ORIGINAL ARTICLE

Eur. J. Anat. 22 (4): 317-322 (2018)

Association of the digit ratio (2D:4D) with sexually dimorphic morphological traits

Varvara Yu. Bakholdina, Alla A. Movsesian, Marina A. Negasheva

Department of Anthropology, Lomonosov State University, Moscow, Russian Federation 119234

SUMMARY

The length ratio of the second to the fourth finger (2D:4D) is a possible biomarker of prenatal sex hormone levels, which play a significant role in determining the sex-related body traits. The aim of this study was to assess the association between the 2D:4D ratio and morphological characteristics, related to sexual dimorphism. We analyzed a group of Russian males (N = 169) and females (N = 193) aged between 17 and 27 years (with mean ages of 18.6±1.50 and 18.9±1.85, respectively) for the association between the 2D:4D ratio and a wide range of morphological characteristics, some of which were considered in this aspect for the first time. The 2D:4D ratio in males was significantly lower than in females ($p < 0.000$). A highly statistically significant correlation was found between 2D:4D and sexually dimorphic morphological traits in the total sample. The association of 2D:4D ratio with morphological signs of masculinity/femininity within male and female samples were revealed only as a trend, which was more distinct for the functional indicators (handgrip strength).

Key words: Digit ratio – Sexual dimorphism – Morphological traits – Masculinity – Femininity

INTRODUCTION

Sexual dimorphism in humans can manifest in many aspects, including morphological, physiological, psychological, and behavioral traits. Although the variability ranges of these traits may overlap, in their extreme expression they are traditionally considered as indicators of sexual dimorphism and morphological masculinity/femininity. The differences between males and females in sexually dimorphic traits develop under the influence of sex hormones both at the prenatal and postnatal periods of ontogenesis, especially in puberty. However, it is not possible to estimate the ratio of androgens and estrogens during the period of growth and development by the level of morphological differences between the sexes. In the recent years, the digit ratio 2D:4D has been widely used for this purpose. The digit ratio is the length ratio of the second (index) finger to the fourth (ring) finger (2D:4D) and it is lower in men than in women. Sex differences in 2D:4D are formed during prenatal development (Malas et al., 2006) and remain relatively stable throughout the life (McIntyre et al., 2005). It was suggested that 2nd to 4th digit ratio (2D:4D) is largely determined prenatally by the level of androgen and estrogen hormone production and might be a marker of prenatal androgens level (Manning and Bundred, 2000). Furthermore, it was assumed that the digit ratio could predict testosterone concentrations in adults (Manning et al., 2004; Garcia-Cruz et al., 2012). The possible relationship between the digit ratio and prenatal sex hormone concentration was supported by a study of congenital adrenal hyperplasia (CAH) – a disease related to high prenatal levels of androgens. It was shown that males with CAH had lower values of 2D:4D (Brown et al., 2002). The usefulness of 2D:4D as a marker of prenatal androgens concentration was corroborated by the study of the relationship between the digit ratios in two-year-old children and the levels of prenatal testosterone and estradiol in the amniotic fluid for the period of their prenatal development. It was revealed that low 2D:4D correlates with high concentrations of prenatal testosterone relative to estrogen (Lutchmaya et al., 2004). It is noteworthy also that the sex differences in the 2D:4D ratio were not

Corresponding author: Dr Alla A. Movsesian. Department of Anthropology, Lomonosov State University 119234, Leninskye gory, MSU 1, Moscow, Russian Federation. Phone: +7 495 939 27 08. E-mail: amovsessyan@gmail.com

Submitted: 18 January, 2018. *Accepted:* 14 April, 2018.

found on bone material that is more inert in relation to hormonal effects (Wallen, 2009; Bakholdina et al., 2016). Since the prenatal and postnatal sex hormones concentration play a significant role in determining the body size and shape, the correlation of the digit ratio with certain sexually dimorphic traits, including morphological characteristics of masculinity/femininity, if found, can serve as additional evidence of its role as a possible marker of prenatal sex hormone levels. Considering the fact that the low digit ratio is typical for men and the high digit ratio is typical for women, one should expect that negative associations with the digit ratio would be observed for masculine features, and positive for feminine features. However, data on digit ratio associations with morphological sexually dimorphic traits are contradictory. For example, a negative correlation was observed between the 2D:4D ratio and the newborns size (Danborno et al., 2010), body weight (Van Dongen, 2009) height (Barut et al., 2008) and waist-to-hip ratio (Manning et al., 2000). In other studies, such relationships were not found, but at the same time, the negative correlations of 2D:4D with the waist-to-chest ratio in women (Fink et al., 2003) and positive ones with waist-to-hip ratio in men (Fink et al. 2006) were revealed. A high 2D:4D ratio correlates with feminine facial characteristics in women (Burriss et al., 2007), whereas statistically significant associations were found between the digit ratio, sub-adult body size and testosterone levels in men (Klimek et al., 2014). However, some of these observations were not confirmed by other studies (Putz et al., 2004; Kalichman et al., 2017). In the study of a large sample of men and women from Melbourne, the fact of the absence of significant 2D:4D ratio relationships with morphological features was even put into the title of the article, though the presence of some low-level associations was yet revealed (Muller et al., 2013). Meanwhile, it was shown that fetal testosterone and fetal estrogen might have wide-ranging organizing effects on different aspects of sex-dependent behavior (Collaer and Hines, 1995; Reinisch et al., 1991), and there are reliable evidences of 2D:4D association with functional indicators, physiological signs and psychological features. Thus, the lower right-hand 2D:4D ratio was associated with higher handgrip strength in German and Mizos Indian males (Fink et al., 2006); in the male students of the University of Miami (Hone, McCullough, 2012); in males of Hani ethnicity of China (Zhao et al., 2013). Significant associations of low 2D:4D ratio in men and high 2D:4D ratio in women with reproductive success, as well as with physiological indicators related to reproduction were also reported (Manning et al., 2000; Manning et al., 2003; Kalichman et al., 2013; Klimek et al., 2016). Statistically significant negative correlations were found between right 2D:4D and indicators of physical aggression in boys in Russian samples of children and adolescents (Butovskaya et al., 2013), and between 2D:4D and dominance in Hadza women (Butovskaya et al., 2015). It can be assumed that 2D:4D, bound in its formation with prenatal hormonal levels, is largely associated with physiological, functional and psychological characteristics, which are obviously more sensitive to sex hormones of the prenatal stage of ontogenesis than morphological traits.

A contradictory picture of associations between 2D:4D and sexually dimorphic morphological traits requires further research. The purpose of our study was two-fold. Firstly, we examined the association between the 2D:4D ratio and a wide range of sexually dimorphic morphological traits some of which, at the best of our knowledge, have not been investigated previously. Secondly, we tested a hypothesis that the 2D:4D ratio could be an indicator of morphological masculinity/femininity within gender groups.

MATERIALS AND METHODS

Participants and measurements

The study was conducted in Samara and Saransk cities in the Middle Volga region of Russia. Participants were recruited among young people of the Russian ethnicity, including 169 males and 193 females between 17 and 27 years old (with mean ages of 18.6 ± 1.50 and 18.9 ± 1.85, respectively). The study was approved by the Bioethics Committee of Moscow State University and performed on the basis of bioethics principles in compliance with the requirements of anonymity and data depersonalization at the subsequent processing stage, with the full consent of the study subjects who were explained the purpose of the research.

Since the purpose of our study was to reveal the associations of 2D:4D ratio with sexually dimorphic morphological traits, the anthropometric survey was aimed at assessing the differences between male and female samples by the characteristics of the body size and shape. We measured height and body weight, body mass index (BMI), shoulder and pelvic width, waist and hip circumference, upper arm, forearm, and shin circumferences, elbow, wrist, knee, ankle width and musculoskeletal mass (MSM) assessed by bioimpedance analysis (BIA). These traits determine the absolute size of the body and are greater in males, as well as such a functional feature as handgrip strength (HGS). The waist-to-hip ratio (WHR) determines the shape of the body, being an indicator of masculinity / femininity of the constitution, especially in females, for which its values are lower than for males. As an important sign of sexual dimorphism, Tanner's index (TI) was also considered, calculated by the following formula: TR = 3 × SHW-PW, were SHW is shoulder width, and PW is pelvis width (Tanner, 1990). The TI values, associated with the typical female (gynoid) body shape, are less than 83.7 in males and less than 73.1 in females; the values, associated with the typical male (android) body shape, are higher than 93.1 in males and higher than 82.1 in females (Tanner, 1990).

Anthropometer (GPM) was used for the measurements, as well as a large spreading caliper

(GPM), sliding caliper (Martin type) (GPM), and plastic tape measure. The whole-body impedance was measured on the right side of the body using the Bioimpedance meter ABC-01 “Medas” (SRC Medas, Russia). The lengths of index and ring fingers were measured from the proximal finger crease to the distal fingertip, as previously described (Manning et al., 1998), using a Preisser digital Vernier caliper with a precision up to 0.01 mm. The measurements of fingers were made twice by the same person; the intra-class correlation coefficient (ICC) was 0.975. All lateral measurements were performed on the right side of the body, including the length of the 2nd and 4th fingers measured on the right hand, since previous studies showed that the right-hand 2D:4D ratio is more sexually dimorphic and consequently a more reliable biomarker for the fetal testosterone level (Manning, 2002; Lutchmaya et al., 2004; Hönekopp and Watson, 2010).

Statistical analysis

The data were evaluated by descriptive statistics and expressed as mean (M) ± standard deviation (SD). The number of individuals measured was 362, and for each individual the number of measurements was 17, bringing the total number of measurements to 6154. Differences between males and females were analyzed by Student's *t*-test ($p < 0.05$ was considered significant). Correlation analysis was performed, and Pearson correlation coefficients (r) were calculated to assess the associations of 2D:4D with morphological traits. Factor analysis of the model multivariate exploratory techniques was also conducted. All data were analyzed using STATISTICA 10 software.

RESULTS

Table 1 shows mean values for 2D:4D ratios and morphological traits in the male and female groups of the participants. The 2D:4D ratio in males is significantly lower than that in females (*t*-value, -4.21; $p < 0.000$), which is consistent with previous findings. Sex differences in morphological traits assessed by Student's *t*-test appeared to be highly statistically significant ($p < 0.000$) with the only exception of hip and shin circumferences. Consequently, sexual dimorphism in the studied sample is high both in terms of absolute body dimensions and strength indicators, as well as in the indices characterizing the body shape.

To assess the level of the 2D:4D ratio association with the sexually dimorphic morphological traits, the correlation between 2D:4D and body morphology was assessed in the whole cohort and

Table 1. Mean (M) and standard deviation (SD) of the analyzed morphological traits.

	Males n=169		Females n=193	
	M	SD	M	SD
Body mass (kg)	70,45	11,04	56,69	9,64
Body length (mm)	1769,30	64,00	1633,62	55,06
Body mass index (BMI, kg/m^2)	16,74	2,51	14,02	2,31
Shoulder width (mm)	400,03	19,44	354,73	19,16
Pelvic width (mm)	283,91	16,62	276,15	17,52
Tanner's index (TI)	91,62	5,14	78,80	5,05
Waist circumference (mm)	776,93	67,03	695,68	70,46
Hip circumference (mm)	948,28	62,61	943,68	71,45
Waist-to-hip ratio (WHR)	0,82	0,04	0,74	0,04
Upper arm circumference (mm)	288,09	32,09	263,58	33,99
Forearm circumference (mm)	262,16	22,89	227,44	18,78
Shin circumference (mm)	363,67	27,67	355,08	33,32
Elbow width (mm)	70,19	4,13	61,38	3,85
Wrist width (mm)	58,21	3,49	50,47	2,73
Knee width (mm)	98,34	6,12	91,08	5,70
Ankle width (mm)	77,91	4,54	69,35	3,47
Handgrip strength (HGS, kgf)	46,93	8,79	27,54	4,71
Musculoskeletal mass (MSM, kg)	33,14	4,11	20,71	2,73
Length of the 2nd finger (mm)	73,66	4,43	68,28	4,01
Length of the 4th finger (mm)	75,25	4,48	68,72	4,31
Digit ratio (2D:4D)	97,94	3,37	99,44	3,39

in males and females separately (Table 2). The results indicated that in the whole cohort the 2D:4D ratio was associated with a number of sexually dimorphic morphological traits, and the vector of these associations corresponds to the expected. Thus, for the 2D:4D ratio the statistically significant negative correlation was observed with height, shoulder width, TI and WHR, shoulder and forearm circumferences, elbow, wrist and ankle widths, HGS, and musculoskeletal mass estimated by BIA. However, when the male and female subgroups were analyzed separately no statistically significant correlation between the 2D:4D ratio and the analyzed traits were detected, as evidenced by small correlation coefficients. The only exception was HGS, which showed in females the same correlation with 2D:4D in absolute magnitude and negative sign as was observed in the whole cohort (-0.21).

The results of the factor analysis, carried out for each sex separately, also do not give statistically significant results, but reveal some characteristic trends. Thus, in females, the load for the third factor for TI is 0.709, and for the digit ratio -0.163, indicating a negative relationship vector between these features. A noticeable load in males is detected by the digit ratio only for the second factor (-0.123), and it is opposite in sign for high factor loads for waist (0.792) and hip (0.717) circumferences.

Table 2. Pearson correlation coefficients (r) for the association of the 2D:4D ratio with morphological traits in the whole cohort and male and female groups.

	Total group	Males	Females
Body weight	-0,12	-0,01	-0,01
Body length	-0.21*	0,02	-0,09
Body mass index (BMI)	-0,10	-0,02	0,00
Shoulder width	-0.20*	0,07	-0,05
Pelvic width	-0,09	-0,07	-0,01
Tanner's index (TI)	-0.19*	0,10	-0,05
Waist circumference	-0,12	-0,04	0,01
Hip circumference	-0,01	-0,11	0,00
Waist-to-hip ratio (WHR)	-0.17*	0,10	0,02
Upper arm circumference	-0.17*	-0,07	-0,10
Forearm circumference	-0.22**	-0,10	-0,07
Shin circumference	-0,01	0,04	0,02
Elbow width	-0.19*	0,04	-0,03
Wrist width	-0.24**	-0,07	-0,04
Knee width	-0,11	-0,09	0,13
Ankle width	-0.20*	-0,03	0,00
Handgrip strength (HGS)	-0.21**	0,10	-0,21
Musculoskeletal mass (MSM)	-0.23**	0,05	-0,07
Length of the 2nd finger	0,02	0,21	0,14
Length of the 4th finger	-0.42**	-0.32**	-0.37**

DISCUSSION

Our study expands the range of sexually dimorphic morphological traits associated with the 2D:4D ratio, which correlates with height; WHR, TI; shoulder and forearm circumferences; elbow, wrist, and ankle widths; handgrip strength and musculoskeletal mass. These characteristics reflect the differences in the body size, body shape, development of the skeleton (latitudinal dimensions such as an elbow, wrist, and ankle widths), and musculature (upper arm and forearm circumferences) between sexes. Highly significant correlations between the 2D:4D ratio and sexually dimorphic morphological traits were revealed in the total sample, confirming the role of 2D:4D ratio as a putative biomarker of prenatal sex hormone levels.

However, in contrast to high correlations of the 2D:4D ratio with morphological traits in the whole cohort, such correlations were either completely absent or statistically insignificant for separate male and female groups. Similar results were obtained in the extensive study of Chuvash, one of the indigenous peoples of the Volga and Ural region, in a sample with mean age 46.9 ± 17.10 for males and 48.6 ± 16.62 for females. For both sexes, no significant associations were found between 2D:4D ratio and BMI, waist, hip and chest circumferences and WHR (Kalichman et al., 2017). At the same time, in the sample of Chuvash women, low 2D:4D ratio type was associated with a later menarche and a shorter reproductive period (Kalichman et al., 2013), which can indicate a possible association of the 2D:4D ratio with physiological manifestations of masculinity/femininity. A similar pattern is observed in the results of an extensive study of J.T. Manning and co-authors: negative associations of 2D:4D with reproductive success were found for men from English and Spanish samples, and positive associations for women from English, German, and Hungarian samples. The weak link of the 2D:4D ratio to WHR was found only for the combined English and Jamaican female sample (Manning et al., 2000). Almost the same results were obtained in the study of 50 males (mean age 22.4 ± 4.88) and 70 females (mean age 22.9 ± 4.25) from the University of Vienna, Austria and Northumbria University, UK (Fink et al., 2003). The authors analyzed a rather wide range of morphological parameters: weight, height, waist, chest and hip circumference, BMI, waist to hip ratio (WHR) and waist to chest ratio (WCR), but the only reliable evidence of the connection of 2D:4D ratio with morphological masculinity/femininity were negative correlations, found between female's 2D:4D ratio, waist and hip circumference and WCR. In our study, a significant but statistically unreliable correlation coefficient was found only in the female sample between the digit ratio and the handgrip strength. Additionally, some trends in association of the digit ratio with Tanner's index of sexual dimorphism in females and with girths in the sample of males can be indi-

cated, and the signs of the factor loads for the digit ratio and Tanner's index, as well as for the digit ratio and waist and hip wraps, are the opposite. Thus, in the sample studied, the relationship of 2D:4D with the signs of masculinity/femininity is revealed only as a trend, which is more distinct for the functional indicators (HGS).

Comparing the results of our study and the data of other authors, we can assume that the 2D:4D ratio could possibly be in a greater degree associated with the functional signs of masculinity/femininity than with the morphological ones.

ACKNOWLEDGEMENTS

We would like to thank the Editage for editorial assistance. We are also grateful to anonymous reviewer for comments that helped to improve the manuscript. Grant sponsor: Russian Foundation for Basic Research. Grant number: RFBR 18-09-00290.

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