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STATURE ESTIMATION FROM ANTHROPOMETRIC MEASUREMENTS OF FOOTPRINTS IN LUN BAWANG, AN INDIGENOUS ETHNIC GROUPS OF EAST MALAYSIA BY LINEAR REGRESSION ANALYSIS

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ABSTRACT

The footprint is a valuable physical evidence encountered in the crime scenes and examination of barefoot impressions is important especially in developing countries like India, Malaysia where the majority of the rural population like to walk barefooted. Most of the foot/foot print studies were conducted on mixed population. But racial and cultural aspects of foot morphology must be considered while conducting such studies. Hence the present study aims to estimate stature from bilateral footprints collected from 230 (115 males, 115 females) consenting adult Lun Bawang ethnics, indigenous groups residing in Sarawak state, east Malaysia. The height of the individuals and footprints were collected following the standard procedure. The data obtained were analyzed with PASW 20 computer software and derived regression formulae to estimate stature from footprint lengths of Lun Bawang ethnics. The investigation revealed that all footprint lengths exhibit statistically positive significant correlation with stature ($p<0.001$). Correlation coefficient (R) values are found to be higher in the pooled sample (0.862–0.883) when compared with males (0.718–0.760) and females (0.754–0.802). The regression formulae derived for the pooled sample can be used to estimate stature when the sex of the footprint remains unknown, as in real crime scenarios.

Key words: Forensic science, stature estimation, footprint, Lun Bawang ethnics, East Malaysia

INTRODUCTION

An aspect of human identification that has received scant attention from forensic anthropologists is the study of human footprints made by the feet (Jahar *et al.,* 2010). Person identification using footprint analysis is also an emerging biometric technique (Ambeth Kumar & Ramakrishnan, 2011). The characteristic features can provide useful clues to establish identity whenever complete or partial footprints are recovered at the crime scenes (Krishan, 2007). Examination of barefoot impressions is important especially in developing countries like India, Malaysia where the 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). Footprints can be found on newly waxed floors, freshly cemented surfaces, moistened surfaces, in dust, oil, paint and can be left in blood at the murder scenes (Qamra *et al*., 1980a,b). Analyses of foot (Anil *et al.,* 1997; Hilmi *et al.,* 2005; Jayadip & Ghosh, 2008; Tanuj *et al.,* 2010; Muktarani *et al.,* 2011; Salina *et al.,* 2012; Naomi *et al.,* 2013) and footprints (Robin, 1986; Krishan, 2008; Irene & Nashwa, 2010; Vidya *et al.,* 2011; Reel *et al.,* 2012; Ukoha, 2013; Nataraja Moorthy *et al.,* 2015) help in estimation of an individual's stature because of the existence of a strong correlation between one's stature and foot size. For stature estimation from footprint parameters, the researchers indicated that toes-to-heel footprint length in a footprint has more reliability of prediction than from any other

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measurements, such as breadth at ball/heel and big toe breadth/length (Qamra *et al.,* 1980b; Krishan & Abihilasha, 2007b; Jayadip & Ghosh, 2008; Muktarani *et al*., 2011; Tanuj *et al.,* 2012).

The researchers have cautioned that the people from different races and regions of a country bear different morphological features depending upon their geographical distribution and primary racial characteristics and hence a single formula cannot represent all parts of the country or world (Nataraja Moorthy *et al.,* 2011; Jayadip & Ghosh, 2008; Salina *et al.,* 2012; Vidya *et al.,* 2011; Nataraja Moorthy & Hairunnissa, 2015). The present study aimed to estimate the stature from all toes-to-heel footprint length measurements in a footprint so that the findings of the study will be applicable to partial and complete footprints of Lun Bawangs of east Malaysia. This study used linear regression analysis since the reliability and prediction of stature estimation is more accurate and reliable with the regression analysis method (Krishan *et al.,* 2012).

MATERIALS AND METHODS

Study area

The study was carried out at Sarawak state, East Malaysia north-central Borneo Island. The subjects were from colleges, universities and the general public. The Lun Bawangs are an indigenous ethnic group, a native of East Malaysia and most Lun Bawangs are residing in Limbang Division (fifth division) primarily in Lawas district, Sarawak, one of the two states in east Malaysia, Sabah and Sarawak.

Sample collection

Since the subjects are an indigenous group in Borneo Island, permission was obtained from Sarawak Chief Minister vide No. JKM.P/DEV/16/005/12(44), for sample collection. Informed consent was also obtained from all participants and followed the procedure in accordance with the ethical standards of University Human Research Ethic Committee A sample of 460 bilateral footprints were collected from 230 (115 males, 115 females) consenting adult Lun Bawang ethnics, ages ranging between 18 to 84 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. The subjects were advised to wash their feet with soap and water. The stature of each subject was measured without head and footwear using a portable body meter measuring device (SECA model 206) following the standard procedure (Nataraja Moorthy *et al.,* 2011; Irene & Nashwa, 2010). Considering the diurnal variation in stature, the height of the subjects was measured approximately at a fixed time in the afternoon. The diurnal change in height of a person was reported and confirmed by the researchers (Krishan *et al.,* 2007; Krishan & Abilasha, 2007).

The subjects were asked to wash their feet with soap solution and remove the moisture using a cotton cloth. The footprints were collected following the standard procedure (Irene & Nashwa, 2010). Following the procedure (Robin, 1986; Krishan, 2008), the designated longitudinal axis (DLA) and base line (BL) were drawn on the footprints. Then five diagonal footprint length measurements were taken from the mid-rear heel point (P) to most anterior point of each left toes (LT1, LT2, LT3, LT4, and LT5). The left footprint length measurements were designated as PLT1, PLT2, PLT3, PLT4, and PLT5. The procedure was repeated for the right footprint and the right footprint length measurements were designated as PRT1, PRT2, PRT3, PRT4, and PRT5. The land marks and diagonal length measurements on right footprint are shown in Figure 1. All footprints and information relating to participants were coded with sample ID for anonymity.

Statistical analysis

The data were analyzed using PASW Statistics version 20 (Predictive Analytic Software). Pearson's correlation coefficient (R) between various footprint lengths and stature was obtained. The linear regression analysis method was employed to derive regression equations for stature estimation from various footprint lengths since stature estimation from footprint length is more accurate and reliable with regression analysis (Krishan *et al.,* 2012).

RESULTS

Table 1 presents the descriptive statistics of stature in males, females and pooled sample (combined male and female subjects). The mean stature of males is found to be comparatively higher (165.3 cm) than females (152.8 cm). Table 2 presents the descriptive statistics of various footprint lengths i.e. diagonal length between the rear heel end (P) and anterior points of each toe in both left (LT1– LT5) and right (RT1–RT5) footprints of males, females and the pooled sample. All the footprint length measurements in males are found to be larger than females both in left and right feet. It is observed that the mean second toe-heel footprint lengths on the left footprint is the longest while the right footprint did not show any variation in lengths between first and second toe-heel lengths. In females, the mean first toe-heel footprint on the right side is the longest while left footprint did not show variation in lengths

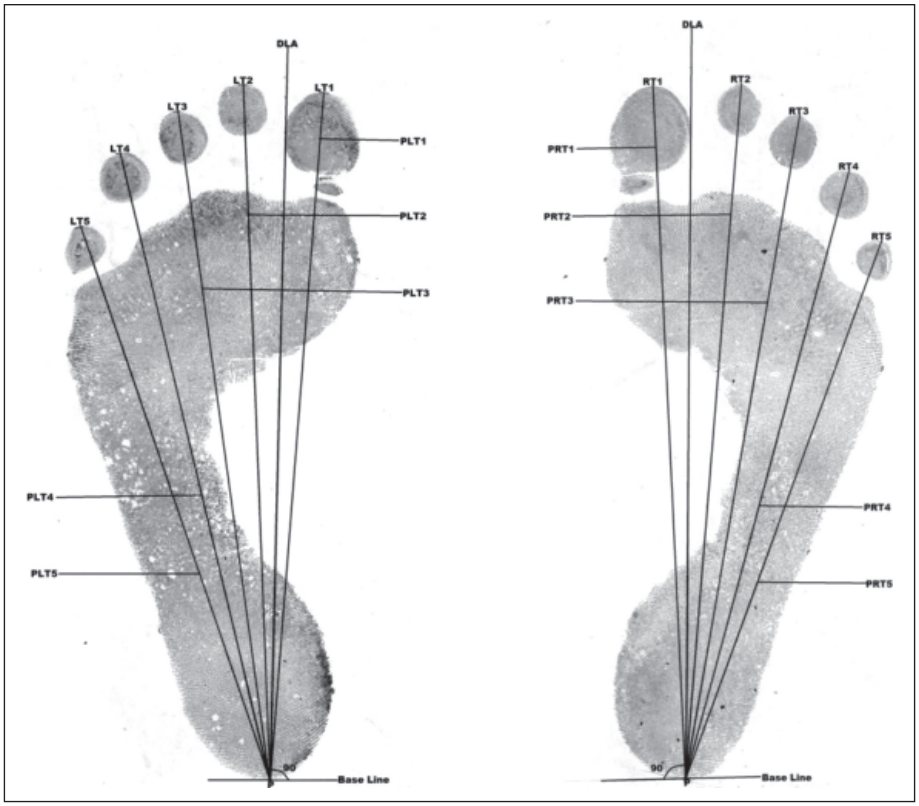

Fig. 1. Landmarks and diagonal length measurements on left and right footprint PLT1-PLT5 and PRT1-PRT5, measurements taken from the mid-rear heel point, pternion (P) to the most anterior point of toes PLT1-PLT5 and RT1-RT5 on the left and right footprints. DLA, designated longitudinal axis.

Table 1. Descriptive statistics of stature in males, females and pooled sample of adult Lun Bawang ethnics (in centimeters)

Variable	Male (N=115)			Female (N=115)			Pooled sample (N=230)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Stature	146.0	183.3	165.3	134.7	170.0	152.8	134.7	183.3	159.0

Min: minimum; Max: maximum; N: sample size

Table 2. Descriptive statistics of footprint length measurements in males, females and pooled sample of adult Lun Bawang ethnics of Sarawak (in centimeters)

Variable	Male (N=115)				Female (N=115)				Pooled sample (N=230)			
	Min	Max	mean	SD	Min	Max	mean	SD	Min	Max	mean	SD
PLT1	20.7	26.6	23.7	1.1	18.7	23.9	21.8	0.9	18.7	26.6	22.8	1.4
PLT2	20.4	27.2	23.9	1.2	18.8	24.2	21.8	1.0	18.8	27.2	22.8	1.5
PLT3	20.0	26.7	23.1	1.2	17.6	23.2	21.0	1.0	17.6	26.7	22.0	1.5
PLT4	17.9	25.1	21.9	1.1	16.5	21.7	19.9	0.9	16.5	25.1	20.9	1.4
PLT5	17.5	23.1	20.3	1.0	15.1	20.3	18.9	0.8	15.1	23.1	19.3	1.3
PRT1	20.3	26.6	23.7	1.1	19.0	24.0	22.0	0.9	19.0	26.6	22.8	1.3
PRT2	20.4	26.9	23.7	1.2	19.0	23.7	21.8	1.0	19.0	26.9	22.8	1.5
PRT3	19.7	26.5	22.9	1.2	17.9	23.2	21.0	1.0	17.9	26.5	22.0	1.5
PRT4	18.4	25.1	21.7	1.1	16.6	21.9	19.9	0.9	16.6	25.1	20.8	1.4
PRT5	16.9	23.1	20.1	1.0	15.2	19.8	18.3	0.8	15.2	23.1	19.2	1.3

Min: minimum; Max: maximum; PLT1 to PLT5: left footprint lengths from anterior part of toes LT1- LT5 to mid-rear heel point P; PRT1 to PRT5: right footprint lengths from anterior part of toes RT1-RT5 to mid-real heel point P; SD: standard deviation; N: Sample size.

between first and second toe-heel lengths. Hence a bilateral asymmetry exists in both males and females but not significant. The standard deviations values are found to be low.

Tables 3–5 present the linear regression equations for stature estimation in adult males, females and the pooled sample through various footprint length measurements with ANOVA. The standard error of estimate (SEE) in the case of females (3.797–4.170) is comparatively lower than that of males (3.823–4.097) and the pooled sample (4.113–4.438). The tables also show that the correlation coefficient (R) between the stature and various footprint lengths among males, females and pooled sample are statistically significant (<0.001). Correlation coefficient values are found to be more in the pooled sample (0.862–0.883) when compared with males (0.718–0.760) and females (0.754–0.802). The coefficient of determination (R^2), the predictive accuracy is found to be statistically significant for stature estimation. Hence statistically significant correlation coefficient exists between stature and all footprint length measurements in Lun Bawangs of east Malaysia.

DISCUSSION

The age range of the subjects in this study is appropriate since stature at 18 years is accepted as an adult (Krishan & Abilasha, 2007; Krishan & Viji, 2007; Nataraja Moorthy *et al.,* 2014). Hence the minimum age was fixed as 18 years to conduct this study. Lun Bawang is formerly known as Murut live in the Kerayan-Kelabit highlands of central northeast Borneo. They are also found in the coastal districts of Trusan and Lawas in Sarawak. They are traditionally farmers involved in the cultivation of both rice on a hill called *lati' tana' luun* and rice from paddy field called *lati' ba* (Bilchar, 1993). The name Lun bawang is a self-labelled phrase which means "the people of the land or the people of the

Table 3. Linear regression equations for stature estimation from different footprint length measurements on left and right sides among adult Lun Bawang male ethnics of Sarawak (in centimeters)

Variables	Regression Equations	SEE	*R*	R^2	ANOVA
PLT1	77.016 + 3.729PLT1	4.097	0.718	0.515	120.119(1, 113) ; P<0.001
PLT2	75.054 + 3.784PLT2	3.857	0.755	0.570	150.085(1, 113) ; P<0.001
PLT3	81.118 + 3.650PLT3	4.053	0.725	0.526	125.243(1, 113) ; P<0.001
PLT4	81.635 + 3.827PLT4	4.021	0.730	0.533	129.088(1, 113) ; P<0.001
PLT5	77.507 + 4.334PLT5	3.938	0.743	0.552	139.348(1, 113) ; P<0.001
PRT1	73.397 + 3.882PLT1	3.853	0.756	0.571	150.682(1, 113) ; P<0.001
PRT2	76.080 + 3.757PRT2	3.823	0.760	0.578	154.749(1, 113) ; P<0.001
PRT3	84.150 + 3.537PRT3	4.096	0.718	0.516	120.290(1, 113) ; P<0.001
PRT4	81.094 + 3.878PRT4	4.046	0.726	0.527	126.037(1, 113) ; P<0.001
PRT5	79.599 + 4.258PRT5	3.862	0.755	0.569	149.373(1, 113) ; P<0.001

PLT1 to PLT5: left footprint lengths from the anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5: right footprint lengths from the anterior part of toes RT1-RT5 to mid-rear heel point P; SEE: standard error of estimate; R^2:coefficient of determination. p-value < 0.001 significant.

Table 4. Linear regression equations for stature estimation from different footprint length measurements on left and right sides among adult Lun Bawang female ethnics of Sarawak (in centimeters)

Variables	Regression Equations	SEE	*R*	R^2	ANOVA
PLT1	32.145 + 5.527PLT1	4.018	0.775	0.600	169.461(1, 113) ; *P*<0.001
PLT2	44.756 + 4.966PLT2	3.898	0.790	0.623	187.104(1, 113) ; *P*<0.001
PLT3	46.299 + 5.065PLT3	3.963	0.782	0.611	177.370(1, 113) ; *P*<0.001
PLT4	44.955 + 5.414PLT4	4.077	0.767	0.588	161.390(1, 113) ; *P*<0.001
PLT5	44.956 + 5.866PLT5	4.170	0.754	0.569	149.196(1, 113) ; *P*<0.001
PRT1	26.493 + 5.744PRT1	3.908	0.788	0.622	185.561(1, 113) ; *P*<0.001
PRT2	47.775 + 4.813PRT2	4.028	0.773	0.598	168.048(1, 113) ; *P*<0.001
PRT3	47.374 + 5.014PRT3	3.797	0.802	0.643	203.358(1, 113) ; *P*<0.001
PRT4	42.781 + 5.536PRT4	3.843	0.796	0.634	195.851(1, 113) ; *P*<0.001
PRT5	42.051 + 6.045PRT5	4.028	0.773	0.598	168.062(1, 113) ; *P*<0.001

PLT1 to PLT5: left footprint lengths from the anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5: right footprint lengths from the anterior part of toes RT1-RT5 to mid-rear heel point P; SEE- standard error of estimate; R^2: coefficient of determination. p-value < 0.001 significant.

Table 5. Linear regression equations for stature estimation from different footprint length measurements on left and right sides among adult Lun Bawang pooled sample (in centimeters)

Variables	Regression Equations	SEE	*R*	R^2	ANOVA
PLT1	34.213 + 5.487PLT1	4.438	0.862	0.743	658.855(1, 228) ; *P*<0.001
PLT2	42.891 + 5.094PLT2	4.113	0.883	0.779	804.628(1, 228) ; *P*<0.001
PLT3	45.784 + 5.138PLT3	4.297	0.871	0.759	718.176(1, 228) ; *P*<0.001
PLT4	46.043 + 5.410PLT4	4.341	0.868	0.754	699.249(1, 228) ; *P*<0.001
PLT5	46.333 + 5.834PLT5	4.251	0.874	0.764	738.679(1, 228) ; *P*<0.001
PRT1	28.077 + 5.736PRT1	4.380	0.866	0.750	682.544(1, 228) ; *P*<0.001
PRT2	40.715 + 5.194PRT2	4.285	0.872	0.760	723.520(1, 228) ; *P*<0.001
PRT3	45.278 + 5.175PRT3	4.362	0.867	0.752	690.218(1, 228) ; *P*<0.001
PRT4	43.071 + 5.577PRT4	4.294	0.871	0.759	719.514(1, 228) ; *P*<0.001
PRT5	45.673 + 5.898PRT5	4.211	0.877	0.769	756.956(1, 228) ; *P*<0.001

PLT1 to PLT5: left footprint lengths from the anterior part of toes LT1- T5 to mid-rear heel point P; PRT1 to PRT5: right footprint lengths from the anterior part of toes RT1-RT5 to mid-rear heel point P; SEE: standard error of estimate; R^2:coefficient of determination. p-value < 0.001 significant.

place or villages. The usage of Lun Bawang phrase gradually became popular and used in official documents after the formation of the federation of Sarawak in the year of 1963 (Bilchar, 1993). The present investigation shows that statistically significant male–female differences exist in the stature in Lun Bawang population. All the footprint length measurements in males are found to be larger than females both in left and right feet. This may be attributed to the general male-female differences and natural size in both sexes (Tanuj *et al.,* 2012). The result shows bilateral asymmetry in footprints but not significant. Some of the researchers have shown the existence of left sided asymmetry in the population under study (Nataraja Moorthy *et al.,* 2011; Irene & Nashwa, 2010; Vidya *et al.,* 2011). It is noted that the correlation coefficient (R) between stature and footprint length measure-ments regardless of sex, i.e. when male and female subjects are pooled together, gave a more significant result than the correlations separately obtained for the males and females. This finding is consistent with earlier studies of Malays (Nataraja Moorthy *et al.,* 2011), Malaysian Chinese (Salina *et al.,* 2012) and Indians (Krishan, 2008). The derived regression equations from footprint length measurements for stature estimation in both males and females show high reliability and accuracy since the SEE values were found to be low. Researchers indicated that regression formulae can be derived for stature estimation using foot and hand measurements with a great accuracy and a small SEE, i.e. about 2–6 cm (Krishan *et al.,* 2012).

CONCLUSION

The results of this investigation provided regression formulae to estimate stature from footprints in Lun Bawang of east Malaysia. The regression equations derived from the pooled sample can be used to estimate stature when the sex of the footprint's owner remains unknown, as in real crime scenarios. It is important to note that the regression equations derived in this research to estimate stature from footprint is suitable only for Lun Bawang population in East Malaysia and it would be incorrect to utilize these equations to any other populations either in Malaysia or any other population in the world.

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