Sex Differences and the Ordering of Lengths of the Proximal phalanges in *Macaca Mulatta*

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Abstract: Background: In accord with past findings, the ordering of lengths of both metapodials for some nonhuman primates was highly similar on the two sides of the body, but the pattern of lengths for these primates was different for the two sexes. **Objective:** To examine sex differences and the ordering of lengths of proximal phalanges in *Macaca mulatta* from the Taihang Mountain in central China. **Materials and Methods:** The lengths of proximal phalanges of hands and feet were obtained from the 35 skeletons of adult *Macaca mulatta*, comprising 12 males and 23 females. SPSS (Version 19.0) was used for statistical analysis. **Results:** For *Macaca mulatta*, the lengths of proximal phalanges showed highly significant sex differences ($P<0.001$); however, no side differences for both hands and both feet were found in the lengths of proximal phalanges. The ordering of lengths of five proximal phalanges in hands, from the longest to shortest, was 3,4>2>5>1, and the ordering of lengths of the proximal phalanges in feet was 3>4>2>5>1. **Conclusions:** There were obvious sex differences among the lengths of all proximal phalanges ($P<0.001$), whereas the sex differences of the lengths of proximal phalanges of hands were greater than those of feet in *Macaca mulatta*.

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1. Introduction

Some reports have displayed that there were sex differences in the lengths of both the metapodials in baboons, rhesus monkeys, gorillas and chimpanzees [1,2,3,4], and the sex differences of proximal phalanges were greater than those of the metapodials [1, 2]. These differences may be related to certain disease and the secretion of sex hormones in early embryonic development [3,4]. For example, sex differences in the relative lengths of metacarpals in gorillas and chimpanzees were affected by developmental mechanisms which involve androgens operating prenatally or postnatally[5,6].

The wild *Macaca mulatta* in Taihang Mountains is the largest and the northernmost population which exists in the area of Macaques distributing in conjunction of Shanxi and Henan province, in central China [7]. It is meaningful to study the morphological features, such as sex difference, asymmetry, the ordering of lengths for hand bones and population affinity distributing in different geography.

To date, sex differences in length ratios have been reported for few other species in non-human primates. At this time, we have some knowledge about sex differences in the absolute length for metapodials in rhesus monkeys, gorillas and chimpanzees, but not for their fingers and toes [7,8,9]. And we have knowledge about sex differences in the length for human fingers and toes, including the proximal, middle and distal phalanges, but not for rhesus monkey phalanges. The purpose of this paper was to extend the study of length to the proximal phalanges of *Macaca mulatta*.

Because the study was motivated by literature on the sex differences of lengths in other non-human primate's fingers, the initial desire was to investigate the possibility of sex differences in lengths for fingers in *Macaca mulatta*. In the end, we were forced to concentrate on the proximal phalanges because our prediction was that sex differences would exist in the lengths for proximal phalanges and the ordering of lengths would be different from human hands and feet [9].

2. Materials and methods

The wild *Macaca mulatta* are situated from 34°54′N to 35°16′N where belong to warm temperate climate. The population has their specificity in ecology, physiology, morphology, heritability and diet compared with the others [10,11]. Measurements were made on 32 specimens (9 males, 23 females) of hand bones and 34 specimens (12 males, 22 females) of foot bones. The skeleton specimens for this study are part of the population in Henan provinces, and are stored in College of Fisheries, Henan Normal University.

Some specimens were obtained from the wild *Macaca mulatta* which distributed from Taihang Mountains; and others were collected from the monkey farm in Henan Normal University; some of them died natrually and others died of injury. Pathological or damaged specimens were excluded. Paired bones were also excluded if postmortem damage influenced the periosteal surface of the diaphysis or precluded accurate measurement of bone length. In addition, all of the skeletons were complete for the five proximal phalanges, and all were adults according to the bone healing seam in skull.

Measurements taken on each proximal phalanges are illustrated in Figure 1.

The length of proximal phalanges was measured as the distance between the midpoint of the basis and distal tip point of all the proximal phalanges with a sliding caliper according to standard measuring techniques [12,13,14] and approximated to the nearest 0.01 mm.

This measurement was used rather than the more conventional maximum length because it allowed for the sampling of partially disarticulated hands. As showed in figure 1, the first proximal phalanx of fingers was marked as 1Pf, and the second proximal phalanx of fingers marked as 2Pf, others were marked analogically. In the same way, the first proximal phalanx of toes was marked as 1Pt, and the second proximal phalanx marked as 2Pt, and others were marked analogically. In order to reduce measurement error, all of samples were measured by trained or professional staff.

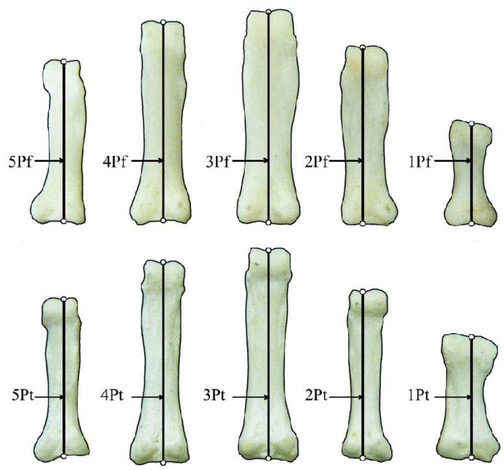

Figure 1. The measurements of proximal phalanges of *Macaca mulatta* (female, right).
Pf= proximal phalanges of fingers; Pt=: proximal phalanges of toes.

All data were then subjected to statistical analysis using the SPSS for Windows (version. 19.0). The t-test was employed in comparing the sex differences and the bilateral differences, and one-way ANOVA was used to study the differences of length among five proximal phalanges. Because homogeneity of the regression slopes for each group was not rejected in ANOVA, we then checked intergroup difference via Tukey's HSD test of post-hoc multiple comparisons using adjusted means. For both hands and both feet of both sexes, the ordering of proximal phalanges by length was obtained from longest to shortest.

3. Results

Descriptive statistics of the length of all five proximal phalanges were summed up in Table 1.

The sex comparison and the ordering of lengths of all five proximal phalanges, whatever the fingers and toes, were showed in Table 2 and Figure 2.

Table 1. Average lengths and *t*-test for the proximal phalanges of fingers and toesin *Macaca mulatta* (mm)

Bones	Male		Female		Male+Female		t-value	Discriminat rate (%)
	Mean±SD	N	Mean±SD	N	Mean±SD	N		
1Pf	13.55±0.75	18	12.51±0.81	46	12.81±0.92	64	4.692*	71.9
2Pf	22.93±0.49	18	20.81±0.83	46	21.40±1.22	64	10.18*	95.3
3Pf	27.60±0.94	18	24.89±0.92	46	25.65±1.53	64	10.49*	95.3
4Pf	26.91±0.77	18	24.39±0.95	46	25.10±1.46	64	10.04*	92.2
5Pf	21.66±0.70	18	19.70±0.68	46	20.26±1.12	64	10.26*	96.9
1Pt	16.44±0.88	24	15.33±0.83	44	15.72±1.00	68	5.11*	73.5
2Pt	23.23±1.16	24	21.74±1.13	44	22.26±1.34	68	5.13*	67.6
3Pt	28.57±0.93	24	26.36±1.00	44	27.14±1.44	68	8.91*	88.2
4Pt	27.45±0.93	24	25.33±0.96	44	26.08±1.40	68	8.78*	82.4
5Pt	22.52±0.83	24	20.87±0.81	44	21.45±1.14	68	7.93*	88.2

Abbreviations: Pf= proximal phalanges of fingers; Pt= proximal phalanges of toes; Data analyses were carried out using both sides; t-value: from independent-samples *t*-test between sexes; * *t*-values significant at $P<0.001$; Discriminat rate: The correctly classified percentages between the sexes for the single variable.

Table 2. Tukey's HSD test of the length of five proximal phalanges for the fingers and toes in *Macaca mulatta*

Order	Males	Females	Total	Order	Males	Females	Total
1Pf	13.55aA	12.51aA	12.81aA	1Pt	16.43aA	15.33aA	15.72aA
5Pf	21.66bB	19.70bB	20.26bB	5Pt	22.52bB	20.87bB	21.45bB
2Pf	22.93cC	20.81cC	21.40cC	2Pt	23.23bB	21.73cC	22.26cC
4Pf	26.92dD	24.39dD	25.10dD	4Pt	27.45cC	25.33dD	26.08dD
3Pf	27.60dD	24.89eE	25.65dD	3Pt	28.57dD	26.36eE	27.14eE

Note：The different letters followed mean values represent the significant differences among those proximal phalanges (P<0.05 or P<0.01), the same letters followed mean values represent no differences among those proximal phalanges (P>0.05). Capital letter indicate statistical significance at P<0.01, and small letter indicate statistical significance at 0.05≤P≤0.01.

As expected, the lengths of all proximal phalanges were uniformly greater for the males than for the females. For both sexes, the average lengths of proximal phalanges of both fingers and toes were remarkably similar.

The results obtained here imply that there were obvious sex differences among the lengths of proximal phalanges for both hands and both feet (P<0.001), whereas the sex differences of the lengths of proximal phalanges for both hands were greater than those for both feet in *Macaca mulatta*.

The ordering of the average lengths, from the longest to shortest, was 3>4>2>5>1 for both hands. Namely, there were no significant differences for the two sides of body (P>0.05). By One-way ANOVA, the total ordering of the average length of proximal phalanges was 3>4>2>5>1, and that every ordering of the five proximal phalanges showed was the same for the two sexes, the two hands and the two feet for *Macaca mulatta*.

However, there were statistically significant differences between sexes at the different level. Summary statistics of the five fingers were shown in the left half of Table 2.

At the P<0.01 or P<0.05 level, the ordering of five Pfs was 3, 4, 2, 5, 1 for both sexes and the total group (males+females), but the differences between 3Pf and 4 Pf were not statistically significant for male and total groups. By contrast, the pattern of lengths for proximal phalanges was different for the two sexes. For the females, the ordering from longest to shortest was 3>4>2>5>1 for both hands, but for the males, the ordering was 3,4>2>5>1 for both hands. Furthermore, the ordering of lengths in the five Pfs of *Macaca mulatta*, as showed in Table 2, may be different between sexes at the certain degree, but the ordering of length of the Pfs in males may be closer to the total ordering.

Similar results were also obtained for the ordering of lengths in the five Pts for both feet by Tukey's HSD test of post-hoc multiple comparisons. For the males, the ordering from longest to shortest was 3>4>2,5>1, but for females and total group the ordering were 3>4>2>5>1 for both feet at the P<0.05 or P<0.01 level (see Table 2).

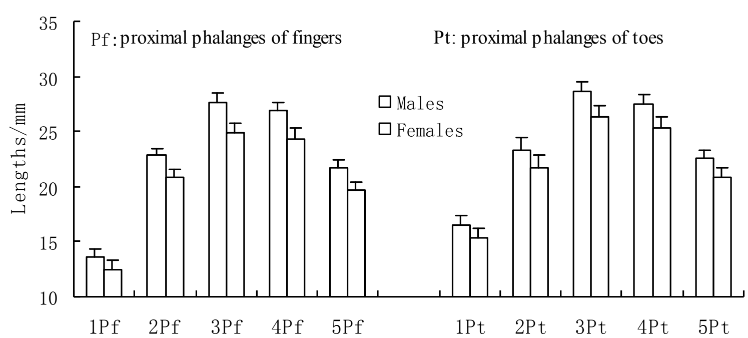

Figure 2. The sex comparison and the orderings of the length of thefive proximal phalanges of the finger and toe in *Macaca mulatta*

4. Discussion

Interspecies similarities and differences in the metapodials and phalanges in nonhuman primates long have been topics of considerable interest to physical anthropologists, biologists and behaviorists [15]. Comparisons across species have been especially informative about interspecies differences in such aspects of behavior as locomotion, use of tools, grip in hand and manual work [16]. For example, some physical anthropology studies had reported sex differences in the relative size of the proximal phalanges [13,14], and they had reported that the finger length ratio of human and non-human primates may reveal some important information during early development [18]. The orderings of length of gorillas, chimpanzee, and human proximal phalanges reported by McFadden et al. also were 3>4>2>5>1 [2]. As expected, for *Macaca mulatta*, the lengths of male proximal phalanges were longer than those of the female. For both sexes, both hands and both feet, the ordering of proximal phalanges by length was 3>4>2>5>1 from longest to shortest.

In this paper, sex differences of lengths of the proximal phalanges were significant ($P \leq 0.001$). Compared with the previous studies on sex differences of metacarpals and metatarsals[9], the lengths of the metapodials for both hands and both feet may be likely to exhibit larger sex difference.

In the direct discriminant analysis included all lengths of metacarpals, the average accuracies (74.2%-96.9%) obtained in this study for the proximal phalanx were higher than those (84.6%-91.7%) reported in previous studies for the metacarpals and metatarsals of *Macaca mulatta*[8,9], particularly as regards to the lengths of proximal phalanx for both hands.

At present, it is interesting to contemplate the origins of sex differences for the metapodials and phalanges in the nonhuman primates. Perhaps the most convincing evidence, which comes from two studies on people with congenital adrenal hyperplasia, was that prenatal sex hormones exposure may affect the changes of relative finger length in human [19,20]. It is a malady in which the adrenal gland produces abnormally high levels of androgens during prenatal development. McFadden et al. [5] reported that both gorillas and chimpanzees were affected by developmental mechanisms, possibly androgenic mechanisms, similar to those in humans. There is some important evidence for sex differences in locomotion, foraging, and other behaviors in primates [20]. In addition, there are some facts to consider when contemplating the various logically possible interpretations about the origins of sex differences. Cillo et al. [21] and Goodman et al. [22] reported that the early developments of finger length are under the control of the highly conserved homeobox genes, and in all mammals, androgens are responsible for producing males from the default state of females.

Sex differences in length of the phalanges may be related to the following factors:

(1) Previously, the results showed that sex differences in length ratios of metapodials in primates were almost related to sex dimorphism in body size [5,8]. This problem can be verified by a simple experiment. Sometimes, as the body size of individuals can not be directly measured, according to previous literature, the cranial length may replace the body size [23,24]. At first, the two larger male specimens and four smaller female specimens were removed on the basis of cranial size. As result, the male and female specimens which were retained were roughly equal in body size, and then the changes of the differences between the sexes were observed in this study. When the larger female specimens were compared with the small male specimens, it also showed that the sex differences of lengths of the phalanges were not significantly reduced except 1Pf. So, the results further confirmed that the sex differences in length of the phalanges can not simply attribute to the body size between the sexes. In addition, body size, as measured by height, was not highly correlated with the metapodial length ratios for different species in humans and non-human primates [25].

(2) Another question is why these sex differences were so different on metacarpal and finger lengths. One possible explanation for these outcomes is that the auditory and finger-length measures are affected by mechanisms operating at different times in ear development and that the growth of the metapodials and phalanges are not synchronization [26]. Perhaps the metapodials achieve their essential development prior to the existence of large sex differences in androgen concentrations, but the phalanges develop while a substantial sex difference does exist [14]. This may be one of the reasons which sexual difference of phalanges are larger than that of metapodials. Another possible type of explanation appeals to the prospect that the dimensions of the extremities (and thus the length ratios) may be affected by the uses to which those extremities are put [25,26].

(3) According to previous studies, there was reason to believe that prenatal androgen exposure in the embryo influenced the growth of ring finger, while the estrogen influences the growth of index finger [5, 26] . That is to say, a reasonable working hypothesis to adopt is that the sex differences reported here for measurements of proximal phalanges are attributable, at least in part, to sex differences in exposure to androgens during early development. Confirming these outcomes was very important because from after about 6 months of age to puberty, hormone levels are not different in boys and girls [2,5].

(4) From the perspective of the etiology, sex hormone levels during the embryo may be related to the adult's disease. A human disease named adrenal hyperplasia produces high levels of androgen during prenatal development [27]. The disease will significantly affect the changes of length of fingers and some characters after birth (such as autism and hyperactivity, etc.). Adults suffering from the diseases, such as myocardial infarction and breast cancer, were all related to the level of sex hormones in the early embryo environment [28,29,30].

For *Macaca mulatta*, the ordering of lengths of all hands and feet proximal phalanges from biggest to smallest was 3>4>2>5>1, which was consistent with the ordering of proximal phalanges in gorillas, chimpanzees and humans, it showed that non-human primates and humans would be homologous in the evolution. However, partial results were inconsistent with past findings [5].

Statistical analysis showed slight differences between the sexes in the ordering of lengths of all hands and feet. By post hoc comparisons, the ordering of lengths in the males did not show significant difference between the 3Pf and the 4Pf (P>0.05), but those in the females showed significant difference between the 3Pf and the 4Pf (P<0.05).

Note that the degree of the sex determination or the ordering of lengths by the phalanges across populations varies, but inter-study comparison is difficult because of methodological differences [13]. Alıcıoĝlu et al. investigated the use of length of phalanges for sex determination in 65 individuals from Turkish people [13]. They measured the interarticular distance of the phalanges through the use of radiographic imaging, whereas we directly measured here the length from the proximal phalanges by means of osteometric in rhesus monkeys.

Note again, that the results for the ordering of phalanges length for both males and females in this study would be different in terms of statistical approaches. For example, in *Macaca mulatta* males, the ordering of lengths of hand proximal phalanges from biggest to smallest was 3,4>2>5>1 by employing Tukey test, whereas the ordering of length was 3>4>2>5>1 by employing SNK test of SPSS at the P<0.05 level. It is clear that the ordering of lengths by employing SNK test in males are similar to those by Tukey's HSD test in females, as are the ordering of lengths of foot proximal phalanges. Another reason may be related to a small number of the male specimens in this study, but this was less likely. The ordering of lengths of phalanges was remarkably similar on both sides.

For the proximal phalanges of feet, the result showed no significant difference between 2Pt and 5Pt in males (P>0.05), while it was significant difference between 2Pt and 5Pt in females (P<0.05). These differences were also found in metatarsal length and weight in *Macaca mulatta* [31]. The relative lengths of the proximal phalanges may be likely affected by the absolute length of the proximal phalanges between sexes, and may be different for two sexes and for two levels.

7. Conclusion

There were obvious sex differences among the lengths of proximal phalanges (P<0.001), whereas the sex differences of the lengths of proximal phalanges of hands were greater than those of feet in *Macaca mulatta*. For both sexes, both hands, and both feet, the ordering of proximal phalanges by length was 3>4>2>5>1 from longest to shortest.

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