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Estimation of body weight from the base of gait and the area swept in one stride—forensic implications

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Abstract

Background: Forensic gait analysis is a new discipline in forensic sciences but gaining popularity worldwide. CCTV camera footages from the scene of a crime can reveal a great detail about the perpetrator, and gait is one of them. Every individual possesses a unique manner of walking, which is the basis of forensic gait analysis. In the absence of CCTV cameras, footprint trails at the crime scene can provide valuable information about the perpetrator. The stature of the perpetrator can be estimated from spatial gait parameters, which can fasten the speed of the identification process. However, previous studies of the spatial gait parameters did not explore the possibility to estimate the body weight from spatial gait parameters. In the present study, two variables of spatial gait parameters, namely "base of gait" and "area swept in one stride," were taken for the estimation of body weight.

Methodology: A sample of 388 adult males ranging in age from 18 to 30 years was taken for the present study. The data were collected from villages situated in district Ludhiana, Punjab, North India. Body weight of each participant was taken using a standard methodology. Two spatial gait parameters namely "base of gait" and the "area swept in one stride" were recorded from the dynamic footprints of the participants using the standard methodology and the novel technique devised by one of the authors (BS) respectively. After checking the normality of the data, a parametric *t* test statistics showed no bilateral asymmetry in both the gait parameters.

Results: Spatial gait parameters, i.e., base of gait (left $R = 0.255$, right $R = 0.243$) and area swept in one stride (left $R = 0.204$, right $R = 0.221$) showed positive, weak, but significant correlation with the body weight of the person. Linear and multiple regression models for the body weight estimation were developed in the present study. The highest accuracy in body weight estimation (SEE = 12.54) was achieved from the left base of gait. The multiple regression models indicate no improvement in the estimation error.

Conclusion: It can be concluded from the present study that the body weight of a person can be predicted from the spatial gait parameters to some extent. However, the weak values of the correlation and higher values of estimation error suggest that the base of gait and area swept in one stride should only be used in such situations when other means of body weight estimation cannot be applied.

Keywords: Forensic science, Forensic anthropology, Forensic podiatry, Spatial gait parameters, Estimation of body weight

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Introduction and background

Forensic science can be defined as the application of scientific methods and techniques for legal purposes. The horizon of crime is increasing and becoming so diverse that traditional methods of crime analysis are unable to solve them. This ever-increasing crime is pushing the forensic community to devise new methods and technologies so that law should at least be one step ahead of crime. In forensic cases, when the task is to identify unidentified human remains or impressions, then the help of forensic anthropologists is sought. Forensic anthropology works on a principle that every human being is unique in term of age, sex, stature, ethnicity, and weight. Any clue about these components of a person's biological profile can help immensely in the investigation process.

In an individual's biological profile, sex and ethnicity remain constant throughout the lifetime; stature increases with time until adult stature is attained; age and weight remain variable throughout life. Age always increases with time, but body weight can fluctuate with time. The variable nature of body weight is the limiting factor for its usefulness in forensic investigation. However, it can provide a great clue about the physiology of the perpetrator or the victim. It has been suggested that the footprints recovered from a crime scene can reveal a great deal about the body weight of the person (Robbins 1986; Krishan 2008; Fawzy and Kamal 2010; Abledu et al. 2016).

Footprints can be recovered from a variety of crime scenes such as polished floor, dirt, sand, mud, snow, and even on walls when criminals try to escape by jumping from walls (Naples and Miller 2004). It is apparent from the forensic literature that sex and stature can reliably be estimated from footprint dimensions (Barker and Scheuer 1998; Kanchan et al. 2014; Khan and Moorthy 2015; Krishan et al. 2015; Atamturk 2010). Many studies also tried to estimate the weight from footprint dimensions. In a study, Krishan (2008) tried to establish the correlation of body weight with footprint dimensions (Krishan 2008). In this study, 300 bilateral footprints were collected from 50 adult male North Indian subjects (age 18 to 30 years). Footprints were collected in three stages; in the first stage, no weight was given to the subject, in the second stage 5 kg, and in the third stage, 20 kg weight was given to the subjects while taking footprints. The results of this study reveal that holding 5 kg of weight in the hands did not affect the dimensions of the footprints; however, a significant ($p < 0.01$) difference in the footprint dimensions had been observed when subjects held 20 kg of weight. Positive and statistically significant correlation of foot dimensions with normal body weight had also been observed in this study. In both left and right footprints, footprint length at first toe (R = 0.75, L = 0.74) and at the second toe (R = 0.74, L = 0.74) showed the highest correlation with normal body weight. Regression models for body weight estimation were also developed from all the left and right footprint dimensions. Similar studies on other populations also tried to formulate regression models for weight estimation from footprint dimensions (Robbins 1986; Fawzy and Kamal 2010; Abledu et al. 2016).

In forensic cases, when only partial footprints are available, then regression formulae for stature or body weight estimation cannot be applied, as they require complete footprint dimension(s). In these types of cases, spatial gait parameters can be used to estimate the body weight of the person, who made those prints. Gait is known to be a function of the body weight (Laroche et al. 2015). Persons with different body weights tend to adopt different gait patterns. Usually, a gait is chosen which brings maximum stability at a minimum energetic cost (Cunningham et al. 2010; Laroche et al. 2015; Raffalt et al. 2017). A study conducted on French children of age between 2 and 12 years revealed that obese children exhibited significantly different spatial and temporal gait parameters from normal weight children (Thevenon et al. 2015).

Looking at the scanty literature regarding the estimation of body weight and its implications in forensic science, the present study attempted to estimate the body weight from the base of gait and the area swept in one stride using a novel methodology.

Materials and methods

Materials

In the present study, a cohort of 388 adult male subjects from Ludhiana district of Punjab was selected. All the subjects belonged to the *Jatt Sikh* community. The age range of the sample was between 18 and 30 years with a mean age of 21.38 years. The data were collected from 11 villages located within Ludhiana district, namely *Sarinh*, *Alamgir*, *Dhandra*, *Mehmoodpur*, *Gill*, *Pmal*, *Dakha*, *Sudhar*, *Dhandari*, *Barwala*, and *Narangwal*. Door-to-door, snowball, and convenient sampling techniques were used for data collection. *Jatt Sikhs* is a peasant community of North India. Agriculture and animal husbandry are the major means of economy in this community.

Ethical permission

The present study is a part of an ongoing Ph.D. research project of one of the authors (BS) in the Department of Anthropology, Panjab University, Chandigarh, India. The ethical approval to conduct the present study was granted by the Panjab University Institutional Ethical Committee vide letter no. PU/IEC/100/13/09 dated 25 October 2013.

Methodology

All the subjects enrolled for the present study were healthy and were free from any foot, ankle, spine, leg, or head injury. In the present study, apart from the weight of the subject, two spatial gait parameters, namely base of gait and area swept in one stride, were also measured. For measuring the body weight and base of gait, standard methods and techniques were used following Krishan (2008) and Wilkinson et al. (1995) respectively.

Body weight measurement

Spring-loaded weighing machine was used to record the body weight of each subject.

Methodology for the acquisition of dynamic footprints

Dynamic footprints of the subjects were taken on a white paper sheet. The subjects were asked to stand on a cotton pad soaked with water-soluble ink and then to walk normally on the white paper sheet lying just in front of them. At least, six consecutive footprints were recorded. First two footprints were discarded as they were initiated from static position of the subject, and the last footprint was also discarded as the subject already knew that he had to stop, which may introduce an error in the gait dynamics.

Gait parameters

Two spatial gait parameters, namely base of gait and area swept in one stride, were recorded from the dynamic footprints. The schematic representation of the left and right base of gait and area swept in one stride is shown in Fig. 1.

Base of gait

It is defined as the distance between the rear most point of the contact of the left and right heels, measured at a right angle.

Area swept in one stride

The area covered in one stride is represented by a triangle. This triangle is obtained by joining the heel markers—two from the ipsilateral and one from the contralateral footprint. This novel parameter was devised by one of the authors (BS) of the present study and was never used previously in any study.

Statistical considerations

The data were first tabulated in an MS Excel sheet and was then transported to SPSS (version 16.0). Descriptive statistics such as range, mean, and standard deviation

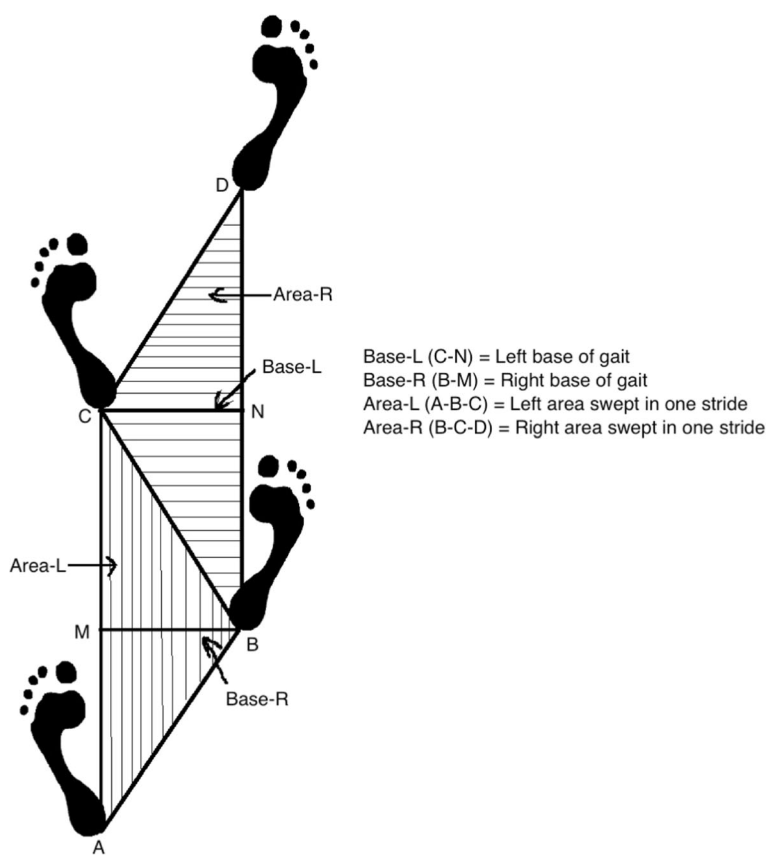

Fig. 1 A schematic representation of "base of gait" and "area swept in one stride"

were used to understand the general trend of the data. The bilateral asymmetry between the base of gait and area swept in one stride was computed with *t* test statistics. Skewness and kurtosis were used to investigate the normality in the data. Karl Pearson's correlation was used to examine the strength of association between the spatial gait parameters and body weight. Regression models were developed using body weight as the dependent variable and the gait parameters as the independent variables. All the results with $p < 0.05$ were considered significant.

Results

Descriptive statistics involving minimum, maximum, mean, and standard deviation of body weight, base of gait and area swept in one stride are shown in Table 1. Body weight ranged from 45 to 121 kg. The base of gait ranged between 0 and 21 cm for the left and ranged between 0.3 and 23.4 cm for the right. Similarly, the area swept in one stride ranged between 22.58 and 1380 cm^2 for the left and ranged between 0 and 1369 cm^2 for the right. For body weight, mean value came out to be 73.55 kg. Mean values for the base of gait came out to be 10.80 cm and 10.79 cm for the left and right side respectively. Similarly, the mean values for the area swept in one stride came out to be 756.81 cm^2 and 243.45 cm^2 for the left and right side respectively. *t* test statistics was used to test bilateral asymmetry in the base of gait and area swept in one stride. The results of *t* test statistics are presented in Table 1 and revealed that no bilateral differences exist in the base of gait and area swept in one stride.

To test the normality within the sample, moment of skewness and kurtosis was computed for weight, base of gait, and area swept in one stride. The results of normality tests are presented in Table 2. To test the normality in data through skewness and kurtosis, Kim (2013) suggests different references values according to the sample size. The present study sample is composed of 388 subjects, which according to Kim (2013) is a large sample ($N > 300$). Kim (2013) suggests that for a larger sample, the reference values for skewness and kurtosis should be adopted provided by West et al. (1995), which is 2 for skewness and 7 for kurtosis. Kim (2013) argued that statistical programs such as SPSS provide kurtosis values by subtracting a factor of 3. In the present study, both values of skewness and kurtosis for all the parameters are less than the corresponding reference values, which confirm that the data were normally distributed. Normal distribution in the data suggested the use of parametric inferential statistical tests for further analysis.

After confirming the normality in the data, *t* test statistics was used to test the bilateral asymmetry in the base of gait and area swept in one stride, and the results are presented in Table 3. The results indicated the absence of bilateral asymmetry in both the gait parameters.

Karl Pearson's correlation of base of gait and area swept in one stride with body weight came out to be small but statistically significant. Linear and multiple regression models for weight estimation are presented in Table 4. The lowest standard error of estimation (SEE = 12.54) was observed in the left base of gait. Multiple regression model for body weight estimation was also developed by using both the base of gait and area swept in one stride of the left and right sides.

Table 1 Descriptive statistics of body weight, base of gait, and area swept in one stride

Measurements	*N*	Side	Min.	Max.	Mean	SD
Body weight (kg)	388	–	45	121	73.55	12.95
Base (cm)	388	L	0	21	10.80	3.70
	388	R	0.3	23.4	10.79	3.81
Area (cm^2)	388	L	22.58	1380.06	726.54	256.81
	388	R	0	1369	722.58	243.45

Base base of gait, *Area* area swept in one stride, *L* left, *R* right

Table 2 Skewness and kurtosis of body weight, base of gait, and area swept in one stride

Measurements	Side	Skewness	Kurtosis
Body weight	–	0.344	− 0.234
Base	L	− 0.067	− 0.019
	R	0.004	− 0.219
Area	L	0.014	− 0.251
	R	− 0.124	0.030

Base base of gait, *Area* area swept in one stride, *L* left, *R* right

Discussion

Humans are efficient walkers, and walking is the most fundamental human movement (Watkins 2006). Every individual possesses a unique style of walking and can be used in identification (Larsen et al. 2007; DiMaggio and Vernon 2011). Many scholars argued its advantage over other means of security surveillance (Cheng et al. 2008). Gait is variable in nature; factors like substrate, shoes, the proximity of other individuals or materials, emotions; and clothes have the ability to change the gait of a person (Birch et al. 2013, 2015; Halovic and Kroos 2018). Identification of individualistic gait characteristics is an inherent property of forensic gait analysis through CCTV video footages (Birch et al. 2013). In the

Table 3 Bilateral asymmetry in the base of gait and the area swept in one stride

Measurements (left-right)	*t* values	*p* values
Base of gait	0.038	0.969
Area swept in one stride	0.573	0.565

Base base of gait, *Area* area swept in one stride

Table 4 Linear and multiple regression models for weight estimation from the base of gait and area swept in one stride

Measurements	Regression model	R	R^2	SEE
Base-L	63.931 + 0.891 (Base-L)*	0.255	0.065	12.54
Base-R	64.642 + 0.825 (Base-R)*	0.243	0.059	12.58
Area-L	66.062 + 0.010 (Area-L)*	0.204	0.042	12.69
Area-R	65.039 + 0.012 (Area-R)*	0.221	0.049	12.64
Base-L, Area-L, Base-R, Area-R	64.018 + 0.271 (Base-L) – 0.013 (Area-L) + 1.186 (Base-R) + 0.004 (Area-R)	0.265	0.070	12.55

Base base of gait, *Area* area swept in one stride, *L* left, *R* right
*$p < 0.001$

present study, the association of body weight with spatial gait parameters, namely base of gait and area swept in one stride, is investigated with a goal to generate regression models for body weight estimation.

The descriptive statistics of the present study is presented in Table 1. The mean values of the base of gait and area swept in one stride on the left side were slightly larger than the right side mean values. The mean base of gait of the present study is larger than the previously published studies on Australian (Wilkinson and Menz 1997) and American (Bruening et al. 2015) populations. Area swept in one stride cannot be compared with other studies as no other study yet used this gait parameter. Moment of skewness and kurtosis was computed to test the normal distribution of data. Kim (2013) suggested reference values of skewness and kurtosis for different sample sizes, and accordingly, the sample size of the present study fell into a large sample size category. For a larger sample, Kim (2013) suggested reference values for skewness and kurtosis as provided by West et al. (1995). The values of skewness and kurtosis from the present study were less than the references values and suggested the normality of the data. By considering the normality of the data, *t* test statistics were performed to test the bilateral asymmetry in the base of gait and area swept in one stride, and the results are presented in Table 3. *t* test revealed no significant bilateral asymmetry in the base of gait and area swept in one stride.

Foot and footprint dimensions have been proved to be a reliable means of stature estimation in forensic casework (Hisham et al. 2012; Krishan et al. 2012). However, little has been known for its relationship with body weight. A handful of studies tried to estimate body weight from footprint dimensions (Robbins 1986; Krishan 2008; Fawzy and Kamal 2010; Abledu et al. 2016). Similarly, gait parameters such as step length and stride length have been explored for their relationship with stature but not with body weight. In a study, conducted on 198 adult male *Jat Sikhs*, Jasuja et al. (1997) tried to estimate stature from step length measurements. In this study, a mean correlation coefficient of 0.289 and 0.433 was observed between step length and stature at a normal and fast speed respectively. Stature estimation regression models were also developed from step length measurements in this study. The association of gait parameters with body weight had never been investigated in a forensic context. In forensic cases, when only partial footprints are available for investigation, then the base of gait and area swept in one stride can be used for weight estimation. In the present study, a weak but significant correlation of the base of gait and area swept in one stride with weight has been observed. A weak correlation suggests that human gait is not a sole function of the body weight. A positive correlation of body weight with the base of gait could be attributed to the fact that if weight increases, then a larger basal support is required for balancing. An increased base of gait could be the balancing strategy achieved by the person during normal walking. Similar arguments can be extended for the positive correlation of body weight with area swept in one stride. In a complete gait cycle (normal walk), a transition of body weight from one foot to another foot happens. A triangular area covered by the body in one stride represents the basal support to the body during the weight transition phase of the gait cycle. A larger area for increased weight seems plausible.

In the present study, the positive correlation of base of gait and the area swept in one stride with body weight was explored, and regression models were developed for body weight estimation. Linear regression model developed from the left base of gait ($r = 0.255$) provided the body weight estimation with minimum error (SEE = 12.54). Multiple regression models by using all the parameters showed increased the correlation with body weight, but estimation error did not improve. The results of the present study cannot be compared with other studies, as no similar study is present in the literature.

The present study was conducted on males of only one ethnic community (*Jatt Sikhs*), so the results may not be applicable to females and other ethnic communities. However, in view of the present novel study, the researchers are encouraged to conduct such investigations on different populations so that the trend of the body weight estimation can be studied on a different group of people. Based upon the results of the present study, the forensic science laboratories and the criminal investigation agencies may have certain indications regarding the body weight of the perpetrators if such cases are presented to them along with the other means of body weight prediction, e.g., the body weight estimation from footprints.

Conclusion

The present study revealed that the body weight estimation accuracies from linear and multiple regression models are lower than the estimated accuracies from the footprint measurements in other studies. Although the present study revealed a poor correlation of the base of gait and the area swept in one stride with a person's body weight, however, it opened a new avenue of research in this direction. It can be established from the present study that body weight can be estimated with reasonable accuracy from the base of gait and the area swept in one stride and may help the forensic scientists in the investigation process. However, this method should only be used when other means of body weight estimation are not available.

Abbreviations

Area-L: Left area swept in one stride; Area-R: Right area swept in one stride; Base-L: Left base of gait; Base-R: Right base of gait; CCTV: Closed-circuit television; MS Excel: Microsoft Excel; *N*: Sample size; *r*: Correlation coefficient; SEE: Standard error of estimate; SPSS: Statistical Package for Social Sciences; *t* test: Student's *t* test

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Availability of data and materials

The study is a part of a large Ph.D. project, and the raw data is available with one of the authors (BS).

Authors' contributions

BS conceived the idea of writing this paper on the estimation of body weight. BS, KK, KJK, and TK wrote the initial draft of the manuscript. BS collected the data, conducted the analysis, and compiled the results.BS, KK, KJK, and TK wrote and approved the final version of the manuscript.

Ethics approval and consent to participate

The ethical approval to conduct the present study was granted by the Panjab University Institutional Ethical committee vide letter no. PU/IEC/100/13/09 dated 25/10/2013.

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

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References

Abledu JK, Abledu GK, Offei EB, Antwi EM (2016) Estimation of stature and body weight from footprint dimensions among a female population in Ghana. Aust J Forensic Sci 48:195–202

Atamturk D (2010) Estimation of Sex from the Dimensions of Foot, Footprints, and Shoe. Anthropol Anz 68:21–29

Barker SL, Scheuer JL (1998) Predictive value of human footprints in a forensic context. Med Sci law 38:341–346

Birch I, Raymond L, Christou A, Fernando MA, Harrison N, Paul F (2013) The identification of individuals by observational gait analysis using closed circuit television footage. Sci Justice 53:339–342 Available from: https://doi.org/10.1016/j.scijus.2013.04.005

Birch I, Vernon W, Walker J, Young M (2015) Terminology and forensic gait analysis. Sci Justice 55:279–284 Available from: https://doi.org/10.1016/j.scijus.2015.03.002

Bruening DA, Frimenko RE, Goodyear CD, Bowden DR, Fullenkamp AM (2015) Sex differences in whole body gait kinematics at preferred speeds. Gait Posture 41:540–545

Cheng M, Ho M, Huang C (2008) Gait analysis for human identification through manifold learning and HMM. Pattern Recogn 41:2541–2553 Available from: https://doi.org/10.1016/j.patcog.2007.11.021

Cunningham CB, Schilling N, Anders C, Carrier DR (2010) The influence of foot posture on the cost of transport in humans. J Exp Biol 213:790–797 Available from: https://doi.org/10.1242/jeb.038984

DiMaggio JA, Vernon OW (2011) Forensic podiatry: principles and methods, 1st edn. Humana Press, New York

Fawzy IA, Kamal NN (2010) Stature and body weight estimation from various footprint measurements among Egyptian population. J Forensic Sci 55:884–888

Halovic S, Kroos C (2018) Not all is noticed: Kinematic cues of emotion-specific gait. Hum Mov Sci 57:478–488 https://doi.org/10.1016/j.humov.2017.11.008

Hisham S, Rozid Mamat C, Ibrahim MA (2012) Regression analysis for stature estimation from foot anthropometry in Malaysian Chinese. Aust J Forensic Sci 0618:1–9

Jasuja OP, Harbhajan S, Anupama K (1997) Estimation of stature from stride length while walking fast. Forensic Sci Int 86:181–186

Kanchan T, Krishan K, Prusty D, Machado M (2014) Heel-ball index: an analysis of footprint dimensions for determination of sex. Egypt J Forensic Sci 4:29–33 Available from: https://doi.org/10.1016/j.ejfs.2014.02.002

Khan HBMA, Moorthy TN (2015) Stature estimation from the anthropometric measurements of footprints among Melanaus: an indigenous population of Malaysian Borneo. Can Soc Forensic Sci J 48:68–84 Available from: https://doi.org/10.1080/00085030.2015.1019225

Kim H-Y (2013) Statistical notes for clinical researchers: assessing normal distribution (2) using skewness and kurtosis. Restor Dent Endod 38:52 Available from: https://doi.org/10.5395/rde.2013.38.1.52

Krishan K (2008) Establishing correlation of footprints with body weight-forensic aspects. Forensic Sci Int 179:63–69 Available from: https://doi.org/10.1016/j.forsciint.2008.04.015

Krishan K, Kanchan T, DiMaggio JA (2015) Emergence of forensic podiatry-a novel sub-discipline of forensic sciences. Forensic Sci Int 255:16–27 Available from: https://doi.org/10.1016/j.forsciint.2015.06.012

Krishan K, Kanchan T, Passi N, DiMaggio JA (2012) Stature estimation from the lengths of the growing foot-a study on North Indian adolescents. Foot 22:287–293 Available from: https://doi.org/10.1016/j.foot.2012.08.005

Laroche DP, Marques NR, Shumila HN, Logan CR, Laurent RS, Goncalves M. (2015) Excess body weight and gait influence energy cost of walking in older adults. Med Sci Sports Exerc 47:1017–1025

Larsen PK, Simonsen EB, Lynnerup N (2007) Gait analysis in forensic medicine. Proc. SPIE 6491, Videometrics IX, 64910M (29 January 2007) https://doi.org/10.1117/12.698512

Naples VL, Miller JS (2004) Making tracks: the forensic analysis of footprints and footwear impressions. Anat Rec B New Anat 279:9–15
Raffalt PC, Guul MK, Nielsen AN, Puthusserypady S, Alkjær T (2017) Economy, movement dynamics, and muscle activity of human walking at different speeds. Sci Rep 7:1–14 Available from: https://doi.org/10.1038/srep43986
Robbins LM (1986) Estimating height and weight from size of footprints. J Forensic Sci 31:143–152 Available from: https://doi.org/10.1520/JFS11868J
Thevenon A, Gabrielli F, Lepvrier J, Faupin A, Allart E, Tiffreau V, Wieczorek V (2015) Collection of normative data for spatial and temporal gait parameters in a sample of French children aged between 6 and 12. Ann Phys Rehabil Med 58:139–144 Available from: https://doi.org/10.1016/j.rehab.2015.04.001
Watkins J (2006) Basic biomechanics of gait/structure and function of the foot. In: Neale's disorders of the foot. Churchill Livingstone, Edinburgh, pp 425–440
West SG, Finch JF, Curran PJ (1995) Structural equation models with nonnormal variable: problems and remedies. In: Hoyle RH (ed) Structural equation modeling: concepts, issues, and applications. Sage, Thousand Oaks, pp 56–75
Wilkinson MJ, Menz HB (1997) Measurement of gait parameters from footprints: a reliability study. Foot 7:19–23
Wilkinson MJ, Menz HB, Raspovic A (1995) The measurement of gait parameters from footprints. Foot 5:84–90