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THE DIGIT RATIO (2D:4D) AND SPORT PERFORMANCE: A study on elite female gymnasts

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INTRODUCTION

The 2D:4D digit ratio is the ratio between the second (index) finger and the fourth (ring) finger lengths. This ratio represents an individual difference variable putatively related to prenatal gonadal hormonal exposure. A lower 2D:4D ratio is indicative of relatively higher prenatal testosterone than estrogen levels, which means that men may have, on average, lower digit ratios than women. So, the 2D:4D may represent sex differences (Manning, 2002). The digit ratio is also related with psychological characteristics like assertiveness and aggression (Manning, 2002), with the onset of menarche (Matchock, 2008, Helle, 2010), with homosexuality (Manning, 2002), with success among financial traders (Coates *et al.,* 2008), and with neck circumference (Fink *et al.,* 2006a). In addition, in different studies associations between 2D:4D and sporting ability were investigated (Hönekopp *et al.*, 2006; Manning & Taylor, 2001; Tester & Campbell, 2007; Manning *et al.,* 2007). The hypotheses set up in these studies were that a lower digit ratio is related to better sport abilities and better motor performance, in both males and females. Results of the studies are contradictory and not unequivocal and difficult to compare because of the use of different procedures to measure the digit lengths. Also, in many studies sporting abilities were not measured objectively, but based on information reported by the subjects themselves. In addition, published data on sporting ability and 2D:4D has mainly focused on male participants, and most of the studies focused on physical fitness or sport ability in general and not on one specific sport. To our knowledge there is no study available that focuses on a large sample of female gymnasts of world class caliber to investigate the association between the digit ratio and artistic gymnastic performance. The aim of this study was to compare the 2D:4D ratio of world-top female artistic gymnasts with the 2D:4D ratio of sedentary reference girls. It is hypothesized that the group of elite gymnasts have a significant lower digit ratio compared to the reference group.

METHODS

Samples

Gymnast sample. The sample (n = 145) of elite female gymnasts was a sub-sample of the participants of the 24th World Championships Artistic Gymnastics held at Rotterdam, The Netherlands, in 1987 (Claessens *et al.,* 1991). All gymnasts were of Caucasian ethnicity. Their chronological age varied from 13.2 to 21.8 years, with a mean age of 16.4 $\pm$ 1.6 years.

Reference sample. Girls from the Leuven Growth Study of Flemish Girls (Simons *et al.*, 1990) were used as the reference sample. Based on three conditions a sample of 178 girls was selected: (1) girls must be 13 years and older; (2) only girls for whom an X-ray of the left hand was available were selected; and (3) and girls in the reference sample must be sedentary, i.e. not practice any sports apart from the mandatory 2 hours/week of physical education classes in school, to be sure of a significant difference in sporting ability between the two samples. The mean chronological age of the selected girls was 15.7$\pm$ 1.3 years, varying from 13.2 to 18.4 years.

Anthropometric dimensions

The following measurements were taken: weight; height; biacromial and bicristal breadths; humerus and femur widths; biceps and calf girths; and triceps, subscapular, supraspinale, and calf skinfolds. Body mass index (BMI) was calculated as weight (kg) / height (m^2). All measurements were taken by well-trained observers according to the measuring procedures as described by Claessens *et al.* (1990).

Body ratios of sexual dimorphism

Two *masculinity indices* were calculated. (1) The Bayer-Bailey ratio relates the breadth of the hips to that of the shoulders: IMAS = (bicristal breadth-cm / biacromial breadth-cm) x 100; and (2) the androgyny index according to Tanner (IADR): (3x biacromial breadth-cm) - (bicristal breadth-cm). Both indices are useful indicators of sex differences in the proportional relationship of the shoulders and hips. (Malina, 1995; Claessens *et al*., 2008).

Somatotype

The three somatotype components endomorphy (ENDO), mesomorphy (MESO) and ectomorphy (ECTO) were anthropometrically determined according to the Heath-Carter technique. For a detailed description how the three components were calculated reference is given to Claessens *et al*. (2008).

Skeletal age

Skeletal age (S-age) was assessed on an X-ray of the left hand and wrist according to the Tanner-Whitehouse II method (TW2L). Detailed information is given by Claessens *et al*. (2008).

Measuring 2D and 4D lengths

Measuring procedure. Radiographs from the left hand of all the subjects of the two samples were available to measure and calculate 2D:4D. The lengths of the second and fourth finger were measured from the proximal end of the proximal phalanx to the distal tip of the distal phalanx using a caliper accurate to 0.1 mm (John Bull British Indicators LtD, England). Digit lengths of each sample were measured by two raters. The mean of the two raters was taken as the final measurement.

Reliability study. Before measuring all X-rays, a reliability study was conducted by three different raters. This study consisted of the measurement of thirty left-hand X-rays twice by each rater in a test and re-test manner. Interobserver measurement repeatabilities for 2D:4D ratios were assessed with intraclass correlation coefficients (ICC; Voracek *et al.,* 2007). The intraclass correlation for interrater reliability showed a reliability of 0.98 (ICC 3.1). ANOVA did not show any significant difference for 2D:4D between the raters. The technical error of measurement for all raters was <0.001 for all raters for 2D:4D. So it can be concluded that all measurements of 2D:4D were measured reliably.

Statistical analyses

Differences in 2D:4D and in anthropometric characteristics between the sample of elite gymnasts and the reference group were analyzed by means of a two-tailed t-test. An ANCOVA was used to compare the two samples for each variable with age as the covariate. The relationship between 2D:4D ratio and anthropometric characteristics for each sample were calculated by Pearson Product Moment correlation coefficients. The Statistical Analysis System program 9.2 (SAS Institute, 1988) was used to analyze the data.

RESULTS

Descriptive statistics (mean $\pm$ SD) of all variables are given in Table 1.
Chronological age (C-age) of the gymnasts is significantly higher compared to that of the reference sample, whereas their skeletal age (S-age) is significantly lower. Height, weight and BMI of the elite gymnasts are significantly lower compared to the reference sample. Also differences in somatotype can be observed. Gymnasts are more mesomorph and less endomorph compared to reference girls. As expressed by the Bayer-Bailey index (IMAS) gymnasts have, on average, broader shoulders relative to their hips, compared to the reference sample. For both groups a mean of 0.92 ± 0.0 for the 2D:4D ratio is observed indicating no difference in the digit ratio between the gymnasts and reference samples.

Because of the significant difference in chronological age between the two samples, a multiple ANCOVA, with C-age as covariate, was conducted. The adjusted means of the 2D:4D ratio and of the anthropometric characteristics are given in Table 2.

Table 1. Descriptive statistics

	Reference girls (n=178)		Gymnasts (n=145)		t-value
	Mean	Sd	Mean	Sd	
C-age (years)	15.7	1.3	16.4	1.6	-3.75**
S-age (years)	14.9	1.1	14.6	1.2	2.59*
2D:4D	0.92	0.02	0.92	0.02	1.88
Height (cm)	162.2	6.4	155.1	6.5	9.87**
Weight kg)	54.1	9.0	46.2	6.2	9.43**
BMI (kg/m^2)	20.5	3.0	19.1	1.6	5.42**
ENDO	3.9	1.2	1.7	0.6	21.89**
MESO	3.0	0.2	3.7	0.6	-6.93**
ECTO	3.0	1.3	3.1	0.8	-1.18
IMAS	76.6	4.7	72.8	3.6	8.05**
IADR	77.2	5.0	76.5	4.5	1.47

**$p \leq 0.01$; *$p \leq 0.05$

Table 2. Adjusted means of 2D:4D and of the anthropometric characteristics

	F-ratio	LSMEAN ref. girls (n=178)	LSMEAN gymnasts (n=15)
2D:4D	3.55	0.92	0.92
Height (cm)	119.26**	162.5	154.7
Weight kg)	118.68**	54.7	45.5
BMI (kg/m^2)	39.80**	20.7	19.0
ENDO	434.46**	4.0	1.7
MESO	36.63**	3.0	3.6
ECTO	3.95*	2.9	3.2
IMAS	67.74**	76.7	72.7
IADR	4.96*	77.4	76.2

**$p \leq 0.01$; *$p \leq 0.05$

Although all variables were adjusted for C-age, it is observed that all the adjusted mean differences for the anthropometric variables between the two samples are still significant. For both samples an adjusted mean of 0.92 for the 2D:4D ratio is observed.

Correlations between the 2D:4D ratio on the one hand and C-age, S-age, and the anthropometric characteristics on the other hand are low and not significant, ranging from r = 0.10 (with BMI) to r = -0.14 (with height) in the reference sample, and from r = 0.11 (with height) to r = -0.11 (with ENDO) in the gymnasts sample.

DISCUSSION

The mean value of 0.92 for the 2D:4D ratio found for the reference sample is very low compared to the female population norms. An inspection of the right-hand 2D:4D ratio from a sample of 531 females showed a mean 2D:4D ratio of 1.00 (SD=0.03) (Manning, 2002).

A possible explanation for this low mean value observed for our reference sample is that the digit lengths were measured on X-rays in contrast to the measuring procedures used in many other studies. Mostly digit lengths were done on photocopies, printed scans or directly from the hand. Previous studies have compared different methods of digit ratio measurement (Kemper and Schwerdtfeger, 2009; Allaway *et al*., 2009; Manning *et al*., 2005; Manning, 2002). The fact that measurements on X-rays seem to yield lower digit ratios may be partially explained by the fact that measurements made on soft tissue or images of the soft tissue on the hand are taken approximately halfway along the proximal phalanx whereas bone measurements began at the proximal end of the phalanx (Manning, 2002). This hypothesis has not been subject to research yet but could possibly provide an explanation and may lead to standardization for the measurement of the 2D:4D ratio. At the same time when measuring on photocopies, printed scans or directly on the hand, the soft tissue is also measured whereas when measuring finger lengths on X-rays only the bone length is recorded. In a study of Paul et al. (2006a), concerning the heritability of the 2D:4D ratio, measurements of the finger lengths were also made on X-rays. In a sample of 456 female twin pairs a mean 2D:4D ratio of 0.92 (SD=0.001) was observed for both hands, which is similar to the 2D:4D ratio found in the present study. Manning *et al*. (2000) had already observed that measurements of 2D:4D from photocopies and radiographs are significantly correlated, although mean radiograph-derived 2D:4D showed lower ratios than those from photocopies and showed less sexual dimorphism. It can thus be stated that the low 2D:4D ratio of 0.92 found in our reference sample is the result of the fact that the measurements were done on X-rays.

For the gymnasts' sample, we hypothesized a lower 2D:4D ratio, compared to the value found for the reference sample, but no significant difference between both mean ratios was observed, 0.92 for both samples. So the 2D:4D ratio, on average, may not be a discriminating factor for artistic gymnastic performance. This is consistent with the findings of a study of Paul *et al.* (2006b) about the relationship between 2D:4D and sporting ability across a range of 12 sports in a sample of 607 female participants. The subjects were asked to give the highest competitive level in their sport activity on a five-point scale, with 'social participation only' as the lowest level (=1) and 'national level' (=5) as the highest level. Measurements of the digit lengths were done on X-rays. The overall age-adjusted level achieved in any sport was significantly negatively associated with mean 2D:4D. But, when analyzed separately, mean digit ratio was only significantly associated with running level. There was no significant relationship between 2D:4D and the level in a subsample of female gymnasts. A mean left-hand 2D:4D ratio of 0.93 ± 0.02 was found, which is similar to the value of 0.92 found in the present study.

Although the findings of our study are consistent with the findings of Paul *et al.* (2006b), they are in contrast with previous studies in which significant relationships between 2D:4D and sporting ability in females were observed. The 2D:4D ratio is moderately related to performance in endurance running of young adults with correlations varying from r = 0.30 to r = 0.50 (Manning *et al.*, 2007). In contrast little evidence is found for the relationship between 2D:4D and acceleration and strength. Correlation coefficients between 2D:4D and sprinting speed were weak ($r = 0.15$; $p = 0.02$) in a study of Manning & Hill (2009). van Anders (2007) found no significant association between 2D:4D and grip-strength in a sample of 99 women (mean age 23.76$\pm$5.66 years). This suggests that the widespread relationship between 2D:4D and sport performance may have more to do with aerobic efficiency than with strength and acceleration (Manning & Hill, 2009). It is possible that strength and acceleration are two more important modifying determinants in artistic gymnastic performance, compared to aerobic capacity. The physical capacities that serve as a basis for gymnastic talent are speed, quickness, flexibility and strength (Brown 2001). Gymnasts do not perform competitive routines longer than 90 seconds. Therefore, the oxidative energy system is probably not a dominant energy system for gymnastics. The anaerobic dominance of gymnastic performance is supported by several studies (Sands *et al.*, 2003).

The masculinity indices and somatotype are, just like the 2D:4D ratio, determinants of sexual dimorphism. Like men have on average a lower 2D:4D ratio, men have on average a higher mesomorphy component, a lower endomorphy component, and a lower Bayer-Bailey masculinity index, compared to women. As expressed in several previous studies (Claessens *et al.*, 1991) elite female gymnasts demonstrate a more 'masculine' body morphology compared to age-related reference girls. This is also demonstrated in the present study. The sample of elite gymnasts has a significant lower masculinity index (IMAS), which means that the gymnasts have on average broader shoulders relative to their hips, compared to the reference girls, 72.8 and 76.6 respectively. When looking to the body as a 'Gestalt', a significant difference was found in somatotype between the two samples. Gymnasts demonstrated on average a somatotype of 1.7/3.7/3.1 compared to an average somatotype of 3.9/3.0/3.0 of the reference sample. Elite gymnasts are characterized by an ecto-mesomorphic somatotype whereas reference girls are characterized as meso-endomorphic. Mesomorphy is characterized by the predominance of muscle, bone and connective tissue, whereas endomorphy describes the degree of roundness and fatness of the body. Although both samples can be sexually discriminated on the basis of anthropometric characteristics, the 2D:4D, ratio does not.

In addition, when testosterone is negatively related to 2D:4D (Manning, 2002), it is expected that more male forms of 2D:4D would correlate with more male forms of anthropometric characteristics like masculinity indices and somatotype. Some previous studies have investigated the relationship between 2D:4D and anthropometric characteristics. Fink *et al*. (2003) investigated the relationship between 2D:4D with body mass index, waist-to-hip ratio and waist-to-chest ratio. Some evidence was found that 2D:4D also correlates with indices of sexually dimorphic traits of the human body. Body fat distribution was in that study measured by the waist-to-hip ratio. However, no significant associations were observed for male and female 2D:4D and the waist-to-hip ratio. In females, neither a significant relationship between body mass index and 2D:4D was found. A higher value of 2D:4D correlated significantly with a lower value of the waist-to-chest ratio. This is consistent with the literature as oestrogens should largely influence chest circumference in females. In a study of Gallup *et al.* (2007) the relationship between handgrip strength and three measures of body morphology (shoulder-to-hip ratio, waist-to-hip ratio, 2D:4D) was investigated in a sample of 82 male and female college students. A significant positive relationship between 2D:4D and waist-to-hip ratio in females could be observed. No significant relationship between handgrip strength and 2D:4D was found. Because mostly other body ratios of sexual dimorphism were used in the literature compared to those used in the present study, comparison of results is difficult. Although most of the anthropometric characteristics used in the present study were discriminating factors between the gymnasts and the reference samples, no significant correlations were observed between 2D:4D and these anthropometric characteristics.

The present study is to our knowledge the first study that investigated the relationship between 2D:4D in a large sample of female gymnasts of world-class level , by comparing their 2D:4D ratio with that of a reference sample of sedentary girls. The high level performance of the gymnast sample is based on the fact that all gymnasts participated at the World Championships Artistic Gymnastics held in Rotterdam, 1987 (Claessens *et al.*, 1991). The reference sample consisted of girls who were all sedentary. There was thus an obvious difference in sporting ability between both groups. In many studies about the relationship between sporting ability and 2D:4D, the level of sporting ability was based on information reported by the subjects themselves. Even, in the present study, all anthropometric variables were measured objectively, whereas in a lot of previous studies data (e.g. height and weight) were reported.

A possible limitation of our study is that all measurements of the digit lengths were taken on the left hand. In most studies the digit lengths were taken on the right hand to calculate 2D:4D. This is based on the fact that results of previous studies have demonstrated that sex differences in 2D:4D and correlations of 2D:4D with target traits are more pronounced for the right hand than for the left hand. Testosterone-dependent physical traits tend to be more strongly expressed on the right side of the body compared to the left side (Manning, 2002).

In conclusion, although other anthropometric characteristics of sexual dimorphism were significantly different between the two samples, the present study cannot discriminate sedentary women/girls from World-class gymnasts using the 2D:4D ratio. Furthermore, no significant correlations were found between 2D:4D ratios and anthropometric and age characteristics, both chronological and skeletal.

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REFERENCES

Allaway, H.C., Bloski, T.G., Pierson, R.A. and Lujan, M.E., 2009, Digit ratios (2D:4D) determined by computer analysis are more reliable than those using physical measurements, photoscopies and printed scans. *American Journal of Human Biology,* 21, pp. 365-370.

Brown, J., 2001, *Sports talent: how to identify and develop outstanding athletes*, (Champaign, Ill.: Human Kinetics).

Claessens, A.L., Beunen, G. and Malina, R.M., 2008, Anthropometry, physique, body composition, and maturity. In *Paediatric Exercise Science and Medicine,* edited by Armstrong, N. and van Mechelen, W. (Oxford: Oxford University Press), pp. 23-33.

Claessens, A.L.M., Vanden Eynde, B., Renson, R. and Van Gerven, D., 1990, The description of tests and measurements. In *Growth and fitness of Flemish girls. The Leuven Growth Study,* edited by Simons, J., Beunen, G., Renson, R. Claessens, A.L.M., Vanreusel, B. and Lefevre, J.A.V. (Champaign, Ill.: Human Kinetic Books), pp. 21-39.

Claessens, A.L.M., Veer, F.M., Stijnen, V., Lefevre, J. Maes, H., Steens, G. and Beunen, G., 1991, Anthropometric characteristics of outstanding male and female gymnasts. *Journal of Sports Sciences*, 9, pp. 53-74.

Coates, J.M., Gurnell, M. and Rustichini, A., 2008, Second-to-fourth digit ratio predicts success among high frequency financial traders. *PNAS*, 106, pp. 623-628.

Fink, B., Manning, J.T. and Neave, N;, 2006a, The 2nd - 4th digit ratio (2D:4D) and neck circumference: implications for risk factors in coronary heart disease. *International Journal of Obesity,* 30, pp. 711-714.

Fink, B., Neave, N. and Manning, J.T., 2003, Second to fourth digit ratio, body mass, waist-to-hip ratio and waist-to-chest ratio: their relationships in heterosexual men and women. *Annals of Human Biology,* 30, 728-738.

Gallup, A.C., White, D.D. and Gallup, G.G., 2007, Handgrip strength predicts sexual behavior, body morphology, and aggression in male college students. *Evolution and Human Behavior,* 28, pp. 423-429.

Helle, S., 2010, Does second-to-fourth digit length ratio (2D:4D) predict age at menarche in women? *American Journal of Human Biology,* 22, pp. 418-420.

Hönekopp, J., Manning, J.T. and Müller, C., 2006, Digit ratio (2D:4D) and physical fitness in males and females: evidence for effects of prenatal androgens on sexually selected traits. *Hormonal Behavior,* 49, pp. 545-549.

Kemper, C.J. and Schwerdtfeger, A., 2009, Comparing indirect methods of digit ratio (2D:4D) measurement. *American Journal of Human Biology,* 21, pp. 188-191.

Malina, R.M., 1995, Anthropometry. In *Physiological assessment of human fitness,* edited by Maud, P.J. and Foster, C. (Champaign, Ill.: Human Kinetics), pp. 205-219.

Manning, J.T., 2002, *Digit Ratio: a pointer to fertility, behavior, and health,* (Brunswick, N.J.: Rutgers University Press).

Manning, J.T. and Hill, M.R., 2009, Digit ratio (2D:4D) and sprinting speed in boys. *American Journal of Human Biology,* 21, pp. 210-213.

Manning, J.T., Fink, B., Neave, N. and Caswell, N., 2005, Photocopies yield lower digit ratios (2D:4D) than direct finger measurements. *Archives Sex Behavior,* 34, pp. 329-333.

Manning, J.T., Morris, L. and Caswell, N., 2007, Endurance running and digit ratio (2D:4D): implications for fetal testosterone effects on running speed and vascular health. *American Journal of Human Biology,* 19, pp. 416-421.

Manning, J.T. and Taylor, R.P., 2001, Second to fourth digit ratio and male ability in sport: implications for sexual selection in humans. *Evolution and Human Behavior,* 22, pp. 61-69.

Manning, J.T., Trivers, R.L., Thornhill, R. and Singh, D., 2000, The 2nd:4th digit ratio and asymmetry of hand performance in Jamaican children. *Laterality,* 5, pp. 121-132.

Matchock, R.L., 2008, Low digit ratio (2D:4D) is associated with delayed menarche. *American Journal of Human Biology,* 20, pp. 487-489.

Paul, S.N., Kato, B.S., Cherkas, L.F., Andrew, T. and Spector, T.D., 2006a, Heritability of the second to fourth digit ratio (2D:4D): a twin study. *Twin Research and Human Genetics,* 9, pp. 215-219.

Paul, S.N., Kato, B.S., Hunkin, J.L., Vivekanandan, S. and Spector, T.D., 2006b, The big finger: the second to fourth digit ratio is a predictor of sporting ability in women. *British Journal of Sports Medicine,* 40, pp. 981-983.

Sands, W.A., Caine, D.J. and Borms, J., 2003, *Scientific Aspects of Women's Gymnastics,* (Basel: Karger). SAS Insitute, 1988, *SAS/STAT user's guide (release 6.03 ed),* (Cary NC).

Simons, J., Beunen, G., Renson, R. Claessens, A.L.M., Vanreusel, B. and Lefevre, J.A.V., 1990, *Growth and fitness of Flemish Girls. The Leuven Growth Study.* (Champaign, Ill.: Human Kinetics Books).

Tester, N. and Campbell, A., 2007, Sporting achievement: what is the contribution of digit ratio? *Journal of Personality,* 75, pp. 663-678.

van Anders, S.M., 2007, Grip strength and digit ratios are not correlated in women. *American Journal of Human Biology,* 19, pp. 437-439.

Voracek, M., Manning, J.T. and Dressler, S.G., 2007, Repeatability and interobserver error of digit ratio (2D:4D) measurements made by experts. *American Journal of Human Biology,* 19, pp. 142-146.