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Technical Note

An Investigation into Whether a Bare Footprint Alters in Length and Width after Jumping from a Fixed Height

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Abstract: The aim of this study was to evaluate whether there was a difference in the length and width between a standing static bare footprint and a bare footprint measured after jumping from a fixed height. This was undertaken using samples from 23 podiatry students. Initially, a static print was taken for each participant for both left and right feet. A jumping print was created for both left and right feet after each participant had jumped from a measured height of 48 cm. On both occasions, the participant stood on an inkless mat and then jumped onto reactive paper, creating a two-dimensional print. Gunn's method was used to analyze each footprint, and the print was measured to see whether a difference existed between length and width of the two prints. For the left foot and the right foot, the results indicated there was a significant increase in length and width between a standing bare footprint and a footprint taken after jumping. There was a more significant increase in length of the left footprint than the right but more of a significant increase in the width of the right footprint than the left. The conclusion from this research was that there was a statistically significant difference in length and width between a static bare footprint and a footprint taken after jumping from a fixed height.

Introduction

There has been increasing interest in the potential of bare footprints being an aid to identification [1]. Although work has been undertaken to demonstrate that bare footprints are highly

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individual because of differences in the foot dimensions of the people who created them (intersubject variations), the potential for footprints to be amended through situational variables (intrasubject variations) is not fully understood. Greater understanding of this potential can be considered important when attempting to compare the form and dimensions of bare footprints together to reach conclusions regarding the potential of two or more different prints to have been left by the same person. The work reported in this paper considers the potential effect of one such variable (footprints left because of jumping from a fixed height) on the basic dimensions of bare footprints.

Bodziak [2] found that there are three types of footprints that can be found at the scene of a crime: (1) the impression left in an insole of a shoe, (2) a true bare footprint, and (3) a foot that had a sock on. Bare footprint comparisons have been widely accepted as a method that can assist with the process of identification. According to Barker and Scheuer [3], in the western world, there is a role for the bare footprint in forensic investigations. Crimes of a sexual nature can see the offender removing his or her clothing beforehand; other forensically aware offenders, who believe they know the system well, may remove their footwear prior to committing a crime because they believe that this would protect them from being caught. In areas such as India [4], such considerations can have greater relevance because of the high proportion of the population who walk barefoot for a variety of socioeconomic, religious, or climatic reasons.

The Bare Footprint

Kennedy [5] considered the uniqueness of bare footprints as an aid to identification in a study which, at the time of publication, had utilized 6000 bilateral bare footprints from 3000 participants. Kennedy assessed these impressions by taking 38 measurements that were entered into a computer database. This database allowed individual footprints to be compared with all other footprints in the database. Kennedy conducted a search using a single footprint by entering three to five precise measurements of a footprint. No matches were found. Kennedy increased the error margin to +/- 5 mm for each measurement, but after entering 12 to 15 measurements, no matches were found. Kennedy then raised the error margin to +/-10 and +/-15 mm for each measurement. When this error margin was applied, three footprints in the database were located.

Krishan [6] considered the individuality of footprints in the Gujjar's population in North India, particularly considering shape, alignment, creases, size, cuts, cracks, and pits to determine whether these characteristics were individual. The study involved 1040 adult males between 18 and 30 years of age. Bilateral prints (2080) were taken. Each print was taken using cyclostyling ink that was applied to the plantar surface of the foot after which the participant would step onto white plain paper and then repeat with the opposite foot. The toe region presented with variable characteristics. It was postulated that there was a T type foot (the first toe is longer than the second), and this was the most common foot type (i.e., 62.50% of the left were T type and 62.21% of right feet were T type). This was followed by the F type foot (the second toe is longer than the first). The footprints were shown to be highly individual and showed a link with personal identity.

Moorthy and Sulaiman [7] conducted a study that involved Malaysians (200 males and 200 females) between 18 and 60 years of age. Eight hundred bilateral prints were collected in total. Participants had to be healthy and free from symptomatic deformities of the foot to participate. The overall results of this study highlighted a valid conclusion that each footprint had individual characteristics, therefore correlating with the results found by both Krishan [4] and Kennedy [5]. Other studies [8, 9] have investigated whether there is an association between stature and bare footprint.

Static and Dynamic Prints

According to Vernon [10], bare footprints can be static or dynamic (static prints are associated with standing and dynamic prints with walking or running).

Mathieson et al. [11] considered static and dynamic footprints. The study involved a small sample of 20 university participants. Mathieson et al. collected three static and three dynamic footprints from each participant. This was completed using the Musgrave Footprint System (previously manufactured by Musgrave Systems, Ltd, Wrexham, U.K.), which recorded the plantar surface. Three measurements were taken: Footprint Angle, Chippaux-Smirak Index, and Stahelis Arch Index. The results showed a 25% increase in the Chippaux-Smirak Index and 28% increase in the Stahelis Arch Index, thus clearly indicating a difference between a static and a dynamic print. However, "Statically calculated parameters must be viewed with caution, as they appear to inconsistently predict even the dynamic dimensions of the foot. The relationship to dynamic motion – the variable perceived to be related to the development of pathology – remains unclear." [11]

Barker and Scheuer [3] completed a study using 105 participants. Before footprints were taken, several measurements were completed including stature, foot length (stick length), and ball and heel widths. Results showed that a walking footprint increased in comparison to the stick length of the foot. The stick length was larger than the mean standing print length. They concluded that a dynamic print was larger, correlating with results found by Mathieson et al. [11]

All the previous studies about static and dynamic footprints concluded that a dynamic footprint was larger than a static print.

However, in a short, unpublished pilot study by Ashford et al. [12], it was found that bare footprints formed on landing after jumping from a height appeared to be consistently shorter in length than static bare footprints formed by that same person. Although the jumping prints collected in this study were not walking prints, they could be another form of dynamic print formed through this different type of activity. Whether this is proved to be the case in additional studies, it would be important to know whether the dimensions of a bare footprint alter when the print is formed through jumping activity to prevent erroneous conclusions from being formed in relation to interpretation of that footprint.

Techniques for Analysis of Bare Footprints

Multiple methods have been used as a way of measuring bare footprints to aid the identification process. One such method devised by Gunn involves taking multiple linear measurements of the footprints that are being compared. Gunn's basic method involves drawing six lines, five of which come from the rear foot and extend to the apex of each digit. A sixth line is then drawn across the ball of the foot at the widest area. These six lines are all measured, and the measurements are used when comparing them to the bare footprints of a suspect. For this study, Gunn's method was selected because this approach has been successfully validated in Reel's Ph.D. work [13] and is a method with which forensic podiatrists are known to be familiar.

Materials and Method

Pilot Study

Three healthy university students were recruited to assist in perfecting the methodology used in the study. The pilot study involved determining the correct use of the inkless pad for bare footprint collection, the proper positioning of the paper to record the prints during stance and during the jump, and checking that the height of the jump was suitable and safe for all participants. The pilot study revealed that the paper was best placed in front of the inkless pad, allowing participants to land directly onto the paper. The optimum height that participants felt comfortable jumping from was 48 cm. The participants felt less safe at any height greater than 48 cm. They jumped off of a wood box, which was completely stable. The pilot study revealed that participants required the paper to be in different positions when they were jumping, based on their stature and jumping style. Taller participants asked for the paper to be further away than the shorter participants, who wanted the paper to be closer to the box. The results from this pilot study were incorporated into the methodology for the main study.

Main Study

Inclusion and Exclusion Criteria

A prescreening process was completed with all participants one week prior to the study where participants were assessed on their ability to jump safely off a 48 cm wood platform. If the participants could undertake this safely and they were willing to participate, they gave their informed consent prior to their participation.

Twenty-three podiatry students took part in this study. Thirteen were females and 10 were males, ranging from 19 to 45 years of age. For each participant, a standing print was first taken separately of the left foot and the right foot. A second print for each foot was then created by jumping from a height of 48 cm.

Standing Print

The inkless pad was placed on the floor. Participants placed their right foot onto the inkless mat in their natural stance position and held it for three seconds. They then transferred their foot onto the reactive paper next to the inkless mat in their natural stance, thus creating a print. This was then repeated with the left foot. This is represented in Figure 1.

Jumping Print

Each participant stepped onto a stable 48 cm wood block. The inkless pad was put on the block, and starting with the right foot, each participant jumped from the inkless pad onto the reactive paper, which was placed on the floor (Figure 2). The paper was placed where participants found it suitable and although not secured using tape, it did not move when the jumping foot landed on it. Taller participants had the paper further away compared to shorter participants who had it closer. The same process was repeated with the left foot. To ensure that the participants were jumping safely, they were advised beforehand to bend their knees and replicate a squat position. In total, 92 prints were collected from the 23 participants (46 standing and 46 jumping prints). The prints were measured with a standard ruler following the Gunn method. Figure 3 shows how each footprint was measured. This method was the same for both standing and jumping footprints.

The following six measures were obtained from each footprint:

- The posterior aspect of the heel to the apex of the first toe (T1).
- The posterior aspect of the heel to the apex of the second toe (T2).
- The posterior aspect of the heel to the apex of the third toe (T3).
- The posterior aspect of the heel to the apex of the fourth toe (T4).
- The posterior aspect of the heel to the apex of the fifth toe (T5).
- The widest part of the ball of the foot (W).

The underlying distribution of the collected measurements for both the length and width of the left and right feet were tested for normalcy using a Shapiro Wilk test. It was found that the data had a normal distribution for both length and width of both feet. Therefore, a paired *t* test was used to investigate whether there was a statistically significant difference between the standing length and width of a bare footprint and a footprint taken after jumping.

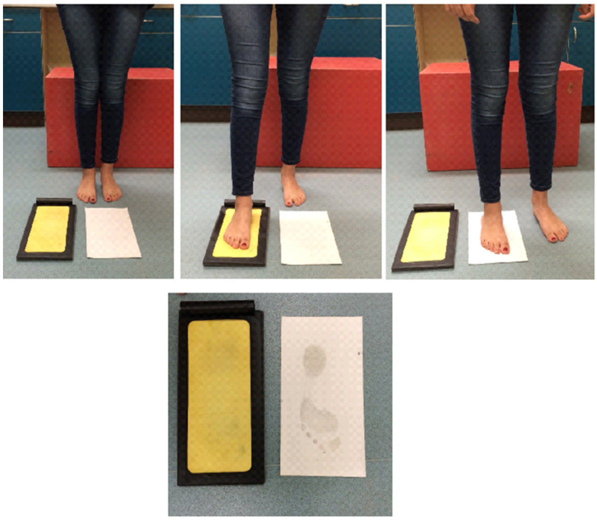

Figure 1

Process of obtaining a standing bare footprint.

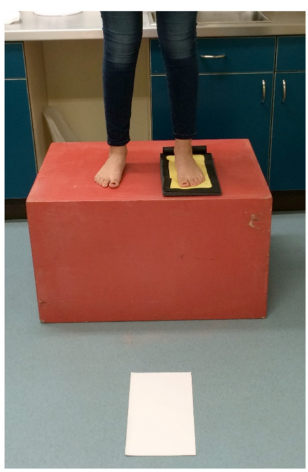

Figure 2

Obtaining a jumping bare footprint.

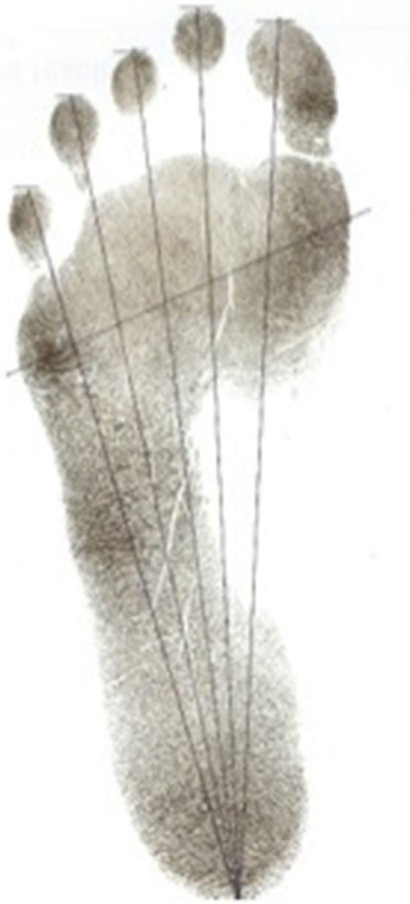

Figure 3
How each footprint was measured.

Results

Table 1 and Table 2 show summary statistics for length and width of both feet measured in centimeters standing and then following a jump (see appendix for individual measurements).

		Mean	*N*	Std. Deviation
Pair 1	Standing Length Left	24.230	23	1.7332
	Jumping Length Left	24.709	23	1.8822
Pair 2	Standing Width Left	9.361	23	.6787
	Jumping Width Left	9.604	23	.7571

Table 1

Summary table for left foot.

		Mean	*N*	Std. Deviation
Pair 1	Standing Length Left	24.183	23	1.8391
	Jumping Length Left	24.587	23	1.7530
Pair 2	Standing Width Left	9.370	23	.6990
	Jumping Width Left	9.743	23	.7134

Table 2

Summary table for right foot.

For the left foot, the number of participants (*N*) was 23. The mean for foot length with participants standing was 24.230 (SD 1.7332), and the mean for foot length following a jump was 24.709 (SD 1.8822), indicating an increase in the length of the left foot following a jump.

The mean for foot width with participants standing was 9.361 (SD 0.6787) and the mean for foot length following a jump was 9.604 (SD 0.7571), indicating an increase in width of the left foot following a jump.

For the right foot, the number of participants (*N*) was also 23. The mean for foot length with participants standing was 24.183 (SD 1.8391), and the mean for foot length following a jump was 24.587 (SD 1.7530), indicating an increase in the length of the right foot following a jump.

The mean for foot width with participants standing was 9.370 (SD 0.6990) and the mean for foot width following a jump was 9.743 (SD 0.7134), indicating an increase in width of the right foot following a jump.

The results of the paired *t* test for the left foot demonstrated that there was a statistically significant difference in measurements between a bare footprint taken during stance and one taken after jumping ($p=.000$). The *t* test was repeated for the right foot, and there was a statistically significant difference in measurements between the standing bare footprint and bare footprint taken after jumping ($p=.000$). Results also revealed that the left length increased slightly more than the right.

A paired *t* test was then repeated for width. The width of the left standing bare footprint was compared with the width of the bare footprint taken after jumping. There was a statistically significant difference in measurements between a standing and a jumping bare footprint ($p=.002$). This was also repeated with the right foot. There was a statistically significant difference in measurements between a standing bare footprint width and the width taken after jumping ($p=.002$).

Discussion

It should be noted that the jumping prints suffered from some smudging and, for some participants, the jump was repeated if the level of smudging was great. Sometimes it was difficult to determine where the true footprint started for the jumping footprint. Participants were all encouraged to jump in their most natural stance, ensuring they landed with both feet at the same time, with their knees bent. However, some participants jumped landing one foot after the other. This had a larger influence on their dominant landing foot because more force was directed through it first. Participants may not have completed the jump in their most natural way, because they were trying to target where the paper was positioned on the floor.

The statistically significant difference found in the measurements between the standing bare footprint and a footprint taken after jumping suggests that jumping from a fixed height increases measurement values taken from the footprint.

The results of this study differ with that of the only other known study on jumping prints, which found a decrease in length of a jumping print compared to a static bare footprint [12]. Possible explanations include differences in methodology used to measure the footprints and whether the inner dark or outer ghosted areas seen in dynamic prints were used for the measurements taken.

Differences between static and dynamic footprints have been investigated by Barker and Scheuer [3] and Mathieson et al. [11]

Barker and Scheuer [3] stated that three main factors can affect a bare footprint: the individual's foot morphology, the surface on which the footprint impacts, and locomotion activity of the individual when the print was created. For this study, a static print was taken and then a dynamic print, but instead of being a walking print, this was a print taken after a jump. Barker and Scheuer's [3] finding that a walking (dynamic) footprint increased in comparison to the standing (static) footprint correlates with the results in this study.

Mathieson et al. [11] also considered static and dynamic footprints. They found that there was a positive increase between the two, with results increasing approximately by 25%.

This was found to correlate with results found by Barker and Scheuer [3] and results found from this study.

Further Research

The results of this study suggest areas for further research. Krishan [4] investigated the role of body weight during stance, finding a 20 kg weight to have statistically significant impact on the measurements in comparison to the 5 kg, which had no significant impact. This could be implemented within a jump to determine whether there is an increase between a footprint with no added weight, a 5 kg weight, and a 20 kg weight. This would be beneficial because during a robbery, the offender may, for example, be holding something that is heavy. Kennedy [5] considered the uniqueness of a bare footprint during stance and found that each static footprint was individual to each person. It may be possible to consider whether a jumping footprint also has unique features related to each individual. A database could be collected of jumping footprints, with several measurements. The current study had participants jumping from a height of 48 cm. This height could be altered, starting with a smaller height such as 25 cm as well as having a larger height of possibly 55 cm, depending on whether this would be safe for participants. Several measurements could be taken and it could be investigated to determine whether the height of a jump impacts on the length and width. This could be further investigated by looking at the surface onto which participants jumped. During a crime, where the offender has jumped onto surfaces such as carpet, concrete, and grass, the subsequent footprint can be three-dimensional. Therefore, three-dimensional footprints could also be investigated to determine whether the effect of jumping has an impact on the length and width of the print.

Conclusion

The results of the study demonstrated that there was a statistically significant increase in both the left and right length and width of the feet after jumping from a height of 48 cm. However, the findings of previous studies that the bare footprint length can shorten with jumping needs to be investigated further to determine the reasons for these differences in the results between studies.

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Appendix

Raw data measured in centimeters.

Participant	Standing Length Left	Standing Width Left	Standing Length Right	Standing Width Right	Jumping Length Left	Jumping Width Left	Jumping Length Right	Jumping Width Right
1	23.4	8.8	23.3	9.2	23.5	8.8	23.8	9.9
2	22.5	9.2	22.1	9.8	22.6	9.4	22.9	9.7
3	21.9	8.2	21.8	8.6	22.4	8.3	22.6	8.6
4	22.9	9.5	22.5	9.4	23.9	9.3	23.6	9.4
5	24.8	8.9	25	9.1	25.3	9.4	25.6	10.5
6	26.3	10.3	26	10.2	27.6	10.3	27.4	10.7
7	25.3	9.3	24.7	8.9	25.2	9.3	24.9	9.7
8	27.3	11.1	27.1	11	28	11.7	27.3	11.3
9	25.4	10.2	25.3	10.5	25.9	10.5	25.9	10.7
10	23.3	9.3	23	8.9	23.9	9.8	23.1	9.2
11	21.8	8.4	21.5	8.8	21.6	8.8	21.2	8.9
12	26.9	9.7	26.7	10.4	27.5	10.4	27	10.3
13	23.6	8.5	24.3	8.6	24.1	9	24.5	9.1
14	23.1	9.4	23.2	9.5	23.7	9.3	23.8	9.4
15	22.4	8.7	22.2	8.2	22.9	8.6	22.4	8.8
16	26.6	10	26.3	9.8	26.8	9.8	26.8	9.9
17	24.6	9	25.1	9.1	25.9	9.4	25.8	9.2
18	23.2	8.9	23.1	8.5	23.6	9	22.9	8.8
19	23.2	9.4	22.8	9.2	23.2	9.8	23.3	10.1
20	22.7	9.6	22.7	9.1	23.2	9.6	23.1	9.7
21	23.9	9.3	24	9.2	23.9	9.9	24	9.5
22	27.2	9.5	28	9.7	27.4	10.5	27.2	10.5
23	25	10.1	25.5	9.8	24.6	10	24.9	10.2