Sex estimation from handprints in a Croatian population sample: developing a tool for sex identification in criminal investigations

Kolić, Andrea; Jerković, Ivan; Anđelinović, Šimun

RESEARCH ARTICLE

Sex estimation from handprints in a Croatian population sample: developing a tool for sex identification in criminal investigations

Andrea Kolić[1], Ivan Jerković[1], Šimun Anđelinović[2, 3]

[1]University Department of Forensic Sciences, University of Split, Split, Croatia

[2]University of Split School of Medicine, Split, Croatia

[3]Clinical Department for Pathology, Legal Medicine and Cytology, University Hospital Center Split, Split, Croatia

Correspondence to:
Ivan Jerković
University Department of Forensic Sciences, University of Split, Ruđera Boškovića 33, 21000 Split, Croatia
ijerkovic@unist.hr

Cite as:
Kolić A, Jerković I, Anđelinović Š. Sex estimation from handprints in a Croatian population sample: developing a tool for sex identification in criminal investigations. ST-OPEN. 2020; 1: e2020.1919.34.

Aim: To test if handprint measurements show sexual dimorphism in the Croatian population, and to develop population-specific sex estimation standards.

Methods: A cross-sectional study was conducted on 100 adult volunteers from a Croatian population (50 males and 50 females) aged between 20 and 45 years. Using a fingerprint ink, we collected handprints of both hands on a paper sheet. We scanned handprints and took 13 measurements. Bilateral asymmetry and sexual dimorphism of the measurements was analyzed and sex estimation models were developed using linear discriminant analysis.

Results: All measurements exhibited statistically significant sexual dimorphism ($P<0.001$). Univariate discriminant functions provided sexing accuracy from 75% to 92%. The highest accuracy rate (92%) and the lowest sexing bias (0%) was obtained using the handprint breadth. A multivariate discriminant function could estimate sex with 93% accuracy, but with more pronounced sexing bias (10%).

Conclusion: We showed that handprint measurements could be used for sex estimation in the Croatian population with a high accuracy level. Therefore, they could serve as a valuable tool for biological profiling of perpetrators in criminal investigations when other evidence is not conclusive.

Introduction

Handprints are a conclusive type of evidence often available at the scenes of various crime types. If they are recovered from the scene and used in forensic examinations, they can help establish the identity of a person included in the crime. Unfortunately, the identification is often not possible as it is required that both the recovered (questioned) prints and those collected from perpetrators/suspect (known prints) are available for comparison [1-

3]. Although in such instance, handprints cannot directly reveal the perpetrator's identity, their dimensions can still provide valuable clues on the biological features of an individual like sex and stature and narrow down the list of potential suspects [1, 2, 4-6].

In forensic sciences, studies that employ the statistical models to classify sex using body dimensions have been extensively conducted on skeletal material or body parts [7-12]. The primary aim of those studies has been to aid the identification process of the human remains in crimes, disasters, or wars by estimating the sex of individuals. On the other hand, a similar approach is more rarely applied in forensic science to reveal the sex of the donor of prints found at the crime scenes. Until now, studies that consider handprint measurements have been conducted only in Western Australian [6] and French [13] population samples but showed great potential for application in forensic investigations. Both studies revealed that dimensions of handprints demonstrate differences between males and females and thus could be used to develop sex classification models. The standards they developed could estimate sex from handprints correctly in more than 90% of cases when multiple variables are used, while accuracy of 88%-90% could be achieved even with a single variable [6, 13]. However, like most of the anthropometric methods, their major limitation is sensitivity to the interpopulation differences in body size, robusticity, and sexual dimorphism [14, 15]. Therefore, they must be developed and validated on each population separately, especially considering the level of scientific rigor inherent in modern forensic science.

Except for the sex, previous studies showed that handprints could also be used to estimate the height of a person, thus providing even more information about the print donor [2, 4, 5, 16]. Nonetheless, as many anthropological studies demonstrated that the error of the height estimates is smaller when males and females are considered separately [17, 18], height estimation equations for handprints are also developed to be sex-specific [2, 5, 16]. For this reason, the initial identification of sex is an inevitable prerequisite for their application.

Since sex estimation standards for handprints were not developed for the Croatian population, our study aimed to test if handprint measurements show sexual dimorphism in a Croatian population sample and, if so, to establish population-specific sex classification standards that could be employed in forensic investigations to examine handprints found at crime scenes.

Methods

Participants

The cross-sectional study was conducted at the University Department of Forensic Sciences (University of Split, Croatia) in the Crime Scene Investigation Laboratory from May to June 2019. The study comprised a convenience sample of 100 adult volunteers (50 men; 50 women) from a Croatian population. Each person was provided with a participant information sheet and signed the informed consent form prior to participation in the study.

Using a brief questionnaire, we collected basic information on participants' sex, age, and handedness as well as information on orthopedic or dermatological health issues used as exclusion criteria.

Ethical approval was attained by the University Department of Forensic Sciences Ethics Committee on 23 April 2019 (2181-227-05-12-19-0003; 024-04/19-03/00007).

Handprint analysis

Using fingerprint ink Dacty ink® (BVDA International, Amsterdam, The Netherlands), we collected paper handprints of both hands. Impressions were scanned with a CANON C3320i at 600dpi. All images were imported into and measured in Adobe Photoshop (version CC 2019, Adobe Systems, San Jose, CA, USA). The images were calibrated, measured using a ruler tool, and recorded using the measurement log. All measurements were taken by the first author (AK).

For each impression, we performed following 13 measurements (**Figure 1**):

1. Handprint length (Point A to B) – the distance between the base line and the tip of the middle finger [5].

2. Handprint breadth (Point C to D) – the distance between the most laterally projected part of the palm print at the 2nd metacarpal and the most medially projected part of the palm print at the distal transverse crease [2, 5].

3. Palm length (Point A to E) – the distance between the base line and the proximal flexion crease of the middle finger [5].

4.-8. Complete thumb, index, middle, ring and little finger length (Point B to E) – the distance from the palmar digital crease of the finger to the tip of the respective finger [5].

9. Distal thumb length (Point F to G) – the distance from the interphalangeal crease to the tip of the respective finger [4].

10.-13. Distal and middle index, middle, ring and little finger length (Point H to B) – the distance from the proximal interphalangeal crease to the tip of the finger [4].

For measurements 4.-13., instead of measuring lengths to the center of the creases as suggested by Ahemad and Purkair [4], we measured lengths as a distance from the tip of the finger to the beginning of the crease.

Statistical analysis

Bilateral asymmetry was tested using a paired sample t-test. For male and female print measurements, we calculated descriptive statistics and analyzed sexual dimorphism by independent samples t-test.

Statistical models for sex classification were developed using linear discriminant analysis with an equal prior probability for male and female measurements. Cut off values for univariate discriminant functions were calculated as a mean of male and female measurements. Multivariate discriminant functions were obtained using the stepwise procedure. For those functions, the sex estimation equations were derived using unstandardized

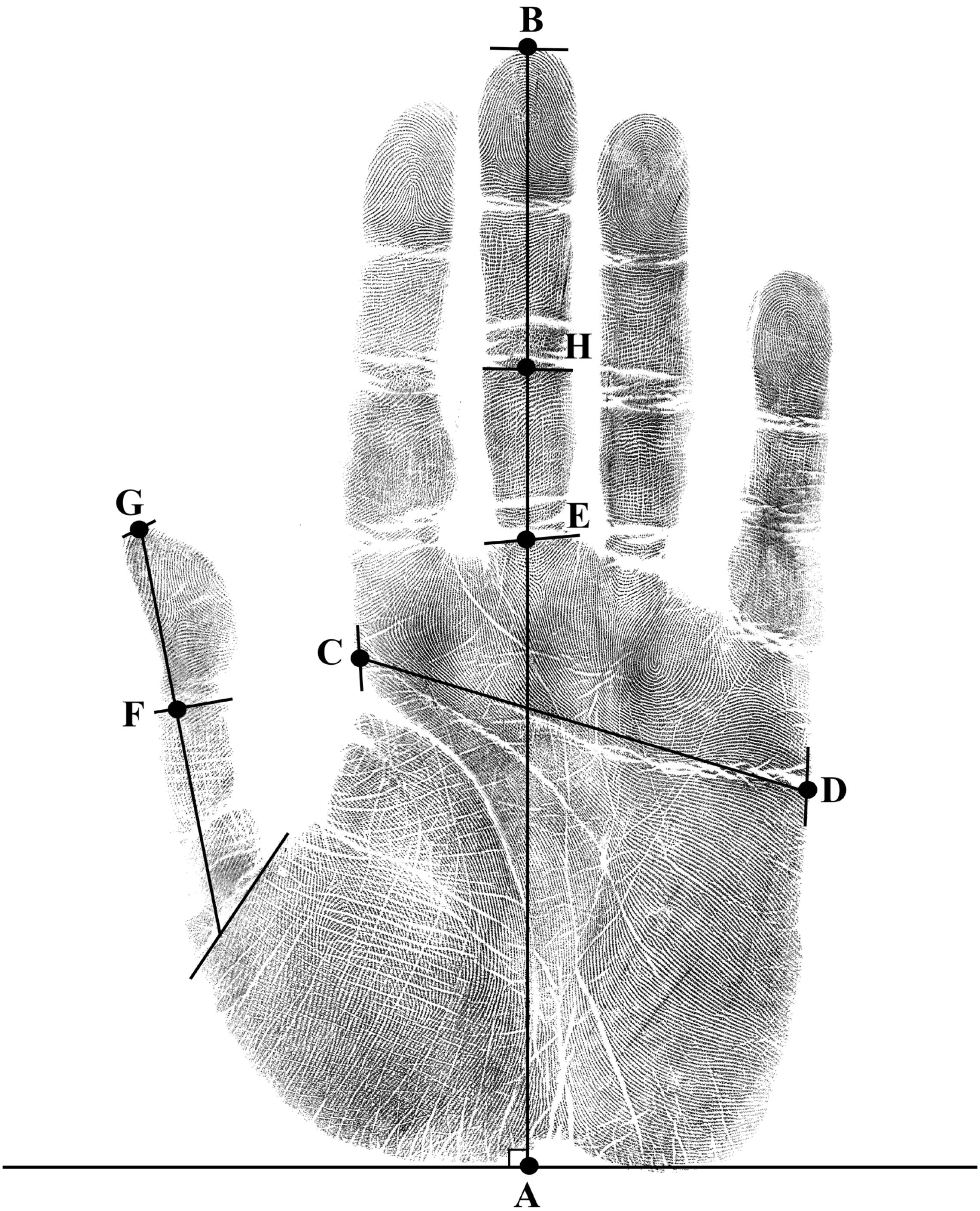

Figure 1. Handprint measurements used in the study.

function coefficients, and cut off values were calculated as a mean of functions' centroids. Those equations were provided as a linear combination of the variables in the following form [19, 20]:

$$F = x_1\beta_1 + x_2\beta_2 + ... + x_n\beta_n + c$$

where *x* represents variables used in the study, *β* weighted coefficients, and *c* a constant. The sex can be estimated by comparing the F score with the provided cut off value. If the score is greater than the cut off, it is estimated that print originates from a male, while if it is smaller, it is estimated that print originates from a female individual [19, 20].

Sex estimation accuracy was examined using a leave-one-out cross-validation (LOOCV) algorithm that provides realistic classification results. In LOOCV, a classification model is tested on each specimen using the functions calculated from all remaining cases except that one [21]. The sex estimation accuracy was given separately for males, females, and for overall results as a proportion of correctly classified and a total number of individuals. Statistical analyses were performed using the IBM SPSS (version 22, SPSS Inc., Chicago, IL, USA) with a statistical significance set at $P \leq 0.05$.

Results

All the participants met inclusion criteria since they did not report orthopedic or dermatological health issues. The median age of male subjects was 27.5 (range 20-45), while for the females, it was 25 (range 20-39). The sample comprised 92 right-handed and seven left-handed individuals, and one person was ambidextrous.

From 13 measurements, 12 measurements were larger on the right prints, while four of them showed statistically significant bilateral differences ($P<0.05$, **Table 1**). For this reason, we analyzed sexual dimorphism for the left and the right prints separately.

Table 1. Bilateral asymmetry of handprint measurements

Measurement	Bilateral difference t-value	P*
Handprint length	-2.471	**0.015**
Handprint breadth	-1.402	0.164
Palm length	-0.897	0.372
Complete thumb length	-7.765	**<0.001**
Complete index-finger length	-5.366	**<0.001**
Complete middle-finger length	-1.917	0.058
Complete ring-finger length	-0.734	0.465
Complete little-finger length	-0.424	0.673
Distal thumb length	-1.816	0.072
Distal and middle index-finger length	-2.425	**0.017**
Distal and middle middle-finger length	0.083	0.934
Distal and middle ring-finger length	-0.222	0.825
Distal and middle little-finger length	-1.336	0.185

*Statistically significant P-values are in bold.

Table 2 and **Table 3** show means and standard deviations (SD) for male and female print measurements. All the measurements, both for left and right prints, were greater in male individuals and showed statistically significant sexual dimorphism ($P<0.001$). According to *t*-values, handprint breadth, handprint length, and palm length demonstrated the highest degree of sexual dimorphism, while for the remaining measurements it was lower and similarly expressed.

Table 2. Descriptive statistics and t-test results for print measurements of the left hand

Measurement	Findings (mm, mean ± SD)		t	P*
	Males	Females		
Handprint length	191.72±9.68	171.94±8.07	11.100	**<0.001**
Handprint breadth	84.86±4.26	74.45±3.68	13.079	**<0.001**
Palm length	107.29±5.61	95.84±4.76	11.005	**<0.001**
Complete thumb length	69.40±5.19	61.64±4.12	8.287	**<0.001**
Complete index-finger length	75.64±4.76	69.03±4.31	7.277	**<0.001**
Complete middle-finger length	84.45±5.06	76.24±4.91	8.233	**<0.001**
Complete ring-finger length	79.07±5.13	70.79±4.77	8.361	**<0.001**
Complete little-finger length	65.14±5.11	57.59±4.06	8.190	**<0.001**
Distal thumb length	31.89±2.32	27.87±2.19	8.881	**<0.001**
Distal and middle index-finger length	49.93±3.57	45.34±3.17	6.802	**<0.001**
Distal and middle middle-finger length	55.71±3.82	50.14±3.59	7.515	**<0.001**
Distal and middle ring-finger length	53.84±4.10	48.05±3.47	7.628	**<0.001**
Distal and middle little-finger length	44.73±4.65	39.27±3.18	6.861	**<0.001**

*Statistically significant P-values are in bold.

Table 3. Descriptive statistics and t-test results for print measurements of the right hand

Measurement	Findings (mm, mean ± SD)		t	P*
	Males	Females		
Handprint length	191.89±9.69	172.37±8.05	10.958	**<0.001**
Handprint breadth	84.93±4.16	74.77±3.90	12.603	**<0.001**
Palm length	107.14±5.39	96.15±4.84	10.721	**<0.001**
Complete thumb length	70.06±5.09	62.95±4.02	7.751	**<0.001**
Complete index-finger length	76.28±4.72	69.63±4.48	7.227	**<0.001**
Complete middle-finger length	84.76±5.17	76.35±5.10	8.191	**<0.001**
Complete ring-finger length	78.97±5.22	71.07±4.95	7.761	**<0.001**
Complete little-finger length	65.15±5.20	57.69±4.49	7.687	**<0.001**
Distal thumb length	31.85±2.61	28.30±2.04	7.587	**<0.001**
Distal and middle index-finger length	50.27±3.57	45.55±3.25	6.914	**<0.001**
Distal and middle middle-finger length	55.64±3.73	50.19±3.51	7.530	**<0.001**
Distal and middle ring-finger length	53.76±3.96	48.19±3.64	7.322	**<0.001**
Distal and middle little-finger length	44.96±4.39	39.41±3.43	7.055	**<0.001**

*Statistically significant P-values are in bold.

Cut off values for univariate discriminant functions and accuracy rates are provided in **Table 4** and **Table 5**. If the measurement is greater than the cut off value, the print belongs to a male individual, otherwise it belongs to a female. For both hands, the highest sex estimation accuracy was achieved for handprint breadth (92%), palm length (87% and

88%), and handprint length (86%). Accuracy for complete finger lengths ranged from 78% to 81%, while for distal and middle finger length, it was between 75% and 80%.

Table 4. Cut off values for sex estimation and cross-validated accuracies for univariate discriminant functions of the left hand

Measurement	Cut off	Accuracy		
		Males (n=50), n (%)	Females (n=50), n (%)	Overall (n=100), n (%)
Handprint length	181.83	42 (84)	44 (88)	86 (86)
Handprint breadth	79.66	46 (92)	46 (92)	92 (92)
Palm length	101.56	44 (88)	44 (88)	88 (88)
Complete thumb length	65.52	38 (76)	43 (86)	81 (81)
Complete index-finger length	72.34	40 (80)	40 (80)	80 (80)
Complete middle-finger length	80.34	40 (80)	40 (80)	80 (80)
Complete ring-finger length	74.93	41 (82)	41 (82)	82 (82)
Complete little-finger length	61.37	37 (74)	42 (84)	79 (79)
Distal thumb length	29.88	41 (82)	43 (86)	84 (84)
Distal and middle index-finger length	47.63	37 (74)	39 (78)	76 (76)
Distal and middle middle-finger length	52.92	37(74)	39 (78)	76 (76)
Distal and middle ring-finger length	50.95	37 (74)	40 (80)	77 (77)
Distal and middle little-finger length	42.00	34 (68)	41 (82)	75 (75)

Table 5. Cut off values for sex estimation and cross-validated accuracies for univariate discriminant functions of the right hand

Measurement	Cut off	Accuracy		
		Males (n=50), n (%)	Females (n=50), n (%)	Overall (n=100), n (%)
Handprint length	182.13	41 (82)	45 (90)	86 (86)
Handprint breadth	79.85	46 (92)	46 (92)	92 (92)
Palm length	101.64	44 (88)	43 (86)	87 (87)
Complete thumb length	66.50	38 (76)	43 (86)	81 (81)
Complete index-finger length	72.95	41 (82)	40 (80)	81 (81)
Complete middle-finger length	80.55	40 (80)	39 (78)	79 (79)
Complete ring-finger length	75.02	39 (78)	40 (80)	79 (79)
Complete little-finger length	61.42	39 (78)	39 (78)	78 (78)
Distal thumb length	30.08	41 (82)	39 (78)	80 (80)
Distal and middle index-finger length	47.91	39 (78)	39 (78)	78 (78)
Distal and middle middle-finger length	52.91	40 (80)	40 (80)	80 (80)
Distal and middle ring-finger length	50.97	37 (74)	39 (78)	76 (76)
Distal and middle little-finger length	42.18	35 (70)	40 (80)	75 (75)

Using the stepwise analyses, we calculated two multivariate discriminant functions, but only for the left hand, it reached accuracy greater than the univariate once. The developed multivariate function for left prints can be calculated using the following equation:

$F = handprint\ breadth \times 0.180 + palm\ length \times 0.084 - 22.826.$

If the score F obtained with the equation is greater than 0, the print belongs to a male, and if it is smaller, it belongs to a female individual. This discriminant function can classify sex of an individual with 93% accuracy (93/100), 88% (44/50) for male, and 98% (49/50) for female prints.

Discussion

This study showed that selected handprint measurements exhibited statistically significant sexual dimorphism in a Croatian population sample and provided statistical models that could estimate sex from handprints in Croatian population. This paper presents the first study of this type conducted in a Croatian population, and it is one of the two studies published on samples from European populations [13].

Right hand measurements were significantly greater than left in four variables as has been reported earlier with handprint measurements [4, 5], but also in the other types of anthropometric studies [22]. This type of asymmetry is often attributed to the use of the dominant hand [9], which conforms the fact that most of our participants were right-handed. However, it is a complex issue since previous studies showed that dimensions of the right side could be larger not only in right-handed individuals but also in left-handed and bimanual ones [9, 22]. So, to avoid additional sources of error, we examined prints from each side separately.

The handprint variables showed a degree of sexual dimorphism similar to the previous study by Ishak et al. [6]. In both that and our study, the measurements with the highest degree of sexual dimorphism were handprint breadth, handprint length, and palm length, whereas sexual dimorphism of complete finger lengths was less pronounced. The dimorphism of distal and middle finger lengths that were not previously used to estimate sex was also statistically significant but less pronounced in comparison to the other variables. The studies that used handprints to estimate height showed that those variables were less correlated to the stature in comparison to the handprint length [2, 16]. So, they are probably more prone to intra-sex variations, and less reflect body size differences between males and females.

The overall accuracy level (75%-93%) was also in line with the previous studies [6, 13], where it was 89%-91% [6] and 92% [13] when the same statistical procedures were applied. In the present study, the univariate discriminant function of the handprint breadth achieved the highest accuracy of 92% with no sexing bias, which is also a variable that performed best in the previous study. However, in that study, only handprint length and breadth achieved accuracy greater than 80% with sexing bias smaller than 5%, so researchers did not include the remaining variables for sex estimation [6]. On the contrary, in our research, five variables for the left hand and four variables for the right hand reached accuracy level equal or greater to 80% with a sexing bias less than 5%, which is why they could also be applicable for sex estimation. In practice, it means that sex can be reliably classified even if the partial handprint is available, e. g., if an interdigital area of the palm is available (handprint breadth), or if finger lengths can be measured.

Using a stepwise analysis, we developed one multivariate discriminant function with two variables that could estimate sex accurately for 93% of prints, which was also in accordance with previous studies [6, 13]. However, due to the high sexing bias (10%), we suggest estimating sex using the univariate function of the handprint breadth that had the highest accuracy and smallest sexing bias. When results of the present research are compared to recent research conducted on the direct hand measurements, it is evident that they follow a similar pattern of sexual dimorphism and show a similar relative contribution of variables in sex estimation models [6, 10]. Specifically, the most important variables were hand breadth, palm length, and hand length, which is probably one of the reasons why some studies use only those variables [12].

As a study limitation, we should consider that the sex estimation standards were developed on the limited sample size, which could be attributed to the type of material used in the study. Specifically, handprints are sensitive biometric data that can be misused, which is probably why many refuse to participate in the research. Due to the convenience sampling strategy, we also could not claim that sample uniformly included people from all regions, even though we collected most of the samples at the second largest university in Croatia that is attended by the students from all over the country. For this reason, the sample should be furtherly extended to target different regions, or the method should be validated on an independent sample of known regional structure. It is also important to stress that, like in previous research of this type [4, 6], handprints were taken in controlled conditions that are not always found in real-life crime scenes. For example, a hand can be in a different position when leaving a handprint; it can be arched, bent, loosened, etc. [1], and the amount of hand pressure could also be different [6]. Additional factors that could impact shape or dimensions could be hand movement to the latent print, as well as visibility of the latent print and print developing method. So, the results of the study should be implemented with caution.

In the present study, we developed statistical models that could be used to classify sex from complete or partial handprints. However, as crime scene can often contain even smaller segments of the prints left and recovered in different conditions, the present research could not cover all the possibilities. Therefore, we plan to extend our research to the others part of the hand, e. g., fingerprints [23] and other isolated palmar regions [24, 25], and to test methods in real-life situations considering the factors that could impact the features of the print.

Provenance: Submitted. Based on the master's thesis by Andrea Kolić „Estimation of stature and sex from handprint dimensions in Croatian population", the first author on this article, at the University of Split Department for Forensic Sciences.

Peer review: Externally peer reviewed.

Received: 24 November 2019 / **Accepted:** 21 April 2020 / **Published online:** 18 May 2020.

Acknowledgements: The authors wish to thank all study participants. We particularly thank our colleagues who assisted with participant recruitment: Lucija Bardić, Ana Banovac, Toni Ljubić, Ana Šarić Gudelj, Toni Perković, Marin Aglić Čuvić, Domagoj Barbarić, and Marijan Božinović Karauz.

Ethics approval: Granted by the University Department of Forensic Sciences Ethics Committee (2181-227-05-12-19-0003; 024-04/19-03/00007).

Funding: This research received no specific grant from any funding agency in public, commercial or not-for-profit sectors.

Authorship declaration: All authors conceived and designed research, AK and IJ conducted data acquisition, AK conducted handprint measurements, all authors analyzed and interpreted data, all authors drafted the manuscript, all authors critically revised the manuscript for important intellectual content, all authors approved the version to be published, all authors agree to be accountable for all aspects of the work.

Competing interests: The authors completed the ICMJE Unified Competing Interest form (available upon request from the corresponding author), and declare no conflicts of interest.

ORCID

Andrea Kolić https://orcid.org/0000-0003-3248-9085

Ivan Jerković https://orcid.org/0000-0003-4716-9375

Šimun Anđelinović https://orcid.org/0000-0002-9017-5634

References

1. Krishan K, Kanchan T, Kharoshah MA. Estimation of stature from handprint dimensions–Positional variations in real crime scene situations. Egypt J Forensic Sci. 2015;5(4):129-31.
2. Paulis MG. Estimation of stature from handprint dimensions in Egyptian population. J Forensic Leg Med. 2015;34:55-61.
3. Jain AK, Feng J. Latent palmprint matching. IEEE Trans Pattern Anal Mach Intell. 2008;31(6):1032-47.
4. Ahemad N, Purkait R. Estimation of stature from hand impression: a nonconventional approach. J Forensic Sci. 2011;56(3):706-9.
5. Ishak N-I, Hemy N, Franklin D. Estimation of stature from hand and handprint dimensions in a Western Australian population. Forensic Sci Int. 2012;216(1-3):199.e1-7.
6. Ishak N-I, Hemy N, Franklin D. Estimation of sex from hand and handprint dimensions in a Western Australian population. Forensic Sci Int. 2012;221(1-3):154.e1-6.
7. Spradley MK, Anderson BE, Tise ML. Postcranial sex estimation criteria for Mexican Hispanics. J Forensic Sci. 2015;60 Suppl 1:S27-31.
8. Bašić Ž, Kružić I, Jerković I, Anđelinović D, Anđelinović Š. Sex estimation standards for medieval and contemporary Croats. Croat Med J. 2017;58(3):222-30.
9. Charisi D, Eliopoulos C, Vanna V, Koilias CG, Manolis SK. Sexual dimorphism of the arm bones in a modern Greek population. J Forensic Sci. 2011;56(1):10-8.
10. Jee S-C, Bahn S, Yun MH. Determination of sex from various hand dimensions of Koreans. Forensic Sci Int. 2015;257:521.e1-10.
11. Kanchan T, Kumar GP, Menezes RG. Index and ring finger ratio—A new sex determinant in south Indian population. Forensic Sci Int. 2008;181(1-3):53.e1-4.
12. Kanchan T, Rastogi P. Sex determination from hand dimensions of North and South Indians. J Forensic Sci. 2009;54(3):546-50.
13. Galeta P, Bruzek J, Lázničková-Galetová M. Is sex estimation from handprints in prehistoric cave art reliable? A view from biological and forensic anthropology. J Archaeol Sci. 2014;45:141-9.
14. Steyn M, Patriquin M. Osteometric sex determination from the pelvis—does population specificity matter? Forensic Sci Int. 2009;191(1-3):113.e1-5.
15. Colman K, Janssen M, Stull K, van Rijn R, Oostra R, de Boer H, et al. Dutch population specific sex estimation formulae using the proximal femur. Forensic Sci Int. 2018;286:268.e1-8.

16. Zulkifly N-R, Wahab RA, Layang E, Ismail D, Desa WNSM, Hisham S, et al. Estimation of stature from hand and handprint measurements in Iban population in Sarawak, Malaysia and its applications in forensic investigation. J Forensic Leg Med. 2018;53:35-45.
17. Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian M, Garg RK. Stature estimation from foot dimensions. Forensic Sci Int. 2008;179(2-3):241.e1-5.
18. Kanchan T, Krishan K, Shyamsundar S, Aparna K, Jaiswal S. Analysis of footprint and its parts for stature estimation in Indian population. The Foot. 2012;22(3):175-80.
19. Soni G, Dhall U, Chhabra S. Determination of sex from humerus: discriminant analysis. Aust J Forensic Sci. 2013;45(2):147-52.
20. Jerković I. Analysis of sexual dimorphism of antique and late antique Salona population [dissertation]. Zadar: University of Zadar; 2019. Croatian.
21. Kovarovic K, Aiello LC, Cardini A, Lockwood CA. Discriminant function analyses in archaeology: are classification rates too good to be true? J Archaeol Sci. 2011;38(11):3006-18.
22. Plato C, Wood J, Norris A. Bilateral asymmetry in bone measurements of the hand and lateral hand dominance. Am J Phys Anthropol. 1980;52(1):27-31.
23. Dhall JK, Kapoor AK. Fingerprint ridge density as a potential forensic anthropological tool for sex identification. J Forensic Sci. 2016;61(2):424-9.
24. Badiye A, Kapoor N, Mishra SD. A novel approach for sex determination using palmar tri-radii: A pilot study. J Forensic Leg Med. 2019;65:22-6.
25. Gutiérrez-Redomero E, Alonso-Rodríguez C. Sexual and topological differences in palmprint and ridge density in the Caucasian Spanish population. Forensic Sci Int. 2013;229(1-3):159.e1-10.