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Patterns of Hand Variation – New Data on a Sardinian Sample

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A B S T R A C T

This study is an analysis of the patterns of variation of the human hand, particularly the metric characters of palm, fingers and distal phalanges. Anthropometric measurements were performed on 146 Sardinian men and women, aged 21 to 31 years. The data were analyzed by inferential statistics (paired Student's t test, analysis of variance), and Principal Components Analysis. The results indicate that size factors are the principal source of variation. A residual adimensional component of variability is related to diversification between the fingers as a whole and the distal phalanges, and between the thumb and the other fingers. Sexual dimorphism is evident. Men present greater dimensions and greater relative length of the thumb with respect to the other fingers than women.

Key words*: hand, fingers, phalanges, principal components, morphometry*

Introduction

Tetrapod limbs are characterized by a maximum of five morphologically diversified digits. In the family *Hominidae*, the hand evolved from an anatomical structure with a combination of human and pongid characteristics[1]. Morphometric comparison with fossil hominids shows that the hand of *Homo sapiens* is characterized by a long thumb, broad ungual tufts and a general capacity for flexion and rotation of the digits, particularly the opposable thumb. These traits allow for the precise human grasp[1–5].

The length of the human hand is about one-quarter the length of the upper limb and one-tenth the height[6]. The area of the palm is about 1% of the total body surface[7]. The embryological development of the hand begins at the 28th–30th day of gestation. The digital rays are delineated at about the 46th day and the fingers are completely separate at the 52nd day[8].

The number and shape of the digits are genetically determined[9]. The homeotic genes, i.e. genes that determine the specialization of body segments, involved in the processes of embryological differentiation of the hand are highly conservative and belong to the HOXA and HOXD clusters. In each cluster, the arrangement of the genes on the chromosome corresponds to the topographical and temporal sequence of their expression during growth of the limb. The genes of the HOXA cluster control the proximo-distal differentiation of the limb, while those of the HOXD cluster control the antero-posterior (radio-ulnar) development. The same homeotic clusters control the differentiation of the urogenital system[10].

The literature on the morphology and dimensions of the human hand involves different fields of bio-medical research. Various investigations deal with phyletic affinities during evolution[2–4], correlations with anthropometric or dermatoglyphic characters[11–14], embryology and development[15], anatomical malformations[16,17], asymmetry[18,19], kinematics[20], and comparison with non-human hominoids[21].

Most studies deal with the relative lengths of the digits, particularly fingers 2 and 4 (digit ratio), and of the distal phalanges[22–25]. Some studies associate the lengths of the fingers with various genetic, physiological and behavioral characteristics[26–31]. Others deal with sexual dimorphism and inter-population variability[25,27,32].

The aim of the present paper is to increase the knowledge of the morphometry of the hand through the description of dimensional relationships between the palm, fingers and distal phalanges in a sample from Sardinia

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(Italy). In particular, sexual dimorphism, handedness and laterality were regarded as possible sources of intra-population variability. Inter-population variability was analyzed by comparisons with literature data.

Materials and Methods

The sample

The sample consisted of 146 individuals (63 men and 83 women), born and resident in Sardinia, aged 21 to 31 years. The subjects were randomly selected among students of the University of Cagliari. Personal, behavioral and medical history data were obtained in a structured interview. All participants were in good general health and presented homogeneous socio-economic characteristics.

The anthropometric variables

The following variables were considered:

– length of the palm;

– length of the fingers;

– length of the distal phalanges.

The hand measurements were taken to the nearest millimeter with a sliding caliper according to methods reported by Hall[23]. The length of the palm is the distance between the distal wrist crease and the 3rd interdigital space; the length of the finger is the distance between the proximal metacarpo-phalangeal flexion crease and the fingertip; the length of the distal phalanx is the distance between the most functional interphalangeal flexion crease and the fingertip.

The »digital formula«[1] was used to indicate the relative lengths of the fingers: the fingers are indicated by numbers 1 (thumb) to 5 (little finger) and listed in order of decreasing length. The »digit ratio«[27] (2D:4D) between the length of the 2nd and 4th fingers was also calculated.

Hand dominance was established on the basis of self-reports.

Statistical analysis

Descriptive statistics for each variable were calculated separately in groups divided by sex and handedness.

Bilateral differences were evaluated by means of paired Student's t test.

The complete model of two factors with fixed effects analysis of variance (ANOVA) was applied to evaluate the effect of sex and handedness, and the possible interaction between them, on the metric variations.

Principal Components Analysis (PCA) was then applied to the whole set of standardized variables with the sexes combined. To analyze possible sex differences in the PCA, we evaluated the sex-conditioned empirical distributions of individual coordinates on the principal components (PCs). If the two conditional distributions on a PC are mainly above or mainly below zero, then the sex is represented in the PC.

Analyses were performed with STATISTICA *release 4.0* (*Statsoft Inc.*) and R *release 2.3.1* [33].

Results

The sample frequency of left-handers was 7 individuals (11%) in men and 6 (7%) in women.

Table 1 reports the descriptive statistics for all the variables (left and right hand) in the groups subdivided by sex and handedness. The table also gives the results of the statistical comparison between sides. An evident direction of lateral divergence does not exist because differences are rather equally distributed between right and left side in both sexes. Nevertheless, differences appear more evident among right-handers than among left-handers (9 significant differences in the former vs. 1 in the latter). In right-handers of both sexes, the size of the first finger (length of distal and total phalanx) is significantly greater on the right side. It is interesting that the only significantly different variable between sides in left-handers (length of finger 2) is on average greater in the left hand.

Table 2 reports the results of ANOVA, with F values relative to the effect of sex, handedness, and their interaction. All differences between the sexes are significant, with men presenting larger dimensions. Differences between right-handers and left-handers are not very pronounced, being significant only in three cases (distal phalanges of left fingers 2, 3 and 4), with higher mean values in left-handers.

Table 3 reports the frequencies of the digital formulas recorded in both hands of the male and female groups. The most common digital formula in both sexes is 3>4>2>1>5.

The 2D:4D finger length ratio (averaged ratio for right and left hands) is 0.98 in males and females. Comparative data from different populations are given in Table 4.

Principal components analysis

Results of the Principal Components Analysis are reported in Table 5. As expected, the correlation matrix of hand measures shows a general positive correlation. Despite this, PCA is not ill-conditioned by the hand scale dimension represented in the first PC, as indicated by the determinant of the inverse of the correlation matrix, which is well above 0 (about 10^{17}), and by the Kaiser-Meyer-Olkin Measure of Sampling Adequacy, which is above 0.6 (0.948). The first three components together explain 86.14% of the variance.

The first component (PC1) explains a very high percentage of the variability (75%) and provides indications about size. All the variables present positive coefficients (greater than 0.75) and the lengths of fingers 2, 3 and 4 contribute most to the function (coefficients above 0.90).

The second (PC2, 6% of the variance) and third components (PC3, 4% of the variance) are bipolar and refer to morphological differentiation. The second component

TABLE 1
DESCRIPTIVE STATISTICS AND BILATERAL COMPARISONS IN GROUPS DEFINED BY SEX AND HANDEDNESS

Men	Right handers (N =56)					Left handers (N =7)				
	Right hand		Left hand			Right hand		Left hand		
Length (mm)	X	SD	X	SD	t	X	SD	X	SD	t
Palm	105.26	4.41	105.83	4.71	–2.118*	104.87	3.51	105.87	4.99	–0.866
Finger 1	63.02	4.52	62.55	4.33	2.012*	63.14	3.85	62.43	5.26	0.778
Finger 2	71.39	3.44	71.86	3.46	–2.163*	71.14	5.01	72.43	4.79	–2.121*
Finger 3	78.93	4.02	79.11	4.19	–0.919	78.71	4.39	78.29	5.02	0.891
Finger 4	73.34	4.06	72.93	4.03	1.987	73.71	4.75	73.43	5.41	0.548
Finger 5	60.14	3.66	59.82	3.75	1.300	59.71	4.11	60.14	5.40	–0.701
Distal phalanx 1	33.64	2.07	32.77	1.99	5.640*	33.29	2.50	33.14	1.77	0.311
Distal phalanx 2	26.07	1.46	26.20	1.54	–1.069	26.14	2.41	26.86	2.04	–1.987
Distal phalanx 3	26.91	1.79	27.11	1.74	–1.628	27.43	2.30	27.14	1.86	0.795
Distal phalanx 4	26.54	1.68	26.71	1.72	–1.458	26.86	1.68	27.14	1.95	0.522
Distal phalanx 5	24.50	1.62	24.57	1.49	–0.600	24.71	1.70	24.57	2.07	0.548

Women	Right handers (N =77)					Left handers (N =6)				
	Right hand		Left hand			Right hand		Left hand		
Length (mm)	X	SD	X	SD	t	X	SD	X	SD	t
Palm	96.05	4.19	95.93	4.33	0.575	97.03	4.92	96.18	5.09	1.399
Finger 1	56.94	3.33	56.44	3.52	2.610*	57.33	4.59	56.33	5.05	0.826
Finger 2	66.38	3.15	66.25	3.20	0.826	67.50	2.88	67.83	2.64	–0.542
Finger 3	73.18	3.59	72.94	3.62	1.520	75.17	3.49	74.83	1.33	0.245
Finger 4	67.78	3.68	67.40	3.52	2.586*	68.83	2.71	68.33	2.07	0.565
Finger 5	55.17	3.14	54.78	3.25	2.045*	56.17	4.36	54.33	2.88	2.200
Distal phalanx 1	30.26	1.68	29.22	1.63	8.075*	30.50	2.26	30.50	2.74	0.000
Distal phalanx 2	23.73	1.45	23.48	1.42	2.318*	24.00	2.00	24.67	1.63	–2.000
Distal phalanx 3	24.31	1.34	24.43	1.34	–1.491	24.83	1.94	26.17	1.33	–1.581
Distal phalanx 4	23.84	1.50	23.92	1.52	–0.725	24.83	1.33	25.50	1.22	–2.000
Distal phalanx 5	21.91	1.44	21.78	1.42	1.343	23.33	1.86	23.17	1.47	0.415

*– $p<0.05$, N – sample size, SD – standard deviation, t – Student's *t* test for the comparison between sides, Palm – distance between the distal wrist crease and the 3rd interdigital space, Finger – distance between the proximal metacarpo-phalangeal flexion crease and the fingertip, Distal phalanx – distance between the most functional interphalangeal flexion crease and the fingertip

discriminates the length of the distal phalanges (positive coefficients: between 0.21 and 0.31) from the length of the fingers (negative coefficients: between –0.22 and –0.33). Palm length loadings are centered (left and right: –0.06).

The third component describes the contrast between the length of the thumb (positive coefficients: greater than 0.44) and the length of the other fingers (negative coefficients: between –0.1 and –0.21).

To highlight the morphological relationships rather than the purely dimensional ones, we present a graphic representation of the results based on the second and third components (Figure 1). The figure illustrates the level of association between the variables. The relative position of the variables in the plane reflects their anatomical relationships. The length of the thumb (right and left) is isolated in the upper left quadrant, while the lengths of the other fingers are concentrated in the lower left quadrant. The length of the palm occupies a central position and the lengths of the distal phalanges are in the right half of the figure. There is an almost systematic association of the right and left sides for all the variables except the length of finger 5. In addition, the positions of the finger lengths on the ordinate follow an almost regular anatomical order. The same applies for the distal phalangeal lengths.

The projection of auxiliary variables, such as sex in this case, allows us to identify sexual dimorphism. The box plots of figure 2 show the empirical conditional distributions of individual scores grouped by sex. Sex tends to be well represented in PC1 and, to a lesser degree, in

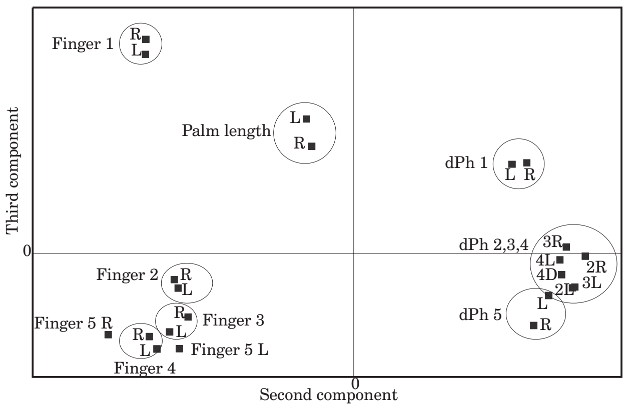

Fig. 1. Position of the anthropometric variables in the principal components plane. Finger – finger length, dPh – distal phalanx, R – right, L – left. If not specified, left and right sides are implied.

PC3. This indicates that men present greater overall dimensions and greater relative length of the thumb with respect to the other fingers than women.

Discussion

The results of the present study reveal definite patterns of hand variation.

In agreement with the data obtained for different populations[24,25], the mean length of finger 3 is greater than that of the other fingers, and the mean length of finger 4 is greater than that of finger 2. The frequencies of 4>2 are slightly lower than those reported by Peters et al.[25] for a sample of Canadians. The values of the 2D:4D finger length ratio in the present study (0.98 in both sexes) fall within the range of variation among populations (0.93 in Finnish and Jamaican men to 1.00 in English women).

The Principal Components Analysis shows that, as usual with anthropometric characters, the size factor explains most of the observed variance (PC1). However, there is a significant amount of variation related to differentiation between the fingers and the distal phalanges (PC2), and between the thumb and the other fingers (PC3). These distinctions seem to reflect the anatomy, mechanics and evolution of the human hand. In modern humans, the hand is characterized by a long thumb, a relatively short distal pollical phalanx and broad ungual tufts with spines[1–5,34,35]. These morphological traits, favoring thumb mobility and opposition to all four fingers, have been related to precision gripping and »tool behavior«[2,35].

Interestingly, the sequential position of the fingers and distal phalanges on the principal components plane (from top to bottom: fingers 1, 2, 3, 4 and 5) agrees with the respective anatomical order. This pattern may reflect the genetic determination and embryological develop-

TABLE 3
FREQUENCIES OF THE DIGITAL FORMULAS IN BOTH HANDS

Digital formula	Men (N=63)		Women (N=83)	
	Right (%)	Left (%)	Right (%)	Left (%)
3 > 4 > 2 > 1 > 5	73.00	62.00	63.80	56.60
3 > 2 > 4 > 1 > 5	15.90	19.00	19.30	22.90
3 > 2 ≈ 4 > 1 > 5	11.10	19.00	16.90	20.50

N – sample size, 1 – thumb, 2 – index finger, 3 – middle finger, 4 – ring finger, 5 – little finger

TABLE 2
ANALYSIS OF VARIANCE FOR THE EVALUATION OF THE EFFECT OF SEX, HANDEDNESS, AND THEIR INTERACTION

Length (mm)	Right hand (N=146)			Left hand (N=146)		
	F sex	F handedness	F sex x handedness	F sex	F handedness	F sex x handedness
Palm	46.638*	0.056	0.303	54.699*	0.012	0.006
Finger 1	27.318*	0.053	0.014	27.437*	0.010	0.000
Finger 2	19.578*	0.199	0.492	26.961*	1.205	0.267
Finger 3	17.654*	0.641	0.988	18.243*	0.228	1.457
Finger 4	21.575*	0.404	0.091	23.170*	0.420	0.038
Finger 5	17.991*	0.080	0.504	27.452*	0.004	0.137
Distal phalanx 1	30.972*	0.011	0.290	33.611*	2.400	0.717
Distal phalanx 2	25.312*	0.149	0.051	31.165*	4.416*	0.357
Distal phalanx 3	30.956*	1.240	0.000	16.689*	3.931*	3.621
Distal phalanx 4	26.372*	2.037	0.529	22.220*	4.548*	1.492
Distal phalanx 5	19.523*	3.322	1.812	23.591*	2.578	2.578

*– $p<0.05$, N – sample size, F sex – F statistics for the intersexual comparisons, F handedness – F statistics for the comparisons between left- and right-handers, F sex x handedness – F statistics for the interaction between sex and handedness, Palm – distance between the distal wrist crease and the 3rd interdigital space, Finger – distance between the proximal metacarpo-phalangeal flexion crease and the fingertip, Distal phalanx – distance between the most functional interphalangeal flexion crease and the fingertip

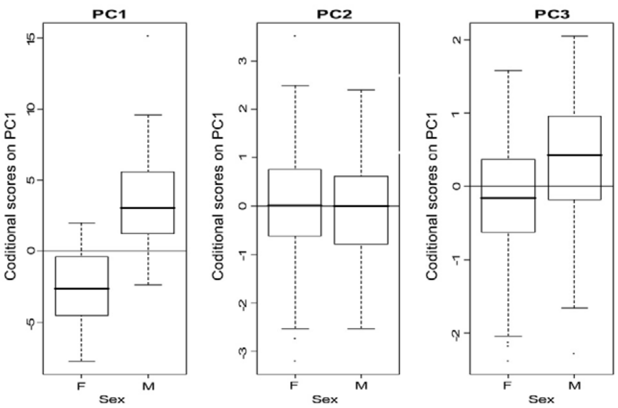

Fig. 2. Empirical conditional distribution of scores by sex. PC – Principal Component, M – males, F – females.

TABLE 4
COMPARISON OF LITERATURE DATA ON THE 2D:4D DIGIT LENGTH RATIO WITH THE PRESENT STUDY

Population	N	Sex	2D:4D
English[4]	400	M	0.98
	400	F	1.00
Finnish[5]	24	M	0.93
	17	F	0.95
Zulu[5]	60	M	0.95
	60	F	0.95
Jamaican[5]	78	M	0.93
	73	F	0.94
American[6]	108	M	0.96
	146	F	0.97
Canadian[7]	98	M	0.95
	402	F	0.97
Sardinian[8]	63	M	0.98
	83	F	0.98

N – sample size, M – males, F – females, 2D:4D – ratio between the length of the second and fourth digit (all values are based on averaged ratios for right and left hands), [4] – reference 31, [5] – reference 27, [6] – reference 30, [7] – reference 25, [8] – present study.

ment of the hand[9]. The overlapping effects of the genes of the HOXD cluster, which activate the regions of embryonic growth of the fingers in a spatio-temporal sequence from the radial (thumb) to ulnar side (little finger), could be responsible for the hierarchically ordered levels of variability.

It is also interesting that the two sexes differ in their patterns of hand variation. The mean lengths of all the variables appear greater in men than in women. A similar dimorphic pattern has been observed for the size of the second metacarpal[32]. Moreover, the two sexes differ in finger proportions. Men exhibit greater relative development of the thumb with respect to fingers 2–5, whereas women show the opposite tendency. However, in the present sample, the digit ratio does not show significant sex differences, as observed instead by other authors[25,27]. Sexual dimorphism of human hand morphometry could be a consequence of different prenatal exposure to testosterone and estrogen in the two sexes[36]. The pleiotropic action of HOXA and HOXD genes responsible for both digital and gonadal differentiation might be involved in this biological mechanism[25]. Sex differences in the hand

TABLE 5
COEFFICIENTS OF CORRELATION WITH THE FIRST THREE PRINCIPAL COMPONENTS

	PC 1		PC 2		PC 3	
	Right	Left	Right	Left	Right	Left
Palm	0.841	0.846	–0.057	–0.064	0.238	0.299
Finger 1	0.757	0.784	–0.281	–0.281	0.476	0.442
Finger 2	0.902	0.904	–0.242	–0.237	–0.058	–0.076
Finger 3	0.916	0.905	–0.224	–0.249	–0.141	–0.173
Finger 4	0.905	0.904	–0.276	–0.266	–0.184	–0.211
Finger 5	0.821	0.870	–0.332	–0.235	–0.180	–0.211
Distal phalanx 1	0.827	0.829	0.233	0.213	0.202	0.199
Distal phalanx 2	0.864	0.887	0.312	0.295	–0.006	–0.076
Distal phalanx 3	0.897	0.896	0.287	0.298	0.015	–0.074
Distal phalanx 4	0.882	0.897	0.280	0.278	–0.046	–0.014
Distal phalanx 5	0.860	0.891	0.243	0.263	–0.159	–0.093
Eigenvalue	16.60		1.44		0.91	
% variance	75.44		6.56		4.14	

PC – Principal Component, Palm – distance between the distal wrist crease and the 3rd interdigital space, Finger – distance between the proximal metacarpo-phalangeal flexion crease and the fingertip, Distal phalanx – distance between the most functional interphalangeal flexion crease and the fingertip may also be related to sexual diversification of roles in the case of functionally relevant characters[32], such as general dimensions and relative proportions of the thumb.

In conclusion, the present paper provides new information on the dimensional relationships between palm, fingers and distal phalanges. The digit ratio and digital formula of the Sardinian sample are similar to those observed in other populations. Laterality and handedness have weak relationships with the observed sample variability. Size factors are the principal source of variation; a lesser percentage of variability is related to diversification between the fingers and the distal phalanges, and between the thumb and other fingers. Sexual dimorphism is apparent, as men have greater general dimensions and greater relative development of the thumb. The new data may be useful for comparative purposes in research on different populations and in systematic studies.

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OBRASCI VARIJACIJE ŠAKE. NOVI PODACI NA UZORKU SA SARDINIJE

S A Ž E T A K

Ovaj rad predstavlja analizu obrazaca varijacije ljudske šake, osobito metričkih značajki dlana, prstiju, i distalnih falangi. Antropometrijska mjerenja provedena su na uzorku od 146 osoba sa Sardinije, oba spola, starosti od 21 do 31 godine. Podaci su analizirani inferencijalnom statistikom (Studentov t-test, ANOVA) i analizom glavnih komponenti (PCA). Rezultati upućuju da su faktori veličine glavni izvor varijacije. Preostala bezdimenzionalna komponenta varijabilnosti povezana je s različitostima između prstiju u cjelini i distalnih falangi, te između palca i ostalih prstiju. Izražen je spolni dimorfizam. Muškarce karakteriziraju veće dimenzije i veća relativna duljina palca u odnosu na ostale prste.