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ANALYSIS OF SEXUAL DIMORPHISM THROUGH ANTHROPOMETRIC MEASUREMENTS OF THE FEET: A LITERATURE REVIEW AND MEASUREMENT METHODOLOGY

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ABSTRACT

This study aims to analyze gender based on footprints from various ethnicities in the World. The method used is a literature study with data sources from various studies by identifying PICO (Population/Patient, Intervention, Comparison, Outcome). For Population: ethnicity in the world, Intervention: -, Comparison or comparison: footprint measurement, and Outcome or result: gender determination. Data collection was done by downloading literature from three search engines, namely Google Scholar, Sciencedirect, and PubMed. The results of this study show that anthropometric foot measurements can be effectively used to determine sex, with various studies showing significant sexual dimorphism in foot size between men and women. On average, men have greater foot length and width than women, which can be utilized for sex estimation with a high degree of accuracy. The diverse measurement methodologies, such as length, width and foot index measurements, reflect flexibility in adaptation based on different population contexts. This study also shows the importance of considering cultural and ethnic factors in anthropometric analysis, which can affect measurement results. The findings have practical applications in a variety of fields, including forensics and product design, and confirm that footprint dimensions can be a strong indicator of gender differentiation.

KEYWORDS *Analysis of Sexual, Dimorphism, Anthropometric, Measurements.*

INTRODUCTION

In the UK, Forensic Podiatry is a specialized field of podiatry regulated by the Health and Care Professions Council (HCPC), which aims to ensure that forensic podiatrists work in accordance with standards and ethics, so as to provide a conclusion to the court that the identification has met legal standards, both in civil and criminal systems (Burrow, 2017). The definition of Forensic Podiatry is the application of valid podiatry knowledge and tested in forensic investigations to show the connection or disconnection of a person to the scene of the crime, as well

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as answering other legal questions relating to the foot or footwear, which requires an understanding of the function of the foot (Vernon, 2006). Forensic Podiatry does not only focus on the foot, but can also involve other parts of the body. Analysis is done to understand the relationship between the body and the function of the foot. There are four main areas in Forensic Podiatry:

1. Identification through podiatry patient records, which compares the body parts of the deceased with the information stored in the podiatry care records.
2. Bare footprint analysis and identification, which identifies a person from the two-dimensional (2D) footprints left at the scene and is compared with those of a known person (suspect).
3. Forensic gait analysis, which is the identification of an individual through their gait patterns, usually from CCTV footage, which is then compared to footage of known individuals.
4. Footwear analysis and identification, which involves analyzing footwear imprints, erosion on the sole, or other signs that can be used for identification.

Crime investigation begins with searching and collecting evidence, in accordance with Dr. Edmond Locard's principle that "*contact leaves traces*"(Mummery, 2021). Evidence connects suspects, perpetrators, and victims to the location of the crime. This evidence connects the suspect, perpetrator, and victim to the location of the crime. Fingerprints, handprints, and footprints are the most common findings at crime scenes (Kanchan & Krishan, 2011). At a crime scene, footprints can leave forensic evidence in the form of marks or traces on contact surfaces. The placement and size of footprints can be analyzed in terms of overall shape or morphology (Vernon, Reel, & Howsam, 2020). Footprints are often found on various surfaces such as floors, tabletops, walls and more (Sharma BR, 2014). Footprint dimensions can assess characteristics such as width, length, shape, and size of the foot (LN, KN, KATTI, & CD, 2012). In the process of identifying bare footprints at a crime scene, the first step is to analyze the existing footprints, then compare them with known footprints by analyzing the footprints formed from the lines on the soles of the feet (Priya, Narayan, & Ghosh, 2023). Footprint identification is analyzing the traces formed from lines on the soles of human feet, similar to fingerprints. (Mia, 2022).

Footprint analysis in forensic investigations using the ACE-V (Assessment and Analysis, Comparison, Evaluation, Verification) method is used to assist the forensic identification process in various fields, such as fingerprints, handwriting, tool marks, and footprints (OBE, Simmonite, Reel, & Reidy, 2017). Footprints found at the scene are referred to as "*questioned" footprints*. The initial examination is to assess the quality of the footprints, such as how clear the footprints are and how many footprints are visible. If the footprints qualify, the examiner will check whether the footprints were made while the person was standing still (static) or walking (dynamic). Dynamic footprints are characterized by alternating left and right footprint patterns and the appearance of faint marks ("*ghosting*"). Irrelevant

information, such as the suspect's criminal history, will be filtered out to prevent bias.

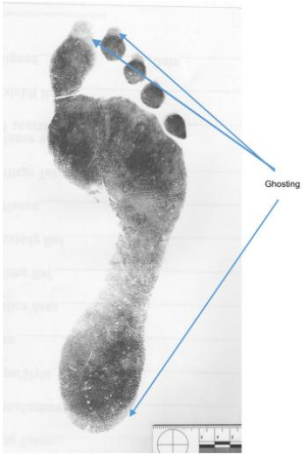


Figure 1. *Ghosting*

Based on Figure 1 *Ghosting* is a mark in the form of two images on a footprint, usually behind the heel and fingertips. The inner image is darker, while the outer image looks fainter or lighter (Burrow, 2015). If the evidence is deemed valid, the initial examiner will have two main tasks. First, they must check whether the footprints are stationary (static) or moving (dynamic). Dynamic footprints are usually characterized by alternating left and right footprint patterns, as well as the presence of faint shadows (ghosting); secondly, ensuring that the reference footprints were taken from a suspect or individual who needs to be excluded from the investigation. Subsequent forensic examinations are conducted by the lead examiner using the ACE-V method, starting from the analysis of the reference footprint (Dimaggio John, Vernon W, 2017).

Footprints are similar to fingerprints in that they are both unique. Both have distinctive features that allow for accurate identification. No two people have the same hand or footprints. A footprint is an imprint produced when a foot touches a surface. The nature of footprints is influenced by various functional aspects, shape, and structure of the foot. These factors can differ between men and women, resulting in differences in footprint dimensions (Mukhopadhyay, Das, & Chowdhuri, 2018). Genetics, lifestyle and climatic factors influence the shape of the human foot. Age, body mass index, gender, and population group also play a role in determining foot shape. If the feet of each individual are different, sex-related differences in foot morphology are very important, especially in footwear and forensic anthropology(Palla & Shivajirao, 2024)(Kanchan & Krishan, 2011). Analysis of feet, footprints, hands, and handprints is helpful in forensic investigations to determine sex(Awais, Naeem, Rasool, & Mahmood, 2018). Sex differences in footprints can be investigated through morphology and anthropometry. Foot morphology reveals differences in footprint shape, while anthropometry is concerned with variations in size (Webster, 2024).

There are various methods for describing and analyzing footprints, which can be divided into two groups: one using linear measurements to connect the anatomical parts of the footprint, and the second using subjective assessment of the shape of the footprint. Nirenberg suggests that at least two different approaches be used in forensic investigations to get a more complete picture of footprint characteristics. Linear measurement methods used in footprint examination include the Gunn, Optical Center, and Rossi methods (Nirenberg, 2016).

Individualization plays a crucial role in evaluating physical evidence found at the scene to associate the evidence with the suspect or victim. Around the world, studies have been conducted on the identification of individuals based on various types of evidence. Once the gender of an individual is known, it completes 50% of the individualization process and helps investigators in narrowing down the number of suspects. Based on the existing data that footprints prove to be unique, it is important to evaluate the sexual dimorphism of footprints. Sex determination in footprints has proven to be helpful in forensic investigations, so it is important to conduct a review of recent literature in the last five years. Therefore, it is necessary to review the methods of sex determination through footprint evidence analysis. The problem formulated in this literature review is: how is sex determined from footprints in different ethnicities of the world?

RESEARCH METHOD

The method used is a literature study with data sources from various studies by identifying PICO (Population/Patient, Intervention, Comparison, Outcome). For Population: ethnicity in the world, Intervention: Comparison: footprint measurement, and Outcome: sex determination. Data collection was done by downloading literature from three search engines, namely Google Scholar, Sciencedirect, and PubMed. The literature search was conducted between journals published from 2019 to 2024.

Table 1. PICO Research Question Framework

P	I	C	O
Ethnicity in the world	*Forensic podiatry*	Footprint measurement	Sex determination

Source: Author's Data

The results of the literature search were then screened using an initial selection instrument using inclusion and exclusion criteria. After the eligible literature was found, further selection was carried out using the methodology selection instrument. Furthermore, duplication checking was carried out using Mendeley. After that, the data was processed using the CONSORT data extraction method.

Table 2. Framework for Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
1. Articles that contain full text 2. Articles published in Bahasa Indonesia and *3. Original research article*	1. Articles published in paid form

4. Articles published in the last 5 years (2019-2024) 5. Articles that discuss sex determination based on footprints in certain ethnic groups in the world	2. Artkel manuscript publication other than journal 3. Article in the form of opinion

Source: Author's Data

To find relevant articles, the authors used three databases, namely Google Scholar, Sciencedirect, and PubMed, with the keywords "*ethnic group*", '*forensic podiatry*", "*anthropometric measurements of footprints*", and "*Determination of gender using footprints*". The article screening process is illustrated in the following chart:

Table 3. Result

No.	Title (author, year)	Research objectives	Population	Measurement	Results
1.	Anthropometric examination of footprints in South Indian population for sex estimation [12].	This study aims to determine the sex of a person, with 7 different anthropometric measurements; measuring length and width, recorded and statistically assessed from bilateral footprints taken with ink.	132 individuals (61 males and 71 females) aged 18-50 years, born in South India	A total of seven dimensions were measured for each footprint using a tape measure. These measurements included: 1. T1: The length between the point of the pternion (heel bone) and the anterior point of the first toe. 2. T2: The length between the pternion point and the anterior point of the second toe. 3. T3: The length between the point of the pternion and the anterior point of the third toe. 4. T4: The length between the pternion point and the anterior point of the fourth toe. 5. T5: The length between the pternion point and the anterior point of the fifth toe. 6. B1: Total Ball Breadth 7. B2: Total Heel Breadth Each measurement is divided into left and right sides, and labeled _L and _R, respectively. HB (Heel Ball index), which is the ratio between the maximum heel width divided by the maximum ball width, multiplied by 100, was calculated for each footprint.	1. This study successfully standardized sex determination in the South Indian population and achieved a significant level of accuracy. 2. The Discriminant Function Analysis (DFA) used in this study showed an accuracy rate of 77% in determining the gender of males and 93% for females.
2.	Sex and stature estimation from anthropometric measurements of the foot: linear analyses and neural network approach on a	This study aims to analyze height and gender in the Eastern Turkish population using foot measurements through Linear	134, consisting of 69 men and 65 women, were students from Malatya, a city in	Measured Leg Dimensions: 1. Right-Left Foot Stature (RFH-LFH) Foot height was measured as the distance between the lower line of the lateral malleolus and the heel. Measurements were taken using an osteometric board with the lower extremity in a relaxed position.	It was found that all foot dimensions in males were significantly larger than those in females. Sex prediction using the linear method yielded 94.8% accuracy, with a height estimation error of 4.15 cm.

No.	Title (author, year)	Research objectives	Population	Measurement	Results
	Turkish sample[15].	Discriminant Analysis and Regression Analysis.	Eastern Turkey.	2. Right-Left Foot Length (RFL-LFL) Leg length is the maximum distance between the front (acropodion) and the back of the heel (pternion). Measurements were taken while the participants were sitting with their legs raised to avoid the influence of body weight, using a caliper with an accuracy of 0.05 mm. 3. Right-Left Foot Breadth (RFB-LFB) Foot width is the distance between the protrusions made by the 1st and 5th metatarsals on either side of the foot. Measurements were taken with the participant in a seated position and legs elevated, using a push-piece with an accuracy of 0.05 mm.	
3.	Sexual dimorphism and determination using foot outlines, foot print angles, and foot indices[16]	This study aimed to examine sexual dimorphism and sex estimation in the Ebira ethnic group in Nigeria by utilizing the footprint angle (Clarke angle) and Chippaux-Smirak index, as well as measuring foot and footprint dimensions.	The study involved 283 males and 317 females of indigenous Ebira ethnicity in Nigeria.	1. Barefoot footprint measurement Footprint measurement process (Left and right barefoot print measurements): • Using manual rollers, blue ink was applied to the improvised footpad. • The participant steps with the left foot on the footpad and the trace is transferred to A4 paper; the process is repeated for the right foot. 2. Footprint Dimension Measurement • The Designated Longitudinal Axis (DLA) and baseline (BL) were drawn on the footprints following the method of Robbins and Krishan. • DLA is measured from the pternion to the first toe pad. • The distance between the pternion (P) and the most anterior point of each toe was measured for the left foot (LFT1 to LFT5) and right foot (RFT1 to RFT5). 3. Footprint Width and Length: • Footprint width is calculated from the first metatarsal (medial) and the fifth metatarsal (lateral), resulting in left (LFPB) and right (RFPB) footprint widths. • The outer (OBFL) and inner (IBFL) ball of foot lengths are measured from the pternion. 4. Barefoot measurement • The maximum foot length is calculated from the longest toe to the heel (pternion).	1. Sexual Dimorphism: - There was sexual dimorphism in all foot dimensions, arch index, Chippaux-Smirak index, footprint angle and ball angle, except for the left ball angle. 2. Sex Determination: - Sexual dimorphism in foot variables is the basis for sex determination. - Left leg width and right leg length were identified as the best predictors of sex. 3. Cut Point - A leg length of 25 cm can be considered as the cut-off point for sex determination. - A foot width of 9 cm was also used as the cut-off point for this analysis among the tribal groups.

No.	Title (author, year)	Research objectives	Population	Measurement	Results
				• The width of the foot is measured between the two widest parts, called BRFB/BRFL (right foot) and BLFB/BLFL (left foot). 5. Plantar Arch Index • A tangent from the medial border of the forefoot to the heel region is made to calculate the arch index (AI) by dividing the value of the perpendicular line from the center point to the footprint. 6. Chippaux-Smirak index, footprint angle, and ball angle • Line D connects the first and fifth metatarsals to calculate the Chippaux-Smirak Index (CSI) by comparing the minimum and maximum widths. • The footprint angle (FPA) is measured between the measurement line and the curved basin, while the sphere angle (β) is measured between the horizontal line and the diagonal.	
4.	Determination of sex from footprint dimensions among nupe ethnic group in minna niger state[17].	1. To determine the relationship between gender and footprint size. 2. To identify the uniqueness of the foot size. 3. To define the footprint size of the Nupe ethnic group	The study involved 421 subjects, consisting of 283 men and 138 women of the Nupe indigenous population, including both parents up to the second generation.	Footprint capture 1. Foam pads are filled with oil-free ink before sample collection. 2. Participants washed their feet to maintain hygiene. 3. Participants stand on an ink pad with minimal pressure. 4. They stepped on two A4 papers to obtain footprint samples. 5. Parameters measured from footprint samples using a scientific ruler include: • Toe length (T1-T5) • Foot ball width / breadth at ball (BAB) • Width at heel / breadth at heel (BAH) • Heel-ball index (BAH/BAB x 100) • Footprint index (maximum width/maximum length x 100) • A base lien perpendicular to the heel.	The results of this study showed highly significant sex differences based on toe length and width (P≤ 0.01), while the footprint index showed no statistical significance. The footprint dimension has sexual dimorphism. This dimension can be used to determine sex, either as a complement or substitute for skeletons such as long bones and skulls. The use of this method can also be applied in forensics for legal cases, as well as in shoe, fashion, and industrial design to optimize products
5.	Gender determination using foot, footprint, hand and hand print measurements in a Sinhalese population in	This study aimed to identify measurement differences between males and females and bilateral	Consisting of 117 students, consisting of 51 males and 66 females with the majority	1. Handprint Taking Process: The participant's right and left handprints were taken using an ink pad that is non-reactive and does not disappear easily. The participant's hand was gently pressed on the ink pad, and then lightly pressed on A4 size white paper to obtain the shape of the handprint. Once dry,	The results of this study were validated using the cross-validation method. The mean comparison test results indicated that the sizes on the left and right sides of men were larger than those of

No.	Title (author, year)	Research objectives	Population	Measurement	Results
	Sri Lanka using supervised learning techniques [18].	asymmetry between the left and right sides in both genders.	ethnic group in Sri Lanka, the Sinhalese, to determine the ethnicity of participants, information on the ethnicity of parents and grandparents was obtained.	eight measurements were taken based on previous studies. 2. Footprint Measurement Process: For each footprint, seven measurements were taken consisting of five length measurements and two width measurements. • Foot Length (FL): The distance between the tip of the longest finger and the tip of the heel (Pternion). • Foot Breadth (FB): The distance between the Metatarsale tibiale and Metatarsale fibulare points on the foot. • Foot Print Breadth (FPB): The distance between the Metatarsale tibiale and Metatarsale fibulare points on the footprint. • Foot Print Heel Breadth: The distance between the point of Sphyrion and Sphyrion fibulare. • Toe Lengths (FPT1L,...,FPT5L): The distance between the tip of each finger and the tip of the heel (Pternion).	women (p value <0.05). The obtained model shows that gender can be determined using the CART algorithm with 95.83% accuracy based on leg length, and 91.67% based on hand length, hand width, and palm length.
6.	Sex determination based on footprint ratio and comparison of toe print pattern in male and female Nigerian students : A case study of Bowen University students [19].	Sex determination based on footprint ratio and comparison of toe print patterns in male and female university students in Nigeria	The subjects in this study consisted of 100 people, with 50 men and 50 women.	Footprint retrieval: 1. Round Bowls: One bowl is used to place the foam, and the other bowl is for washing participants' feet after ink application. 2. Thin Round Foam: Gentian Violet (GV) is poured over foam placed in a bowl. 3. Magnifying Glass: Used in the analysis process. 4. Spiritus: Used to clean the GV ink from the participants' feet. 5. Cotton: Used with methylated spirits to remove GV. 6. White Drawing Paper: A place to paste the participants' footprints that have been colored with GV. 7. Gloves: Protects hands from dirt and stains when cleaning participants' feet. 8. Ruler Meter: Used in measurement analysis. Footprint measurement 1. Maximum Length: Measured from the tip of the largest toe to the midpoint behind the heel (called the pterion). 2. Maximum Width: Measured from medial metatarsal to lateral metatarsal.	1. The toe mold ratio showed standard values of 0.371219 and 0.3737645 with 51% accuracy. 2. Footprint prints with a ratio below this value are predicted to be female, while those above it are predicted to be male.

No.	Title (author, year)	Research objectives	Population	Measurement	Results
				3. Descriptive statistics were analyzed, with the number of footprint patterns displayed through pie charts. Footprint ratio was calculated based on the ratio between the maximum width and maximum length of footprints.	
7.	Determination of Sex by Foot and Footprint Dimensions in the Sinhalese Population of Sri Lanka[20]	This study aims to assess the extent to which sexual differences are seen in foot size and foot prints, and to create a population-appropriate sex determination formula based on foot size and foot prints that show differences between males and females in the Sinhalese population of Sri Lanka.	A total of 116 young and healthy dental students consisting of 51 males and 66 females.	Battery trace retrieval 1. The participants' right and left footprints were generated using ink pads. 2. The ink used is non-reactive and non-erasable. 3. Participants placed their feet on the ink pads with very light pressure. 4. Then, the participant's feet were pressed firmly onto A4-sized white paper on a flat surface to print footprints. 5. After trace retrieval, the paper is left to dry. 6. A total of seven measurements were taken according to the procedure described in previous studies Footprint measurement 1. Foot Length (FL): The maximum distance from the rearmost point on the heel (pternion) to the front tip of the longest toe (first or second toe). 2. Foot Breadth (FB): The distance between the surface of the head of the first and fifth metatarsal bones. 3. Foot Heel Breadth (FHB): The maximum distance from the most prominent point on the lateral side of the heel to the most prominent point on the medial side of the heel. 4. Footprint Breadth (FPB): The distance between the most lateral and medial points on the front of the footprint. 5. Footprint Heel Breadth (FPHB): The widest distance at the ball of the footprint heel. 6. Footprint heel to toe 1 length: • Heel to 1st Finger Length (FPT1L): The distance from the pternion to the foremost point of the first toe. • Heel to Finger 2 Length (FPT2L): The distance from the pternion to the foremost point of the second toe. • Heel to 3rd Finger Length (FPT3L): The distance from the pternion to the most forward point of the third toe.	All foot measurements and foot prints of men were significantly larger than those of women ($P < 0.001$). Univariate discriminant analysis showed the percentage of correct sex classification ranged from 73.9% to 96.6% for the right foot and 77.4% to 94% for the left foot. The parameter that showed the most dimorphism was foot length, with a sex prediction accuracy of 96.6% for the right foot and 94.0% for the left foot. This study concludes that foot measurements and foot prints are effective for classifying sex with a high degree of accuracy in the Sinhalese population in Sri Lanka.

No.	Title (author, year)	Research objectives	Population	Measurement	Results
				• Heel to 4th Finger Length (FPT4L): The distance from the pternion to the foremost point of the fourth toe. • Heel to 5th Finger Length (FPT5L): The distance from the pternion to the most forward point of the fifth toe.	
8.	Sexual dimorphism and anthropometric measurements of foot in adult Oyemekun ethnic group population in Akure, South-West Nigeria[21]	This study was conducted on sexual dimorphism using anthropometric foot measurements in an adult population of Oyemekun ethnicity in Akure, Southwest Nigeria.	The study population consisted of 500 randomly selected adult subjects 250 males 250 females	Measurements taken include: 1. Foot length: Measured as the straight distance between the rearmost point of the heel (pternion) and the foremost point on the head of the first or second toe (acropodion), whichever is longer, when the subject is standing upright on a flat surface. This measurement does not include nails that extend beyond the fingertips. 2. Foot breadth: Measured as the straight distance from the medial border of the first metatarsal head to the lateral border of the fifth metatarsal head. 3. Foot index: Calculated using a formula: Foot Index is calculated by dividing Foot Length by Foot Width, then multiplying by 100. 4. All measurements were taken twice, and the average of the two measurements was recorded in centimeters (cm). Measurements were taken according to the protocol recommended by the International Society for the Advancement of Kinanthropometry.	On average, the length and width of men's feet are about 1 cm larger than women's, with statistically significant differences ($p<0.05$). Legs with a length of less than 26 cm and a width of less than 11 cm are likely to belong to females, while sizes above that are likely to belong to males. These findings suggest sexual dimorphism in foot dimensions, with 26 cm as the limit for length and 11 cm as the limit for foot width in this area.

Source: Author's Data

RESULT AND DISCUSSION

Disscussion

The studies from the literature review included in this table highlight various approaches to determining sex using anthropometric foot measurements. Studies from different populations show significant sexual dimorphism in foot size, which can be utilized for sex estimation.

On Foot Size Variation by Gender most studies show that men have a greater average foot length and width than women. For example, a study conducted by Palla and Shivajirao (2024) recorded an accuracy rate of 77% for male gender recognition and 93% for female (Palla & Shivajirao, 2024). On the other hand, 94.8% in predicting gender using foot dimensions. These findings suggest that anthropometric measurements of the feet can provide a strong indicator for sex determination (Parlak, Özkul, Oruç, & Celbiş, 2024).

In methodology, measurement, the measurement methods in this study varied, including measurements of length, width, and foot index. In the study

conducted by Suleiman et al. (2023), more complex measurement techniques were applied, including footprint angle and Chippaux-Smirak index measurements. This variety of approaches reflects the flexibility and adaptability of the method based on different population contexts (Suleiman, Danborno, Musa, & Timbuak, 2023). As a result, the footprint measurement process was performed barefoot using a manual roller applying blue ink on an improvised footpad, where the participant stepped on the footpad and the left and right footprints were transferred to A4 paper. Next, footprint dimensions were measured by drawing the longitudinal axis (DLA) and baseline on the footprint, following the method of Robbins and Krishan; the DLA was measured from the pternion to the first toe pad, and the distance between the pternion and the most anterior point of each toe was measured for the left and right feet. The width of the footprint was then calculated between the first and fifth metatarsals, resulting in left and right footprint widths, while the length of the outer and inner ball of the foot was measured from the pternion. In barefoot measurements, the maximum length of the foot is measured from the longest toe to the heel, and the width of the foot is measured between the two widest parts. In addition, the arch index is calculated by making a tangent line from the medial border of the forefoot to the heel region and dividing the value of the perpendicular line from the midpoint to the footprint. Finally, the Chippaux-Smirak index is calculated by connecting the first and fifth metatarsals to compare the minimum and maximum widths, while the footprint angle is measured between the measurement line and the arch basin, and the ball angle is measured between the horizontal line and the diagonal.

Footprinting begins by preparing foam pads filled with oil-free ink to ensure a clean and harmless result. Before the footprinting process, participants are required to wash their feet to keep them clean and free from dirt. Afterward, participants stand on the ink pad applying minimal pressure, allowing the ink to be evenly distributed. Then, they stepped on two sheets of A4 paper to print the footprints that would be used as samples as shown in Figure 2, Figure 3, and Figure 4. (Alabi, Aniyikaye, Odunnaike, & Adunmo, 2022)

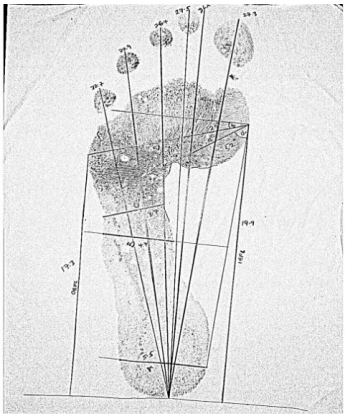
Figure 3. Stepping on the Ink

Figure 4. Stepping on A4 Paper

Figure 5. ***Measuring the Footprint***

Seven main dimensions were measured using a tape measure, including the length from the pternion to each toe, and the width at the ball of the foot and heel. Measurements were taken for each side of the foot, i.e. left (L) and right (R), and the heel-ball index ratio was also calculated as an indicator (Kanchan, Krishan, Prusty, & Machado, 2014). In the measurement process, first, the length of the foot (T1-T5) was measured from the pternion to the most forward point of each toe, where the length of the left and right foot was also recorded to see the difference, while the width of the foot (B1 and B2) was measured from the first and fifth metatarsals, resulting in a measure of the width at the ball of the foot and heel. Next, for barefoot footprint measurements, a manual roller and ink were used to print the footprints on A4 paper, where the participant stepped on a pre-prepared footpad. Then, the longitudinal axis (DLA) and baseline were determined based on a specific method, followed by measurement of the footprint width and length for each foot, which was performed while the participant was in a seated position to ensure accuracy. Finally, the Chippaux-Smirak index and footprint angle were calculated to provide more detailed characteristics of the footprint structure, so this analysis can help

detect sexual dimorphism and variations in anthropometric data as seen in Figure 2.



Landmarks and measurements on the footprints to obtain foot index and angle

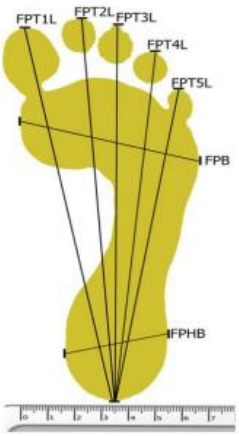


Figure 7. Footprint measurement (Nanayakkara, Nandasena, Nawarathna, & Ariyasinghe, 2020)

Based on Figure 6 Footprint measurement is performed by measuring seven dimensions using a tape measure, which includes the length from the pternion, which is the heel bone, to each toe. The measured dimensions consist of T1, which is the length between the pternion and the anterior point of the first toe; T2, the length between the pternion and the anterior point of the second toe; T3, the length from the pternion to the anterior point of the third toe; T4, the length from the pternion to the anterior point of the fourth toe; and T5, the length from the pternion to the anterior point of the fifth toe. In addition, the total width at the ball of the foot (B1) and the total width at the heel (B2) were measured. Each measurement was differentiated based on the side of the foot, marked _L for the left foot and _R for the right foot. In addition, the HB index (Heel Ball index) was calculated for each footprint by dividing the maximum heel width by the maximum ball width, then multiplying by 100 (Krishan, Kanchan, Passi, & Dimaggio, 2012).

On Sexual Dimorphism, most studies confirm the existence of clear sexual dimorphism, where parameters such as foot length, width, and footprint index show

significant differences between males and females. Research by Adelakun revealed that foot length limitations below 26 cm and width below 11 cm tend to belong to females, so these parameters can be used as indicators to distinguish between the sexes (Adelakun, 2019). While the practical applications of the findings from this research are not only relevant in anthropometric studies, but can also be applied in various fields such as forensics, shoe design, and gender-oriented product development. For example, the method developed by Alabi et al. (2022) showed the potential of using footprint dimensions as an additional method in forensic analysis (Alabi et al., 2022). Furthermore, the cultural and population relevance of this research also shows how cultural and ethnic factors can influence foot dimensions. Research on a specific ethnic group, the Sinhalese population, showed that anthropometric measurements should be considered in the local context to make the results more accurate (Dayarathne, Nawarathna, & Nanayakkara, 2021).

CONCLUSION

The conclusion of this study is that foot anthropometric measurements can be effectively used to determine sex, with various studies showing significant sexual dimorphism in foot size between males and females. On average, men have greater foot length and width than women, which can be utilized for sex estimation with a high degree of accuracy. The diverse measurement methodologies, such as length, width and foot index measurements, reflect flexibility in adaptation based on different population contexts. This study also shows the importance of considering cultural and ethnic factors in anthropometric analysis, which can affect measurement results. The findings have practical applications in a variety of fields, including forensics and product design, and confirm that footprint dimensions can be a powerful indicator of sex discrimination.

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