methodology designed for identifying individuals based on shoeprints left at crime scenes. The methodology is exemplified through a real case study involving bloody shoeprints, which served as a pivotal clue in a homicide investigation. The methods and findings of this study can serve as a framework to be used in similar cases.

KEYWORDS: shoeprint, footprint, body height, forensic identification, gait biomechanics

Introduction

One of the most important tasks of a forensic investigator is the identification of a suspect. This identification must be reliable to avoid prolonging the investigation and, above all, to prevent miscarriages of justice. It is not always possible to use unambiguous methods such as fingerprints for identifying a person. Very often, small, indirect information helps to identify a person, which aids in narrowing down the pool of suspects.

One of the most common pieces of information that can be utilized is a person's height. If the perpetrator leaves footprints, shoeprints, etc., it is possible to use these to estimate their height (Krishan, 2008b; Nataraja Moorthy et al., 2014). If the footprints follow the course of a person's movement, e.g. walking, it is also possible to use the distance between individual footprints to estimate the person's height (Tiwari & Bajpai Tripathy, 2022).

A significant contribution to the study of footprints and their use in applied biosciences has been the emergence of the discipline of forensic podiatry (Krishan et al., 2015). Forensic podiatrists possess the expertise to identify individuals from footprints using various methods. Analysis of barefoot footprints involves examining distinctive features such as flat feet, ridges, humps, grooves, missing toes, cuts, cracks, and other unique characteristics. These individualistic features play a crucial role in establishing the identity of the individual associated with the footprints (Astolfi et al., 2020; Barker & Scheuer, 1998). All of these individualistic features can link criminals to crimes. In addition to identification from a bare footprint and individualistic features, footprints may, for example, also provide information about a person's body weight (Krishan, 2008a). Furthermore, it is possible to distinguish between walking and running states using parameters derived from two-dimensional footprints or shoes (Neves et al., 2018).

The correlation of footprints with height has been discussed several times (Giles & Vallandigham, 1991; Kanchan et al., 2008; Krishan, 2008a; Krishan et al., 2015; Neves et al., 2018) and always for a specific purpose. Mostly, it is an anthropometric correlation of height and leg length (Agnihotri et al., 2007; Pawar & Pawar, 2012) specific to a particular ethnic population (Curran et al., 2019; Sen & Ghosh, 2008) or an age group, for example children (Grivas et al., 2008). In forensic investigations, shoeprints are frequently encountered and can serve various purposes. Primarily, they help to identify the footwear present at the crime scene or worn by the individual during the incident. Additionally, shoeprints offer insights into the person's activity, for example whether they were walking or running, and can even provide an estimate of their speed (Mukhra et al., 2021). The relationship between shoeprints and body height has also been discussed in literature (Gordon & Buikstra, 1992), but much depends on the type of shoe. Footprints and/or shoeprints are one of the most common criminal traces left at crime scenes (Malik & Bashir, 2023).

In addition to the length of the footprint, input parameters for regression relationships to determine height can include the width of the footprint (Sen & Ghosh, 2008), the width and length of the shoeprint (Giles & Vallandigham, 1991; Jasuja et al., 1991), the length of the stride, or even the length of the step (Jasuja et al., 1997; Porada & Straus, 2014). Gender can also be determined from footprints (Zeybek et al., 2008).

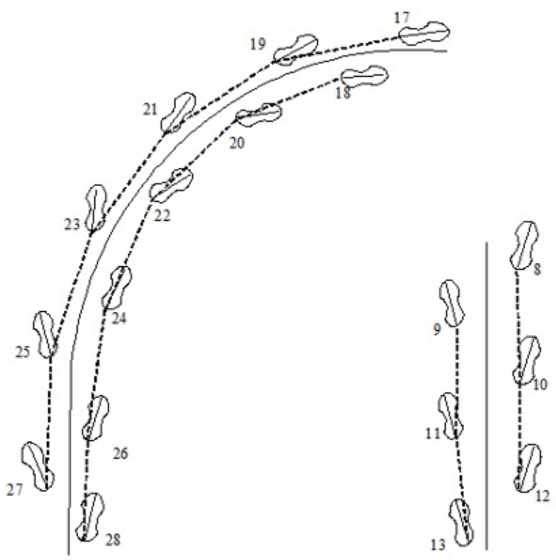
The objective of this paper is to utilize several previously established correlations between leg and gait parameters to estimate the potential height of the individual who left the footprints. However, when confronted with shoeprints from an unknown individual, the challenge arises regarding the selection of the appropriate correlation or equation that accurately reflects the relationship between body height and the input parameters derived from the shoeprints. If the outcomes from various correlations align, the decision is straightforward. However, it is common for different correlations to yield divergent results when calculating height. Hence, determining the correct relationship to use is crucial and can have severe consequences if misjudged, particularly within forensic practice.

Materials and methods

This paper presents a case study involving the utilization of bloody shoeprints discovered at a crime scene to aid in the investigation. The forensic expert was provided with the shoeprint records for a thorough examination. The suspect had left behind two sets of shoeprints upon exiting the scene. The first set comprised 12 shoeprints, that showed a portion of the gait curved to the right, and the second set contained 6 shoe prints that were in a straight line as illustrated in Figure 1. These shoeprints, tinged with blood, were imprinted on the tiled floor inside the house.

Figure 1

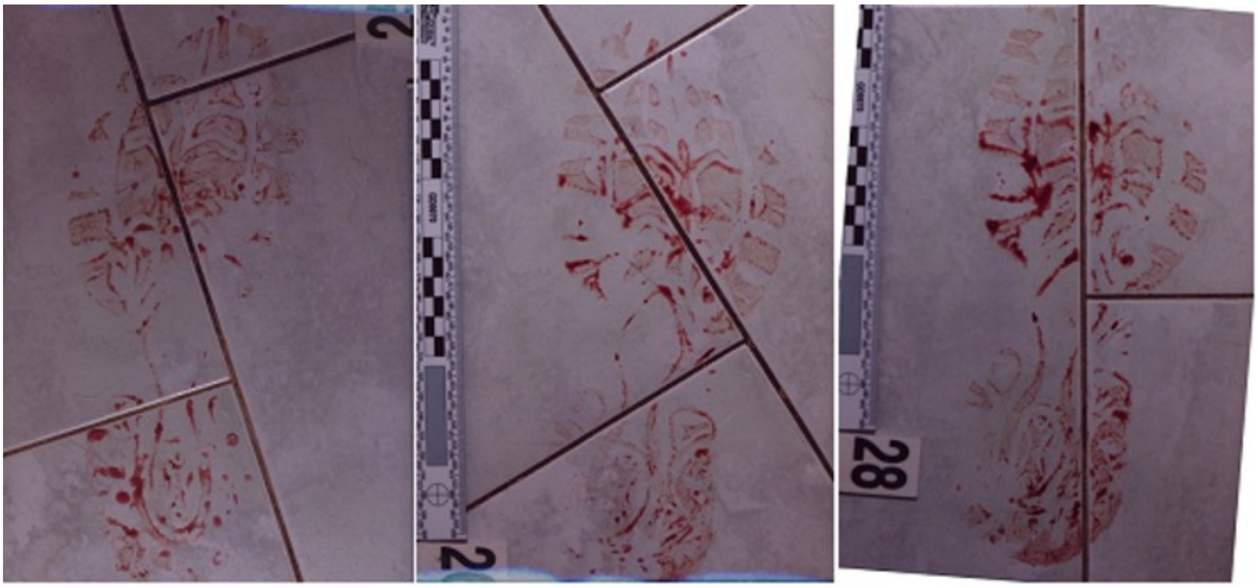
Scheme of two groups of shoeprints, curved and straight



Those closer to the crime scene exhibited a distinct sole pattern, as depicted in Figure 2, suggesting they were likely outdoor sports shoes. Although the shoes themselves were not recovered at the outset of the investigation, the shoeprints were meticulously documented in a standard manner. Each shoeprint's relative position and proximity to the nearest shoeprint was reconstructed and documented, facilitating the determination of gait parameters such as step length, stride length, step angles from the direction of motion, and distances between them.

Figure 2

Bloody shoeprints on the floor



Estimating the height of the person who left the bloody shoeprints was the focal point of the forensic examination of these traces. Therefore, there was a need to conduct literature research on the relationship between stature height and shoeprint length. Several experimental studies were found to have been published regarding this relationship, as well as other gait parameters (Titlbach et al., 1971; Porada & Straus, 2014; Lee, 2022). It was imperative to include studies involving the Czech population, as utilizing studies from other populations would not be appropriate. Various input parameters, such as for example stride length or shoeprint length, were considered, with some studies involving a combination of both. At the time of the study, the perpetrator was unknown, but was later identified based on the research. The latter admitted the crime, which confirms the suitability of the method.

Results

Gait parameters were determined from shoeprints. The mean value of stride length was measured as $L_{SD}=111.5\ cm$. The mean value of step length was measured as $L_{ST}=56\ cm$. The mean value of foot progression angle for left foot was measured as $\alpha_L=21.7°$. The mean value of foot progression angle for right foot was measured as $\alpha_P=10.6°$. Shoeprint parameters were measured: length was $d_{LP}=29.5\ cm$, and width was $d_{WP}=11cm$.

Several regression relationships were used to determine height. Firstly, we applied the following equations using shoe length and width (d_L, d_W), and shoeprint length and width (d_{LP}, d_{WP}) as input parameters:

$$v_H = 2.7d_L + 4.8d_W + 47 \qquad \text{(Titlbach et al., 1971)} \tag{1}$$

$$v_H = 2.6d_L + 4.3d_W + 55 \qquad \text{(Valenta, 1993)} \tag{2}$$

$$v_H = 2.6d_{LP} + 4.3d_{\wp} + 56 \qquad \text{(Porada \& Straus, 2014)} \tag{3}$$

$$v_H = 3.1d_{LP} + 4.0d_{\wp} + 45 \qquad \text{(Porada \& Straus, 2014)} \tag{4}$$

Then we used the shoeprint length dLP and a coefficient which varies with the print length k_{LP}:

$$v_H = k_{LP}d_{LP} \qquad \text{(Porada\& Straus, 2014)} \tag{5}$$

The following relationships use the step length d_S and the stride length d_{ST}:

$$v_H = 0.157d_{ST} + 155 \qquad \text{(Porada \& Straus, 2014)} \tag{6}$$

$$v_H = 0.153d_S + 0.083d_{ST} + 155.5 \qquad \text{(Porada\& Straus, 2014)} \tag{7}$$

Finally, four relations combine the parameters step length d_S, stride length d_{ST}, shoe length d_L and width d_W, footprint length d_L and footprint width d_{WP}:

$$v_H = 0.153d_S + 2.2d_{ST} + 108 \qquad \text{(Porada \& Straus, 2014)} \tag{8}$$

$$v_H = 0.083d_{ST} + 2.2d_L + 106 \qquad \text{(Porada \& Straus, 2014)} \tag{9}$$

$$v_H = 0.076d_S + 0.041d_{ST} + 2.2d_L + 107.5 \qquad \text{(Porada \& Straus, 2014),} \tag{10}$$

$$v_H = 0.076d_S + 0.041d_{ST} + 1.35d_L + 2.4d_{LP} + 107.5 \qquad \text{(Porada \& Straus, 2014)} \tag{11}$$

A negligible discrepancy between the width of the shoe and the width of the shoeprint is noted in the literature. The literature indicates an average difference between the length of the shoe and the length of the shoeprint, with the shoe being 0.4 cm longer than the length of the shoeprint (Porada & Straus, 2014). Therefore, the shoe length is assumed to be 29.9 cm and the shoe width is assumed to be the same size as the shoeprint width of 11 cm. The coefficient k_{ds}= 5.95 corresponds to a shoeprint length of 30 cm (Porada & Straus, 2014). The height determined from each equation is given in Table 1.

Table 1

Body heights calculated using the regression relationships

Used equation	Calculated height of the body [cm]
(1)	180.5
(2)	180.0
(3)	180.0
(4)	180.5
(5)	178.5
(6)	172.5
(7)	173.3
(8)	181.5
(9)	180.2
(10)	181.2
(11)	182.5

Note. Equations using shoe length and width, shoe print length and width are (1-5); equations which use the step length and the stride length are (6) and (7); equations (8-9) use a combination of all shoe and gait parameters.

The equations utilizing the step and stride lengths, (6) and (7) yielded a height of approximately 173 cm. Conversely, the calculated height using equations based solely on foot length and width was approximately 180 cm. However, when integrating both stride and step length alongside shoe print parameters, the estimated height increased to approximately 182 cm, as indicated in Table 1. Notably, this produced the highest results. Nonetheless, there was a variance of approximately 10 cm in the determined height of the individual who left the shoeprints, identified as the perpetrator of the crime. Such variability is impractical for forensic investigations.

Height estimates derived from various relationships had to be critically evaluated. Gait parameters, such as stride length and double stride length, are influenced by locomotion speed and may vary individually, influenced by gait stereotypes. Hence, in this investigation, we chose to prioritize shoeprint parameters, which are less susceptible to variations caused by gait speed or individual gait patterns. Consequently, the newly established height of the suspect was based only on the width of the shoeprint and its length and was approximately 180 cm.

Discussion

In the case of a wanted person whose height should have been determined from the footprints left behind, critical caution should be exercised. It is not correct to use just any published correlation between height and footprint dimensions or gait parameters, as not all correlations are always applicable and may lead to quite varied results. It is particularly important to consider the year of the publication of the research we would like to use, the number of people measured, the population area and the influence of the type of footwear used. The conditions of the research should then be critically evaluated and compared with the real conditions of the forensic investigation we are conducting (Porada & Straus, 2014). The average height of people increases gradually (NCD Risk Factor Collaboration, 2016).

In some cases, where shoeprints or footprints are left, it is possible to use the findings of the so-called forensic podiatry to anthropologically identify the person. This means that the knowledge of foot and lower limb anatomy, musculoskeletal function, deformities and diseases of the foot, ankle, lower limb and gait stereotype are used when examining foot-related evidence in criminal investigations (Vernon et al., 1999). From bare foot impressions, it is possible to analyze individual features such as flat feet, various bumps, grooves, cuts, cracks, pits, blisters or any deformities such as missing toes. When leaving an impression of the shoe, it is also possible to observe the physiological rotation of the foot, called pronation or supination, which may not be symmetrical with respect to the right and left feet (Krishan et al., 2015). This physiological condition is usually evident in the asymmetrical wear of the sole of the shoe (Vernon, 2004).

During the investigation of the case in question, two individuals emerged as primary suspects, one standing at 180 cm tall and the other at 172 cm tall. In a scenario where the results of the regression relationships based on height were not critically limited, both could be considered as potential perpetrators from the crime scene. However, when the regression was confined solely to the height derived from the shoeprint, the evidence pointed to only one of the two suspects.

It was determined that deriving height from the dimensions of the shoeprint was more conclusive in this case compared to the determination of height from gait parameters. This decision was based on the assumption that the dimensions of the footprint are closely linked to body weight and foot size (Sundip et al., 2019), parameters that exhibit a high degree of uniformity and serve as definitive indicators of a particular individual or type of footwear. On the other hand, gait parameters are subject to variation and can be influenced by factors such as direction of movement, shape, and narrowness of the pedestrian's path, among others (Lee et al., 2022). Another criterion was the consideration that in this case the person did not always move in a direct, i.e. ideal, direction for a tracer examination. The assumption was that the body height of the person who left the trasological marks was actually higher than 179 cm, and would be close to 180 cm, according to relations (1) to (4), which depend only on the size of the shoeprints.

The footprints left by the suspect consisted of two distinct segments: a "circular" segment and a "straight" segment, as illustrated in Figure 1. Interestingly, the length of the step for both the left and right legs exhibited no significant difference between the straight and circular segments, with a variance of approximately 2 cm. However, a notable dissimilarity was observed in the magnitude of the foot angle, particularly with the left foot displaying a significantly greater angle, differing by 10° compared to the right foot. This variation was evident in both the circular and straight segments of the footprints. While this difference may partly arise from the shape of the circular trajectory and the relatively short straight trajectory used to determine camber angles, it could also signify a unique gait stereotype characteristic of the individual who left these tracks (Horst et al., 2019).

Upon determining the perpetrator's height to be approximately 180 cm, one of the two suspects confessed to the crime. Further investigation led to the discovery of the shoes worn by the perpetrator during the crime. Subsequently, an experiment was conducted where the perpetrator walked in a straight line with the recovered shoes, replicating the right arch, and gait parameters were re-measured from the footprints left behind. Interestingly, all of the perpetrator's gait parameters during the experiment matched those measured at the crime scene. Additionally, the suspected movement stereotype, particularly the greater angle of the left leg from the direction of movement, was corroborated by the footwear impressions left behind.

Given the evolving dimensional relationships between body height and other anatomical features within populations over time, ongoing experimental investigations into the correlations between human height and gait parameters, including shoe impression dimensions, are warranted. Furthermore, documenting the usage habits associated with different types of shoes can provide valuable constraints for identifying individuals of interest in such cases.

Conclusions

This paper has outlined a specific application of the relationship between height and shoeprint dimensions or gait parameters. It emphasizes the importance of maintaining a critical stance toward all research and published correlations in forensic investigations. In this case study, an average height of 180 cm was calculated from the shoeprints, derived from averaging all relevant empirical relationships. The height determination was based on the shoeprint dimensions rather than the gait parameters. This decision stemmed from the assumption that shoeprint dimensions are primarily influenced by body weight and foot size, factors which exhibit a high degree of consistency and minimal variation. These parameters may be altered if the individual intentionally wears shoes of a different size. In our case, the suspect's height was corroborated through subsequent verification and measurement of gait parameters from the left track. It is important to note that identification based on shoeprints serves as supportive evidence and aids in narrowing down the pool of suspects, rather than providing individual identification.

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Povzetek

Na področju forenzike je ena najpomembnejših nalog kriminalističnega preiskovalca identifikacija osumljencev. Med različnimi antropometričnimi značilnostmi imajo dimenzije stopala, zlasti njegova dolžina in širina, pomembno vlogo pri ugotavljanju identitete osebe. Vsebina članka predstavi metodologijo, osnovano za identifikacijo posameznikov na podlagi odtisov čevljev, ki jih pustijo na krajih zločinov. Metodologija je prikazana na primeru, v katerem so bili odtisi krvavih čevljev ključen namig v preiskavi umora. Metode in ugotovitve te študije lahko služijo kot okvir za uporabo v podobnih primerih.

KLJUČNE BESEDE: odtis čevlja, odtis stopala, telesna višina, forenzična identifikacija, biomehanika hoje.