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Digit ratio (2D:4D) and physical fitness in males and females: Evidence for effects of prenatal androgens on sexually selected traits

Johannes Hönekopp [a,*], John T. Manning [b], Constanze Müller [a]

[a] Department of Psychology, Technische Universität Chemnitz, Germany
[b] Department of Psychology, University of Central Lancashire, Preston, UK

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Abstract

It has been suggested that male achievement in sports and athletics is correlated with a putative measure of prenatal testosterone the 2nd to 4th digit ratio (2D:4D). It is not known whether this association also extends to females, or whether the association results from an effect of testosterone on behavior (such as exercise frequency) or on physical fitness. Here, we report for the first time data from two studies which consider associations between 2D:4D and physical fitness in females in addition to males: Study I—in a sample of teenage boys (n = 114) and girls (n = 175), their 'physical education grade' was negatively associated with 2D:4D of the right hand (boys), and right and left hand (girls), and Study II—among a sample of young men (n = 102) and women (n = 77), a composite measure of physical fitness was negatively related to right hand 2D:4D in men and left hand 2D:4D in women. We conclude that 2D:4D is negatively related to physical fitness in both men and women. In Study II, there was evidence that the relationship between physical fitness and 2D:4D in men was mediated through an association with exercise frequency. Thus, 2D:4D in males may be a negative correlate of frequent exercise which then relates to achievement in sports and athletics.

Keywords: Digit ratio; 2D:4D; Physical fitness; Sexual selection

Introduction

It has been suggested that direct competition among men for women or for resources which attract women (i.e., intra-sexual selection) may account for sex differences in sports and athletic performances (Manning and Taylor, 2001). Men and women are sexually dimorphic in athletic abilities such as running speed, with men showing speeds which are about 12% faster over a range of distances (Coast et al., 2004). The male advantage in sport and athletics may arise in part from sex differences in such variables as maximal oxygen uptake (VO2max), anaerobic threshold, and running economy (Helgerud, 1994; Helgerud et al., 1990). However, the physiological factors which underlie this male advantage are probably multifactorial and could include the influence of behaviors such as male competitiveness in the frequency and intensity of exercise. For example, the sex difference in VO2max may be due in part to higher frequency of exercise in the former compared to the latter or to genetically influenced factors such as sex-dependent differences in amounts of hemoglobin in the blood. The influence of multiple factors on physical fitness is illustrated by the work of Cureton et al. (1986) who found that equating hemoglobin concentration between the sexes by removal of blood from male participants did not completely remove the sexual dimorphism in VO2max. They concluded that the sex difference in hemoglobin volume accounted for a significant but small proportion in the dimorphism of VO2max with other sex-dependent factors such as the dimensions of the oxygen transport system and size of musculature being more important.

The multifactorial nature of the male advantage in sports and athletics is very likely to arise as the result of the organizational (prenatal) or activational (adult) effects of testosterone on the brain and/or on the vascular system including the heart. One possible correlate of prenatal testosterone is the relative lengths of the 2nd (index finger) and 4th (ring finger) digits (2D:4D). 2D:4D is thought to negatively correlate with fetal testosterone because (i) 2D:4D is sexually dimorphic with lower ratios in

* Corresponding author.
E-mail address: johannes.hoenekopp@phil.tu-chemnitz.de (J. Hönekopp).

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males compared to females (Manning et al., 1998; Peters et al., 2002), (ii) the sexual dimorphism in 2D:4D is seen in prepubertal children (Manning et al., 2004), (iii) the 2D:4D of children is strongly correlated with their adult 2D:4D (Trivers et al., in press), (iv) the sexual dimorphism in 2D:4D of infants explains up to 20% of the variance in 2D:4D of adults (McIntyre et al., 2005), (v) children with congenital adrenal hyperplasia (CAH is an enlargement of the adrenal glands which results in high prenatal androgen) have lower mean 2D:4D than controls (Okten et al., 2002; Brown et al., 2002; but see Buck et al., 2003), (vi) females from opposite-sex twins are thought to be affected by testosterone from their male twin and such females have lower 2D:4D ratios than controls (Van Anders et al., in press), (vii) 2D:4D is positively correlated with insensitivity to androgen as determined by the number of CAG repeats in the androgen receptor gene. In this gene, the length of the CAG repeat chain is inversely correlated with testosterone sensitivity, and CAG number is positively related to 2D:4D (Manning et al., 2003a), (viii) the ratio of fetal testosterone to estrogen obtained from routine amniocentesis has been reported to be negatively related to 2D:4D in children (Lutchmaya et al., 2004).

The 2D:4D ratio has been reported to be negatively correlated with male performance in soccer, running, and slalom skiing (Manning, 2002a,b; Manning and Taylor, 2001). High performance in sports and athletics may result from a number of attributes, e.g., visuo-spatial ability, competitiveness in training, and high physical fitness. The latter two factors are likely to interact. Here, we test associations between 2D:4D and measures of physical fitness in German populations including (i) teenagers taken from schools and (ii) young adults sampled from universities and the general population. Because Manning and colleagues have not considered associations between 2D:4D and athleticism in females, and because testosterone may have broadly similar effects on men and women, we consider for the first time female associations between 2D:4D and athleticism.

Materials and methods

General methods

Assessment of 2D:4D

We took digital photographs from the ventral surfaces of both hands. Participants lightly pressed their stretched hands against a glass plate, which was perpendicularly mounted on a table top. Photographs were taken through the glass plate. Finger lengths were measured from the tip of the finger to the crease proximal to the palm. Three independent raters unaware of all other data measured all finger lengths using Morph Man 2.01 software, which allows storing the coordinates of specified points. In all three samples, the reliability of 2D:4D measurements was high (Cronbach's alpha from 0.91 to 0.96). We base all 2D:4D analyses on the mean across the three measurements.

Statistical analysis

We used independent-samples t test to investigate mean differences between females and males. We used first-order correlations to analyze relationships between two variables (particularly, between indicators of physical fitness and right hand or left hand 2D:4D). We used stepwise regression analyses and partial correlation analyses to test if third variables affected these relationships. Whenever we had clear hypotheses about the direction of effects (female 2D:4D > male 2D:4D; negative first-order correlations between either right hand or left hand 2D:4D and measures of physical fitness), we employed one-tailed tests of significance. All values reported are mean ± SD.

Study 1

Participants

The sample consisted of 289 11th graders (175 girls) from six Gymnasiums in Chemnitz (gymnasiums are about equivalent to British grammar schools). The girls and boys took part in a study on intelligence in adolescents to be reported elsewhere. Age was 16.9 ± 0.6 years for females and 17.2 ± 0.7 years for males. All participants and teenagers' parents gave their informed consent. All children were Caucasian.

Assessment of physical fitness

Participants reported their physical education grade (henceforth *PE grade*; 15 = best, 0 = worst) from their most recent school certificate. This grade pertained to a course that offered pupils some choice regarding the kind of exercises to be engaged in. Thus, PE grades reflected attainment levels in a variety of physical activities.

Study 2

Participants

Study 2 comprised two samples. The female sample consisted of 77 women (age 20.1 ± 1.9 years), who were recruited at Westfälische Wilhelms-Universität, Münster (Germany). Hönekopp et al. (2004) previously reported about facial attractiveness and physical fitness in this sample. The male sample consisted of 102 men (age 22.4 ± 1.3 years) recruited in Chemnitz (Germany). 80% of them were local university students, and 20% were local residents. Hönekopp et al. (in press) previously reported about 2D:4D and number of sex partners in this sample. All participants were Caucasian. The participants gave their informed consent.

Assessment of physical fitness

Physical fitness was measured by the Haro fitness test (Haag, 1981). This gym-based test consists of six exercises that require running and crawling beneath an obstacle; sit ups; repeated jumps over a hurdle; push ups; running and repeatedly picking up a rope from the floor; and throwing a basket ball repeatedly while lying on the belly. Each exercise lasted 30 s; exercises were separated by breaks of 120 s. For each Haro exercise, there is a scoring rule easy to apply; the six single scores are summed into a total score, which we denote PF (for physical fitness).

Assessment of potential confounds

We asked participants for their age, weight and height, how much they smoked and how much they exercised. We considered these variables and Body Mass Index (BMI) as potential confounds of physical fitness.

Statistical analysis

In addition to the analyses mentioned above, we entered the six single exercise scores and dummy-coded sex into a principal component analysis. We did so to check (i) whether the six diverse exercises can be regarded as indicators of the same construct 'physical fitness' and (ii) whether this construct differentiates between females and males.

Results

Study 1

2D:4D was 0.974 ± 0.031 for females' right hands, 0.992 ± 0.027 for females' left hands, 0.953 ± 0.035 for males' right hands, and 0.972 ± 0.032 for males' left hands. Thus, females showed higher 2D:4D than males in the right ($t(287) = 5.3$, $P < 0.0001$) and in the left hand ($t(286) = 4.9$, $P < 0.0001$). (One girl had no left hand, which is why *df* is lower in the second analysis). As expected, right hand and left hand 2D:4D significantly correlated in girls ($r = 0.52$, $P < 0.0001$) and in boys ($r = 0.56$, $P < 0.0001$).

PE grade was 10.9 ± 2.4 in girls and 10.9 ± 2.7 in boys. Of course, PE grades must not be used to compare the physical fitness of girls and boys because evaluation criteria are sex specific.

In girls, PE grade significantly correlated with 2D:4D in the right hand ($r = -0.17$, $P = 0.013$) and in the left hand ($r = -0.16$, $P = 0.016$). When both digit ratios where entered into a stepwise regression analysis to predict physical education grade, only right hand 2D:4D was incorporated in the solution but not left hand 2D:4D (partial $r = -0.09$, $P = 0.241$).

In boys, PE grade significantly correlated with right hand ($r = -0.19$, $P = 0.021$) but not with left hand 2D:4D ($r = -0.12$, $P = 0.100$). Fig. 1 shows the relationship between right hand 2D:4D and PE grade for girls and boys, respectively.

Study 2

2D:4D was 0.961 ± 0.030 for females' right hands, 0.961 ± 0.027 for females' left hands, 0.958 ± 0.034 for males' right hands, and 0.966 ± 0.035 for males' left hands. Thus, females did not show higher 2D:4D than men (right hand: $t(177) = 0.7$, $P = 0.245$). The sexual dimorphism in 2D:4D is so well established that the lack of a dimorphism may be the result of sampling effects. For example, mean 2D:4D differs geographically (Manning, 2002a) and also in relation to academic ability (Romano et al., in press). Thus, the 500 km distance between Münster and Chemnitz may account for the absence of a sex difference, or the fact that the Münster sample was made up entirely of undergraduates, while the Chemnitz sample contained some 20% of participants who were not students. The fact that digit ratios were almost identical in both male Chemnitz samples supports the first possibility. As expected, right hand and left hand 2D:4D significantly correlated in women ($r = 0.68$, $P < 0.0001$) and in men ($r = 0.68$, $P < 0.0001$).

The principal component analysis yielded a one-factor solution. The factor explained 73% of the variance in the data. All six exercise scores and dummy-coded sex loaded strongly (≥0.75) on that factor. We thus conclude that (i) all six exercises, although diverse, can be regarded as indicators of the same construct 'physical fitness', and PF is a valid indicator of this construct; (ii) this construct differentiates between females and males. Accordingly, PF was higher in males (174.7 ± 19.5) than in females (122.2 ± 15.9; $t(177) = 19.3$, $P < 0.0001$).

In females, left hand ($r = -0.32$, $P = 0.003$) but not right hand 2D:4D ($r = -0.16$, $P = 0.08$) significantly correlated with PF (see Fig. 2, left hand panel). Among the potential confounds of PF, only hours exercising per week proved significant ($r = 0.27$, $P = 0.017$). When hours of exercising and left hand 2D:4D were entered into a stepwise regression analysis, both variables independently explained PF (total model: $F_{2,74} = 8.3$, $P = 0.001$, $R^2 = 0.18$; left hand 2D:4D: standardized $\beta = -0.33$, $P = 0.002$; hours exercising: standardized $\beta = 0.29$, $P = 0.007$).

In males, right hand ($r = -0.18$, $P = 0.037$) but not left hand 2D:4D ($r = -0.16$, $P = 0.057$) significantly correlated with PF (see Fig. 2, right hand panel). Among all potential confounds of PF, only hours of exercising ($r = 0.38$, $P = 0.0001$) and number of cigarettes smoked per week ($r = -0.30$, $P = 0.003$) were significantly related to PF. When smoking, exercising, and right hand 2D:4D were entered into a stepwise regression analysis, only exercising and smoking were incorporated into the model to predict PF (total model: $F_{2,99} = 11.5$, $P < 0.001$, $R^2 = 0.19$; exercising: standardized $\beta = 0.33$, $P = 0.001$; smoking: standardized $\beta = -0.22$, $P = 0.023$; right hand 2D:4D: partial $r = -0.13$, $P = 0.21$). When only exercising and right hand 2D:4D were entered into the stepwise regression analysis (which is the same analysis as in the female sample), 2D:4D was again not incorporated into the model (partial $r = -0.14$, $P = 0.18$). Thus, in males, the effect of prenatal androgenization on PF appears to act (at least partly) via exercising habits. In females, however, this effect was not apparent. The correlation between left hand 2D:4D and PF did not diminish when hours of exercising per week was controlled for.

There was a strong sex difference in PF. In order to examine to what extent 2D:4D, exercise frequency, height and weight mediate the sexual dimorphism in PF we pooled the male and

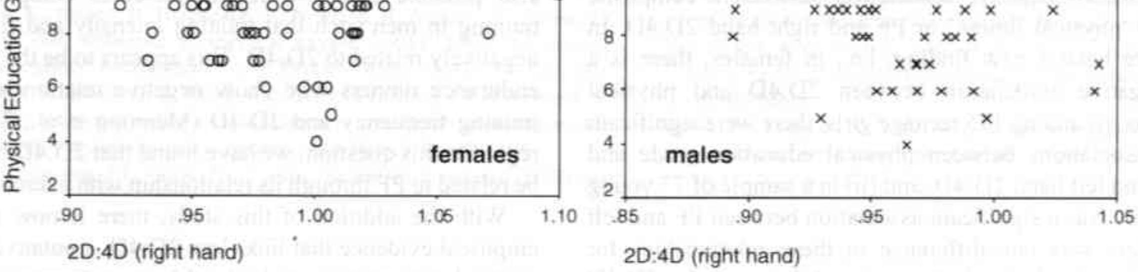

Fig. 1. Relationship between right hand 2D:4D and physical education grades (higher = better) in a teenage sample (with line of best fit).

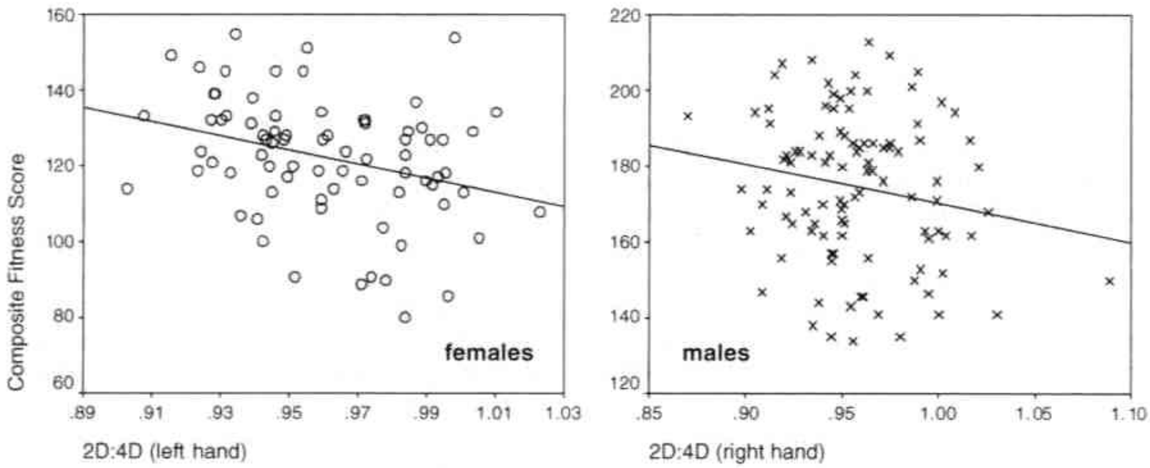

Fig. 2. Relationship between 2D:4D and composite fitness score (PF) in a sample of young adults (with line of best fit).

female data, coded sex as a dummy variable (female = 1, male = 2) and examined relationships using partial correlation analysis. We ran two sets of analyses. In the first set, we looked at PF's relationships with right hand 2D:4D, sex, height, weight, and exercise frequency. For each of these five correlations, the four remaining variables were controlled for (thus, $df = 169$ in all subsequent analyses). The second set of analyses differed from the first set in that not right hand but left hand 2D:4D was considered. Sex remained the strongest correlate of PF for both the right and left hand analysis (in both cases $r = 0.75$; $P = <0.001$). In both sets of analyses, we found relationships of PF with exercise frequency (in both cases $r = 0.38$, $P < 0.001$) and 2D:4D (right: $r = -0.17$, $P = 0.015$; left: $r = -0.21$, $P = 0.003$; one-tailed testing in both cases). In neither set of analyses, a relationship between PF and height (right: $r = -0.05$, $P = 0.54$; left: $r = -0.03$, $P = 0.68$) or weight (right: $r = -0.05$, $P = 0.54$; left: $r = -0.03$, $P = 0.68$) showed.

Discussion

We have found support for a negative relationship between 2D:4D and measures of physical fitness in males. This is in accord with previous findings of negative associations between 2D:4D and performance in soccer, running, and skiing (Manning, 2002a,b; Manning and Taylor, 2001). Thus, we have found (i) in a sample of 114 teenage boys that there was a significant negative association between physical education grade and right 2D:4D, and (ii) among 102 young men, there was a significant negative association between a composite measure of 'physical fitness' or PF and right hand 2D:4D. In addition, we have a new finding, i.e., in females, there is a similar negative association between 2D:4D and physical fitness. Thus, (i) among 175 teenage girls, there were significant negative associations between physical education grade and both right and left hand 2D:4D, and (ii) in a sample of 77 young women, there was a significant association between PF and left 2D:4D. There was one difference in these relationships for males and females. In Study 2, we found that in males 2D:4D acts, at least in part, through frequency of exercising. In women, this effect was not apparent. Analysis of the pooled data in Study 2 showed that sex, exercise frequency, and 2D:4D were independent correlates of PF. The sexually dimorphic traits of height and weight were not strongly related to PF.

Our data support the possibility that an association between low 2D:4D and sports and athletic achievement results at least in part from the action of prenatal testosterone on such achievement. For prenatal testosterone to have this effect, it may improve the efficiency of the heart and vascular system, and/or it may influence behaviors which impact on sports achievement such as frequency of exercise (Manning and Taylor, 2001). With regard to the first possibility, the frequency of heart disease is higher in men than in women, and the use of testosterone by athletes and bodybuilders is associated with an increased risk of heart disease (reviewed by Rosana, 2000). This has led to the popular belief that testosterone is associated with factors which may result in early heart attack or myocardial infarction (MI) and angina. However, male MI patients and men with coronary artery disease often have lower serum testosterone levels than age-matched healthy controls, and testosterone has been used to treat coronary artery disease (Rosana, 2000; English et al., 2000). In addition, there is evidence that low 2D:4D is associated with late age of presentation of MI in men, and this has been suggested to support a link between high prenatal testosterone and the efficiency of the heart (Manning and Bundred, 2001; Manning et al., 2003b). In addition, neck circumference, a positive predictor of heart disease, is positively related to 2D:4D in men (Fink et al., in press). However, it is also possible that low 2D:4D increases competitiveness in training in men such that training intensity and frequency are negatively related to 2D:4D. This appears to be the case in male endurance runners who show negative relationships between training frequency and 2D:4D (Manning et al., 2003b). With regard to this question, we have found that 2D:4D in males may be related to PF through its relationship with exercise frequency.

With the addition of this study, there is now considerable empirical evidence that links low 2D:4D, a putative measure of prenatal testosterone, to high athletic performance (Manning, 2002a,b; Manning and Taylor, 2001; Manning et al., 2003b).

These results suggest that male–male competition may have been an important selection pressure in the evolution of the sex difference in prenatal testosterone. This may be because there are many aspects of sport and athletics which appear to mimic the abilities required in male–male fighting and competition. Kicking, punching, throwing, and running are all common components of sports and athletic disciplines. Of course prenatal testosterone is not the only influence on male–male competition. Our finding that sex and exercise frequency are independently related to PF suggests that genetic differences and adult testosterone are also important in the evolution of intra-sexual conflict behaviors. On the other hand, we found that height and weight are not strongly related to PF, indicating that their influence does not remove the effect of exercise frequency. This finding appears contrary to the notion that behavioural sex differences arise not from sex hormones but as the indirect result of cultural responses to physical sex dimorphisms such as height and weight (Wood and Eagly, 2002).

In conclusion, we suggest that aspects of sport and athletics mimic behaviors which are important in male–male fighting. Performance in these behaviors is important in the overall performance levels of many sports. We therefore suggest that our finding of a negative association between 2D:4D and physical fitness is best interpreted within an evolutionary framework of intra-sexual selection. The protection against early MI that high prenatal testosterone appears to offer (Manning and Bundred, 2001) may then be seen as a by-product of the selection for high male–male competitive ability.

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