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DETERMINATION OF BODY WEIGHT FROM FOOTPRINT AND FOOT OUTLINE BREADTH ANTHROPOMETRY AMONG MELANAU ETHNICS OF BORNEO ISLAND, EAST MALAYSIA FOR FORENSIC INVESTIGATION

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ABSTRACT

The crime scene investigators use forensic footprint analysis to obtain vital information to solve crime. These include the estimation of stature, body weight, gender and age. Literature review shows that limited studies were conducted on body weight determination using foot impressions. This study aims to develop body weight determination models for an indigenous Melanau population residing in Borneo Island of east Malaysia from footprint and foot outline anthropometry. Footprint study results showed that breadth measurements provided better result in body weight determination than length measurements. Anthropometric measurements were made from a sample of 210 adults, with equal representation of 105 males and 105 females, following the standard procedure. Informed consent and ethical approval were obtained. The obtained data were analysed with PASW 20 computer software and developed population specific model to determine living body weight from footprint and foot outline breadth measurements. Correlation coefficient (R) values in footprint are found to be higher in the pooled sample (0.592–0.602) when compared with males (0.509–0.527) and females (0.569–0.591) separately. Correlation coefficient (R) values in foot outline are found to be higher in females (0.677-0.681) when compared with male (0.559-0.641) and the pooled sample (0.642-0.665).

Key words: Forensic science, body weight estimation, footprint, footoutline breadth, Melanau ethnics, East Malaysia

INTRODUCTION

Identification is the primary motto for any forensic investigators. The need for personal identification arises whenever foot impressions are found in scenes of crime like homicide, robbery, sexual assaults etc., and also in any other type of crime incidents. An aspect of human identification that has received scant attention from forensic anthropologists is the study of human footprints made by the feet (Bhasin & Malik, 2002). Violent crime scenes often register incomplete/broken bloodstained footprint impressions (Samir *et al.,* 2016). Many crimes are committed where the culprit must walk around the crime scene leaving tell-tale foot impressions. Examination of barefoot impressions is important especially in developing countries like India, Malaysia where majority of the rural population like to walk barefooted because of socio-economic and climatic reasons. Foot impressions are still found at crime scenes, since offenders often tend to remove their foot wears either to avoid noise or to gain better grip in climbing walls, etc., while entering or exiting (Nataraja Moorthy *et al.,* 2011). The footprint provides the size dimensions of the foot's plantar surface actually touching the floor or hard surface, which produces a two-dimensional footprint. On the other hand, the foot outline provides the size parameters of the fleshed bare foot and also represents the boundaries of the foot's impression in soft soil, mud, or any other substances that produces a three-dimensional footprint

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impression (Robin, 1986). Researchers have concluded that foot prints can be used to estimate stature (Robin, 1986; Krishan, 2008; Irene & Naswa, 2010; Vidya *et al.,* 2011; Reel *et al.,* 2012; Ukoha, 2013; Nataraja Moorthy *et al.,* 2014), gender (Derya, 2010; Naomi *et al*., 2013; Kanchan *et al.,* 2014) and body weight (Robin, 1986; Irene & Nashwa, 2010; Abledu *et al*., 2016). Researchers have cautioned that the morphology of human feet show the variations due to heredity, life style, food habits and climatic factors (Nataraja Moorthy *et al.,* 2011, 2014; Nataraja Moorthy & Hairunnisa, 2015; Jayadip & Shila, 2008; Salina *et al.,* 2012; Vidya *et al.,* 2011; Nataraja Moorthy *et al.,* 2015). Hence the present study aims to estimate body weight based on footprints and foot outline for Melanau ethnics, an indigenous groups residing in Borneo Island, east Malaysia.

MATERIALS AND METHODS

Study area

The study was carried out at East Malaysia, north-central Borneo Island. The subjects were from colleges, universities and general public. The Melanaus are an indigenous ethnic group mostly residing in East Malaysia.

Sample collection

The present study was started only after obtaining proper permission from Sarawak Chief Minister vide No. JKM.P/DEV/16/005/12 (44), since the subjects are from an indigenous ethnics in Borneo Island. Informed consent from the participants and ethical approval from University Human Research Committee were obtained following the standard procedure. A sample of 420 bilateral footprints and 420 bilateral foot outlines were collected from 210 (105 males, 105 females) consenting adult Melanau ethnics, ages ranging between 18 and 59 years. Subjects with any apparent foot-related disease, pregnancy, orthopedic deformity, physical impairment, injury, disorders or under the age of 18 years were excluded from the study. Just prior to sample collection, the subjects were advised to wash their feet with soap and water. The weight of the subjects was measured and recorded following the standard procedure (Irene & Nashwa, 2010). Then the subject was requested to place the left foot on an A4 size white paper and the foot outline was drawn with a sharp-pointed pencil. The pencil was held perpendicular to the paper as it traced around the margin of the foot. With the foot still on the paper, the anatomical landmarks of the foot, namely mid-rear heel point (pternion, OP) in the base line BL and foot outline breadth measurements viz. ball breadth (BB) and heal breadth (HB) were marked. Then a cleaned left foot of the subject was advised to step on a footprint ink stained plain glass plate of 8 mm thickness with minimal pressure. Then the inked foot was placed on an A4 plain white paper kept aside on a uniform surface and thus the left footprint was transferred.

Before lifting the sole from the paper, anatomical land marks of the feet were marked on the papers close to the footprints which are mid-rear heel point (P) and (OP) for foot outline, ball breadth (BB) and heel breadth (HB). The left footprint ball breadth measurements were taken from the medial metatarsal point (B) to lateral metatarsal point (B) as designated as (LPBB) and (RPBB) for left and right footprint. For foot outline it is designated as (ROBB) for right foot outline and (LOBB) for left foot outline. The heel breadth measurement is the distance between calcaneal tubercle lateral (H) and calcaneal concavity medial (B), in both footprint and foot outline. The heel breadth measurements were designated as (LPHB) for left footprint and (RPHP) for right print. Similarly, the heel breadth measurements were designated as (LOHB) for left foot outline and (ROHB) for left foot outline. The land marks and breadth measurements on footprint and foot outline are shown in Figure 1. All footprints and information relating to participants were coded with sample ID for anonymity.

Statistical analysis

The data were analysed using PASW Statistics version 20 (Predictive Analytic Software). Pearson's correlation coefficient (R) between various footprint breadth and body weight was obtained. The multiple regression analysis method was employed to derive formulae for body weight estimation from various footprint and foot outline breadth measurements.

RESULTS

Table 1 presents the descriptive statistics of body weights in males, females and pooled sample (combined male and female subjects). The table also shows that the mean body weight of male is found to be comparatively higher (60.9 kg) than the body weight of females (52.5 kg). Table 2 presents the descriptive statistics of various ball breadth and heel breadth measurements in the footprints among male, female and pooled sample on both sides. The ball breadth measurements (left- LPBB, right- RPBB) are comparatively larger than the heel measurements (left- LPHB, right- RPHB) which is generally common to a normal human foot. The result shows that the size of both ball and heel breadth measurements are found to longer in males

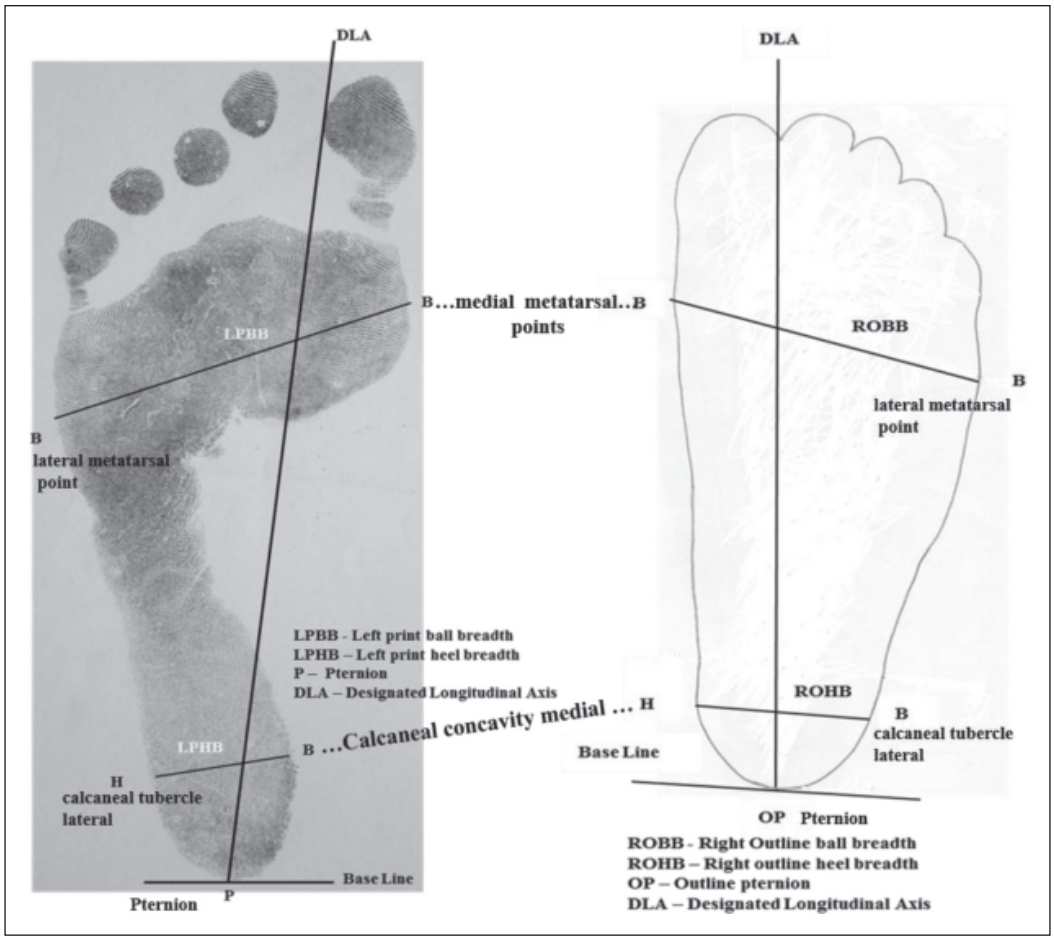

Fig. 1. Landmarks and breadth measurements on footprint and foot outline.

Table 1. Descriptive statistics of body weight in adult males, females and pooled sample among Melanau ethnics of east Malaysia (in kg)

Variable	Male (N=120)				Female (N=120)				Pooled sample (N=240)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Body weight (kg)	35.0	103.1	60.9	12.3	31.0	102.6	52.5	1.8	31.0	103.1	56.7	1.3

Min: minimum; Max: maximum; N: sample size; SD: standard deviation.

Table 2. Descriptive statistics of ball and heel breadth measurements in the footprints of adult males, females and pooled sample among Melanau ethnics of east Malaysia (in cm)

Variable	Male (N=105)				Female (N=105)				Pooled sample (N=210)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
LPBB	8.0	11.0	9.44	0.5	7.5	10.0	8.51	0.5	7.5	11.0	8.97	0.7
LPHB	3.5	6.5	4.68	0.5	2.9	5.7	4.10	0.5	2.9	6.5	4.39	0.6
RPBB	8.2	11.2	9.48	0.5	7.5	9.9	8.60	0.5	7.5	11.2	9.04	0.7
RPHB	3.8	6.8	4.75	0.6	2.8	5.5	4.14	0.5	2.8	6.8	4.45	0.6

Min: minimum; Max: maximum; N: sample size; SD: standard deviation; LPPB: ball breadth in left footprint; RPBB: ball breadth in right footprint; LPHB: heel breadth in left footprint; RPHB: heel breadth in right footprint.

compared to females as observed in body weight. The size of footprints shows bilateral asymmetry and the right foot breadth measurements are larger than the left in both ball and heel area.

Table 3 presents the descriptive statistics of various ball breadth and heel breadth measurements in the foot outline among male, female and pooled sample on both sides. The ball breadth (LOBB, ROBB) measurements are comparatively larger than the heel measurements (LOHB, ROHB) as observed in footprints. The result indicated that the size of both ball and heel breadth measurements are found to longer in males compared to females. Table 4 describes the multiple regression equations for body weight determination in adult males, females and the pooled sample through various breadth measurements in footprints with ANOVA. The standard error of estimate (SEE) did not show much variation among the genders and pooled sample. The table also shows that the correlation coefficient (R) between body weight and various footprint breadths among males, females and pooled sample are statistically significant (<0.001). Correlation coefficient values are found to be more in the pooled sample (0.592–0.602) when compared with males (0.509–0.527) and females (0.569–0.591).

Table 5 shows the multiple regression equations for body weight determination in adult males, females and the pooled sample through various breadth measurements in foot outline with ANOVA. The standard error of estimate (SEE) is comparatively lower in females than male and pooled sample. The table also shows that the correlation coefficient (R) between body weight and various foot outline breadth measurements are statistically significant (<0.001). Correlation coefficient values are found to be more in females (0.677–0.681) when compared with males (0.559–0.641) and the pooled samples (0.642–0.665).

DISCUSSION

The demographics of Malaysia are represented by the multiple ethnic groups that exist in this country. East Malaysia, also known as Sabah, Sarawak and Labuan or Malaysian Borneo, is the part of Malaysia located on the island of Borneo. The indigenous ethnics in east Malaysia include Iban, Bidayuh, Melanau, Orang Ulu and so on. Melanau or *A-Likou* (meaning River people) are an ethnic group indigenous to Sarawak state, Malaysia. They are

Table 3. Descriptive statistics of ball and heel breadth measurements in the foot outlines of adult males, females and pooled sample among Melanau ethnics of east Malaysia (in cm)

Variable	Male (N=105)				Female (N=105)				Pooled sample (N=210)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
LOBB	8.5	11.9	10.60	0.5	8.5	11.3	9.61	0.6	8.5	11.9	10.11	0.7
LOHB	5.4	7.9	6.56	0.5	4.0	7.0	5.81	0.5	4.0	7.9	6.18	0.6
ROBB	9.0	11.9	10.56	0.5	8.3	11.2	9.57	0.5	8.3	11.9	10.07	0.7
ROHB	5.5	7.9	6.45	0.5	4.4	7.1	5.81	0.5	4.4	7.9	6.14	0.6

Min: minimum; Max: maximum; N: sample size; SD: standard deviation; LOBB: ball breadth in left foot outline; ROBB: ball breadth in right foot outline; LOHB: heel breadth in left foot outline; ROHB: heel breadth in right foot outline

Table 4. Multiple regression equations to determine body weight (kg) through ball and heel measurements and ANOVA in the footprints of adult males, females and pooled sample among Melanau ethnics of east Malaysia

Gender	Side	Multiple regression equations	R	R^2	*Adj* R^2	SEE	ANOVA
Male N=105	Left	W = 54.827 + 11.488(LPBB) + 4.577(LPHB)	0.509	0.259	0.244	10.71	17.807(2, 102) ; p < 0.001
	Right	W = 54.584 + 12.325(RPBB) + 7.277(RPHB)	0.527	0.278	0.278	10.57	19.622(2, 102) ; *p* < 0.001
Female N=105	Left	W = 54.854 + 9.663(LPBB) + 6.110(LPHB)	0.569	0.324	0.311	10.65	24.453(2, 102) ; *p* < 0.001
	Right	W = 55.773 + 8.822(RPBB) + 7.808(RPHB)	0.591	0.349	0.336	10.45	27.334(2, 102) ; *p* < 0.001
Pooled sample N=210	Left	W = 40.059 + 9.033(LPBB) + 3.577(LPHB)	0.592	0.350	0.344	10.73	55.778(2, 207) ; *p* < 0.001
	Right	W = 42.756 + 9.516(RPBB) + 3.020(RPHB)	0.602	0.362	0.356	10.63	58.740(2, 207) ; *p* < 0.001

W: body weight; Max: maximum; N: sample size; R: correlation coefficient; R^2: coefficient of determination; SEE: standard error of estimation; LPPB: ball breadth in left footprint; RPBB: ball breadth in right footprint; LPHB: heel breadth in left footprint; RPHB: heel breadth in right footprint.

Table 5. Multiple regression equations to determine body weight (kg) through ball and heel measurements and ANOVA in the foot outlines of adult males, females and pooled sample among Melanau ethnics of east Malaysia

Gender	Side	Multiple regression equations	R	R^2	*Adj* R^2	SEE	ANOVA
Male N=105	Left	W = 94.271 + 10.588(LOBB) + 6.549(LOHB)	0.641	0.411	0.399	9.549	35.542(2, 102) ; $p < 0.001$
	Right	W = 80.588 + 10.884(ROBB) + 4.130(ROHB)	0.559	0.313	0.299	10.31	23.211(2, 102) ; $p < 0.001$
Female N=105	Left	W = 68.590 + 2.998(LOBB) + 15.879(LOHB)	0.677	0.458	0.448	9.530	43.140(2, 102) ; $p < 0.001$
	Right	W = 82.206 + 5.884(ROBB) + 13.489(ROHB)	0.681	0.463	0.453	9.486	44.028(2, 102) ; $p < 0.001$
Pooled sample N=210	Left	W = 49.683 + 4.760(LOBB) + 9.426(LOHB)	0.665	0.442	0.436	9.945	81.933(2, 207) ; $p < 0.001$
	Right	W = 55.061 + 6.087(ROBB) + 8.242(ROHB)	0.642	0.412	0.406	10.21	72.518(2, 207) ; $p < 0.001$

W: body weight; N: sample size; R: correlation coefficient; R^2: coefficient of determination; SEE: standard error of estimation; LOBB: ball breadth in left foot outline; ROBB: ball breadth in right foot outline; LOHB: heel breadth in left footprint; ROHB: heel breadth in right foot outline

among the earliest settlers of Sarawak. They speak Melanau language, which is part of north Bornean branch of Malayo-Polynesian languages (Bilcher, 1993). The Melanaus were traditionally fishermen as well as paddy and sago farmers. Some were skilled boat builders. The age range of the subjects in this research is appropriate since stature at 18 years is accepted as adult (Natarajamoorthy *et al*., 2014; Krishan & Abihilasha, 2007). Hence the minimum age was fixed as 18 years to conduct this study. The footprint and foot outline breadth measurements in males are found to be larger than females, both in left and right side. This may be attributed to the general male-female differences and natural size in both sexes (Tanuj *et al.,* 2012). It is noted that the correlation coefficient (R) values between body weight and footprint breadth measurements are found be more in the pooled sample, whereas in foot outline, the R values are found to be more in females. In many countries, footprint evidence is considered "unimportant" and neglected evidence during their crime scene investigation. But footprints have a considerable value in forensic science, and they can be collected from the crime scene and utilized as a kind of evidence for estimation of body size, i.e., stature, body weight and individual characteristics for personal identification (Krishan, 2008). Researchers have conducted a study on body weight estimation from footprint lengths among 50 male medical students in Egypt and the correlation coefficient (R) was found to be in the range of 4.05–5.28 (Irene & Nashwa, 2010). The present study used multiple regression analysis since researchers have shown that the standard error of estimate decreases if the multiple regression equation is used when compared with linear regression analysis in a footprint study (Nataraja Moorthy *et al.,* 2014). Many studies have been conducted on estimation of stature from foot and footprint dimensions but unfortunately very few studies have reported the relationship of body weight with footprints. Body weight determination can provide a valuable information to the crime scene investigators and may also further help in narrowing down the possible suspects considered as crime perpetrators.

CONCLUSION

This study developed population specific regression equations for body weight determination through foot prints and foot outlines obtained from consented Melanaus of east Malaysia using multiple regression statistical method. It would be incorrect to utilize these equations to any other populations either in Malaysia or any other population in the world. The researchers are encouraged to conduct similar studies in different parts of the world so that the effect of genetic and environment can be investigated in forensic terms.

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