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Estimation of Height and Sex from Footprint Length among Dhimals from Darjeeling, West Bengal

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ABSTRACT Footprint length (FPL) is a valuable evidence in forensic investigation. The present study aimed to estimate height and sex from FPL (left and right sides) in adults. Participants were adults (53 men and 51 women) from Dhimal community in Darjeeling, West Bengal. Linear regression models were used to estimate height from FPL. Sectioning point (SP) values of FPL to estimate sex [(mean value in men + mean value in women)/2] was based on: men >SP, women ≤SP values. Young adults (age: 28 and 27 years in men and women) had height (men: 164 cm, women: 154 cm) and FPL (left and right sides: men 25 cm, women 23 cm) that showed significant sex differences ($p<0.001$). Correlation coefficients between height and FPL were high ($r>9.5$, $p<0.0001$). FPL-to-height ratio was fifteen percent. Linear regression models significantly estimated height and SP values showed reasonable agreement to estimate sex (>65%).

INTRODUCTION

In forensic investigation, in absence of eye-witness, bare footprints are available evidence that call for research to find its relationship with height and to presume sex of the suspects. Studies on estimation of height from footprints are age-old but relatively scanty (Giles and Vallandigham 1991). Earlier studies reported that an average foot length relative to height in humans was fifteen percent (Giles and Vallandigham 1991; Ozaslan et al. 2003; Sen et al. 2011). Reports on estimation of height from foot length in adults from several Indian populations included samples from North India (Kanchan et al. 2008, 2010; Krishan 2008a; Krishan et al. 2011, 2012; Krishan and Kanchan 2013; Rani et al. 2011), Gaur Brahmins (Sharma et al. 1978), Jat Sikhs (Jasuja et al. 1991), individuals from Punjab (Qamra et al. 1980, 1986), Rajput community in Himachal Pradesh (Krishan and Sharma 2007), young adult university students from Maharashtra (Khanapurkar and Radke 2012), Odisha (Mohanty et al. 2012) and Rajbanshi community in West Bengal (Datta Banik 2016; Sen and Ghosh 2008). Multiplication factors, correlation, and linear regression analysis were used to interpret the interrelationships between foot dimensions and height and the authors confirmed the reliability of the use of regression models. The authors estimated errors from the differences between actual and estimated height from foot lengths in left and right sides among men and women. Foot length among adults were recorded from Rajput (men: 24.7 cm, women: 22.6 cm) (Krishan et al. 2012), and Gujjars from North India (men: 26.3 cm, women: 23.8 cm) (Kanchan et al. 2008) and Rajbanshis from West Bengal (men: 24 cm, women: 22 cm) (Sen and Ghosh 2008). Studies on the same aspect from abroad included young university students in Mauritius (Agnihotri et al. 2007) and Turkey (Sanli et al. 2005), adults from Turkey (Zeybek et al. 2008), and Nigeria (Danborno and Elupko 2008). Studies from Mauritius and Turkey reported similar foot length of adults (men: 26 cm, women: 23 cm) (Agnihotri et al. 2007; Sanli et al. 2005; Zeybek et al. 2008) that were different from foot length values from adults of Western Australia (men: 27.3 cm, women: 24.5 cm) (Hemy et al. 2013).

Reports on estimation of height from footprints (Giles and Vallandigham 1991; Pawar and Pawar 2012; Reel et al. 2012; Robbins 1986) are relatively less from India (Kanchan et al. 2012; Krishan 2008b; Moorthy et al. 2014; Oberoi et al. 2006; Vidya et al. 2011) and other countries including Australia (Hemy et al. 2013), China (Hu

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et al. 2005), Egypt (Fawzy and Kamal 2010) and Malaysia (Moorthy et al. 2013). Footprint length measurements from Gujjar men of North India (24 cm) (Krishan 2008b), university students from Mangalore, South India (men: 24 cm, women: 22 cm) (Kanchan et al. 2012), (men: 24.6 cm, women: 22.4 cm) (Oberoi et al. 2006), and Tamil men from Tamil Nadu, India (left: 24.7 cm, right: 24.6 cm) (Moorthy et al. 2014), and footprint length (men: 25 cm, women: 23 cm) of adults from Western Australia (Hemy et al. 2013) and of adult Chinese in Malaysia (men: 23.8 cm, women: 21.7 cm) (Moorthy et al. 2013) were different. Studies from India and abroad reported that foot and footprint lengths both had high correlation with height, which indicate immense potential in forensic investigation.

Objectives

The aim of the present study was to estimate height and sex from footprint length (left and right sides separately). The specific objectives were:

1) To estimate height from footprint length of left and right sides in adults.
2) To record difference between actual and estimated height in men and women.
3) To estimate sex using sectioning point (SP) values of footprint length (left and right sides).

METHODOLOGY

The present cross-sectional study among 104 adult Dhimal individuals (53 men, 51 women) was carried out during November-December in 2012. The participants were selected from 182 adult Dhimals aged 18 to 39 years, living in the villages at Naxalbari community development block (an administrative division), which was approximately 35 kilometers away from Siliguri Town in Darjeeling District of West Bengal, India (Datta Banik 2011; Datta Banik et al. 2007). Measurement of height (cm) was recorded by a single researcher, following standard protocols (Lohman et al. 1988); Martin's anthropometer was used for the purpose to the nearest tenth of a centimeter. Dermatoglyphic data of footprints (left and right sides separately) were collected following standard procedure (Cummins and Midlo 1943). Maximum footprint length was measured using a segmometer (Cescorf, Brazil), as a straight distance between the highest points on the first or the second toe (whichever was longer) and the lowest point on the margin of the heel (Moorthy et al. 2014; Oberoi et al. 2006). A multiplication factor (MF) for estimation of height was derived by dividing height by footprint length. The MF along with footprint length ratio (footprint length to height ratio in percent) provided overall estimates of the interrelationships between height and the measured dimension. Sectioning point (SP) values of footprint length (left and right sides separately) were the cut-off values to estimate sex [(mean value in men + mean value in women)/2] (Datta Banik 2016; Kanchan and Rastogi 2009; Krishan et al. 2011). Ethical approval was obtained from the appropriate authority before the commencement of the study as an additional data collection in a research project (see acknowledgements). Informed consent was obtained from the participants. All statistical analyses were done using the SPSS statistical package (version 13.00). Student's t-test was performed to test for differences in mean values of characteristics between men and women. Simple linear regression models to predict height, separately for left and right footprint lengths were computed. Sex was explained as male (=1) and female (=2) in the database. After estimation of sex using SP cut-off values, sex was also explained in the same way (male=1, female=2). Subsequently, frequencies of agreement (=0 in male and female) and disagreement [1(absolute) =male and female] of cases were calculated. For every analysis, it was fixed the five percent rejection level of null hypothesis ($p<0.05$).

RESULTS

The sample represented young adult men (27.96 ± 6.63 years) and women (26.65 ± 4.28 years) that showed no significant sex difference in age ($p = 0.24$). Mean values of height (men: 164.38 ± 4.58 cm, women: 153.95 ± 4.54 cm), and footprint length (left: men: 24.69 ± 1.48 cm, women: 23.21 ± 1.18 cm; right: men: 24.71 ± 1.45 cm, women: 23.24 ± 1.10 cm) showed significant sex differences ($p<0.001$) (Table 1). The mean values of MF and footprint length ratio were not significantly different in men and women ($p>0.05$). The MF of footprint length (approximately 6.65 in either sex) and of footprint length

ratio (approximately 15% in either sex) indicate interrelationships with height (Table 1).

Height prediction through linear regression analysis from footprint length, separately for left and right sides and adjusting for age and sex, displayed significant interrelationships (Table 2). In all cases, models were statistically significant (F-values in ANOVA with $p<0.0001$). Regression models therefore, in all cases showed that footprint length measurements significantly estimated height. Age was not found to have any significant relation with estimation of height in any regression model (left and right sides). In two models, sex and footprint dimensions had significant contributions to predict height ($p< 0.001$). Footprint lengths had significant correlation ($p<0.0001$) with height in men (both sides $r = 0.96$) and women (left $r = 0.98$, right $r = 0.96$). Regression coefficients in the models for footprints were similar in both sides (left and right). Therefore, the null hypothesis was not accepted, and regression coefficients indicated reliability in estimation of height from footprint length. The standard error of estimate (SEE) predicted the deviation of estimated height from footprint length measurements. The SEE values were found to be small for footprint length (left side 1.23 and right side 1.45). Residuals showed no pattern and were at random (Table 2).

The values of estimated height from footprint lengths of either side showed marginal differences with actual height (Table 3). The estimated values of height from footprint length in men (left 164.48 cm, right 164.50 cm) were not very different from the actual height measurement (164.38 cm). Likewise, in women, estimated values of height from footprint length (left 153.93 cm, right 153.94 cm) were not very different from the actual measurement (153.95 cm). The estimated SP values were 23.95 cm and 23.98 cm for

Table 1: Descriptive statistics of age, height and bilateral footprint length in men (53) and women (n=51)

Variables	*Men Mean (SD)*	*Women Mean (SD)*	*t*	*p-value*
Age (years)	27.96 (6.63)	26.65 (4.28)	1.19	0.24
Height (cm)	164.38 (4.58)	153.95 (4.54)	11.66	<0.001
FPLL (cm)	24.69 (1.48)	23.21 (1.18)	5.64	<0.001
FPLR (cm)	24.71 (1.45)	23.24 (1.10)	5.84	<0.001
Multiplication factor (FPLL)	6.67 (0.23)	6.64 (0.15)	0.79	0.43
Multiplication factor (FPLR)	6.66 (0.22)	6.63 (0.14)	0.95	0.34
Footprint length ratio (FPLL) (%)	15.01 (0.51)	15.07 (0.35)	-0.68	0.50
Footprint length ratio (FPLR) (%)	15.02 (0.49)	15.09 (0.32)	-0.83	0.40

SD: Standard deviation; FPLL: Footprint length (left), FPLR: Footprint length (right)
Note: Minus sign indicates higher mean value in women

Table 2: Linear regression models predicting height from footprints (length) in men (n= 53) and women (n=51)

Predictors	*Estimated equation*	*t*	*p-value*	*95% CI*		*Adj R^2*	*SEE*	*R^2 change*	*F change*	*p-value*
				Lower bound	*Upper bound*					
Age	89.66 - 0.014 x Age (years) – 5.682*Sex + 3.272 x FPLL	-0.64	0.53	-0.06	0.03					
Sex		-17.87	<0.001	-6.31	-5.05					
FPLL		35.75	<0.001	3.09	3.45	0.97	1.23	0.97	1039.17	<0.0001
Age	88.00 - 0.035 x Age (years) – 5.736*Sex + 3.361 x FPLR	-1.34	0.18	-0.09	0.02					
Sex		-15.39	<0.001	-6.48	-4.50					
FPLR		30.06	<0.001	3.14	3.58	0.96	1.45	0.96	747.80	<0.0001

Response variables: Height; FPLL: Footprint length (left); FPLR: Footprint length (right); SEE: Standard error of estimate; Adj R^2: Adjusted R^2;
CI: Confidence interval; Sex: male =1, female = 2

Table 3: Estimated height from footprint length and difference with actual height in men (n= 53) and women (n=51)

Derived characters	*Men Mean (SD)*	*Women Mean (SD)*	*t*	*p-value*
Estimated height from FPLL (cm)	164.48 (4.40)	153.93 (4.28)	12.39	<0.0001
Difference between actual and estimated height from FPLL (cm)	-0.11 (0.18)	-0.02 (0.91)	-0.61	0.54
Mean value of actual and estimated height from FPLL (cm)	164.43 (4.44)	153.94 (4.39)	12.11	<0.0001
Estimated height from FPLR (cm)	164.50 (4.38)	153.94 (4.20)	12.53	<0.0001
Difference between actual and estimated height FPLR (cm)	-0.13 (1.35)	-0.02 (1.33)	-0.53	0.60
Mean value of actual and estimated height from FPLR (cm)	164.44 (4.43)	153.94 (4.32)	12.22	<0.0001
Difference between FPLL minus SP value	0.74 (1.48)	-0.74 (1.18)	5.62	<0.0001
Difference between FPLR minus SP value	0.74 (1.45)	-0.73 (1.10)	5.81	<0.0001

SD: Standard deviation; FPLL: Footprint length (left); FPLR: Footprint length (right). Sectioning point (SP) value of FPLL= 23.95 cm; Sectioning point (SP) value of FPLR: 23.98 cm

footprint length of left and right sides separately. The difference values of actual footprint length and SP in men (left: 0.74 ± 1.48 cm, right: 0.74 ± 1.45 cm) and women (left: -0.74 ± 1.18 cm, right: -0.73 ± 1.10 cm) showed significant sex difference ($p<0.0001$). Agreement of estimation of sex for two sides, using the SP values were sixty eight percent and sixty five percent for left and right footprint lengths respectively.

DISCUSSION

In the present study, MF of footprint length (approximately 6.65 in either sex) and of footprint length ratio (approximately 15% in either sex) indicate interrelationships with height. Studies on interrelationships between height and foot lengths may be discussed in this context. Foot length had significant correlation ($p<0.05$) with height in 19 to 22-year-old students from Maharashtra, India (Khanapurkar and Radke 2012). In that study, height was estimated from foot length (in cm) (height = 72.8 + 3.70xfoot length). In the present study, regression coefficients estimating height from footprint length were lower than that estimated in the Maharashtrian sample. A study among Nigerian women (>18 years) reported mean values for anthropometric dimension of foot length (right 25.00 ± 1.33 cm, left 24.75 ± 0.17 cm) (Bob-Manuel and Didia 2008). In the present study in Indian sample, footprint length in adult Dhimals (left: men 24.69 ± 1.48 cm, women 23.21 ± 1.18 cm; right: men 24.71 ± 1.45 cm, women 23.24 ± 1.10 cm) showed smaller foot size (in women) compared to the Nigerian women. However, there was a small difference in the measurement values of foot length and footprint length.

Estimation of height and sex was done from footprint lengths of 200 adults (100 men and 100 women) from Mangalore, in Karnataka, India (Oberoi et al. 2006). Footprint length (men: 24.6 cm) was similar to the values that had been recorded among Dhimal men in the present study. The standard error of estimates (men: 4.66 and women: 4.53) in the regression models to predict height was much higher than that were found in the present study. The regression models estimating height from footprint length (FPL) was 72.997 + 3.933 x FPL for men and 59.312 + 4.367 x FPL for women. Correlation coefficient values between height and footprint lengths were also high ($r>7.0$) and significant ($p<0.01$). Another study from India, bilateral footprints (left: 24.7 cm, right: 24.6 cm) were collected from 1,020 adult Tamil-speaking men (19 to 42 years) (Moorthy et al. 2014). Correlation coefficient between the two dimensions (height and footprint length) was significant ($r= 0.55$, $p<0.05$). This study also showed similar values of footprint length that had been recorded among Dhimal men. Footprint length of Gujjar men (24 cm) in North India (Krishan 2008b) and university students from Mangalore, South India (men: 24 cm, women: 22 cm) (Kanchan et al. 2012), showed lower values among men and women compared to the present study. A report from Western Australia (Hemy et al. 2013) showed men had longer and women

had similar footprint length compared to Dhimal men and women respectively. Adult Chinese students in Malaysia (Moorthy et al. 2013) had lower footprint length than Dhimals. In the present study, correlation coefficients between height and footprint lengths (left and right sides) were higher in comparison with the values reported earlier.

CONCLUSION

In conclusion, the present study among adult Dhimals reports that fitted regression models to predict height from footprint lengths and the use of SP values to estimate sex (at least an approximation) are significant. However, the results need to be verified in future research from other populations.

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