Digit Ratio (2D:4D) and Rowing Ergometer Performance in Males and Females

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ABSTRACT Fetal and adult testosterone may be vital in the establishment and maintenance of sex-dependent abilities associated with male physical competitiveness. It has been shown that digit ratio (2D:4D) is negatively associated with prenatal testosterone, and it is also negatively associated with ability in sports such as football, skiing, middle distance running, and endurance running, which are dependent upon an efficient cardiovascular system. The relationship between digit ratio and sports requiring high power (physical strength) output in addition to well-developed cardiovascular systems has not been defined. This study investigated this association in male and female young adult rowers. Participants (77 male and 70 female) were student rowers encompassing a range of abilities from the University of Cambridge. Bilateral digit measurements were taken blind from each subject using Mitutoyo vernier calipers. Rowing performance over 2,000 m was assessed using the Concept 2 rowing ergometer. Significant negative correlations were observed between 2,000 m ergometer performance and male digit ratios, which persisted following adjustment for rowing experience and height. However, no such significant association was found in females despite a comparable sample size. Our data indicate that digit ratio is a predictor of ability in rowing, a sport which requires both cardiovascular efficiency and high power output, in males but not females. This in turn suggests that fetal testosterone exposure has long-term effects on traits associated with physical power in males but not females, suggesting a sex-difference in the capacity to respond to such exposures. Am J Phys Anthropol 144:337–341, 2011.

Since Baker's (1888) initial investigation into the sexually dimorphic nature of digit ratio (2D:4D), much work has been performed to explain the phenomena. Although evidence for a link between prenatal androgenization and digit growth is indirect due to the complexities associated with obtaining direct data, various studies have compiled persuasive evidence that such a link exists (see below). In turn, digit ratio is increasingly used as a proxy for fetal hormonal environment, to investigate early life predictors of later phenotype, and sex differences therein. We briefly summarize the evidence for the fetal origins of digit ratio variability, its association with later phenotypic traits, and the use of sport as a valuable arena for testing evolutionary hypotheses regarding digit ratio and intrasexual competition.

The ontogenetic development of digit ratio variability

Evidence supporting the establishment of digit ratio early in prenatal development has been provided by Galis and Van Dongen (2009), who analyzed the finger lengths of deceased human fetuses (14 to 42 weeks old), and showed a significant sexual dimorphism in the 2D:4D ratio, with males exhibiting a lower ratio. Prenatal androgens have been identified as a possible stimulant of this prenatal digit development. Homeobox genes have been found to control the development of both the urinogenital system and fingers (Kondo et al., 1997; Mortlock, 1997), implying a link between prenatal androgen exposure and digit growth.

Further evidence for such a link has arisen through understanding of congenital adrenal hyperplasia (CAH), an inherited condition which affects the adrenal glands, resulting in excessive androgen exposure in the gestational period. Males and females with CAH have significantly smaller 2D:4D ratios than members of the respective sex without CAH. This supports the evidence that digit ratio is established by intrauterine androgen levels, and proposes that finger lengths may therefore offer a retrospective marker of prenatal androgen exposure (Brown et al., 2002; Okten et al., 2002).

Lutchmaya et al. (2004) provided evidence for a direct relationship between fetal hormones and 2D:4D ratio (measured at age 2 years) through the analysis of amniotic fluid. This study revealed a significant negative relationship between right hand digit ratio and the ratio of fetal testosterone/fetal estrogen, supporting previous findings (Wilson, 1981) that high estrogen levels are associated with high digit ratios and suggesting that estrogen may stimulate the *in utero* growth of the second

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digit. There is therefore an association between low digit ratio and high androgen exposure, and between high digit ratio and low androgen exposure, and further work is required to ascertain which of these hormones is of greater importance.

Although it has been suggested that digit ratio may not provide a reliable representation of individual differences in prenatal androgen exposure (Berenbaum et al., 2009), and that the sex differences in digit ratio between males and females could be exaggerated by size differences (Kratochvil and Flegr, 2009), the majority of evidence suggests digit ratio is a valid and useful tool for study. Hoenekopp et al. (2007) conducted a meta-analysis of data suggesting associations between fetal and hormone levels and digit ratio. The review, together with new data from two nonclinical samples, reported that digit ratio is not associated with adult sex hormone levels, thus supporting the validity of 2D:4D as a suitable instrument for investigating effects of prenatal androgen exposure on subsequent phenotype.

There is evidence that digit ratios correlate positively with male reproductive success, while high digit ratios correlate positively with female reproductive success (Manning et al., 2000). These results supported earlier observations that low digit ratios are associated with high sperm counts and testosterone levels (Manning, 1998) in men, and conversely, that high digit ratios are associated with high estrogen and luteinizing hormones in women (Manning, 1998). A large multinational study (Manning et al., 2000) confirmed the earlier work showing that 2D:4D ratio predicts reproductive success once the effects of age and population have been removed. Thus, digit ratio variability emerging in early life has significant implications for fitness.

Sport as a proxy for male–male competition

In this context, digit ratio may offer insight into male–male competition, which in the contemporary environment may be investigated through studies of athletes (Manning, 2001). General characteristics of successful athletes include visual-spatial awareness, speed, endurance, and strength. For example, elite footballers require spatial judgment, cardiovascular efficiency, speed, and occasionally strength. All of these qualities would be beneficial in direct male–male competition. In addition, the observation that there often exists intense rivalry between opponents on a sports field adds to the viability of sport being seen as a proxy for male combat. The behavioral limits as dictated by the rules of sporting events are constantly tested by competitors, to the point where an official with total control is almost always required to police the contest (Manning and Taylor, 2001). Furthermore, the monetary and status rewards of achieving sporting success can often make the athletes more desirable to members of the opposite sex. It follows that sport mirrors intrasexual selection in that being successful in competition between males leads to the acquisition of resources which in turn promotes access to females.

To date, athletic ability has been linked to digit ratios in a variety of sports. Pokrywka et al. (2005) found that female elite athletes in a range of sports had significantly lower 2D:4D digit ratios when compared to a control group of females not involved in sporting activities. Similarly, Paul et al. (2006) demonstrated that participation in the highest levels of sport (competition at national level at least) was significantly and negatively associated with digit ratio, with the strongest correlations being found in the analysis of running ability.

The same patterns have been found with male athletes, again encompassing a variety of sporting disciplines. Ability in slalom skiing (Manning, 2002) was found to significantly correlate with digit ratio. The study found that skiers had lower digit ratios than nonskiers, and that the skiers with the lowest digit ratios recorded the fastest times over a 200-m slalom course. Similarly, an extensive study into English professional football (Manning and Taylor, 2001) found that first team players had lower mean 2D:4D ratios than reserve players, and that that the tested international players had lower mean 2D:4D ratios than players yet to play internationally. The authors provided early evidence that prenatal androgen exposure may enhance development of the cardiovascular system, as later suggested by Pokrywka et al. (2005). Further work, considering endurance running, found that men with low 2D:4D ratio tend to run faster than men with high 2D:4D ratio, and that digit ratio explained up to 25% of variance in endurance running (Manning et al., 2007). This value is significantly greater than the figure of 10% reported for other sports which require a combination of strength and aerobic efficiency (Manning and Taylor, 2001). This study was significant as male endurance running may have been an important method of hunting in early populations of the genus *Homo*. If this was the case, a link between endurance running ability and prenatal testosterone may have resulted in selection for increased androgenization. If so, it would follow that digit ratio could explain more of the variation in endurance running ability than it does for measures of physical fitness that require strength in addition to aerobic efficiency.

It is not yet known, however, if the association between digit ratio and sporting performance is only related to well-developed cardiovascular systems, or if the list of associated traits is more extensive. Further characteristics may include the ability of muscle to generate power. This may be an important factor, as it has been shown that a positive relationship exists between maximal aerobic capacity and physical strength and performance in elite soccer leagues (Wisloff et al., 1998), and that young elite players have higher isometric strength than nonelite players (Hansen et al., 1999). In addition, an investigation considering elite skiers (Neumayr et al., 2003) reported that two main factors are crucial in success at international level: high levels of aerobic capacity and muscle strength. However, the most compelling suggestion for a link between 2D:4D and strength is the relationship reported with hand-grip strength (Fink et al., 2006), as hand grip strength is correlated to strength in other muscle groups.

Aims of the study

The purpose of this study was to investigate the association between digit ratio and aerobic capacity, as well as the possible link to strength, through use of the sport of rowing. Rowing was deemed appropriate because 70–79% of the energy required to row the standard 2,000 m distance is aerobic, with the remainder being anaerobic (Secher, 1990). At the same time, the strongest correlate of performance of the rowing ergometer is the power output of the rower at $VO_{2\ Max}$ (Ingham, 2002). A massive 98% of the variation in performance over 2,000 m is explained by power output at $VO_{2\ Max}$, maximal power and power at a blood lactate concentration of 4 mmol/l

TABLE 1. Descriptive characteristics of the subjects

	Males (n = 77)			Females (n = 70)		
	Mean	SD	Range	Mean	SD	Range
2,000 m time (s)	413	30.4	363–501	496	31.7	458–571
Height	186	5.45	172–197	171	6.94	151–195
Years rowed	2.92	1.89	1–10	2.10	1.50	1–9
Age	21.7	3.29	18–39	20.7	3.08	19–33
Right 2D:4D	0.972	0.0345	0.895–1.07	0.985	0.0285	0.919–1.04
Left 2D:4D	0.974	0.0351	0.905–1.05	0.992	0.0299	0.915–1.07

(the concentration at which the onset of blood lactate accumulation occurs). Success in the sport of rowing therefore requires the characteristics of power and cardiovascular efficiency. When the associations between digit ratio and performance over 2,000 m on the rowing ergometer are weak, it may suggest that the extent of physiological associations with digit ratio is limited to the cardiovascular system. Conversely, if a strong relationship exists, digit ratio may then relate to power output and strength in addition to cardiovascular development.

METHODS

The participants in the study were 77 male and 70 female student rowers from The University of Cambridge, with testing being carried out in Cambridge, UK. Ethical approval for the study was given by the Cambridge University Human Biology Ethics Committee.

Finger lengths were measured blind to ergometer performance. The subjects were asked to place their hands on a flat surface, straightening their fingers with the palm facing upwards. Measurements were taken bilaterally (Manning et al., 2007) from the tip of the finger to the center of the digit crease proximal to the palm using Mitutoyo vernier calipers (Manning et al., 2008) accurate to 0.01 mm. Each measurement was taken blind (the measurer was not able to see the digital measurement display while setting the calipers) twice, with the mean average of the two being used in analysis. 2D:4D ratio was calculated separately for each hand.

The simplest and most accurate metric to use in assessing rowing potential is the rowing ergometer. This device is useful to rowers and coaches because it facilitates training when it is not possible to row on water, and provides a controllable and reproducible tool to use in the assessment of rowing performance. The Concept 2 machine (manufactured by Concept 2, Vermont, USA) and its standard fitness test over 2,000 m are ubiquitous throughout the rowing world and the clubs of the University of Cambridge. It is for these reasons that personal best score over 2,000 m (as reported by rowers' coaches, to the nearest 0.1 s, with a drag factor of 130–135) was used as the metric by which rowing ability was assessed in this study. (This assumes the machines provide identical data for a given rowing performance, an assumption which was impossible to test in practice).

In addition to digit lengths and 2,000 m performance, participants' age, height, and consecutive years rowed were also recorded, as these factors were considered to be of possible importance in the determination of 2,000 m ergometer performance.

Statistics

Differences between the sexes were tested using independent-sample t-tests. Crude associations between predictors and rowing performance were explored in each sex using correlation analysis. Multiple regression analysis was then used to investigate the same associations, adjusting for the possible confounders.

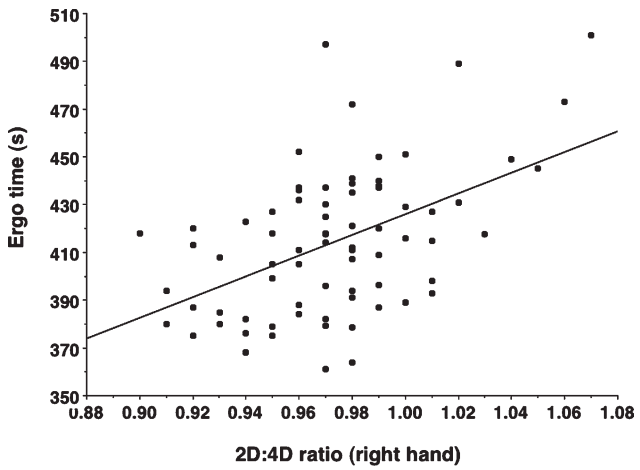

Fig. 1. Scatter plot of male right hand 2D:4D ratio versus 2,000 m ergometer performance (seconds).

RESULTS

Digit lengths from the first measurement were strongly correlated with the lengths recorded from the second measurement for the individual subject (all $r \geq 0.95$). In addition, the means of right and left hand digit ratios were significantly positively correlated (male $r = 0.66$, $P < 0.001$; female $r = 0.48$, $P < 0.05$). These associations allowed confidence in the reliability of the measurement of digit ratio, and therefore in the conclusions reached.

A description of the male and female samples is given in Table 1. Males were significantly taller, and had significantly lower digit ratios, but did not differ from females in age or years of rowing experience. Both male and female samples shared a similar ability range.

Among the male subsample there was a significant positive correlation between right hand 2D:4D and 2,000 m time ($r = 0.50$, $P < 0.001$; Fig. 1), and between left hand 2D:4D and 2,000 m time ($r = 0.37$, $P < 0.001$).

In addition, there were significant negative correlations between height and 2000 m time ($r = -0.33$, $P = 0.003$), and between years rowed and 2,000 m time ($r = -0.47$, $P < 0.001$). Regression analysis, controlling for height and experience, revealed that for every standard deviation increase in male right hand digit ratio, the 2,000 m time increased by 9.1 s, with 13.3% of variance in ergometer performance being explained by right hand digit ratio. Similarly, for every standard deviation

TABLE 2. Regression of rowing time in seconds on digit ratio, rowing experience, and height

	B	Standard error	*t*-value	*P*-value
Right hand				
Constant	763.114	87.386	8.733	0.000
Height	−1.804	0.468	−3.854	0.000
Years rowed	−4.980	1.443	−3.452	0.001
FA Z-score	7.325	2.672	2.741	0.008
R 2D:4D Z-score	9.110	2.759	3.302	0.002
Left hand				
Constant	788.908	90.935	8.676	0.000
Height	−1.929	0.488	−3.955	0.000
Years rowed	−5.905	1.446	−4.085	0.000
FA Z-score	7.346	2.836	2.590	0.012
L 2D:4D Z-score	6.204	2.812	2.206	0.031

Male right hand: R-square = 0.52; SEE = 21.79. Male left hand: R-square = 0.48; SEE = 22.64.

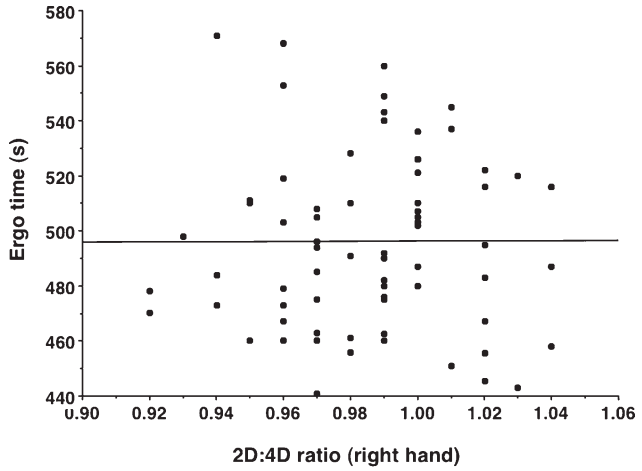

Fig. 2. Scatter plot of female right hand 2D:4D ratio versus 2,000 m ergometer performance (seconds).

increase in male left hand digit ratio the 2,000 m time increased by 6.2 s, with 6.4% of variance in ergometer performance explained by left-hand digit ratio (Table 2).

Among the female subsample, there were no significant correlations between either right hand or left hand 2D:4D and 2,000 m performance (right hand $r = 0.031$, $P = 0.798$, left hand $r = -0.038$, $P = 0.755$) (Fig. 2). There was a significant negative correlation between height and 2,000 m time ($r = -0.51$, $P < 0.001$), and between years rowed and 2,000 m performance ($r = -0.29$, $P = 0.15$). Multiple regression analysis confirmed the lack of a significant association between digit ratio and ergo time (Table 2).

DISCUSSION

The results revealed statistically significant positive correlations between right hand and left 2D:4D and 2,000 m rowing time among males, i.e., low (more masculine) digit ratio is related to better performance. In contrast, no meaningful relationships were found between digit ratio and ergometer performance in female participants. These findings have implications for our understanding of the development of phenotypic characteristics associated with intrasexual competition.

The sporting disciplines that have so far been linked to digit ratio share a common characteristic; they are all heavily dependent upon a well-developed cardiovascular system. Examples include football, which requires a "sustained demonstration of cardiovascular efficiency" (Manning, 2001), skiing that requires large amounts of energy to be released via the aerobic system (Tesch, 1978), and endurance running that both depend significantly upon aerobic energy systems (Lacour, 1990). As a significant portion of energy release in rowing is aerobic (Secher, 1990), this study is in accordance with the suggestion of Pokrywka et al. (2005); that prenatal androgen exposure may enhance development of the cardiovascular system.

The findings presented in this article show that low (more masculine) digit ratios are related to better performance in a discipline requiring major energetic contributions from both aerobic and anaerobic systems (Ingham, 2002). This supports previous work that has found an association between sports requiring high levels of aerobic capacity and muscle strength, namely skiing and football (Wisloff et al., 1998; Hansen et al., 1999; Manning and Taylor, 2001; Manning, 2002; Neumayr et al., 2003).

The strengths of our associations (0.50 and 0.37 for right and left 2D:4D, respectively) are similar to that of the relationship between 2D:4D and endurance running ($r = 0.35$–0.50; (Manning, 2007). While Manning and Hill (2009) have suggested that the widespread relationships between 2D:4D and sports performances may have more to do with aerobic efficiency than strength, the results reported here provide some support for a link with measures of power. An explanation for the lack of significant relationship in females, a result that does not support the findings of Hoenekopp and Schuster (2010), may simply be that power is not under either natural or sexual selection in women.

The outcome of this study suggests there may be a link between early-life androgen exposure and the precursors required for the generation of muscular strength in men, in addition to a possibly stronger link to a well developed cardiovascular system. Perhaps, as well as promoting development of the cardiovascular system, fetal androgen exposure is a precursor to muscle growth, or alternatively to muscle metabolism and hence function. This could lead to increased power generation and be beneficial in anaerobic power based sports such as power lifting. Another possible explanation is a system of positive developmental feedback between increased fetal androgen, aerobic capacity and exercise or muscular activity during development. Such a system could arise from low 2D:4D ratio, causing better sporting ability during development (childhood and adolescence) and resulting in sports being enjoyed and therefore practiced more, leading to enhanced performance.

However, this study is insufficient for any conclusions to be drawn on this matter as it may be the aerobic aspect of rowing that caused the relationship with digit ratio, rather than strength. More research, particularly in sports requiring physical strength and not aerobic capacity, needs to be performed.

The main weakness of this study was the use of personal best times obtained from different machines, as it is possible that minor differences between individual ergometers could influence the data obtained. However, the Concept 2 rower is a high-quality piece of equipment, which is used in rowing competitions and is ubiquitous in the training regimes of Olympic rowing squads throughout the world. Although it was not possible to

practically ensure that identical rowing performances resulted in identical ergometer times, the authors are confident that the results were not be adversely affected by such variation.

To conclude, this investigation has shown that digit ratio has for the first time been significantly and positively correlated with levels of attainment in a sporting discipline requiring major energetic contributions from both the aerobic and anaerobic systems. This suggests there may be a link between androgen exposure and the precursors required for the generation of muscular strength in men, in addition to a well-developed cardiovascular system.

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