Science and Justice xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Science and Justice

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

An investigation into the cause of the inner dark areas and outer lighter areas (ghosting) seen in dynamically-created two-dimensional bare footprints

Wesley Vernon OBE [a,*], Neil Simmonite [a], Sarah Reel [a,*], Selina Reidy [b]

[a] Division of Podiatry and Clinical Sciences, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK
[b] Forensic Podiatry Unit, Podiatry Services, Primary and Community Services, Sheffield Teaching Hospitals NHS FT, Jordnathorpe Health Centre, 1 Dyche Close, Sheffield S8 8DJ, UK

ARTICLE INFO

Article history:
Received 20 December 2016
Received in revised form 20 March 2017
Accepted 28 March 2017
Available online xxxx

Keywords:
Forensic
Bare footprint
Ghosting
Gait analysis

ABSTRACT

Dynamic bare footprints differ from static bare footprints through the presence of additional, lighter markings around the rear of the heel print and apices of the toe print areas. These images can appropriately be described as inner dark and outer ghosting features. To date, the functional cause of both features has not been understood. To gain such an understanding could potentially allow the further development and use of these features in forensic identification.
The aim of this project was to investigate the causes of the inner dark and outer ghosting features seen in dynamic bare footprints through an observational, practice-based action research approach within a gait laboratory. Volunteer male participants provided bare footprints on inkless paper taped to a Kistler force plate with video cameras situated either side. Ground reaction force data were collected as the footprints were formed and the event recorded using video cameras to allow these data to be correlated later.
The findings suggest that the ghosting at the heel is the result of splaying of the fibro fatty pad, while that at the toes is the result of the distal ends of the toes coming into contact with the ground as the heel is lifted.
Footprint, ground reaction force and video data comparisons showed that the inner dark area of the heel print corresponded with the main body of the heel contacting the ground. Outer ghosting corresponded with a backward splaying of the fat pad and the heel strike transient spike in vertical ground reaction force during increased loading. The inner dark area of the toes corresponded with a longer period of toe contact with the ground. Outer ghosting corresponded with the decreasing vertical ground reaction force and shorter contact time as the toes were leaving the ground towards the end of the contact phase of gait.
Although the sample size was limited, these are new appreciations which could facilitate the use of the inner dark features in identification to provide additional points for comparison in cases involving dynamic bare footprints. Further work is now indicated to study these features in different populations and under varying conditions.

1. Introduction

The term “bare footprints” refers to the marks made by the plantar surface of an unshod foot on a hard surface – a two-dimensional representation of a three-dimensional foot [1]. Bare footprints can be static or dynamic; static prints are associated with standing and dynamic prints with walking or possibly running. In recent times the forensic community has begun to consider the potential of bare footprints to show individuality [2–9]. Practitioners in various forensic science disciplines use bare footprints in identification including anthropologists, marks examiners, ridge detail analysts and podiatrists albeit from different perspectives. For the purposes of this article, the term ‘bare footprint’ refers to the shape and size of the footprint and not the ridge detail that might be present in these prints. Podiatrists consider bare footprint individuality to be the product of a complex relationship between functional anatomy of the lower limb (foot, ankle and leg) weight transfer between the foot and ground, and “body caricature” [10].

Interest in using bare footprints in identification has increased since the mid-1990s. Previous use of bare footprints in identification assumed that footprints are highly individual, possibly unique. This was tested by the Royal Canadian Mounted Police (RCMP) in a 10 year study [4,5,11,12] which indicated that footprints are highly individual. Subsequent to this work, the limits of knowledge regarding bare footprint form began to be questioned, through research [1] and Appeal Court judgements [13,14] suggesting a need for further studies in this area.

Bare footprint examination uses the ACE-V approach (Analysis, Comparison, Evaluation and Verification) [15]. For the comparison, crime scene footprints are compared with reference footprints from

* Corresponding authors at: Podiatry and Clinical Sciences, University of Huddersfield, Queensgate, Huddersfield HD1 3DH, UK.
E-mail addresses: W.Vernon@hud.ac.uk (W.V. OBE), S.M.Reel@hud.ac.uk (S. Reel).

http://dx.doi.org/10.1016/j.scijus.2017.03.007
1355-0306/© 2017 Published by Elsevier Ireland Ltd on behalf of The Chartered Society of Forensic Sciences.

known persons [2]. The evidential weight of the comparison is stated – i.e. how strongly the matching and mismatching of features indicates that the prints are or are not from the same person [2].

Various techniques exist to enable the analysis and comparison of bare footprints, a number of which use lines drawn between recognizable areas of each print being compared [1–3,16].

Experience has shown that the dynamic form of bare footprints typically presents with two features not usually seen in static prints; namely inner dark and outer ghosting areas at the posterior (heel) and various anterior (toe) areas (Fig. 1). With the exception of Reel's validation work [1], Burrow's recent observations [17] and possibly Barker and Scheuer's earlier work on bare footprint analysis [18], these features are not mentioned in any other past publications involving considerations of bare footprints [19]. As such, it is not known whether the inner dark or outer ghosting areas were used in much of the published research that has attempted to develop an understanding of the nature and behaviour of bare footprints under various conditions. Additionally there have been no previous investigations into what causes these inner dark and outer ghosting features. Such uncertainties are problematic when considering the use of bare footprints in the context of human identification as it is not known which areas are the most appropriate to be used when measuring bare footprints for comparison purposes. Methods used in forensic comparisons should be standardised, valid, reliable, controlled, error free and fit for purpose [19]. Ideally, these features need to be understood in order to support their use in practice. However, if these features simply relate to randomly created anomalies for example, further use in a forensic context could be inadvisable. Furthermore, while the measurement and comparison of the outer ghosting areas has been validated [1], the inner dark features of footprints have not been considered further.

Preliminary work was therefore indicated to investigate what causes the inner dark and outer ghosting features. Additional work would then consider how these features can be used in identification and what their operating parameters are. Such work has the potential to improve the evidential value of bare footprints and through greater understanding, to consolidate the use of these features in line with the demands for improved standards and governance in forensic practice [20,21].

Fig. 1. Dark and ghosted areas seen in dynamic bare footprints.

2. Materials and methods

2.1. Project aim

The aim of this project was to investigate the cause of the inner dark and outer ghosting areas which are frequently seen in dynamic bare footprints. The focus was therefore on functional print formation during the stance phase of walking, particularly the phases of loading response which occurs between initial contact (at the heel) and opposite toe-off, and pre-swing which occurs between opposite initial contact and toe-off as these are the phases where the inner dark and outer ghosting features are expected to form.

2.1.1. Ethics

Ethics approval for the work was granted by School of Human and Health Sciences, School Research Ethics Panel of the University of Huddersfield where the project work was carried out.

2.1.2. Methodology

The work carried out was exploratory and akin to the case study methodology described by Robson [22] although multiple case studies were used in this project. However, as the intention of the work was to inform and guide forensic podiatry practice, the overall project could be considered in its widest sense to be an action research project. The purpose of action research is to act as a tool for change [23,24], or more specifically as "a form of disciplined enquiry in which a personal attempt is made to understand, improve and reform practice" [25].

2.2. Materials/equipment

Multiple data were collected using an inkless bare footprint kit,[1] a calibrated Kistler Force platform[2] and a Simi® motion digital video recording system used with two mvBlueCOUGAR® – X' high speed cameras recording at a default 100 frames/s (fps) (Fig. 2). The cameras were controlled by the Simi® software and video capture calibration was undertaken within the Simi software every time the cameras were moved. The high resolution, high frame rate video cameras allowed video-assisted observation with frame-by-frame playback during later observational analysis and comparison.

2.3. Working methods

An opportunistic sample of six male volunteers was recruited to provide dynamic bare footprints from left and right feet under controlled conditions. The volunteers were over 18 and less than 65 years of age, in good general health and by self-evaluation free from significant foot/gait disorders.[3] Participants and/or results were to be excluded if any undeclared gait-related disorder became apparent, where any deliberate attempts to alter gait were noted during data collection or where their feet were too large to fit onto the inkless paper or pad. This sample size was adequate to show what caused the investigated phenomena; no statistical analysis was to be undertaken. As the sample involved was greater than a single case study, it also had the potential to show whether the cause was consistent or not.

For each data capture, a sheet of impregnated paper from the inkless bare footprint collection kit was taped to the Kistler force platform. The

[1] A commercially available product consisting of a mat impregnated with a colourless chemical [26] and sheets of coated paper allowing an image to form as a subject steps onto the mat, picking up and transferring the chemical to the paper, producing a clear and detailed bare footprint.

[2] Technology considered to the most accurate in its field which uses piezo-electric sensors and Bioware® software to record multiple data on dynamic forces occurring at the foot/ground interface [27].

[3] As podiatry students & staff only were involved, in all cases this self-evaluation was believed to be relatively expert. A visual assessment of all participants was also made by the project lead prior to their inclusion in the study.