Science & Justice xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Science & Justice

journal homepage: www.elsevier.com/locate/scijus

A comparative study of standing fleshed foot and walking and jumping bare footprint measurements

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ARTICLE INFO

Keywords:
Bare footprint
Measurement
Static
Dynamic
Forensic

ABSTRACT

Approximating true fleshed foot length and forefoot width from crime scene footprints is primarily based on anecdotal observations and fails to consider effects of different dynamic activities on footprint morphology. A literature search revealed numerous variables influencing footprint formation including whether the print was formed statically or dynamically. The aim of this study was to investigate if length and width measurements of the fleshed foot differ to the same measurements collected from walking and jumping footprints.

Measurements of standing right foot length and forefoot width were collected from thirteen participants. Walking and jumping right footprints were then obtained using an Inkless Shoeprint Kit and digitally measured with GNU Image Manipulation Programme. Descriptive analysis compared standing fleshed foot length and forefoot width against the same measurements taken from walking and jumping footprints with and without ghosting.

Results suggested walking footprint length with ghosting ($\bar{x}$ = 268.61 mm) was greater than standing fleshed foot length ($\bar{x}$ = 264.3 mm) and jumping footprint length with ghosting ($\bar{x}$ = 261.57 mm). However, standing fleshed foot length was found to be greater than walking ($\bar{x}$ = 254.85 mm) or jumping ($\bar{x}$ = 255.63 mm) footprint lengths without ghosting. Forefoot widths showed standing fleshed foot width ($\bar{x}$ = 105.66 mm) was greater than walking ($\bar{x}$ = 95.63 mm) or jumping ($\bar{x}$ = 98.03 mm) footprint widths. This study identifies variation in measurements of the standing fleshed foot and those of walking and jumping footprints, including variability between different dynamic states.

1. Introduction

Measurement of crime scene footprints can support the process of forensic biological profiling and the identification of unknown perpetrators [1]. This is important when epidermal ridge patterns, such as those seen in fingerprints are absent [2]. Previous research has investigated uniqueness of footprints. Kennedy et al. [3] suggested high levels of individuality with the odds of a chance match reported as one in 1.27 billion. Barker and Scheuer [2] suggested variations in footprint morphology result from three main factors: individual foot shape, method of locomotion and the substrate which the foot impacts on. With such high levels of variation, forensic examination can be undertaken to compare unknown and known footprints to support match or mismatch propositions. Furthermore, literature highlights numerous variables, such as ethnicity, age, gender, body weight and method of locomotion influencing foot morphology and footprint formation [2, 4–7].

Bare footprints may be left in blood, dust, sand, oil, mud or paint on hard surfaces, such as wood, laminate or waxed floors [8, 9]. If the length and width of a person's foot is measured and compared to the same measurements of their bare footprint impression, it is likely that these will not match because the foot is a three-dimensional structure and the footprint a two-dimensional impression. It is recognised by DiMaggio and Vernon [1] that hard surface footprints only represent those parts of the feet which have made ground contact. This is because foot shape is rounded at heel and toe ends and in most cases these areas would not have contributed to footprint formation, unless as DiMaggio and Vernon [1] suggest the print was left in a soft substrate permitting the foot to sink into the ground forming a deeper impression. It is therefore suggested by DiMaggio & Vernon [1] that footprints identified on hard surfaces would be shorter in length and width from the actual foot which left the impression. However, it is the extreme parts of the heel and toe ends which form the overall fleshed foot shape including length.

Approximating actual fleshed foot length from an unknown crime scene footprint may assist forensic examiners in building a biological profile of an individual or perpetrator present at the scene. Furthermore, this is also important if a suspect is detained in custody

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https://doi.org/10.1016/j.scijus.2018.06.003
Received 11 March 2018; Received in revised form 21 May 2018; Accepted 10 June 2018

and comparison is performed between their foot and an unknown footprint to establish correspondence or incompatibility or further investigative leads. However, it is unclear how this approximation from footprint dimensions can be robustly performed. Currently a 'rule of thumb' approach of adding 1.5 cm to 2 cm to footprint length is used to approximate its true value [1], with no objective figure for forefoot width. However, this approach lacks supporting empirical evidence as it is largely based on anecdotal observations. Furthermore, no studies have explored potential variations in forefoot widths between the fleshed foot and bare footprints.

Greater understanding of the variation and significance between measurements of the fleshed foot and those of footprints is indicated to develop underpinning knowledge to support the reporting of pedal evidence in forensic investigation. This contribution to the volume of collected physical evidence may also strengthen its evidential value to assist in positively linking a suspect to a crime or to prove an individual innocent. From the literature, Barker and Scheuer [2] compared standing fleshed foot and walking footprint measurements ($n = 105$) and found walking footprint length ($\bar{x} = 255.40$ mm) exceeded standing fleshed foot length ($\bar{x} = 254.20$ mm). However, results were exposed to measurement error from the use of a crude pen and ruler approach and it is unknown whether differences were statistically significant.

Few studies have examined bare footprint formation across different dynamic activities, such as walking or jumping. Barker and Scheuer [2] suggested that footprint morphology may vary depending on what activity is performed. Neves et al. [10] have shown that walking footprints are larger than standing footprints by an average of 17.89 mm +/− 4.81 mm (first 'Great' toe to heel length). The same was found comparing walking and running footprints, but by a smaller average difference (7.07 mm +/− 7.98 mm). However, this study used the Gunn method to measure footprint lengths which has not been validated regarding its repeatability. Furthermore, it was also limited to a small number of participants ($n = 11$).

In a recent study, Bailey et al. [11] compared standing and jumping footprint measurements. Standing footprints were taken from both feet of 23 participants. This was repeated after participants jumped down from a height of 48 cm. Results showed that after jumping, mean footprint length was significantly greater for both feet ($p = .000$) compared to standing footprint lengths. A similar increase, reported as statistically significant ($p = .002$) was shown when the widths of jumping footprints were compared to standing footprints. Although sample size was small, with no comparative data collected for standing fleshed foot measurement, results clearly suggest variation in footprint morphology between standing and jumping states. Variation is also acknowledged by Reel [12] who suggested an average difference of 18 mm in length measurements between standing and walking footprints. In a previous study, Reel et al. [13] established a reliable and robust footprint measurement approach ($n = 61$), using three walking and three standing footprints from each participant's right foot. Although this was predominantly a reliability study, secondary findings showed mean footprint length measurements to be greater in walking compared to a standing state. This may be explained by the fact that Reel [12] and Reel et al. [13] measured walking footprints and included ghosting features at the heel and toe ends. Vernon et al. [14] describe ghosting as additional lighter markings at the outer edges of the heel and toe print areas, which are largely absent in standing footprints. Burrow [15] concurs suggesting that ghosting can be seen as lighter shading extending beyond areas of the footprint, which is characterised by the appearance of 'extensions' to the toe ends. It is suggested that ghosting is more likely to result from the dynamic and hence propulsive phase of gait, where the resulting bare footprint is composed of an inner weight-bearing dark impression with additional outer ghosting features at peripheral edges. Considering distinction between these areas and consistency of approach when measuring length, Burrow [15] suggests this phenomenon has implications for deciding which areas of the footprint to measure. Furthermore, Reel [16] adds that ghosting is not a stable feature, that is, it may not always appear in dynamically created footprints and that dimensions can vary.

From a literature search, no other investigations have addressed these issues with only one study investigating the cause of ghosting in dynamic footprints [14]. Although the sample in this latter study was small ($n = 7$), with no statistical analysis of results, exploratory observations identified that the inner dark area represents the true or main footprint formed from a prolonged contact of the foot with the ground [14]. It was reported that the outer ghosting feature at the heel and toe ends corresponded with shorter periods of ground contact where the fibro fatty heel pad splayed posteriorly at initial contact, followed by the distal aspect of the toes briefly contacting the ground following heel lift. Crucially, it was reported that while the measurement of footprints with ghosting has been validated by Reel et al. [13] this has not been established for measurement of the inner dark area of bare footprints. Furthermore, Vernon et al. [14] suggests previous research has not defined which areas of the footprint have been used for measurement and data analysis. This represents a key issue for further research, with distinction between these two areas considered in context. A literature review revealed no previous studies comparing measurements across different dynamic states using the inner dark and outer ghosting areas of footprints.

Therefore, the aim of this study was to examine variation between standing fleshed foot measurement and walking and jumping footprint measurement, to develop understanding of potential differences and to the factors which may explain their existence. It is hoped this will provide forensic examiners with new insight into interpretative aspects of bare footprint analysis. As identified by DiMaggio and Vernon [1] this is of particular importance for the consideration of the implied fleshed foot size represented within crime scene footprints. Consideration is afforded to the variability in footprint morphology between different dynamic states, such as walking and jumping and to differences resulting from the inner dark areas and outer ghosting features of footprints. The latter is important in forensic practice as this will contribute to understanding of the comparative significance for the collection of additional identification points, namely, the inner dark areas to strengthen the value of bare footprint evidence in criminal justice systems.

2. Material and methods

This study followed a repeated measures design across three conditions (standing, walking and jumping) to compare differences in length and forefoot width of the fleshed foot and bare footprints. Measurements of length and forefoot width of the right fleshed foot were obtained from each participant standing in a full weight bearing position. Dynamic footprints from the right foot, that is, footprints formed from the activities of walking and jumping forward were obtained to measure length and forefoot width. Burrow [15] defines dynamic footprints as those left from walking as opposed to static footprints, which are prints left standing still with no movement. The width of the forefoot or ball of foot has been reported by Reel et al. [13] as the MPJ width (metatarsophalangeal joint width) and by Burrow [17] as the cross ball width or line. Ethics committee approval was obtained prior to the start of the study, with ethical principles of research practice followed in compliance with the Declaration of Helsinki [18].

Table 1
Sample Characteristics.

	Age (years)	Weight (Kg)	Height (cm)	BMI (kg/m^2)
Mean ($\bar{x}$)	32.23	82.33	176.79	26.40
SD	10.66	14.31	8.19	4.31

BMI: Body Mass Index, SD: Standard Deviation.