[in press, *Early Human Develoment*, May 2024]

Associations between 2D:4D from direct and radiographic measurements with handgrip strength in young adult Tuvans

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Abstract

Background: Digit ratio (2D:4D) – the relative lengths of the index and ring finger – is sexually dimorphic (male < female), possibly because of the sex-differentiated impact of prenatal androgenization on fetal development in the 1st trimester. The sex difference remains stable with age and has been reported in children, adolescents, and adults from industrialized and non-industrialized societies. Handgrip strength (HGS) also is sexually dimorphic (males > females) and correlates positively with 2D:4D.

Aims: To examine in a sample of young adult Tuvans from Siberia (Russian Federation): i) the association between 2D:4D measured directly from the palms with 2D:4D measured from radiographic images of the same individuals and ii) the associations between 2D:4D and HGS in Tuvan men and women.

Study design and subjects: The study was cross-sectional. Participants were Tuvans (n = 185; 80 men; mean age = 21.02 years). 2D:4D was measured with a caliper from the ventral surface of the palm (both hands) and from radiographic images (left hand). HGS of both hands was measured with a digital hand dynamometer. Body height and weight were measured with an anthropometer and a body composition scale.

Results: 2D:4D ratios and anthropometric measures (including HGS) were sexually dimorphic. Men had lower 2D:4D and higher HGS than women. Direct measures of 2D:4D correlated positively with 2D:4D measured from radiographs. Body mass index (BMI) was a significant predictor of HGS for both sexes. Male right 2D:4D and female right and left 2D:4D correlated negatively with HGS after controlling for the influence of BMI. There were no associations with radiographic measurements of 2D:4D.

Conclusion: Our findings provide evidence of sexual dimorphism in 2D:4D among young adult Tuvans. Together with previous research on Tuvan children and adolescents, these findings provide clear evidence of 2D:4D sexual dimorphism in pre- and postpubertal Tuvans. The small negative association between 2D:4D and HGS corresponds to similar reports across populations, suggesting that 2D:4D is a weak correlate of muscular fitness.

Keywords: Soft-tissue and radiographic 2D:4D; prenatal androgenization; handgrip strength; sex differences; Tuvan

1. Introduction

Research documents robust sex differences across populations in digit ratio (2D:4D), i.e., the relative length of the 2nd (2D; index) to 4th (4D; ring) fingers, in healthy humans. Males typically have lower 2D:4D than females. This sex difference has been reported in postnatal humans of all ages in large international samples, such as the BBC internet study (n > 250,000), and in samples from large world populations (Europeans, East Africans, Central Asians) [1–8]. This sex difference is argued to be a consequence of early developmental processes, particularly prenatal sex-steroid action. 2D is more strongly affected by prenatal oestrogen (PE), whereas 4D is more strongly affected by prenatal testosterone (PT), within the 1st trimester during intrauterine fetal development [9,10]. Thus, a lower 2D:4D indicates greater exposure to PT relative to PE during prenatal growth [10,11]. However, not every digit ratio study has detected this sex difference [1,9–13]. It remains to be understood whether the discrepancy in findings reflects population-specific adaptive processes or is caused by variation in study protocols, including, for example, sample sizes and analytical approaches [4,12,14-18].

Negative relationships with 2D:4D have been found with trait masculinity [19–21] and with sports performance, both in men [22–25] and women [26,27]. Handgrip strength (HGS) is a well-established predictor of muscular strength [28,29] and health status [30,31]. It is strongly sexually dimorphic, with men typically being stronger than women [32,33], and attributed to sex differences in androgen levels [34]. HGS shows high heritability (~80-90%) and women are more susceptible to environmental effects on HGS than men, suggesting that androgen-mediated mechanisms shape the development of HGS in men but are of lesser importance in women [35,36]. Sexual dimorphism in physical strength suggests the role of sexual selection in human evolution, particularly in male-male physical competition, protection from predators, and hunting success [37-39]. Several studies document an association between HGS and 2D:4D in men. For example, negative associations between 2D:4D and HGS were reported in men residing in the US and North India, among the Han in China, and Turkish men [36,40-42]. However, not all studies detected an association between 2D:4D and HGS in men [43]. The 'challenge hypothesis' [44] may explain, at least partly, the discrepancies in findings, as short-term endocrine changes of testosterone were found to correlate with both 2D:4D and physical strength [45,46]. Recent evidence in young Polish adults revealed a negative association between 2D:4D and HGS after exposure to challenging conditions in both sexes, but the effect was stronger in women [28].

In the present study, we examine the association of HGS with sex, body mass index, and 2D:4D from direct (soft tissue) measurements and radiographs in women and men of the Tuvan population in Siberia (Russian Federation). Research using radiographic 2D:4D is scarce, possibly because of the requisite logistic effort and, in consequence, most digit ratio studies have used direct measurements of finger length hand scans to assess 2D:4D. We have reported evidence for a positive correlation between direct and radiographic 2D:4D in Tuvan children and adolescents aged 7-18 years [3]. The current study extends this research by considering Tuvan young adults. In addition to investigating the correspondence between direct and radiographic 2D:4D, we investigated associations of 2D:4D with HGS. We expected to identify a sex difference (men < women) for both direct and radiographic 2D:4D, and a negative relationship between 2D:4D and HGS, particularly in Tuvan young men.

2. Methods

2.1 *Study sample*

The current study was cross-sectional and analyzed data from a sample of 185 (80 males) young adult Tuvans from 17 to 31 years with a mean age of 21.02 ± 2.34 years. The data were collected in 2018 in Kyzyl (N 51°43', E 94°27'), the capital of the Republic of Tuva (Russian Federation). The Tuvans are one of the two most numerous ethnic groups in Siberia. The population of Tuvans is estimated at 260,000 in Russia. Most of the study participants were born in rural areas and their families only recently settled in urban areas. The Tuvan language belongs to the Sayan group of Turkic origin of the Altai family, and most Tuvans today speak both Tuvan and Russian, with Russian especially common in the younger generation [47].

2.2 *Anthropometric and soft tissue 2D:4D measurements*

The 2nd and 4th fingers were measured directly from the palms of the right and left hands and from radiographic images (left hand only) recorded during fieldwork. Direct measurements of right and left 2D and 4D from the tip of the digit to the metacarpophalangeal crease were conducted using a Vernier caliper (Emil Lux GmbH & Co. KG, Germany) with an accuracy of 0.01mm. All measurements were made twice for each hand. Participants who reported injuries or deformities of 2D or 4D were excluded from the analysis. The means of the two measurements, respectively, were used to calculate the digit ratio of the right and left hand. The interclass correlation coefficient

(ICC) for each hand was high: right-hand ICC = 0.965, $n = 180$, $p < 0.0001$; left-hand ICC = 0.972, $n = 185$, $p < 0.0001$.

Body height was measured with an anthropometer (GPM Instruments GmbH, Switzerland) with an accuracy of ±0.1 cm and body weight with a digital body composition scale (Tanita BC-601; Tanita Corp., Tokyo, Japan) with an accuracy of ±10 g. Handgrip strength (in kgf) was assessed with a digital hand dynamometer (DMER-120, Tulinovsky Instruments, Tulinokva, Russia). Participants were instructed to squeeze the handle as hard as they could, in a standing position, and with the arm stretched downwards. Right and left HGS were measured twice and the higher of each hand measurement was used in the statistical analyses. Five per cent of the participants were left-handers (by self-report).

2.3 *Radiographic assessment of 2D:4D*

Single radiographs of the left hand were recorded from each participant in the posteroanterior position with the X-ray source located 90 cm above the hand using the radiographic technique described by Pavlovsky [48]. The hand was exposed for 1.5–2 sec at 100-150 mA, without intensifying screens, at 75 kV. Finger length measurements from radiographs ("OST 2D:4D") included the three phalanges and the interphalangeal joints.

2.4. Statistical analysis

We report descriptive statistics, i.e., the means (*M*) and standard error of means (*SE*) for male and female anthropometric measurements. Sex differences were assessed using *t*-tests (2-tailed) with a significance level of $p < 0.05$. Pearson (r) correlations (2-tailed) were used to assess relationships among anthropometric measurements/indices and age. Linear regressions were performed to assess the association between right and left HGS, separately for male and female participants. The regressions were performed by considering right/left 2D:4D from soft tissue ("direct measurements") and left 2D:4D from radiographs. All statistical analyses were performed in SPSS 23.

2.5. Ethical considerations

The study protocol was approved by the Scientific Council of the Institute of Ethnology and Anthropology of the Russian Academy of Sciences (protocol N◦1, dated 19 February 2015). All participants provided written or verbal consent for participation.

3. Results

3.1 Descriptive statistics

Table 1 reports descriptive statistics for male and female anthropometric measurements, including HGS (both hands), direct measurements of 2D:4D (right and left hand) and 2D:4D from radiographs ("OST 2D:4D"; left hand).

--- Insert Table 1 about here ---

There were sex differences in anthropometric measurements. Male participants were taller and heavier than female participants and had a slightly higher BMI. Men were physically stronger (both hands). Digit ratio from direct measurements was sexually dimorphic (men < women) for both hands. However, right-left differences in 2D:4D (Dr-l) did not show a sex difference. Digit ratio from radiographic measurement also was sexually dimorphic (men < women).

3.2. Correlations among anthropometric measures and with age

Zero-order correlations (Pearson *r*) indicated a positive relationship between right and left HGS ($r = .96$, $p < .001$) and a positive relationship between right ($r = .37$, $p < .001$) and left ($r = .35$, $p < .001$) HGS with BMI, but not with age (right HGS: $r = .10$, $p = .168$; left HGS: $r = .10$, $p = .162$) for the total sample or when considering men and women separately (data omitted for brevity). Therefore, we did not consider age as a covariate in the subsequent analysis. Moreover, we did not consider the impact of handedness on HGS as most participants reported being right-handed (right-handed $n = 173$, left-handed, $n = 9$, ambidextrous $n = 2$).

Right and left-hand 2D:4D from direct measurements were positively correlated ($r = .75$, $p < .001$). In addition, radiographic 2D:4D (left hand only) correlated with left-hand ($r = .63$, $p < .001$) and right-hand ($r = .52$, $p < .001$) 2D:4D from direct measurement in the total sample.

There were no correlations between body height and 2D:4D either from direct measurement or from radiographs in men (direct 2D:4D right: $r = -.009$, $p = .936$; left: $r = .086$. $p = .454$; OST 2D:4D: $r = -.005$, $p = .967$) and women (direct 2D:4D right: $r = -.077$, $p = .441$; left: $r = .017$, $p = .865$; OST 2D:4D: $r = .060$, $p = .551$). None of the 2D:4D ratios correlated with BMI (men: all $r < .10$, all *p*s > .40; women: all $r < .07$, all *p*s > .47).

3.3. Predicting HGS from 2D:4D and BMI

Table 2 reports linear regressions between HGS (dependent variable) and 2D:4D (independent variable) from direct measurements, separately for male and female participants. The analysis was performed for right/left HGS. The predictors were right and left 2D:4D and BMI. The regression with radiographic 2D:4D ("OST 2D:4D") was performed separately (Table 3).

--- Insert Table 2 about here ---

Right HGS was predicted by right 2D:4D and BMI in men and by BMI only in women. For men, the ANOVA model was significant ($F_{3,70} = 9.23$, $p < .001$) and explained 28% of the variance; after adjustment, $R^2 = .25$. Likewise, the model for women was significant ($F_{3,96} = 5.16$, $p < .01$) with $R^2 = .14$, and adjusted $R^2 = .11$.

Left HGS produced a significant model for men ($F_{3,70} = 9.35$, $p < .001$), $R^2 = .29$, and after adjustment $R^2 = .26$ with BMI as the predictor. The ANOVA model for women also was statistically significant ($F_{3,98} = 5.24$, $p < .01$) and explained the same proportion of variation as the right-hand model ($R^2 = .14$, adjusted $R^2 = .11$). Left 2D:4D and BMI were predictors of HGS.

--- Insert Table 3 about here ---

The ANOVA model for the association between male HGS and OST 2D:4D and BMI was significant for men ($F_{2,74} = 9.35$, $p < .001$; $R^2 = .24$, adjusted $R^2 = .22$) and women ($F_{2,97} = 5.83$, $p < .001$). BMI (but not OST 2D:4D) predicted right and left HGS.

3.4.Partial correlations between HGS and 2D:4D controlling for BMI

Linear regressions showed that the association between HGS and 2D:4D from direct and radiographic measurements is significantly influenced by BMI. Therefore, we performed additional partial correlations (one-tailed) between HGS and 2D:4D, thus controlling for the influence of BMI (Table 4).

--- Insert Table 4 about here ---

For direct (soft tissue) 2D:4D, right HGS correlated negatively with right-hand 2D:4D in men. Women's left-hand 2D:4D correlated negatively with HGS of the right and left hands. No relationships were detected for radiographic HGS and radiographic 2D:4D.

4. Discussion

The present study indicates sex differences in young adult Tuvans in anthropometric measures and 2D:4D. Specifically, physical strength (as measured via HGS) was greater in men than in women, and men were taller and heavier than women. BMI was slightly higher in men than in women. Consistent with previous reports addressing differential effects of prenatal androgenization (PA) on the development of digit lengths, 2D:4D was lower in men than in women, for direct (soft tissue) and radiographic assessments of 2D:4D. BMI had a significant impact on HGS. After partialling out the influence of BMI on the relationship between HGS and 2D:4D, there was a negative correlation between right HGS and right 2D:4D in men. In women, the relationship was significant for left-hand 2D:4D, for both right and left HGS. No significant associations were detected between HGS and 2D:4D measurements from radiographs after controlling for the influence of BMI. Our findings suggest small negative correlations of HGS with 2D:4D in Tuvan men and women, indicating an influence of PA on the development of muscular strength in both sexes.

We have previously reported 2D:4D sex differences (boys < girls) in Tuvan children and adolescents [3]. These differences were found for direct 2D:4D measurements from the palms and radiographs. In addition, direct 2D:4D correlated positively with 2D:4D measurements from radiographs. The present study also included two types of 2D:4D measurements (direct and radiographic) to assess 2D:4D in young adults. Like in Tuvan children and adolescents, 2D:4D was sexually dimorphic, independent of measurement protocol, and the two types of 2D:4D measurements correlated positively for the left hand (n.b. only the left hand was radiographed). This suggests that 2D:4D - assessed from direct measurement of finger length from the palms - maps onto the combined lengths of (three) phalanges for 2D and 4D, respectively, and the interphalangeal joints [3]. Studies using radiographic 2D:4D are scarce (for an Afro-Carribbean sample, see [49]). Thus, it is important to secure evidence addressing the accuracy of finger length measurements from soft tissue in children and adults given the wide use of direct measurements (or imaging) of finger lengths from the ventral surface of the palms [5].

Although sex differences in the present study (including in 2D:4D) appear robust, the 2D:4D relationships with HGS were small, and not found for radiographic 2D:4D assessments. Small to moderate effect sizes are typical for 2D:4D relationships with sexually dimorphic target traits. A common finding of previous 2D:4D research has also been an association with right-hand 2D:4D for male-typical traits [50]. The reason for this observation remains to be investigated. In the present study, 2D:4D sex differences were similar in terms of size for both hands (see [23]). However, the pattern of associations between 2D:4D and HGS suggests a sex-differentiated effect for HGS correlations (right-hand 2D:4D in men and left-hand 2D:4D in women). We suggest interpreting this pattern with caution. First, the linear regressions showed that BMI was a strong (positive) predictor of HGS for both Tuvan men and women. Thus BMI accounted for a large proportion of variance in modelling the associations with HGS (together with 2D:4D). The relationships between 2D:4D and HGS were evident only after controlling for BMI. Second, the absence of a more coherent pattern of relationships between 2D:4D and HGS in both sexes may be a consequence of low statistical power associated with relatively small samples. Larger samples, such as in the BBC study [7,8] and recent reports based on large, cross-cultural samples [2,17,18] provide more robust conclusions, especially when 2D:4D relationships are small.

Previous research investigating 2D:4D and HGS relationships [36,40,42,46,51] indicated negative relationships between 2D:4D and HGS, especially in men and after controlling for the influence of BMI (or height and weight). This evidence was obtained from samples in Germany, India, Poland, Russia, Turkey, the UK, and the USA. The findings of the present study add to this list, corroborating the suggestion that negative relationships between 2D:4D and HGS may be universally detected in younger and older individuals. A meta-analysis of the results of 22 studies of over 5,000 individuals in 11 countries investigating the relationship between 2D:4D and muscular fitness [52] concluded that 2D:4D is correlated negatively with HGS. The CI was -.020 to -.009. Thus the correlations between 2D:4D and HGS in the present study fall within or are above that range. One source of variation in effect size across studies (as noted in [52]) is the heterogeneity of study protocols (including the reporting of participant inclusion/exclusion criteria), variation between studies in testing conditions, and consideration of confounding variables (e.g., ethnicity). The present study examined 2D:4D and HGS relationships in an ethnically homogeneous group with a narrow age range (95% of the participants were not older than 24 years). These methodological restrictions thus eliminated at least two potential sources of confounding effects.

The absence of correlations between HGS and radiographic 2D:4D was puzzling given the positive and significant correlations between direct and radiographic 2D:4D assessments (r = .63 for the left hand). Protocol differences are a probable cause of this discrepancy, but we cannot rule out the possibility of a soft-tissue effect that may impact direct but not radiographic finger length measurements, as has been reported for direct vs. photocopy 2D:4D assessments [53].

Some 2D:4D studies have used an experimental setting that presented a 'challenging condition' (e.g., male rugby) to participants, thus provoking short-term endocrine changes in testosterone [28,45,46] that were predicted by 2D:4D (lower 2D:4D associated with higher testosterone spikes) and moderating aggression. In the current study, we did not use such an experimental paradigm but recorded HGS of participants when they were not 'challenged'. It may be that the association between 2D:4D and HGS (and aggression) is evidenced in competitive (challenging) situations and that discrepancies across studies in effect sizes and sex for which an effect was detected, depend on context.

In conclusion, the present study identified sex differences in 2D:4D ratios – both from direct measurement and from radiographic assessment. Direct (soft tissue) 2D:4D measurements correlated with HGS in young adult Tuvans. Together with corroborative evidence from Tuvan children, the sexual dimorphism in 2D:4D in the Tuvan population seems to be robust. However, the correlation between 2D:4D and HGS was found to be low and inconsistent across hands. We emphasize the importance of consistent protocols in 2D:4D research to assess whether variations in the strength of relationships between 2D:4D and measures of muscular strength are influenced by context.

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Tables

Table 1. Descriptive statistics for anthropometric measurements and indices (2D:4D) in male and female Tuvan participants.

	Men	**Women**			
Variable	**M (SE)**	**M (SE)**	**t**	**Df**	**p**
Height (m)	1.72 (.007)	1.59 (.005)	14.78	179	<.001
Weight	68.58 (1.30)	55.70 (.88)	8.22	142.30	<.001
BMI	23.28 (.39)	22.08 (.32)	2.43	179	<.05
HGS right	43.42 (.84)	24.52 (.46)	19.74	123.00	<.001
HGS left	38.65 (.67)	22.90 (.43)	19.72	138.59	<.001
2D:4D right	0.95 (.004)	0.98 (.002)	-6.51	179	<.001
2D:4D left	0.95 (.003)	0.97 (.003)	-6.32	182	<.001
OST 2D:4D	0.90 (.002)	0.91 (.002)	-3.46	183	<.001

Note: If the assumption of equal variances in the *t*-test was violated (Levene's test), adjusted *df*s are reported. The *df*s also vary because, for some male:female comparisons, information was missing from a few participants.

Table 2. Linear regressions (split by sex) with right/left HGS as dependent variables and 2D:4D from direct (soft tissue) measurements and BMI as predictors.

HGS right					
Men	**B**	**SE B**	**Beta**	**t**	**p**
2D:4D right	-76.24	33.80	-.34	-.2.26	<.05
2D:4D left	47.95	41.60	.18	1.15	.253
BMI	1.09	0.22	.51	4.97	<.001
Women	**B**	**SE B**	**Beta**	**t**	**p**
2D:4D right	15.70	21.03	.09	0.74	.457
2D:4D left	-38.40	21.28	-.23	-1.81	.074
BMI	0.48	0.14	.33	3.46	<.001
HGS left					
Men	**B**	**SE B**	**Beta**	**t**	**p**
2D:4D right	-32.91	26.89	-.19	-1.22	.225
2D:4D left	14.76	33.09	.07	0.45	.657
BMI	0.908	0.18	.54	5.19	<.001
Women	**B**	**SE B**	**Beta**	**t**	**p**
2D:4D right	23.08	19.10	.15	1.21	.230
2D:4D left	-51.38	18.67	-.34	-2.75	<.01
BMI	0.35	0.13	.26	2.76	<.01

Table 3. Linear regressions (split by sex) with right/left HGS as dependent variables and 2D:4D from radiographic measurements (OST 2D:4D) and BMI as predictors.

HGS right					
Men	**B**	**SE B**	**Beta**	**t**	**p**
OST 2D:4D	-19.43	40.13	-.05	-0.48	.630
BMI	1.01	0.21	.48	4.73	<.001
Women	**B**	**SE B**	**Beta**	**T**	**p**
OST 2D:4D	6.88	22.24	.03	0.31	.758
BMI	0.47	0.14	.32	3.37	<.001
HGS left					
Men	**B**	**SE B**	**Beta**	**t**	**p**
OST 2D:4D	-13.89	30.97	-.05	-0.45	.655
BMI	0.81	0.17	0.48	4.67	<.001
Women	**B**	**SE B**	**Beta**	**t**	**p**
OST 2D:4D	0.02	20.34	0.0001	0.001	.999
BMI	0.346	0.13	0.26	2.64	<.01

Table 4. Partial correlations between HGS and 2D:4D controlling for BMI (split by sex) between right/left HGS and direct (right and left) and radiographic (left) 2D:4D.

	Men		**Women**	
	HGS right	HGS left	HGS right	HGS left
2D:4D right	**-.24 (*p* < .05)**	-.16 (*p* = .091)	-.06 (*p* = .278)	-.07 (*p* = .248)
2D:4D left	-.09 (*p* = .220)	-.08 (*p* = .243)	**-.18 (*p* < .05)**	**-.24 (*p* < .05)**
OST 2D:4D	-.06 (*p* = .306)	-.11 (*p* = .184)	.03 (*p* = .379)	.02 (*p* = .410)