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ESTIMATION OF BODY WEIGHT FROM FOOT OUTLINE LENGTH MEASUREMENTS IN MELANAU POPULATION OF EAST MALAYSIA

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ABSTRACT

Forensic resources use footprint analysis to obtain vital information during specific crime scene investigations. The examination of bare foot impression is important especially in Asian countries like India and Malaysia where some of the rural population still walk barefooted. Literature review shows that countable research work was conducted to estimate body weight from foot outline anthropometry. The researchers cautioned that racial and cultural aspects of foot morphology must be considered while conducting the foot print study. Hence the present study aims to derive population specific equations to estimate body weight from foot outline anthropometry from 200 (100 males, 100 females) consented adult Melanau ethnics of east Malaysia. The collected data were analysed with PASW 20 computer software. There is a positive correlation exists between body weight and foot outline length measurements. Correlation coefficient (R) values are found to be higher in the pooled sample (0.257–0.286) when compared with males (0.158–0.264) and females (0.179–0.247). The regression formulae derived from the pooled sample can be used to estimate body weight from foot outline when the sex of the foot outline remains unknown, as in real crime scenarios.

Key words: Forensic science, body weight estimation, foot outline, Melanau population, East Malaysia

INTRODUCTION

Person identification is considered as one of the mainstay crime scene investigation. Establishing a relationship between the accused and crime is of paramount importance in each and every crime scene investigation. An aspect of human identification that has received scant attention from forensic anthropologist is the study of human foot and foot impressions made by the foot (Jahar *et al.,* 2010). Person identification using footprint analysis is also an emerging biometric technique (Ambeth Kumar & Ramakrishnan, 2011). There is a relationship between each part of the body and the whole body (Philip, 1990). Examination of bare foot impression is important, especially in Asian countries like India, Thailand, Indonesia and Malaysia where some of the rural population walk barefoot (Nataraja Moorthy *et al.,* 2014). Foot impressions are found at crime scenes since offenders often remove their footwear, either to avoid noise or to gain better grip in climbing walls, etc, while entering and exiting (Nataraja Moorthy *et al.,* 2011). It is shown that some of Asian forensic researchers have been probing investigation through footprint anthropometry and come up with fruitful findings for crime scene application. The footprint provides the size dimensions of the foot's plantar surface actually touching the floor or hard surface, which produces a two-dimensional (2D) footprint impression. 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 (3D) footprint impression (Nataraja Moorthy & Jessica, 2016). While considering footprint length, researchers have used both a bare footprint (plantar footprint), recorded using ink on a hard surface (2D) , as well as foot outline recorded by tracing the outline (3D)

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of the foot (Robin, 1986). Examination of footprint (Kanchan *et al.,* 2012; Reel *et al.,* 2012; Naomi *et al.,* 2013; Nataraja Moorthy *et al.,* 2013a), foot outline (Hairunnisa & Nataraja Moorthy, 2013; Nataraja Moorthy *et al.,* 2013b; 2014) and foot (Ilayaperuma *et al.,* 2008; Mansur *et al.,* 2012; Petra *et al.,* 2013) can help in estimation of an individual's stature because of the existence of a strong correlation between one's stature and foot/footprint/foot outline length. Literature review shows that very limited studies were conducted for determination of body weight from footprint anthropometry (Robin, 1986; Irene & Nashwa, 2010; Abledu *et al.,* 2016). It has also been cautioned that the multiplication factors of one population cannot be used for other populations as the various body measurements, including the foot, are bound to show regional and ethnic variations due to hereditary and various environmental conditions, such as climate, nutrition, etc. (Jasuja *et al.,* 1991). The present study aims to determine the body weight from various foot outline anthropometry in Melanau population.

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

Since the subjects are from 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 400 bilateral foot outlines were collected from 200 (100 males, 100 females) consenting adult Melanau ethnics, ages ranging between 18 to 64 years. Subjects with any apparent foot-related disease, pregnancy, orthopaedic deformity, physical impairment, injury, disorders or under the age of 18 years were excluded from the study. The weight of the subjects was measured and recorded following the standard procedure (Irene & Nashwa, 2010). Just prior to sample collection, the participants were advised to wash their feet with soap and water. Then a participant was requested to place the right 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, P) in the base line BL and most anterior points of all toes (OT1–OT5) were marked. The procedure was repeated for the left foot and for the other subjects (Hairunnisa & Nataraja, 2013; Nataraja Moorthy *et al.,* 2013b). The land marks on right foot outline are shown in Figure 1. All foot outlines 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 foot outline lengths and stature was obtained. The linear regression analysis method was employed to derive

Fig. 1. Illustrative example showing the mid-rear heel end, pternion (P) to the most anterior point of first toe/big toe OT1 on right foot outline.

regression equations for body weight estimation from various foot outline lengths.

RESULTS

Table 1 presents the descriptive statistics of body weights in males, females and pooled sample (combined male and female subjects) of body weight among Melanau population. The table also shows that the mean body weight of male is found to be comparatively higher (58.7 kg) than the body weight of females (49.4 kg). Table 2 presents the descriptive statistics of various foot outline lengths i.e. diagonal length between the mid-rear heel end (P) and anterior points of each toe in both left (LOT1– LOT5) and right (ROT1–ROT5) footprints of males, females and the pooled sample. Here pooled sample (N=200) represents the combination of both male (N=100) and female (N=100) samples. In real crime scenarios, it is cumbersome to know the gender of 3D foot impression and hence pooled sample is created and derived formulae to estimate body weight. The table shows that various mean foot outline lengths of male are found to be larger than the mean foot outline lengths of female showing the general gender difference. It is interested to note that the mean first toe–heel foot outline lengths in both left and right (LPOT1, RPOT1) are found to be the longest in both genders. The investigation reveals the existence of bilateral asymmetry in both the genders but not significant. The standard deviations are very low in both males and females.

Tables 3–5 present the linear regression equations for body weight estimation in adult males, females and the pooled sample of adult Melanaus through various foot outline length measurements with ANOVA. The standard error of estimate (SEE) in case of males (7.881–8.068) and females (6.998–7.105) are comparatively lower than that of pooled samples (9.762–9.845). The tables also depict that the correlation coefficient (R) between the stature and various footprint lengths among males, females and pooled sample are statistically significant (<0.001). It is shown that the correlation between body weight and foot outline length regardless of sex, i.e. when the male and female subjects are pooled together, gave comparatively higher value (0.257–0.286) than the correlations separately obtained for the males

Table 1. Descriptive statistics of body weight in adult males, females and pooled sample of Melanaus of east Malaysia (in centimetres)

Variable	Male (N=100)				Female (N=100)				Pooled sample (N=200)			
	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Body weight (kg)	45.8	76.7	58.7	8.1	38.1	68.9	49.4	7.2	38.1	76.7	56.7	10.2

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

Table 2. Descriptive statistics of footprint length measurements in males, females and pooled sample of adult Melanau ethnics of east Malaysia (in centimeters)

Variable	Male (N=120)				Female (N=120)				Pooled sample (N=240)			
	Min	Max	mean	SD	Min	Max	mean	SD	Min	Max	mean	SD
LPOT1	23.3	28.2	25.17	1.0	21.0	25.0	22.94	0.9	21.0	28.1	24.18	1.3
LPOT2	23.4	28.2	25.10	0.9	20.3	24.8	22.68	1.0	20.3	28.2	24.02	1.4
LPOT3	22.5	27.1	24.30	0.9	19.5	24.3	21.93	0.9	19.5	27.0	23.25	1.3
LPOT4	21.4	25.9	23.00	0.8	18.4	23.2	20.82	0.9	18.4	25.9	22.02	1.2
LPOT5	19.8	23.7	21.29	0.8	16.8	21.5	19.26	0.9	16.8	23.7	20.35	1.2
RPOT1	23.5	28.2	25.20	0.9	20.9	25.3	23.01	0.9	21.2	28.2	24.23	1.3
RPOT2	23.4	28.1	25.01	0.9	20.3	25.1	22.68	0.9	20.3	28.1	23.98	1.3
RPOT3	22.5	27.1	24.19	0.8	19.7	24.3	21.87	0.9	19.7	27.1	23.15	1.3
RPOT4	21.0	25.7	22.91	0.8	18.7	22.9	20.78	0.9	18.7	25.7	21.95	1.2
RPOT5	19.4	24.2	21.18	0.8	17.4	21.0	19.16	0.8	17.4	24.2	20.26	1.2

Min: minimum; Max: maximum; LPOT1 to LPOT5: left footprint lengths from anterior part of toes OT1- OT5 to mid-rear heel point P; RPOT1 to RPOT5: right footprint lengths from anterior part of toes OT1-OT5 to mid-real heel point P; SD: standard deviation; N: Sample size.

Table 3. Linear regression equations for body weight estimation from different foot outline length measurements on left and right sides among adult Melanau males of east Malaysia (in centimeters)

Variables	Regression Equations	SEE	*R*	ANOVA
LPOT1	2.015 + 2.251OPLT1	7.881	0.264	7.318(1, 98) ; p = 0.008
LPOT2	0.778 + 2.307OPLT2	7.881	0.264	7.324(1, 98) ; p = 0.008
LPOT3	7.989 + 2.086OPLT3	7.956	0.227	5.346(1, 98) ; p = 0.023
LPOT4	4.734 + 2.346OPLT4	7.946	0.232	5.596(1, 98) ; p = 0.020
LPOT5	7.123 + 2.422OPLT5	7.946	0.232	5.593(1, 98) ; p = 0.020
RPOT1	15.261 + 1.723OPRT1	8.026	0.186	3.531(1, 98) ; p = 0.063
RPOT2	12.480 + 1.847OPRT2	8.006	0.199	4.039(1, 98) ; p = 0.047
RPOT3	22.173 + 1.509OPRT3	8.068	0.158	2.494(1, 98) ; p = 0.118
RPOT4	16.675 + 1.834OPRT4	8.030	0.184	3.436(1, 98) ; p = 0.067
RPOT5	16.865 + 1.974OPRT5	8.014	0.194	3.844(1, 98) ; p = 0.053

LPOT1 to LPOT5: left foot outline lengths from anterior part of toes OT1- OT5 to mid-rear heel point P; RPOT1 to RPOT5: right foot outline lengths from anterior part of toes OT1-OT5 to mid-rear heel point P; SEE: standard error of estimate; R: correlation coefficient.

Table 4. Linear regression equations for body weight estimation from different foot outline length measurements on left and right sides among adult Melanau females of east Malaysia (in centimeters)

Variables	Regression Equations	SEE	*R*	ANOVA
LPOT1	4.708 + 1.949OPLT1	6.998	0.247	6.383(1, 98) ; p = 0.013
LPOT2	11.021 + 1.693OPLT2	7.037	0.225	5.230(1, 98) ; p = 0.024
LPOT3	9.698 + 1.811OPLT3	7.020	0.235	5.725(1, 98) ; p = 0.019
LPOT4	12.066 + 1.794OPLT4	7.045	0.220	4.977(1, 98) ; p = 0.028
LPOT5	20.270 + 1.514OPLT5	7.102	0.182	3.348(1, 98) ; p = 0.070
RPOT1	6.021 + 1.886OPRT1	7.005	0.243	6.165(1, 98) ; p = 0.015
RPOT2	18.375 + 1.369OPRT2	7.105	0.179	3.256(1, 98) ; p = 0.074
RPOT3	14.645 + 1.590OPRT3	7.077	0.199	4.061(1, 98) ; p = 0.047
RPOT4	12.927 + 1.756OPRT4	7.057	0.213	4.645(1, 98) ; p = 0.034
RPOT5	13.109 + 1.895OPRT5	7.052	0.216	4.792(1, 98) ; p = 0.031

LPOT1 to LPOT5: left foot outline lengths from anterior part of toes OT1- OT5 to mid-rear heel point P; RPOT1 to RPOT5: right foot outline lengths from anterior part of toes OT1-OT5 to mid-rear heel point P; SEE: standard error of estimate; R: correlation coefficient.

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

Variables	Regression Equations	SEE	*R*	ANOVA
LPOT1	2.869 + 2.225OPLT1	9.762	0.286	17.636(1, 198) ; p = 0.000
LPOT2	6.816 + 2.074OPLT2	9.781	0.279	16.774(1, 198) ; p = 0.000
LPOT3	7.080 + 2.132OPLT3	9.775	0.282	17.063(1, 198) ; p = 0.000
LPOT4	7.805 + 2.218OPLT4	9.804	0.272	15.780(1, 198) ; p = 0.000
LPOT5	12.188 + 2.185OPLT5	9.845	0.257	13.978(1, 198) ; p = 0.000
RPOT1	3.204 + 2.206OPRT1	9.783	0.279	16.674(1, 198) ; p = 0.000
RPOT2	9.533 + 1.965OPRT2	9.839	0.259	14.261(1, 198) ; p = 0.000
RPOT3	9.872 + 2.021OPRT3	9.825	0.264	14.867(1, 198) ; p = 0.000
RPOT4	8.652 + 2.186OPRT4	9.814	0.268	15.341(1, 198) ; p = 0.000
RPOT5	10.125 + 2.296OPRT5	9.810	0.270	15.528(1, 198) ; p = 0.000

LPOT1 to LPOT5: left foot outline lengths from anterior part of toes OT1- OT5 to mid-rear heel point P; RPOT1 to RPOT5: right foot outline lengths from anterior part of toes OT1-OT5 to mid-rear heel point P; SEE: standard error of estimate; R: correlation coefficient.

(0.158–0.264) and females (0.179–0.247). Hence statistically significant correlation exists between body weight and all foot outline length measurements in Melanaus of east Malaysia.

DISCUSSION

Malaysia is a multi-racial, multi-ethnic and multi-cultural country (Muhammad *et al.,* 2013). The indigenous ethnic groups of Sarawak include Iban, Bidayuh, Melanau, Orang Ulu and so on. Melanaus are an ethnic group indigenous to Sarawak, east Malaysia. They speak Melanau language, which is part of North Bornean branch of Malayo-Polynesian language. The Melanau have their own calendar which beings in March. They were traditionally fishermen as well as padi and sago farmers. The age range of the subjects in this research is appropriate since stature at 18 years is accepted as adult (Nataraja Moorthy *et al*., 2014; Krishan & Abihilasha, 2007). Hence the minimum age was decided as 18 years to conduct this study. The study shows that statistically significant male–female differences exist in the body weight of Melanau population. All the foot outline 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 of the study indicated bilateral asymmetry in foot outline lengths but not statistically significant.

Correlation coefficient (R) is regarded as a mathematical expression of the degree of association existing between paired measures. All the R values have shown positive correlation in terms of the relationship between foot outline length and body weight. Researchers have conducted study on body weight estimation based on footprint (2D) examination (Abledu *et al.,* 2016). Literature review shows the lack of study in body weight estimation based on 3D foot impression (foot outline). It has to be borne in mind that the limitation in applying foot outline length for estimating living body weight is that the regression equations provide only ranges and do not aid in arriving at the exact height of an individual. That is, a 3D foot impression (foot outline) left by the criminal can be used to estimate the approximate body weight of the individual and hence due care has to be taken during inclusion or exclusion of suspects.

CONCLUSION

This pilot study, the first of its kind in Malaysia, developed population specific regression equations for body weight estimation from foot outlines of Melanaus of east Malaysia using linear regression statistical method. Inclusion of the length of the foot outlines, which provide size parameters of the fleshed bare foot, which represents the boundaries of the foot impression in soft soil or mud would enable estimation of body weight while dealing with the sunken (3D) foot impressions that are found in crime scenes. The regression equations derived for the pooled sample can be used to estimate body weight when the sex of the foot outline's owner remains unknown, as in real crime scenarios. It would be incorrect to utilize these equations for body weight estimation from foot outline lengths to any other populations either in Malaysia or any other population in the world.

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