MORPHOMETRIC ANALYSIS OF THE HAND IN YOUNG ADULTS

MORFOMETRIJSKA ANALIZA ŠAKE OSOBA MLAĐE ŽIVOTNE DOBI

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Abstract
Introduction. The hand is the distal part of the upper limb and has a complex structure that enables a high degree of mobility and grasping. Hand morphometric characteristics exhibit sexual dimorphism, as well as ethnic and racial variations. Contemporary studies indicate that hand morphology changes throughout ontogenesis, with sex differences becoming fully expressed in adulthood. This study aimed to conduct a morphometric analysis of the hand in young adults and determine differences by body side and sex. **Material and Methods.** The study included 140 participants of both sexes, with a mean age of 19.83±0.98 years. The anthropometric parameters analysed included hand widths (S1–S3), palm lengths (D1–D5), and finger lengths (P1–P5). **Results.** In both sexes, thumb length (P1) was significantly greater on the right hand. In females, parameters S1 and S3 were significantly higher on the right hand, whilst D4 and D5 were higher on the left. In males, D3, D4, D5, and P5 were significantly greater on the left hand, whereas S2 was higher on the right. Comparison between sexes revealed statistically significant differences across all measured parameters, with males consistently exhibiting higher values. **Conclusion.** Significant sex-related differences in hand morphometric parameters were observed, with males showing higher values across nearly all measured dimensions. Bilateral asymmetry was present in both sexes.
Key words: Anthropometry; Anatomy, Regional; Hand; Upper Extremity; Young Adult; Sex Factors; Functional Laterality

Sažetak
Uvod. Šaka predstavlja distalni deo gornjeg ekstremiteta i odlikuje se složenom građom koja omogućava visok stepen pokretljivosti i funkciju hvata. Morfometrijske karakteristike šake pokazuju polni dimorfizam, kao i etničke i rasne razlike. Savremena istraživanja ukazuju da se morfologija šake menja tokom ontogeneze, pri čemu polne razlike postaju potpuno izražene u odraslom dobu. Cilj ovog istraživanja bio je da se izvrši morfometrijska analiza šake kod odraslih osoba i utvrde razlike u odnosu na telesnu stranu i pol. **Materijal i metode.** Istraživanjem je obuhvaćeno 140 ispitanika oba pola, prosečne starosti 19,83 ± 0,98 godina. Analizirani su antropometrijski parametri šake: širine šake (S1–S3), dužine dlana (D1–D5) i dužine prstiju (P1–P5). **Rezultati.** Kod oba pola, dužina palca (P1) pokazala je statistički značajno veće vrednosti na desnoj šaci. Kod ispitanica su parametri S1 i S3 bili značajno veći na desnoj šaci, dok su D4 i D5 bili izraženiji na levoj. Kod ispitanika su D3, D4, D5 i P5 imali značajno veće vrednosti na levoj šaci, dok je S2 bio veći na desnoj. Poređenje između polova pokazalo je statistički značajne razlike u svim merenim parametrima, pri čemu su muškarci imali veće vrednosti. **Zaključak.** Utvrđene su značajne polne razlike u morfometrijskim parametrima šake, pri čemu su muškarci pokazali veće vrednosti u gotovo svim dimenzijama. Bilateralna asimetrija uočena je kod ispitanika oba pola.
Ključne reči: antropometrija; regionalna anatomija; ruka; gornji ekstremitet; mladi ljudi; polne razlike; funkcionalna asimetrija

Introduction

The hand is the distal part of the free portion of the upper limb [1]. It consists of 27 bones, arranged into three groups: the carpal bones, the metacarpal bones, and the bones of the fingers [1,2]. These bones are interconnected by 15 joints, whose complex and fine movements are enabled by the flexor and extensor muscles of the fingers, together with 19 intrinsic muscles of the hand [2,3]. From a topographical perspective, the hand is divided into the root of the hand or carpus, the metacarpus, and the fingers [1]. Anatomically, the hand can be described as having anterior and posterior surfaces [2]. The palm and the dorsum of the hand refer, more specifically, to the anterior and posterior parts of the metacarpal region [1,2].

The complex anatomy of the hand - a combination of mobile joints, muscles, and tendons - enables various forms of grip and grasp, which are essential for work efficiency [4–6]. Ergonomics and tool design are often based on the dimensions and functional capacities of the hand to increase productivity and reduce the risk of injury [7,8]. The hand therefore functions not only as an anatomical part of the body but also as a primary tool in interacting with the environment and performing work-related tasks [5,9].

Contemporary research confirms that hand morphology and its parameters change throughout on-

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togenesis, with growth patterns and shaping differing between sexes. Sexual dimorphism becoming more pronounced during development and ultimately fully expressed in adulthood [6,9]. The process of morphological growth and development of the hand is completed between 18 and 25 years of age, and after that period pathological or degenerative changes may occur. Physiological age-related changes of the hand are primarily characterized by gradual alterations in hand size and proportions, while in later stages of life a slight decrease in muscle mass and functional parameterscapacity is observed, without necessarily being accompanied by pronounced morphometric changes in the bones [10]. The functional aspects of the hand also exhibit age-related changes, as ageing is associated with a physiological decline in handgrip strength, which is more pronounced in men [11].

Differences between the right and left hands are manifested as functional and morphological lateralisation, with the dominant hand often exhibiting greater dimensions and strength. This is associated with use and mechanical loading, although these differences are usually small and vary across populations [12]. Sexual dimorphism of the hand is well documented, reflected in the fact that men, on average, have larger absolute hand dimensions - length, palm width, and finger length - than women [8]. These differences are statistically significant, and recent studies have confirmed the ratio of the lengths of the second and fourth digits (2D:4D) as a stable indicator of sexual dimorphism, with women tending to show higher values of this ratio than men, an association attributed to prenatal hormonal influences [12].

In ergonomics, the key dimensions of the hand include hand length, palm width, finger lengths, and finger span. These dimensions have significant applications in ergonomics and biomedical design, as they directly influence the design of tools, prostheses, and the working environment [7].

Previous anthropometric studies indicate that average hand dimensions vary according to sex and population. Adult men most commonly have a hand length of approximately 18–20 cm, whilst in women the range is 16–18 cm, with proportionally smaller palm widths and finger lengths [13–15]. Contemporary studies confirm that hand length, palm width, and finger length are among the most stable and reproducible anthropometric parameters, with relatively low intraindividual variability in adulthood [6,16]. Population differences can also be substantial, indicating the need for regional reference values in anthropometric and ergonomic analyses [13,14,16]. Combining multiple linear hand measurements enables a more accurate assessment of body characteristics and has wide application in forensic anthropology and biomedical engineering [15,16].

Previous morphometric analyses indicate that ethnic differences in hand dimensions and proportions also exist. Populations of European ancestry generally exhibit larger absolute hand dimensions; Asian populations tend to have shorter, relatively wider hands; and African populations tend to have relatively longer fingers in relation to palm length. Although these differences are statistically significant, they overlap across populations and are influenced by factors such as sex, height, and environmental adaptation, and therefore cannot be used as discriminatory criteria [6,16–19].

This study aimed to perform a morphometric analysis of the hand in young adults to determine bilateral (right-left) and sex-related differences in hand dimensions.

Material and Methods

The study was conducted on 140 participants (48 males and 92 females), all first-year students at the Faculty of Medicine, University of Novi Sad, mean age for men below is stated as 19.93±1.03. Inclusion criteria required that participants had no congenital hand malformations, visible deformities, or signs of pathological processes, and no self-reported history of hand injury or previous surgical intervention in the hand region.

The study was carried out at the Department of Anatomy, Faculty of Medicine, University of Novi Sad, following approval from the Faculty of Medicine Ethics Committee (01-39/138/1). All participants provided written informed consent following a detailed briefing about the study.

Photography of the palmar surfaces of both hands was obtained using a Nikon D3400 camera (24 MP), positioned 40 cm from the centre of the palmar surface of the photographed hand, in a room with constant artificial lighting; a single investigator took all photographs. Participants were seated, with the elbow placed close to the trunk and the forearm flexed at 90° relative to the upper arm. The hands were placed in a supinated position, with the fingers maximally abducted, on a table in front of them. A ruler was placed next to each hand and subsequently used for calibration. The digital images were processed using ImageJ 1.48v software, following calibration based on the ruler included in each image. A single investigator performed all measurements.

Statistical analysis was performed using IBM SPSS Statistics v.24. Data distribution was assessed using the Shapiro–Wilk test. Owing to non-normality, continuous variables are presented as median and interquartile range (IQR; 25th–75th percentile), along with

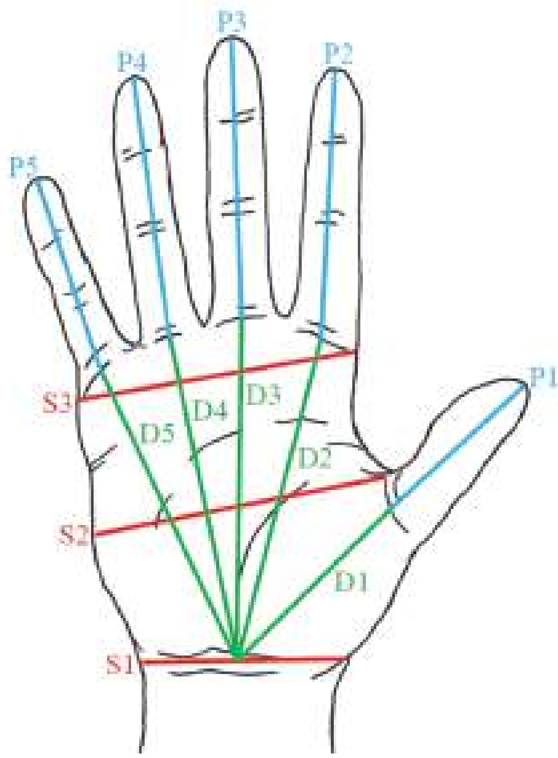

Figure 1. Morphometric parameters of the hand

minimum and maximum values. Differences between the right and left hands within the same group were analysed using the Wilcoxon signed-rank test. Comparisons between male and female participants were performed using the Mann–Whitney U test. A p-value < 0.05 was considered statistically significant.

During measurement, the distal (lower) wrist crease was used as the main anatomical landmark. After measuring the length of this crease, its midpoint was determined and used as the reference point for all other parameters.

The following parameters were measured **(Figure 1):**

– S1 – hand width at the level of the distal wrist crease;

– S2 – hand width from the medial edge of the proximal crease at the base of the thumb to the midpoint of the medial palmar border;

– S3 – hand width from the lateral edge of the proximal crease at the base of the index finger to the medial edge of the proximal crease at the base of the little finger;

– D1 – palm length from the midpoint of the distal wrist crease to the midpoint of the proximal crease at the base of the thumb;

– D2 – palm length from the midpoint of the distal wrist crease to the midpoint of the proximal crease at the base of the index finger;

– D3 – palm length from the midpoint of the distal wrist crease to the midpoint of the proximal crease at the base of the middle finger;

– D4 – palm length from the midpoint of the distal wrist crease to the midpoint of the proximal crease at the base of the ring finger;

– D5 – palm length from the midpoint of the distal wrist crease to the midpoint of the proximal crease at the base of the little finger;

– P1 – thumb length, measured from the midpoint of the proximal thumb crease to the most distal tip of the thumb;

– P2 – index finger length, measured from the midpoint of the proximal index finger crease to the most distal tip of the index finger;

– P3 – middle finger length, measured from the midpoint of the proximal middle finger crease to the most distal tip of the middle finger;

– P4 – ring finger length, measured from the midpoint of the proximal ring finger crease to the most distal tip of the ring finger;

– P5 – little finger length, measured from the midpoint of the proximal little finger crease to the most distal tip of the little finger.

Results

The study included 140 participants, of whom 92 (65.7%) were female, and 48 (34.3%) were male. The mean age of the participants was 19.83±0.98 years (males: 19.93±1.03; females: 19.72±0.9) considering that the number of women in relation to men is higher than in the population.

Table 1 presents all 13 measured anthropometric parameters in female participants, along with differences between the right and left hand.

In female participants, bilateral asymmetry between the right and left hand was observed, with statistically significant differences detected in some parameters. Right-hand dominance was found for S1 ($p = 0.011$), S3 ($p < 0.001$), and P1 ($p < 0.001$), whereas left-hand dominance was found for D4 ($p < 0.001$) and D5 ($p < 0.001$). Most remaining parameters showed no statistically significant difference between sides ($p > 0.05$), indicating that lateralisation was not equally present across all measurements.

Table 2 presents all 13 measured anthropometric parameters of male participants, along with differences between the right and left hand.

In male participants, bilateral asymmetry between the right and left hand was also observed. Statistically significant right-sided dominance was found for S2 ($p = 0.002$) and P1 ($p = 0.001$), whereas left-sided dominance was observed for D3 ($p = 0.022$), D4 ($p =$

Table 1. Morphometric parameters of the right and left hand in femal

	Right hand		Left hand		IQR (mm)		Z	p	Direction
	Min-Max (mm)	Median (mm)	Min-Max (mm)	Median (mm)	R	L			
S1	55.06-77.03	64.25	53.31-75.63	63.65	62.01 - 67.69	61.02 - 68.10	-2.53	**0.011***	R > L
S2	68.51-105.03	88.69	56.14-109.96	85.93	82.04 - 91.42	81.40 - 92.13	-1.79	0.073	/
S3	63.07-102.93	89.41	65.25-105.51	87.98	84.85 - 94.52	82.60 - 93.46	-3.39	**<0.001***	R > L
D1	55.26-113.47	73.66	55.11-114.85	73.51	67.01 - 76.19	68.09 - 77.91	0.89	0.373	/
D2	65.83-124.30	109.99	94.25-126.75	110.18	104.83 - 114.34	105.42 - 115.56	0.16	0.867	/
D3	54.89-131.02	108.67	95.13-130.98	109.12	103.74 - 113.46	105.70 - 115.63	1.90	0.057	/
D4	87.96-125.61	103.52	90.65-125.08	104.28	99.01 - 107.03	101.41 - 110.33	3.42	**<0.001***	L > R
D5	76.32-121.13	93.39	65.76-111.06	95.82	89.75 - 97.77	90.84 - 101.33	3.49	**<0.001***	L > R
P1	48.33-77.74	61.08	39.68-88.67	59.66	56.55 - 64.97	54.81 - 64.20	-3.37	**<0.001***	R > L
P2	59.44-85.27	70.14	56.25-84.95	70.11	67.27 - 73.44	66.83 - 73.21	-1.29	0.196	/
P3	63.39-92.91	76.91	72.41-88.62	77.05	73.96 - 80.17	73.24 - 79.99	1.66	0.971	/
P4	58.84-88.63	71.98	58.42-85.07	71.13	67.08 - 74.90	67.57 - 74.32	-1.09	0.275	/
P5	44.31-72.61	55.48	45.56-74.59	56.11	53.15 - 58.40	53.63 - 59.63	1.40	0.168	/

R – right hand; L – left hand; IQR - interquartile range (25th - 75th percentile); Z - standardised test statistic; *$p < 0.05$ considered statistically significant; R > L – right hand value was significantly higher than left; L > R – left hand value was significantly higher than right

Table 2. Morphometric parameters of the right and left hand in mal

	Right hand		Left hand		IQR (mm)		Z	p	Direction
	Min-Max (mm)	Median (mm)	Min-Max (mm)	Median (mm)	R	L			
S1	61.19-77.95	71.65	63.48-82.82	71.26	68.26-74.26	67.66-73.76	-1.03	0.305	/
S2	86.96-121.94	99.59	82.15-120.25	96.41	93.60-105.96	92.71-105.15	-3.09	**0.002***	R > L
S3	81.25-115.51	97.80	72.72-114.94	97.30	94.29-103.59	93.24-102.92	-1.85	0.065	/
D1	63.33-98.73	78.85	67.85-97.98	79.66	75.71-83.42	76.45-85.17	0.75	0.454	/
D2	105.33-147.95	119.66	108.02-148.49	119.55	114.39-126.50	117.08-124.81	1.48	0.138	/
D3	103.55-148.95	121.88	109.65-146.92	122.89	114.11-127.53	118.52-126.89	2.30	**0.022***	L > R
D4	96.11-142.01	115.10	105.45-144.86	117.57	110.34-123.83	113.74-124.04	2.82	**0.005***	L > R
D5	86.17-133.87	105.33	95.62-133.88	109.13	100.12-114.95	102.92-113.11	2.13	**0.034***	L > R
P1	54.04-88.99	66.55	43.15-88.61	64.32	62.02-73.21	55.71-70.85	-4.27	**< 0.001***	R > L
P2	66.16-96.75	76.25	66.97-93.84	75.66	73.32-79.96	71.81-79.97	0.91	0.360	/
P3	74.18-100.01	82.30	74.36-100.09	81.99	79.40-87.85	79.58-89.31	1.20	0.230	/
P4	67.12-94.99	76.58	68.95-93.77	77.37	74.25-82.16	74.01-83.09	-0.38	0.704	/
P5	49.91-78.25	63.20	54.02-76.89	63.08	59.78-69.09	61.83-70.02	2.69	**0.007***	L > R

R – right hand; L – left hand; IQR - interquartile range (25th - 75th percentile); Z - standardised test statistic; *$p < 0.05$ considered statistically significant; R > L – right hand value was significantly higher than left; L > R – left hand value was significantly higher than right

0.005), D5 ($p = 0.034$) and P5 ($p = 0.007$). The remaining parameters showed no statistically significant differences between sides ($p > 0.05$) **(Table 2)**. Overall, these findings suggest that hand asymmetry does not follow a uniform pattern across all parameters, although it is present across different segments.

A comparison between male and female participants revealed statistically significant differences in all measured morphometric parameters of both the right and left hand. In general, male participants had consistently higher values across all segments than females ($p < 0.001$ for most parameters). The only exception was P1L, where the difference, although still statistically significant ($p = 0.015$), was slightly less pronounced **(Table 3).**

Discussion

The results of this study indicate bilateral hand asymmetry in both sexes, as well as morphometric differences between males and females in segmental hand parameters. In both sexes, thumb length (P1) was greater on the right hand, suggesting a possible influence of functional dominance. In female participants,

Table 3. Comparison of morphometric hand measurements between males and females (Mann–Whitney U test

Parameters	Males Median (IQR) (mm)	Females Median (IQR) (mm)	U	p
S1R	71.65 (68.26 - 74.26)	64.25 (62.01 - 67.69)	712.5	**< 0.001***
S2R	99.59 (93.60 - 105.96)	88.69 (82.04 - 91.42)	397.0	**< 0.001***
S3R	97.80 (94.29 - 103.59)	89.41 (84.85 - 94.52)	802.5	**< 0.001***
D1R	78.85 (75.71 - 83.42)	73.66 (67.01 - 76.19)	967.5	**< 0.001***
D2R	119.66 (114.39 - 126.50)	109.99 (104.83 - 114.34)	776.0	**< 0.001***
D3R	121.88 (114.11 - 127.53)	108.67 (103.74 - 113.46)	646.0	**< 0.001***
D4R	115.10 (110.34 - 123.83)	103.52 (99.01 - 107.03)	686.5	**< 0.001***
D5R	105.33 (100.12 - 114.95)	93.39 (89.75 - 97.77)	609.5	**< 0.001***
P1R	66.55 (62.02 - 73.21)	61.08 (56.55 - 64.97)	1169.0	**< 0.001***
P2R	76.25 (73.32 - 79.96)	70.14 (67.27 - 73.44)	870.0	**< 0.001***
P3R	82.30 (79.40 - 87.85)	76.91 (73.96 - 80.17)	740.5	**< 0.001***
P4R	76.58 (74.25 - 82.16)	71.98 (67.08 - 74.90)	812.0	**< 0.001***
P5R	63.20 (59.78 - 69.09)	55.48 (53.15 - 58.40)	687.5	**< 0.001***
S1L	71.26 (67.66 - 73.76)	63.65 (61.02 - 68.10)	748.5	**< 0.001***
S2L	96.41 (92.71 - 105.15)	85.93 (81.40 - 92.13)	559.5	**< 0.001***
S3L	97.30 (93.24 - 102.92)	87.97 (82.60 - 93.46)	823.5	**< 0.001***
D1L	79.66 (76.45 - 85.17)	73.51 (68.09 - 77.91)	901.0	**< 0.001***
D2L	119.55 (117.08 - 124.81)	110.18 (105.42 - 115.56)	616.0	**< 0.001***
D3L	122.89 (118.52 - 126.89)	109.12 (105.70 - 115.63)	428.0	**< 0.001***
D4L	117.57 (113.74 - 124.04)	104.28 (101.41 - 110.33)	434.0	**< 0.001***
D5L	109.13 (102.92 - 113.11)	95.82 (90.84 - 101.33)	518.0	**< 0.001***
P1L	64.32 (55.71 - 70.85)	59.66 (54.81 - 64.20)	1652.0	**0.015***
P2L	75.66 (71.81 - 79.97)	70.11 (66.83 - 73.21)	959.5	**< 0.001***
P3L	81.99 (79.58 - 89.31)	77.05 (73.24 - 79.99)	798.5	**< 0.001***
P4L	77.37 (74.01 - 83.09)	71.13 (67.57 - 74.32)	739.0	**< 0.001***
P5L	63.08 (61.83 - 70.02)	56.11 (53.63 - 59.63)	526.0	**< 0.001***

IQR-interquartile range (25^{th} - 75^{th} percentile); U – value of Mann-Whitney test; * $p < 0.05$ considered statistically significant

higher values on the right hand were also observed for S1 and S3, whereas D4 and D5 were more pronounced on the left hand. In male participants, higher values were observed in the left hand for D3, D4, D5, and P5, whilst S2 was more prominent on the right hand.

Unlike some studies that report more consistent dominance of one side [8,9], the present findings indicate that asymmetry is parameter-specific and does not follow a clear directional pattern. This may reflect individual variability in hand use, as well as differences in daily activities and motor habits among participants. The influence of differing morphometric techniques across studies should also be considered, along with the impact of racial and ethnic differences among the populations studied. Additionally, the relatively young age of the study population may suggest that cumulative functional adaptations are still developing, which could contribute to the absence of a uniform asymmetry pattern.

These findings are consistent with Agnihotri et al. [5], who reported greater overall hand width - measured as the distance between the most lateral point on the head of the second metacarpal and the most medial point on the head of the fifth metacarpal - in males (right hand: 18.89 ± 0.88 cm; left hand: 18.90 ± 0.87 cm) than in females (right and left hand: 17.22 ± 0.92 cm), confirming marked sexual dimorphism. Although that study did not report significant differences between the left and right hand, the present study demonstrates more pronounced bilateral asymmetry, owing to its analysis of segmental parameters (D1–D5, P1–P5), which may be more sensitive to functional influences and patterns of hand use. It should be noted that hand dominance was not assessed in this study.

Similarly, a study conducted in Egypt [16] demonstrated that all hand dimensions were significantly larger in males, particularly hand breadth - defined as the distance between the heads of the second and fifth metacarpals - which was identified as the best discriminator of sex, with an accuracy of up to 71.8% for the right hand. This finding is consistent with the present study, as width-related parameters (S1, S2, S3) also showed consistent differences between the left and right hands, further confirming sexual dimorphism in these parameters.

Likewise, a study conducted in Nigeria [18] reported that males had significantly greater hand length (18.3 ± 0.6 cm) than females (16.8 ± 0.7 cm), as well as greater hand width (7.5 vs 6.3 cm; $p < 0.001$), together with marked sexual dimorphism in the hand index. In that study, hand width was defined as the distance between the most lateral point of the second metacarpal head and the most medial point of the fifth metacarpal head. These findings are consistent with the present study, in which males exhibited higher values in segmental finger lengths (P3–P5) and width-related parameters (S1, S2, S3).

In addition to sex-related differences, the present study identified bilateral asymmetry between the right and left hands, though not a uniform pattern across all parameters. Previous studies have shown that the dominant hand generally exhibits greater anthropometric values and functional capacity than the non-dominant hand. Napier [9] emphasised the importance of prehensile activity and hand function in shaping hand morphology, whilst Pheasant and Haslegrave [7] suggested that occupational and habitual activities may contribute to asymmetrical development of the hands. Similar findings were reported by Kanchan and Rastogi [8], and by Żuchowska and Żarów [11].

The present study demonstrated clear sex-related differences in hand morphometry, together with parameter-dependent bilateral asymmetry. Whilst sex-related differences were consistent and pronounced across nearly all measured parameters, patterns of asymmetry between the right and left hand were less uniform. These results further support the applicability of hand anthropometry in fields such as forensic science, ergonomics, and clinical practice. Nevertheless, future research involving larger and more diverse populations, along with functional and behavioural variables, would offer a more comprehensive understanding of the factors influencing hand morphology.

This study has several limitations that should be considered when interpreting the results. First, the research was conducted in a relatively homogeneous population of young adults, limiting the generalisability of the findings to other age groups or populations with different demographic characteristics. Although the sample size was sufficient for basic statistical analysis, it may not be adequate for more detailed stratification or more complex statistical modelling, particularly about inter-individual variability in morphometric parameters. A further limitation is the absence of information on hand dominance and participants' levels of physical activity, both of which may significantly influence patterns of bilateral asymmetry. Functional loading and daily manual activities may contribute to morphological differences between the right and left hands, and their absence represents a potential source of unexplained variability. Finally, the study relied on classical morphometric measurements rather than advanced techniques such as 3D scanning or geometric morphometrics, which could provide a more precise and comprehensive analysis of hand shape and structure.

Conclusion

This study demonstrated significant sex-related differences in hand morphometric parameters, with males consistently exhibiting higher values across nearly all measured dimensions compared with females. Bilateral hand asymmetry was also observed in both sexes; however, it did not follow a uniform pattern across all parameters, suggesting that lateralisation is segment-specific rather than consistently directional.

The findings confirm the presence of clear sexual dimorphism in hand dimensions, alongside evidence of asymmetry.

Given the limitations of the study, future research involving larger, more heterogeneous populations, along with additional functional and behavioural variables, is needed to provide a more comprehensive understanding of hand morphological variability.

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