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Original Research Article

FORENSIC APPLICATION OF HAND AND FOOT BIOMETRICS AS MODELS FOR HEIGHT, WEIGHT AND SEX DETERMINATION AMONG GHANAIANS

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ABSTRACT

Hand and footprints recovered from crime scenes are important for identification in criminal investigations. Unlike Ghana, developed countries have well-established data on population-specific hand and footprint dimensions for identification in anthropometric, biometric and forensic studies. This study therefore aimed at determining the relationship between hand and footprint dimensions, height, weight and sex in Ghana. A total of 118 participants aged 17 to 35 years participated in the study. Height, weight, hand and footprint dimensions were taken and analysed. Males were significantly taller, heavier and had generally greater anthropometric parameters than females. Generally, in both hand and footprint dimensions, bilateral asymmetry existed with the right parameters being greater than the left parameters. However, the left handprint length was longer than the right. The best parameters for height estimation were left handprint length and left pternion-toe 1 length. The best predictors of weight were right handprint length and breadth, right pternion-toe 2 length, right footprint breadth at heel and right heel-ball index. The most sexually dimorphic parameters among the hand and footprint dimensions were right hand breadth, left footprint breadth at ball and left pternion-toe 1 length. Overall, footprint dimensions were better estimators of height and weight while handprint breadth predicted sex best.

KEYWORDS: Forensic, Sex, Handprint, Footprint.

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INTRODUCTION

The establishment of biological profile including height, race, age and sex is the foremost in personal identification [1]. It employs the use of various algorithms for the measurement of the physical parts of the human body [2].

The ratios obtained from the measurements of these body parts could depict sex, age, physical activity or height of an individual since these body parts exhibit consistent proportions among themselves [3]. Anthropometry which is the measurement of body parts is therefore essential in the identification of an individual [4]. In cases of mass disasters, explosions and physical assaults, dismembered body parts could be used for establishing the identity of victims through the use of male and female-specific generated formulae [5]. Notwithstanding variations among populations, there exist important relationships between body parts and the entire body as a whole. Literature is replete on the use of bony structures of the body such as the skull, bones of the extremities and pelvis in height and sex determination [6,7].

The hand and foot are specialized portions of the body which form the distalmost aspects of the upper and lower limbs respectively [4,8]. The palm is the inward surface of the hand located between the wrist and the digits [9]. Weight can conveniently be predicted from the use of hand length alone [10]. Footprint length could be used in the determination of height and it is proven to show little change with age [11]. Forensically, footprints could reveal the estimated weight of an individual [12]. The use of hand and foot dimensions in sex determination is known to reduce uncertainty in identification by half [13]. Height and weight estimation also provides useful information on growth assessment, nutritional status, physical capacity and drug dose adjustment in individuals who for one reason or another cannot stand upright for their stature or weight to be determined [14-16]. There are regression models for the determination of height, weight and sex of individuals. Inter-population differences existing in body proportions necessitate that these regression equations be population-specific for better accuracy since it is inappropriate to apply the formulae of one population to another [17-19].

Advanced countries have well-established databases on hand and foot dimensions and have used them in circumstances such as the forensic identification of victims of disasters [20]. There is an increase in crime cases, road traffic accidents and natural disasters in Ghana lately. However, there appears to be limited data in Ghana on hand and footprint dimensions which could help identify individuals in such circumstances. Therefore, this study seeks to determine hand and footprint dimensions in relation to height, weight and sex. Specifically, the study aims to determine:

· The relationship between handprint dimensions and height, weight and sex of the participants.

· The relationship between footprint dimensions and height, weight and sex of the participants.

· The best regression formula for the prediction of height, weight and sex using the hand and footprint dimensions.

MATERIALS AND METHODS

This cross-sectional quantitative study was conducted at the Kwame Nkrumah University of Science and Technology. The number of participants who voluntarily took part in this study were 118 of which 56 were males and 62 were females with an age range of 17 – 35 years. Participant informed consent was sought after ethical approval was obtained from the Committee on Human Research and Publication Ethics, School of Medicine and Dentistry, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana, prior to the study. Participants with any form of abnormal morphology of the hand and foot (deformity) such as wrist drop, clubfeet, fracture or amputation or posture disorder such as kyphosis and lordosis were excluded from this study. The age and sex of each participant was recorded. The height of each participant was taken with a Shahe height meter (Shanghai, China). The weight was taken with a constant mechanical personal scale (model 14192-73; Shanghai) having the participants in bipedal erect orientation as described by Gripp et al. 2013 [21]. Participants hands and feet were cleaned and asked to remove any rings from their fingers and to place the hand flat on the scanner and afterwards scans of feet were also taken (Neyse 2014,Gallizi, 2015)using Canon MF 500 series scanner (Japan). This method was compared to the ink method [7,12]. A pilot study showed no significant difference between the two methods. The scan method was adopted since it was easier and does not stain the participants hands and feet. Five diagonal footprint length measurements were taken from the pternion (P) to the most anterior point of each toe (T1, T2, T3, T4, T5), and designated PT1, PT2, PT3, PT4 and PT5. The widest distance across the heel, breadth at heel (BHEL), and the maximum breadth between the medial margin of the head of the metatarsal print and lateral margin of the fifth metatarsal print, breadth at ball (BBAL), were measured [7] (Figure 1). Handprint breadth was taken with a pair of Shahe calipers (Shanghai, China) from metacarpal ulnare to metacarpal radiale while handprint length was taken from the distal crease (interstylion) of the wrist to the most distal aspect of the third digit (dactylion) [13] (Figure 2).

Collected data were analysed using version 20.0 of IBM Statistical Package for Social Sciences (SPSS). Regression analyses of hand and footprint dimensions generated equations for height, weight and sex predictions.

Fig. 1: A diagram showing the footprint landmarks and measurements: DLA = Diagonal longitudinal axis; P = Pternion, BL = Base line; breadth at ball (BBAL), breadth at heel (BHEL) and diagonal length measurements of the footprint PT1 - PT5.

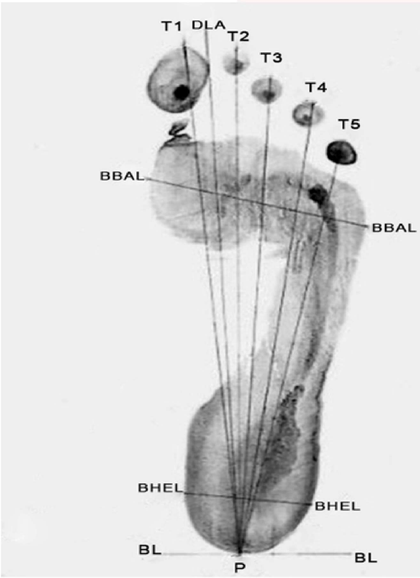
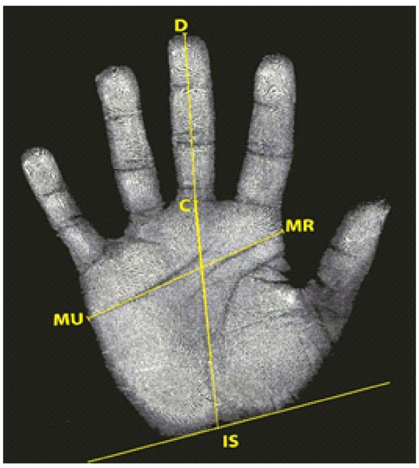


Fig. 2: Diagram showing handprint landmarks and measurements: Dactylion (D), interstylion (IS), metacarpal ulnare (MU), metacarpal radiale (MR); Handprint breadth (HB) = MU – MR, handprint length (HL) = IS – D.



RESULTS

Sample characteristics: The mean age of the study participants was 21.75 ± 3.37 years (range: 17 – 35 years). Whereas the male participants recorded a mean age of 21.75 ± 3.37 years (range: 17 – 35 years), that of the females was 20.87 ± 3.26 years (range: 17 – 35 years).

Descriptive statistics of height, weight, hand and footprint dimensions: The mean height of the male participants was 170.80 ± 8.34 cm (range: 153.70 – 187.00 cm) with the females recording 160.51 ± 5.90 cm (range: 145.30 – 176.20 cm). The difference was statistically significant ($p < 0.01$).

Mean right and left handprint lengths for the male participants was 187.49 ± 10.68 cm (range: 164.09 – 213.66 cm) and 187.47 ± 9.78 cm (range: 164.66 – 210.89 cm) respectively while that of the females was 174.62 ± 9.52 cm (range: 136.46 – 204.48 cm) and 174.85 ± 9.16 cm (range: 156.05 – 208.42 cm) respectively. Males recorded mean right and left handprint breadths of 84.03 ± 4.98 cm (range: 74.69 – 98.78 cm) and 82.87 ± 5.57 cm (range: 70.42 – 97.73 cm) respectively whereas that of the females was 75.60 ± 4.63 cm (range: 63.63 – 88.69 cm) and 74.19 ± 4.79 cm (range: 62.16 – 87.13 cm) respectively.

Males recorded significantly greater mean footprint dimensions than females ($p < 0.01$) (Table 1). However, no statistically significant mean difference of right heel-ball index in males, 0.57 ± 0.05(range: 0.49 – 0.72) and females, 0.57 ± 0.05 (range: 0.45 – 0.66) was observed. Likewise, no statistically significant mean difference was observed between the male participants' left heel-ball index, 0.57 ± 0.05 (range: 0.48 – 0.70) and that of the females, 0.56 ± 0.05 (range: 0.43 – 0.66).

Correlation between hand and footprint dimensions with height: There was statistically significant moderate to strong correlations observed between height and the various pooled handprint dimensions ($r = 0.614 – 0.776$, $p < 0.01$)in the study population.Similarly, with the exception of heel-ball indices, statistically significant moderate to strong correlations were observed between the footprint dimensions and height ($r = 0.518 – 0.820$, $p < 0.01$) (Table 2).

Correlation between hand and footprint dimensions with weight: There was statistically moderate to strong significant correlations between weight and the pooled handprint dimensions (r = 0.531 – 0.561, p < 0.01). Meanwhile, significantly moderate correlations were observed between weight and the footprint dimensions (r = 0.500 – 0.638, p < 0.01). Weak statistically significant correlation was observed between left heel-ball index and weight (p = 0.045). However, there was no statistically significant correlation between weight and right heel-ball index (p > 0.05) (Table 3).

Regression analyses for height estimation: As shown in Table 4,regression equations for height estimation using hand and footprint dimensions were developed with the best predictor being left pternion-toe 1 length in the pooled data (adjusted R^2 = 0.702) as well as in the female population (adjusted R^2 = 0.576). In males however, the best parameter for height estimation was right pternion-toe 2 length (adjusted R^2 = 0.589).

Regression analyses for weight estimation: As shown in Tables 5, regression equations for weight estimation using hand and footprint dimensions were developed with the overall best predictors being the right pternion-toe 2 length, right footprint breadth at heel and right heel-ball index (adjusted R^2 = 0.463). In males, the best model for weight estimation employed right pternion-toe 2 length, right footprint breadth at ball, right footprint breadth at heel, right heel-ball index and right pternion-toe 4 length (adjusted R^2 = 0.553)whereas in females, it was right pternion-toe 3 length and right footprint breadth at heel (adjusted R^2 = 0.371).

Sex determination: As shown in Table 6, using handprint dimensions, the most sexually dimorphic parameters were right and left handprint breadths. The model generated using right hand breadth correctly classified 76.8% of males and 87.1% of females with a total accuracy of 82.2% (R^2= 0.591, p < 0.01). Left handprint breath utilization correctly classified 83.9% of males and 85.5% of females with a total accuracy of 84.7% (R^2 = 0.579, p < 0.01).

Two models were derived from left foot print measurements with different prediction accuracy rates. The best predictor utilized left foot print breadth at ball and left pternion-toe 1 length (R^2 = 0.586, p < 0.01) yielding male, female and overall classification rates of 80.4%, 83.9% and 82.2% respectively. Left footprint breadth at ball alone predicted sex with an overall accuracy rate of 77.1% (R^2 = 0.515, p < 0.01). Male and female classification rates were 73.2% and 80.6% respectively.

Also, with the right foot, two models were derived with different prediction accuracy rates. The better predictor of the two utilized both right footprint breadth at ball and right pternion-toe 5 length (R^2 = 0.559, p < 0.01) yielding male, female and overall classification rates of 80.4%, 80.6% and 80.5% respectively. Right footprint breadth at ball alone predicted sex with an overall accuracy rate of 78.8% (R^2 = 0.522, p < 0.01) with male and female classification rates of 75.0% and 82.3% respectively.

Table 1: Descriptive statistics of footprint measurements.

	RIGHT (cm)		LEFT (cm)			
	MEAN ± SD (cm)	RANGE (cm)	MEAN ± SD (cm)	RANGE (cm)	t - test	p
BHEL	5.42 ± 0.55	4.10 – 7.00	5.35 ± 0.55	3.90 – 7.30	2.227	0.028
BBAL	9.56 ± 0.66	8.20 – 11.40	9.50 ± 0.68	8.20 – 11.10	2.28	0.024
PT1	24.19 ± 1.48	20.60 – 27.80	24.08 ± 1.43	20.90 – 27.90	2.661	0.009
PT2	23.85 ± 1.46	20.50 – 27.70	23.77 ± 1.10	20.80 – 27.30	2.296	0.023
PT3	22.88 ± 1.39	19.70 – 26.60	22.85 ± 1.41	19.20 – 26.40	0.853	0.395
PT4	21.83 ± 1.29	19.00 – 25.30	21.76 ± 1.33	18.60 – 25.00	1.729	0.086
PT5	20.49 ± 1.25	18.00 – 24.20	20.40 ± 1.25	17.60 – 23.80	2.53	0.013
FL	24.24 ± 1.47	20.60 – 27.80	24.14 ± 1.43	21.10 – 27.90	2.64	0.009

N = 118; SD = Standard deviation, N = Sample size, T-Test =Student's T-Test; p = Significance level; BHEL = Footprint breadth at heel; BBAL = Footprint breadth at ball; PT1- PT5 = Pternion- toe 1 to toe 5 lengths; FL = Footprint length

Table 2: Pearson's correlation between height and footprint measurements.

	RIGHT		LEFT	
	r	p	R	P
HL	0.757**	0.000	0.776**	0.000
HB	0.629**	0.000	0.614**	0.000
BHEL	0.518**	0.000	0.498**	0.000
BBAL	0.554**	0.000	0.535**	0.000
HBI	0.155	0.094	0.177	0.055
PT1	0.820**	0.000	0.839**	0.000
PT2	0.813**	0.000	0.822**	0.000
PT3	0.801**	0.000	0.810**	0.000
PT4	0.813**	0.000	0.815**	0.000
PT5	0.809**	0.000	0.808**	0.000
FL	0.820**	0.000	0.834**	0.000

N = 118; SD = Standard deviation, N = Sample size, p = significance level; BHEL = Footprint breadth at heel; BBAL = Footprint breadth at ball; PT1 - PT5 =Pternion-toe 1 to pternion toe 5 lengths; FL = Footprint length

Table 3: Pearson's correlation between weight and footprint dimensions.

	RIGHT		LEFT	
	r	p	R	P
HL	0.561**	0.000	0.554**	0.000
HB	0.540**	0.000	0.531**	0.000
BHEL	0.575**	0.000	0.500**	0.000
BBAL	0.534**	0.000	0.523**	0.000
HBI	0.234*	0.094	0.185*	0.045
PT1	0.619**	0.000	0.632**	0.000
PT2	0.637**	0.000	0.629**	0.000
PT3	0.616**	0.000	0.624**	0.000
PT4	0.613**	0.000	0.604**	0.000
PT5	0.604**	0.000	0.609**	0.000
FL	0.624**	0.000	0.638**	0.000

N = 118; SD = Standard deviation, N = Sample size, p = significance level; BHEL = Footprint breadth at heel; BBAL = Footprint breadth at ball; PT1- PT5 =Pternion- toe 1 to toe 5 lengths; FL = Footprint length

Table 4: Regression analysis for height estimation using hand and footprint dimensions.

EQUATION	SEE	ADJ. R^2	p-value
0.602 * LHL + 56.577	5.57869	0.598	< 0.05
0.558 * RHL + 64.600	5.78078	0.569	< 0.05
5.161 * PLT1 + 41.114	4.80831	0.702	< 0.05
RFL * 4.924 + 46.034	5.05588	0.67	< 0.05
2.869 * RFL + 2.488 * PRT4 + 41.562	4.95147	0.684	< 0.05

SEE = Standard error of the estimate; ADJ. R^2 = Adjusted R squared; LHL = Left hand length; RHL = Right hand length; PLT1 = Left pternion – toe 1 length; RFL = Right foot length; PRT4 = Right pternion – toe 4 length

Table 5: Regression analysis for weight estimation using hand and footprint dimensions.

EQUATION	SEE	ADJ. R^2	p-value
0.540 * LHL – 36.279	9.25791	0.301	< 0.05
0.346 * LHL + 0.441 * LHB – 35.672	9.07783	0.328	< 0.05
0.520 * RHL – 32.508	9.20716	0.308	< 0.05
0.330 * RHL + 0.476 * RHB – 36.109	9.01884	0.336	< 0.05
4.933 * LFL – 57.606	8.56326	0.402	< 0.05
3.992 * LFL + 3.032* LBBAL – 63.714	8.45326	0.447	< 0.05
4.842 * PRT2 – 54.033	8.57035	0.401	< 0.05
3.464 * PRT2 + 5.918 * RBHEL – 34.382	8.22107	0.449	< 0.05
2.926 * PRT2 + 9.926 * RBHEL – 48.887 * RHBI – 34.382	8.11377	0.463	< 0.05

SEE = Standard error of the estimate; ADJ. R^2 = Adjusted R squared; LHL = Left hand length; LHB = Left hand breadth; RHL = Right hand length; RHB = Right hand breadth; LFL = Left foot length; LBBAL = Left footprint breadth at ball; PRT2 = Right pternion – toe 2 length; RBHEL =Right footprint breadth at heel; RHBI = Right heel-ball index

Table 6: Sex determination using hand and footprint dimensions.

EQUATION	p-value	Nagelkerke R^2	ACCURACIES (%)		
			MALES	FEMALES	TOTAL
-0.329 * RHB + 34.495	0.000	0.591	76.8	87.1	82.2
-0.305 * LHB + 33.259	0.000	0.579	83.9	85.5	84.7
-2.149 * LBBAL– 0.799 * PLT1 + 39.746	0.000	0.586	80.4	83.9	82.2
-2.596 * RBBAL– 0.600 * PRT5 + 37.195	0.000	0.559	80.4	80.6	80.5
-3.141 * RBBAL + 30.132	0.000	0.522	75	82.3	78.8
-2.912 * LBBAL + 27.777	0.000	0.515	73.2	80.6	77.1

Nagelkerke R^2 = =Nagelkerke R squared; LHB = Left hand breadth; RHB = Right hand breadth; PLT1 = Left pternion – toe 1 length; PRT5 = Right pternion – toe 5 length; LBBAL = Left footprint breadth at ball; RBBAL = Right footprint breadth at ball

DISCUSSION

Hand and footprints left at crime scenes and human remains from mass disasters could be recovered for the purpose of identification. Though variations exist, there are consistent relationships between body parts and the entire body [3,4]. It has been documented that the adult foot size of females and males is reached at ages 13.5 and 16 years respectively [21]. The minimum age of the study participants was 17 years. The male participants of this study were significantly taller than the females which is in line with other reports [22,23]. This observation may be largely due to the higher level of oestrogen in females than in males causing the early epiphyseal line formation in the former than the latter although genetics plays a vital role [24,25].

The male participants of the study were significantly heavier than the females which is in line with another report in Sevagram in India [5]. This could be attributed to the enhanced bone mass, greater muscle mass and more frequent exercise in males than in females [26-28]. The result of this study is however inconsistent with a study in Nigeria in which females were heavier than males [16]. This difference could be attributed to the fact that the participants in the Nigerian study were at pre-pubertal age and an expected spurt of growth occurs more markedly in females than in males during that period.

Participants' left handprint length was significantly longer than that of the right. However, the right hand breadth was broader than that of the left. Similar trends have been observed in studies in India [29,30].

This is probably because of the contracting strength of muscles attached to bones of the hand which account for hand breath being more pronounced in the right than the left hand. Moreover, bilateral dimorphism is more prominent in adults than in the young and is manifested more profoundly in the upper than the lower extremities of the body [31].

However, in a study which recruited right-handed Northern and Southern Indians, it was found that the right hand was longer than the left [1]. Males recorded significantly greater hand dimensions than females which is consistent with that reported by Kanchan and Rastogi (2009) in an Indian population and Kornieieva and Elelemi (2016) in a Saudi population [1,32]. High testosterone to oestrogen ratio is suggested to account for the male pattern of hand dimensions and morphology [33].

Results of this study showed that males significantly possessed greater footprint dimensions than females and this is in line with that reported by Zeybek*et al.* (2008) [34]. This could be as a result of the epiphyseal plate fusion occurring about two years earlier in females than in males [35]. Bilateral asymmetry existed in the foot measurements with the right parameters being greater than those of the left. This opposes a study about three decades ago using a United State population where no asymmetry existed [36] and that reported by Mohamed (2013) in which adult Upper Egyptians were used. Inter-population differences that affect body proportions like diet, genetics, socioeconomic status and climate could account for these differences [24]. Statistically significant sexual dimorphism was observed in all the foot dimensions except heel-ball indices. The finding is in agreement with other investigators [14,37,38]. Genetics and lifestyle are factors that could affect foot morphology [39].

Left hand length and pternion-toe 1 length (PLT1) gave the strongest correlation with height among the hand and footprint dimensions respectively. They were also used to generate model equations for height estimation. Some investigators have also found hand length to correlate better with height than breadth [16,40,41]. Likewise, a study which recruited Indians showed that, foot dimensions were very good predictor of height [42]. Contrary to this finding, a study among adult male Indian Tamils showed left pternion-toe 2 length (PLT2) to be the most strongly correlated parameter with height [10]. This difference could be explained by the fact that, for this study, the predominant toe was the T-type (toe 1 being the longest among the toes) possibly due to environmental, nutritional factors and genetic constitution of the participants.

Right hand length and left foot length gave the highest correlation with weight among the hand and footprint dimensions respectively. This is consistent with previous works where hand length correlated strongly with weight [12,14]. By way of contrast, an Egyptian study reported that the left foot breadth at ball was the best estimator of weight [12]. These differences could be due to occupation and lifestyle disparities among the different populations. The best regression equation developed for weight estimation utilized right hand length and breadth for hand dimensions and could explain an individual's weight change by approximately 34% and for the footprint dimensions, right pternion-toe 2 length, right footprint breath at heel and right heel-ball index were the best parameters utilized in the model for weight estimation with prediction accuracy of about 46%.

The most sexually dimorphic handprint parameters were right hand breadth ($R^2 = 0.591$, $p < 0.01$) and left hand breadth ($R^2 = 0.579$, $p < 0.01$) whereas for the footprint dimensions, it was left footprint breadth at ball and pternion-toe 1 length ($R^2 = 0.586$, $p < 0.01$). The findings of this study is consistent with that reported using Western Australian population in which hand breadth was the most sexually dimorphic parameter [43]. This finding is also consistent with others reported in an Indo-Mauritian population [44],college-going students of Mangalore, Karnataka, India [23] and North Indians [35].

CONCLUSION

Males were significantly taller, heavier and had generally greater anthropometric indices than females. In both hand and footprint dimensions, bilateral asymmetry existed with the right parameters being greater than the left with the exception of hand length in which the left was longer than the right. The best parameters of the hand and footprint dimensions for height estimation were left hand length and left pternion-toe 1 length. The hand dimensions which best estimated weight were right hand length and breadth while that of the foot were right pternion-toe 2 length, right footprint breadth at heel and right heel-ball index. The most sexually dimorphic parameters among the hand and footprint dimensions were right and left hand breadths, left footprint breadth at ball and left pternion-toe 1 length. Overall, footprint dimensions were better estimators of height and weight while the best sex predictor was hand breadth. The findings from this study would be useful in medico-legal and forensic settings where only hand or footprints are recovered.

Conflicts of Interests: None

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