Bull. Natl. Mus. Nat. Sci., Ser. D, 43, pp. 1–6, December 22, 2017

Sexual dimorphism in the human hand proportion: A radiographic study

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Abstract The proportion of the human hand, i.e., the length relationships between the fingers and palm, is known to differ between males and females. However, sexual dimorphism in the proportions of individual metacarpals and phalanges has not been investigated in detail. In the present study, we analyzed patterns of variability in the human hand in a modern Japanese population based on planar radiography. A total of 197 anteroposterior X-ray images of the adult hand were obtained. The lengths of 19 metacarpals and phalanges were measured by digitizing the images. Variation patterns in hand proportions were extracted and compared based on a principal component analysis. Our results demonstrated that males have significantly longer metacarpals and phalanges than females. Furthermore, there is a significant difference in hand proportion between males and females, with males having relatively longer distal phalanges among finger bones. Also males have relatively shorter second but relatively longer fourth fingers than females. This indicates that hand bone dimensions could possibly be used as a good indicator of sex. We also found that individuals with relatively longer fingers tend to possess relatively shorter metacarpal lengths and vice versa, but this tendency was not associated with sex. Our results may be useful for understanding normal growth of hand proportions and in designing gender-specific hand tools.
Key words: Sexual dimorphism, Metacarpals and phalanges, Length relationships, Human hand proportion, Planar radiography

Introduction

The proportion of the human hand, i.e., the length relationships between the fingers and palm, is known to differ between males and females. For example, it has been historically known that males tend to have relatively shorter second but longer fourth digits than females (e.g., Baker, 1888; George, 1930; Peters *et al.*, 2002; Robertson *et al.*, 2008), possibly due to prenatal hormonal environment (Putz *et al.*, 2004; Honekopp *et al.*, 2007; Zheng and Cohn, 2011; Klimek *et al.*, 2016). Furthermore, previous studies have reported that the length data of hand bones can be used for sex determination (Case and Ross, 2007), indicating that there is a certain degree of sexual dimorphism in the proportion of the human hand. However, we are aware of no previous studies that have systematically analyzed sexual dimorphism in the patterns of correlation and covariation among the lengths of all individual metacarpals and phalanges. This may be the case mainly due to the difficulty of collecting hand bone length data. Therefore, detailed patterns of sexual dimorphism in the human hand proportion have remained unclear.

In the present study, based on planar radiography, we analyzed patterns of variability of the human hand proportion among individuals of a modern Japanese population. Specifically anteroposterior X-ray images of modern Japanese adult hands were obtained, and the lengths of all 19 metacarpals and phalanges were measured. We aimed to analyze the pattern of variations in the hand proportion based on a principal component analysis. By using the X-ray images, bone lengths could be directly measured with high precision, hopefully extracting unknown sexual differences in hand proportions.

Several previous studies have measured the metacarpal and phalangeal bone lengths from planar radiographs to analyze the relative lengths of the bones (Hamilton and Dunsmuir, 2002; Park *et al.*, 2003). However, the aim of these studies was to test if the bone lengths of the human hand correlated with the Fibonacci sequence (Littler, 1973), and not to clarify sexual differences in the human hand proportion.

Fig. 1. Anteroposterior X-ray image of the hand with some digitized points connected by line segments representing bone lengths.

Materials and Methods

In the present study, we used anteroposterior X-ray images of the right hands of a total of 197 adult individuals (61 males and 136 females) who participated in the Ogi Growth Study performed by the Saga University School of Medicine from 1979 to 1988 (Takai, 1990; Takai and Shinoda, 1991). This study was a longitudinal growth study of Japanese students who resided in Ogi city, Saga prefecture, Japan. Along with standard anthropometric measurements, an anteroposterior X-ray image of the right hand was taken every year from the age of 6 to 18 years (all the X-ray films are currently housed in the Department of Anthropology, National Museum of Nature and Science). In the present study, we selected only the X-ray images (anonymized in an unlinkable fashion) after epiphyseal fusion since our focus was on the adult hand proportion.

The X-ray films were scanned with the resolution of 150 dpi (a pixel size of 0.169 mm) using a film scanner (EPSON GT-X980). On each digital image, the most proximal and distal ends of metacarpals (MC), proximal phalanges (PP), middle phalanges (MP), and distal phalanges (DP) were manually digitized along the shaft axis (Figure 1). This was done using custom-made software named Dicom&16Tiff Viewer Ver.2.2 (Ogihara Lab., Dept. Mech. Eng., Keio University). Using this program, we calculated the distances between the proximal and distal ends of the bones. The measurement was conducted by one of the authors (S.A.). Each length was measured twice (on different days), and the mean value was used as the length of each MC or phalanx. The intra-observer error of the length measurement was approximately 0.3 mm for all the bones, corresponding to $<1\%$ of the length of the MCs and PPs, and $<2\%$ of the MPs and DPs, indicating that the measurements were made in a highly reproducible fashion.

In the present study, hand proportion variation among individuals were examined by computing the principal components (PCs) from the variance-covariance matrix of 19 hand bone dimensions (lengths) using R version 3.2.4 (The R Project for Statistical Computing). To extract possible size-related change of hand proportions, correlations between the PC scores and the log of the stature of the participant (at the time of radiography) were tested. In order to test for significant differences in PC scores between females and males, one-way analysis of variance (ANOVA) was conducted using the same software.

The present study was approved by the Ethics Committee of the National Museum of Nature and Science.

Results

The means and standard deviations of the measured metacarpal and phalangeal bone lengths are presented in Table 1. The results of PCA concerning variability in hand proportions of the modern Japanese population are presented in Figure 2 as plots of the first principal component (PC1) versus PC2, and as PC1 versus PC3. Based on a scree plot and cumulative variance, we considered the first three principal components to be dominant and thus retained them for further analyses. The remaining components were interpreted as secondary components showing scarce morphological variation as represented in the hand proportion. The first three PCs accounted for 92.5% of the variation (85.4%, 4.9%, and 2.2% for PC1, PC2, and PC3, respectively).

Only PC1 exhibited a significant positive linear relationship with log stature ($r=0.781$, $p<0.001$). Plots of the PC scores in Figure 2 showed clear separation between female and male hands along the PC1 axis, indicating that

Table 1. Mean values and standard deviations of metacarpal and phalangeal bone lengths (mm)

	Male (n=61)		Female (n=136)	
	Mean	SD	Mean	SD
MC1	48.3	3.1	43.4	2.7
MC2	71.0	4.7	64.4	3.6
MC3	66.7	4.3	60.7	3.5
MC4	59.9	3.7	54.6	3.2
MC5	55.0	3.4	50.0	3.1
PP1	32.6	2.4	29.2	1.9
PP2	42.9	2.7	39.4	2.2
PP3	47.9	2.9	43.9	2.4
PP4	44.8	2.7	40.8	2.2
PP5	35.0	2.2	31.9	1.9
MP2	23.8	1.7	21.7	1.5
MP3	28.6	1.9	26.1	1.6
MP4	27.2	1.8	24.6	1.6
MP5	18.5	1.7	16.3	2.1
DP1	22.4	1.8	19.8	1.7
DP2	17.9	1.3	15.9	1.1
DP3	19.2	1.3	17.0	1.2
DP4	20.0	1.4	17.5	1.2
DP5	17.6	1.5	15.6	1.2

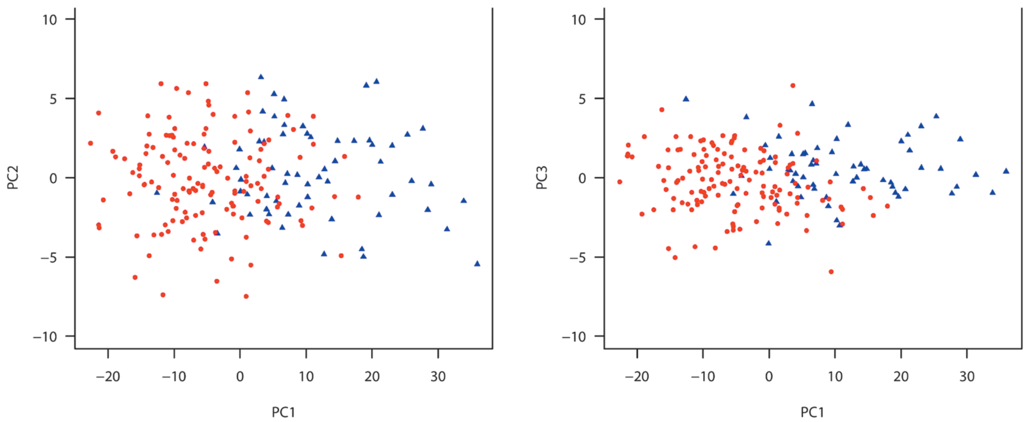

Fig. 2. The results of principal component (PC) analysis. Left, PC1 (x-axis) versus PC2 (y-axis); right, PC1 (x-axis) versus PC3 (y-axis). Red circle, female; blue triangle, male.

size-related variation due to sexual dimorphism is represented by PC1. Significant differences of PC1 scores between the sexes were detected by ANOVA ($p < 0.001$). Besides PC1, there was a significant sexual difference only in PC3 (Figure 2), with males tending to have slightly higher PC3 sores ($p < 0.01$).

The factor loadings of each PC axis were presented in Figure 3. Figure 3 demonstrates that with increasing PC1 values, all 19 bones tend to be longer, indicating that the variation represented by PC1 is mostly size-related. On the other hand, PC2 represents relative elongation of all the phalanges and a relative contraction of MC2-5 with increasing PC2 values. It is interesting to note that the PC2 loadings of the four MPs were much greater than those of the PPs and DPs.

PC3 represents relative elongation of the DPs and a relative contraction of MPs with increasing PC3 values. The PC3 factor loading was noticeably high in the DP1, suggesting that males tend to possess relatively long DPs, particularly in the thumb. We also note that the factor loadings of the MPs tended to decrease (more negative) with distance from MP2.

Discussion

The present study analyzed possible statistical differences between male and female hand pro-

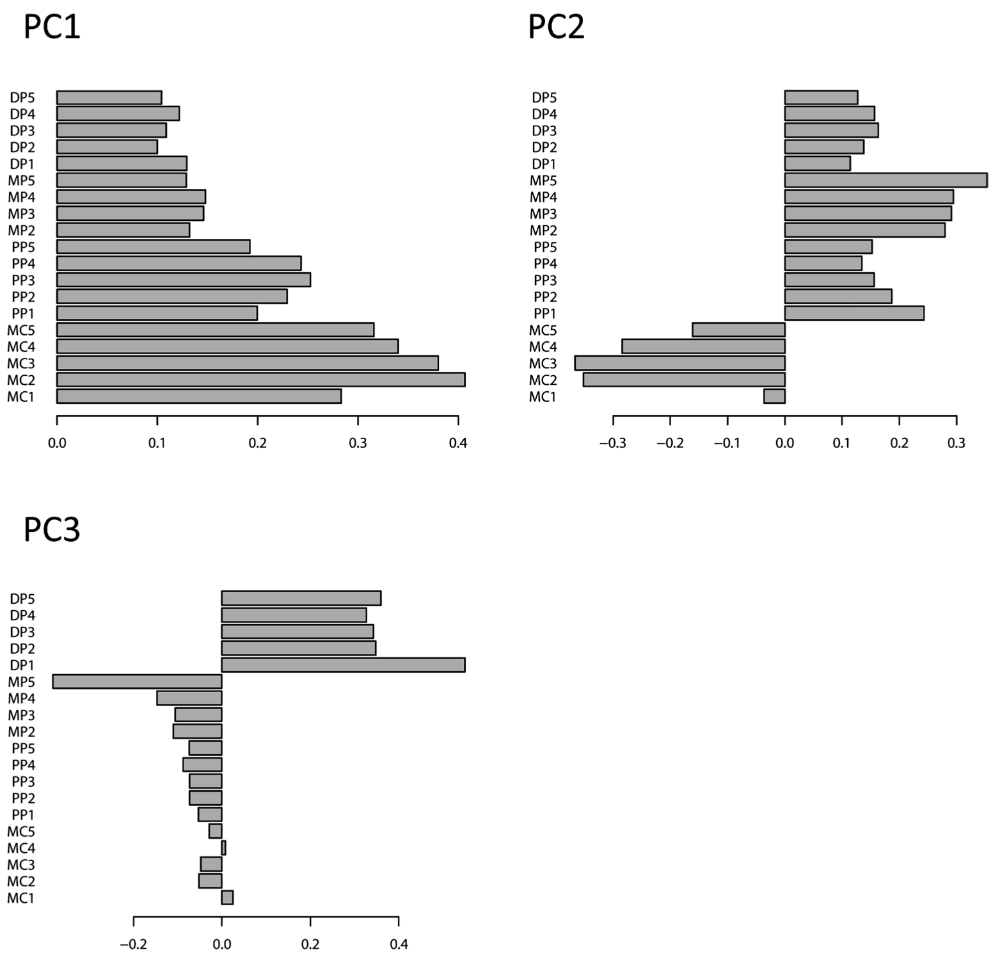

Fig. 3. Factor loadings for the 19 hand bones.

portions using 19 metacarpal and phalangeal bone dimensions. To our knowledge, this is the first study to apply a multivariate statistical analysis to identify sexual differences in the human hand proportion. From the results of the present study, we have demonstrated that the DPs, particularly that of the first ray, are relatively longer in male phalanges than in female phalanges. The change in phalangeal proportion might be related to the grasping capability of the hand. The difference in the relative lengths of the three phalanges may alter kinematics and force-generating capacity of the fingers and thumb, possibly leading to a change in grasping capability of the hand. However, the is also a possibility that the change in phalangeal proportion might simply emerge due to differences in the timing of secondary sexual development and fusion of epiphysis, but has nothing to do with the functional difference of the hand between males and females. The functional significance of this difference in hand proportion between males and females should be investigated in future studies.

It is well established that males tend to have relatively shorter second but longer fourth digits than females (e.g., Baker, 1888; George, 1930; Peters *et al.*, 2002; Robertson *et al.*, 2008). In our analysis, this was observed in the factor loadings of the PC1 presented in Figure 3. If we compared the factor loadings of PPs, MPs and DPs between the second and fourth fingers, the values were always larger in the fourth finger. The PC1 score was significantly larger in the male hands than in female hands. Therefore, our result is consistent with the previous findings reporting that males tend to have relatively shorter second but relatively longer fourth fingers than females. This tendency was also confirmed by the fact that there was a significant difference ($p<0.01$) in the ratio between the second and fourth digit lengths (PP + MP + DP) between males and females using the same sample.

We also found that there is a certain trend in variability of hand proportions that is independent of both size and sex. The human hand tends to possess relatively short metacarpal bones if the phalangeal bones are relatively long, and vice versa. And if the fingers become relatively long, the MPs tend to get relatively longer than the PPs and DPs. Understanding the pattern of variability of hand proportions is important in designing gloves as well as hand tools (Kouchi *et al.*, 2005). The present description of possible patterns of hand proportion variability may be useful in the field of ergonomics.

One limitation of the present study is that we here studied only the hand of a Japanese population. However, hand proportions are known to differ geographically (Manning *et al.*, 2004, 2007; Loehlin *et al.*, 2006), because of environmental factors such as climate. Studying variability in the hand proportions of different populations is an issue for future research. Another limitation is that we studied the sexual difference of the hand proportion using adult radiographs, and did not study ontogenetic changes of proportion. Since longitudinal radiographs of the same participants are available, in future studies, we plan to investigate the developmental change of hand proportions by adding the longitudinal data.

Acknowledgement

We wish to express our thanks to anonymous reviewers for constructive and useful comments which improved the manuscript, and to the Editor of this journal, Dr. Kazuhiro Sakaue, for his generous help.

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