Anthropological Review
Available online at: https://doi.org/10.18778/1898-6773.85.2.07

2D:4D digit ratio and its relationship to BMI, sporting choices and physiological predispositions among women

Agnieszka Tomaszewska, PhD, Julia Anna Lubońska MSc

Department of Anthropology, Institute of Environmental Biology, Wrocław University of Environmental and Life Sciences Kozuchowska Street 5, 51-631 Wroclaw

Abstract: The 2D:4D digit ratio has been established as a biomarker of the level of exposure to prenatal sex hormones' balancebetween prenatal testosterone (PT) and estrogenne levels. Higher 2D:4D indicates lower PT exposure and vice versa. Data suggests that PT exposure is linked to a risk-taking attitude and physical aggressiveness, both of which are requirements in contact sport. A possible correlation between 2D:4D and human body mass index has also been identified. The aim of the study was to examine the relation between 2D:4D ratio and choice of sport. It was assumed that female soccer players who choose a contact sport would have a lower 2D:4D ratio (thus experiencing higher exposure to PT) than female volleyball players (selecting non-contact sport). The analysis was also aimed at identifying whether a correlation between prenatal testosterone level and BMI exists. The participant sample consisted of 103 women – 36 volleyball players, 33 soccer players and a control group (N=34). Measurements were collected in 2019–2020. The results suggest that 2D:4D was significantly different in women practicing various sports (contact and non-contact sports). Women engaged in contact sports had lower 2D:4D than women engaged in non-contact sports, and vice versa ($p<0.05$). 2D:4D correlated positively with BMI and body weight – the higher the 2D:4D ratio, the higher the BMI and body weight (and vice versa) ($p<0.05$). Low 2D:4D (high PT exposure) may predict the choice of more risky, aggressive contact sports, and vice versa. High 2D:4D may predict a higher BMI and body weight, and *vice versa*.

Key words: contact sport, non-contact sport, volleyball, soccer, prenatal testosterone, weight

Original article

Received: 11.10.2021; Revised: 12.05.2022; Accepted: 19.05.2022

Introduction

The digit length ratio 2D:4D has repeatedly featured as an object of study. The latter is a ratio of the index finger length (2D) and ring finger length (4D) (Manning et al. 2014). The value of digit length ratio is a biomarker of prenatal sex hormones' balance between testosterone and estrogene levels. A high level of prenatal exposure to testosterone decreases the value of the 2D:4D ratio, while the low level of prenatal testosterone boosts the value of this index (Lutchmaya et al. 2004; Manning and Fink 2011; Manning et al. 2014; Bovet 2019). During the fetal stage, the synthesis of prenatal testosterone is one of many factors that influence development of gender and reproductive glands. If prenatal testosterone dominates prenatal estrogen, it directs the development towards the male gender, and vice-versa (Lichtenberg-Kokoszka 2016). For this reason, male individuals have a lower digit ratio (and at the same time a higher level of testosterone) than women (Manning et al. 1998). An abundance of scholarly work confirms the dimorphic character of this index (Putz et al. 2004; Rahman et al. 2005; Malas et al. 2006; Galis et al. 2010; Manning et al. 2014; Mularczyk et al. 2014; Zaleska et al. 2017; Manning and Fink 2020).

The 2D:4D ratio is established whilst still in the prenatal development phase, identifiable during the fetal stage *in utero* and is constant across all stages of ontogenetic development (Manning et al. 1998). The difference between the 2D:4D ratio in male and female individuals can already be observed at the end of the first trimester of pregnancy (Malas et al. 2006; Galis et al. 2010). In order to explain the mechanism responsible for the establishment of the length ratio between the ring and index digit, as well as its correlation with the level of exposure to hormones during the prenatal stage, it should be noted that the development of digits correlates with the formation of the genitourinary system through common control of their development by homeotic genes (Hox) (Kondo et al. 1997; Manning et al. 1998; Manning 2011). This accounts for the correlation between the process of the prenatal sex steroid production and fetal digit formation patterns. It appears, however, that this correlation is limited only to prenatal androgens, as no reliable evidence has been identified to explain the correlation between the 2D:4D ratio values and the level of testosterone in adults (Manning et al. 2004; Hönekopp et al. 2007). Since the 2D:4D ratio is a sex dimorphic trait that develops *in utero* (Manning et al. 1998; Manning 2002; Malas et al. 2006), this suggests a correlation with many other traits that are determined during prenatal development. Intrauterine hormone balance influences also adult behavioral traits (Hines 2006). Proneness to aggressive behavior is one of the differences between genders in humans – men exhibit a greater tendency for aggressive behavior than women (Campbell 2006). Male individuals tend to make risky decisions more often than women (Hersch 1996). Researching the correlation between the 2D:4D ratio and aggressiveness, Schwerdtfeger et al. (2010) identified a negative correlation in male individuals, indicating that the lower the 2D:4D ratio (and concurrently a higher level of PT), the higher the level of aggressiveness in the examined cases. In research involving a large study group (N=2200), Hönekopp (2011) confirms a negative correlation between the

2D:4D ratio and physical, as well as verbal, aggressiveness. Millet (2011) and Millet and Dewitte (2007) have linked low values of this ratio with a greater tendency for aggressive behavior in competitive circumstances. Hönekopp and Watson (2011) confirm these results for men, yet failed to identify a similar correlation in examined female individuals. Kociuba et al. (2015) and Koziel et al. (2018) noticed the relationship between 2D-4D with choices of relatively risky professions such as military and police officers.

Tamiya et al. (2012) and Perciavalle et al. (2013) consider aggressiveness to be one of the potential factors for success in sport, suggesting it may be useful in certain sports that involve high risk (of, for instance, injuries). For example, soccer is classified as one such sport since it involves a high risk of a body collisions between players (Mitchell et al. 2005). Perciavalle et al. (2013) note that soccer players ranked higher, in terms of tendency for aggressive behavior, than other sportsmen from the control group. Moreover, soccer players exhibited a lower 2D:4D ratio than other surveyed individuals. In their study, Kim and Kim (2016) argue that low 2D:4D values might positively impact the success rate in aggressive sports. Additionally, they demonstrate that low 2D:4D values might serve as a predictor of the choice of competitive sport, involving high levels of aggressiveness and risk. Hönekopp (2011) also noted a significant positive correlation between 2D:4D values and a tendency to risky behavior (in females). Reed and Meggs' (2017) research sought to measure testosterone levels during the prenatal development as a predictor of the choice of sport. Their research introduces a categorization of sports as either openly aggressive (contact sports) or non-aggressive (non-contact). As a result, it has been demonstrated that athletes training for contact sports display significantly lower 2D:4D values by comparison to athletes training for non-contact sports. These conclusions have been corroborated by Kociuba et al.'s (2017) research, which determined that women who chose contact sports that involved risky and aggressive behavior (boxing and judo) possessed significantly lower 2D:4D values than women who chose non-contact sports.

One of the sex dimorphic features *in utero* is BMI (Body Mass Index) (Broere-brown et al. 2016; Galjaard et al. 2019). It may be assumed that sex hormones are the main regulators of male and female dimorphic morphological sex characteristics during puberty (as well as in adult individuals). Contrary to body fat deposition, which changes its character as a dimorphic trait across development stages (the differences between males and females are in certain stages evident, while in others barely visible), characteristics such as body mass index, waist to hip perimeter ratio and waist to chest perimeter ratio, are stable dimorphic traits (Fink et al. 2003). In this regard, the differences between males and females are constantly visible, as they are not dependent, to such a degree, on postnatal sex hormones (which are ontogenetically changeable) (Fink et al. 2003). For this reason, the changeability of these traits may, at least partly, depend on the effect of masculinization or feminization during the fetal stage. For instance, a low waist-hip ratio (WHR) in females usually results from a high level of exposure to prenatal testosterone (which is characteristic of males) (Evans et al. 1983, Manning et al. 1998), however there is new evidence that the

2D:4D is not a reliable indicator of the levels of testosterone (Hollier et al. 2015; Whitehouse et al. 2015; Apicella et al. 2016). Female BMI is also usually lower than that of males (Erkec 2019). Drawing on digit length index as a biomarker of prenatal exposure to sex hormones, Fink et al. (2003) explore the hypothesis that typically male (low) values of the 2D:4D ratio correlate with typically male (androgenized) BMI values. They confirm a significant positive correlation between BMI and 2D:4D values in males (higher BIM, higher 2D:4D value). Bagepally et al. (2020) reach similar conclusions. Although research has not attested similar correlations in surveyed women (Manning 2002; Fink et al. 2003; Erkec 2019), some studies argue for the existence of a correlation between a higher estrogen level and obesity, in both males and females (Kley et al. 1980; Kirschner et al. 1981), which prompts further studies and research of the issue.

In addition to the biological importance of the feature under the study, the finger length index can be a good tool to select the best, most predisposed to specific disciplines Athletes, and it can therefore be used in coaching work.

Material and Methods

The research sample for this study consisted of 103 women: 36 soccer players athletes training on a semi-professional level, 33 volleyball players training volleyball on a semi-professional level and 34 non-athletes. Their average age was 22 years (SD=6.38). The survey was conducted in 2019–2020. The inclusion criterion for participation in the study for female athletes was practicing a given sport for at least three years or more.

The length of digits was measured in one part of surveyed individuals: index and ring fingers were measured using an electronic caliper gauge accurate to 0.01 mm. The surveyed individuals placed their hands on a table palm up and with outstretched fingers. Digits were measured from epiphysis (*pseudophalangion* II and IV) to tip (*dactylion* II and IV) (Manning et al. 1998). Each of the measurements was repeated thrice and the arithmetic mean of all these measurements was subsequently calculated, which was then used to calculate the 2D:4D ratio. When direct measurements were not possible, measurements were conducted by means of an electronic hand scanner where measurements were conducted in ImageJ software in the same way as measurements taken by electronic caliper.

Student's t-test did not reveal any statistically significant differences between measurements taken by electronic caliper gauge (Mean=0.99; SD=0.03) and those taken using an electronic hand scanner (Mean=0.99; SD=0.03) (Table 1).

Table 1. Comparison of right hand measurements conducted by electronic scanner and electronic caliper gauge.– not significant, *p* – significance level, *t* – Student's t-test result for relevant groups

Trait	Electronic scans (N=10)	Electronic caliper gauge (N=10)	Difference volleyball – soccer players	
	Mean	mean	*t*	*p*
2D:4D	0.988	0.988	0.053	ns

Respondents provided their age, body height and mass. Based on these data, their BMI was calculated. Participation in the survey was voluntary. In order to assess the significance of the difference between three mean values of the 2D:4D index (interval features) taken separately for the left and right hand, a one-way analysis of variance (ANOVA) was first used, and then a *post-hoc* analysis was conducted. In order to assess the existence of a correlation between 2D:4D and BMI, Pearson r correlation was used.

Results

Descriptive statistical data of the 2D:4D ratio – such as the mean, median, minimum, maximum and standard deviation for left and right hand respectively – are presented in Table 2.

Average values of the 2D:4D ratio for non-athletes (N=34), volleyball players (N=33) and soccer players (N=36), were compared using the category of left and right hand. This analysis did not reveal any statistically significant differences (p>0.05) (Table 3).

During the course of further analysis, the *post-hoc* analysis for the left hand demonstrated a statistically significant difference between two surveyed groups – volleyball players and soccer players. Significantly higher 2D:4D values were noted in the case of volleyball players (Mean=0.987) than in the case of soccer players (Mean=0.968). Female soccer players exhibited significantly lower

Table 2. Basic descriptive characteristics of the 2D:4D index in groups of women engaged in volleyball, soccer and non-athletes

Trait	Control group		Volleyball		Soccer	
	2D:4DL	2D:4DR	2D:4DL	2D:4DR	2D:4DL	2D:4DR
N of valid measurements	34	34	36	36	33	33
Mean	0.984	0.994	0.987	1.001	0.968	0.983
Median	0.987	0.999	0.989	1.000	0.971	0.979
Minimum	0.916	0.914	0.916	0.929	0.915	0.926
Maximum	1.099	1.121	1.084	1.051	1.030	1.064
SD	0.044	0.040	0.039	0.030	0.028	0.031

SD – standard deviation

Table 3. Comparison of average 2D:4D values in female volleyball and soccer players and non-athletes, for left and right hand respectively

Study group	2D:4DL		2D:4DR	
	Mean	*SD*	Mean	*SD*
Control group (N=34)	0.984	0.044	0.994	0.040
Volleyball (N=36)	0.987	0.039	1.001	0.030
Soccer (N=33)	0.968	0.028	0.983	0.031
Difference	F=2.331; p=ns		F=2.276; p=ns	

F – variance analysis result, p – significance level, *SD* – standard deviation, ns – not significant.

values of the index in question (Table 4). The *post-hoc* analysis for the right hand also revealed a statistically significant difference between the two surveyed athlete groups – volleyball players and soccer players. As in the case of the left hand, significantly lower values of the 2D:4D index were noted in the soccer players (Mean=0.983) than volleyball players (Mean=1.001), and vice versa (Table 5).

Descriptive statistics of BMI (mean, median, minimum, maximum and standard deviation) for individual survey groups are presented in Table 6.

The conducted analysis attested to the existence of a statistically significant positive correlation between BMI and the value of the 2D:4DL index (r=0.332; p=0.001). The index 2D:4DR also displayed a statistically significant positive correlation (r=0.406; p<0.001) with BMI. These results demonstrate a directly proportional correlation – the lower the BMI values, the lower the 2D:4D ratio values, and *vice versa* (Table 7).

Table 4. *Post-hoc* test – differences between average 2D:4DL values in specific study groups

Study group	[control group] $\bar{x}$ =0.984	[volleyball] $\bar{x}$ =0.987	[soccer] $\bar{x}$ =0.968
Control group (N=34)		ns	Ns
Volleyball (N=36)	ns		0.045
Soccer (N=33)	ns	0.045	

ns – not significant, $\bar{x}$ – mean

Table 5. *Post-hoc* analysis – differences between average 2D:4DR values in specific study groups

Study group	[1] $\bar{x}$ =0.994	[2] $\bar{x}$ =1.001	[3] $\bar{x}$ =0.983
Control group [1] (N=34)		ns	Ns
Volleyball [2] (N=36)	ns		0.036
Soccer [3] (N=33)	ns	0.036	

ns – not significant, $\bar{x}$ – mean

Table 6. Basic descriptive characteristics of BMI in groups of women engaged in volleyball, soccer and non-athletes

Trait	Control Group	Volleyball	Soccer
N of valid measurements	34	36	33
Mean	23.492	21.274	21.951
Median	22.026	20.659	22.308
Minimum	15.987	16.529	18.750
Maximum	41.522	26.881	24.974
SD	5.730	2.223	1.628

SD – standard deviation

Table 7. Pearson's r correlation between BMI and 2D:4D index for left and right hand

Trait	BMI	
	r	*p*
2D:4DL	0.332	0.001
2D:4DR	0.406	<0.001

r – correlation value, *p* – significance level.

Discussion

The research conducted aimed to establish whether a correlation exists between ratio 2D:4D – a biomarker of exposure to testosterone during the prenatal stage – and the choice of sport in the case of female athletes. Two athlete groups, volleyball players and soccer players, were examined. Volleyball is perceived as a sport with a significantly lower risk of injury by contrast with soccer (Kujala et al. 1995). The results suggest that 2D:4D was significantly different in women practicing various sports (contact and non-contact sports). Women engaged in contact sports had lower 2D:4D than women engaged in non-contact sports, and vice versa ($p<0.05$). 2D:4D correlated positively with BMI and body weight – the higher the 2D:4D ratio, the higher the BMI and body weight (and vice versa) ($p<0.05$). Low 2D:4D (high PT exposure) may predict the choice of more risky, aggressive contact sports, and vice versa. High 2D:4D may predict a higher BMI and body weight, and vice versa. Predominantly, the latter results from the difference in the rate of body contact of the sports in question. In this regard, soccer is considered a sport with a high risk of injury (Złotkowska et al. 2015). Additionally, soccer has been classified as a sport involving a high risk of body clash, while in the case of volleyball, which is a non-contact sport, this risk is very low (Mitchell et al. 2005). Given the high risk of injury inherent to soccer, it may be assumed that the choice of this sport is indicative of a congruent awareness of the risk of injury.

The high risk of injury characteristic of soccer correlates with aggressiveness, which is significant to contact sports. Aggressiveness allows players to achieve specific aims; for instance, scoring a goal during a soccer match, intercepting the ball and blocking the opponent's influence on the course of the game (Soroka 2011). In order to block the opponent and prevent their domination in the field, soccer players often opt for risky and aggressive behavior, such as fouls, for instance. Moreover, not all aggressive behavior is considered a foul and penalized with a red card, a punishment reserved for the most brutal actions. Taking all of the latter into account, it may be concluded that women who choose and train for soccer should exhibit a higher tendency towards risky and aggressive behavior, by comparison with women who choose a non-contact sport such as volleyball.

It has been established that the tendency to risky and aggressive behavior correlates with low, masculine 2D:4D values, indicative of high exposure to testosterone during prenatal development (Millet and Dewitte 2007; Schwerdtfeger et al. 2010; Hönekopp 2011; Hönekopp and Watson 2011; Millet 2011). Brañas-Garza et al. (2018) also connect low 2D:4D values in women with a tendency towards risky behavior. Perciavalle et al. (2013) further conclude that soccer players with low 2D:4D values were more prone to aggressive behavior than players with higher values of this index. Moreover, Mailhos et al. (2016) note that the most aggressive soccer players (receiving red cards or penalties for more brutal actions) exhibited a significantly lower 2D:4D ratio than the rest of the players. Manning et al. (2014) suggest a correlation between the 2D:4D values and physical aggressiveness in sports as circumstances of challenge. Following this reasoning, this study hypothesizes that female soccer players who select a contact sport, entailing both aggression and higher risk, exhibit lower values of the 2D:4D ratio than volleyball players. Female athletes engaged in soccer exhibit lower values of both the 2D:4DL, as well as 2D:4DR ratio, than women engaged in volleyball (Tables 4 and 5). This suggests that women with a high exposure to testosterone during prenatal development choose contact sport, while women with less exposure to testosterone during this period, choose non-contact sport.

These results align with Kociuba et al.'s (2017) research, which highlights that women who chose contact sports (boxing and judo) exhibited lower 2D:4D ratio values than women who chose safer sports. It should be noted that, as with soccer, boxing and judo are classified as sports with a high risk of injury (Złotkowska et al. 2015). Kim and Kim's (2016) research also corroborates these results, concluding that a low 2D:4D index is indicative of a greater predisposition for more competitive sports and may positively impact the success rate in sports that require an aggressive attitude. Additionally, Ribeiro et al.'s (2016) research with men concludes that the level of testosterone rises (triggering an increase in aggressiveness and strength) as the result of aggressive challenges (for instance, a body clash in a contact sport) more often in individuals with a low 2D:4D ratio, predisposing them to contact sports. Similar conclusions are evidenced in Kociuba et al. (2019) and in Joyce et al.'s (2013) research, where they determine that more aggressive athletes (both men and women) exhibit a significantly lower 2D:4D ratio. Drawing on the results of a survey involving 200 men, Reed and Meggs (2017) note that athletes who had chosen contact sports had a lower 2D:4D ratio than athletes engaged in non-contact sports.

Bailey and Hurd (2005) confirm the negative correlation between the 2D:4D ratio and aggressive tendencies in men, yet failed to obtain similar results for women. Similarly, Hönekopp and Watson (2011) do not note this correlation in females, prompting the need for further studies on the existence of this correlation in women. bo Bagepally et al. (2020) also confirm this correlation. However, all of these studies were conducted on male individuals. In the case of women, Manning (2002), Fink et al. (2003) and Erkec (2019) fail to observe any significant correlations between the discussed indexes. Nevertheless, it should be noted that BMI is a stable dimorphic trait. The latter is contrary to, body fat for instance, which displays a dimorphic character that changes across different development stages (the differences during infancy, early and later childhood are negligible, while they significantly increase during puberty), thus depending on the relationship of (postnatal) estrogen and testosterone (Nelson et al. 1999). The main reason behind the stability of BMI's sex dimorphism is the individual profile of sex hormones (Fink et al. 2003), which indicates that this trait can be dependent on the effect of masculinization or feminization during the fetal stage. These results provide an incentive for further research.

A small number of surveys conducted on women who train for specific sports, as well as discrepancies across some studies that have been conducted thus far, encourage further exploration of this issue. If the hypothesis put forward by this study is correct, further evidence will be forthcoming in the future. Digit measurements, as well as the establishment of length index values, do not pose any research difficulty and may be easily obtained for future useful studies – for instance, during a selection of young athletes – which may be helpful in the training of new generations of better (physiologically predisposed to specific sports) players.

The authors are aware of the limitation, concluding that such an approach and possible biases resulting from the small sample size and possible hormonal disorders may affect the obtained results. None of the participants declare hormonal disorders, but it was only based on personal declarations.

A small number of surveys conducted on women who train for specific sports, as well as discrepancies across some studies that have been conducted thus far, encourage further exploration of this issue. If the hypothesis put forward by this study is correct, further evidence will be forthcoming in the future. Digit measurements, as well as the establishment of length index values, do not pose any research difficulty and may be easily obtained for future useful studies – for instance, during a selection of young athletes – which may be helpful in the training of new generations of better physiologically predisposed to specific sports players.

Authors' Contribution

JL collected the data, performed statistical computations and drafted the manuscript.

AT was project supervisor, drafted the manuscript, edited the final version of the manuscript.

All authors carefully read and accepted the final version of the manuscript.

With the submission of this manuscript I would like to undertake that the above mentioned manuscript **is without any conflict of interest** and has not been published elsewhere.

Corresponding author

Agnieszka Tomaszewska, agnieszka.tomaszewska@upwr.edu.pl

References

Apicella CL, Tobolsky VA, Marlowe FW, Miller KW. 2016. Hadza hunter-gatherer men do not have more masculine digit ratios (2D:4D). Am J Phys Anthropol 159, 223–232. https://doi.org/10.1002/ajpa.22864

Bagepally BS, Majumder J, Kotadiya S. 2020. Association between the 2d:4d and cardiovascular risk factors: Body mass index, blood pressure and body fat. Early Hum Dev 151:105–193.

Bailey AA, Hurd PL. 2005. Finger length ratio (2D:4D) correlates with physical aggression in men but not in women. Biol Psychol 68(3):215–222.

Bovet J. 2019. Evolutionary Theories and Men's Preferences for Women's Waist-to-Hip Ratio: Which Hypotheses Remain? A Systematic Review. Front Psychol 10:1221. https://doi.org/10.3389/fpsyg.2019.01221

Brañas-Garza P, Galizzi MM, Nieboer J. 2018. Experimental and Self-reported Measures of Risk Taking and Digit Ratio (2D:4D): Evidence from a Large, Systematic Study: Measures of Risk Taking and Digit Ratio. Int Econ Rev 59(3):1131–1157.

Broere-Brown ZA, Baan E, Schalekamp-Timmermans S. et al. 2016. Sex-specific differences in fetal and infant growth patterns: a prospective population-based cohort study. Biol Sex Differ 7, 65, https://doi.org/10.1186/s13293-016-0119-1

Campbell A. 2006. Sex differences in direct aggression: What are the psychological mediators? Aggress Violent Behav 11(3):237–264.

Erkec OE. 2019. Relationships Between the 2D:4D Digit Ratio, Waist Circumference, Hand Preferences, Weight, Height, Waist-to-Height Ratio and BMI in a Turkish Population. Int J Morphol 37(4):1299–1304.

Evans DJ, Hofmann RG, Kalkhoff RK, Kissebah AH. 1983. Relationship of Androgenic Activity to Body Fat Topography, Fat Cell Morphology, and Metabolic Aberrations in Premenopausal Women. J Clin Endoclinol Metab 57(2):304–310.

Fink B, Neave N, Manning JT. 2003. Second to fourth digit ratio, body mass index, waist-to-hip ratio, and waist-to-chest ratio: their relationships in heterosexual men and women. Ann hum Biol 30(6):728–738.

Galis F, Ten Broek CMA, Van Dongen S, Wijnaendts LCD. 2010. Sexual Dimorphism in the Prenatal Digit Ratio (2D:4D). Arch Sex Behav 39(1):57–62.

Galjaard S, Ameye L, Lees C.C. et al. 2019. Sex differences in fetal growth and immediate birth outcomes in a low-risk Caucasian population. Biol Sex Differ 10, 48, https://doi.org/10.1186/s13293-019-0261-7

Hersch J. 1996. Smoking, seat belts, and other risky consumer decisions: Differences by gender and race. Manage Decis Econ 17(5):471–481.

Hines M. 2006. Prenatal testosterone and gender-related behaviour. Eur J Endocrinol. 155 Suppl 1:S115–21. https://doi.org/10.1530/eje.1.02236. PMID: 17074984.

Hollier LP, Keelan J, Jamnadass E, Maybery M, Hickey M, Whitehouse A. 2015. Adult digit ratio (2D:4D) is not related to umbilical cord androgen or estrogen concentrations, their ratios or net bioactivity. Early Hum Dev 91, 111–117. https://doi.org/10.1016/j.earlhumdev.2014.12.011

Hönekopp J. 2011. Relationships between digit ratio 2D:4D and self-reported aggression and risk taking in an online study. Pers Individ Differ 51(1):77–80.

Hönekopp J, Bartholdt L, Beier L, Liebert A. 2007. Second to fourth digit length ratio (2D:4D) and adult sex hormone levels: new data and a meta-analytic review. Psychoneuroendocrinology 32(4):313–321.

Hönekopp J, Watson S. 2011. Meta-analysis of the relationship between digit-ratio 2D:4D and aggression. Pers Individ Differ 51(4):381–386.

Joyce CW, Kelly JC, Chan JC, Colgan G, O'Briain D, et al. 2013. Second to fourth digit ratio confirms aggressive tendencies in patients with boxers fractures. Injury 44(11):1636–1639.

Kim TB, Kim KH. 2016. Why is digit ratio correlated to sports performance? J Exerc Rehabil 12(6):515–519.

Kirschner MA, Ertel N, Schneider G. 1981. Obesity, Hormones, and Cancer. Cancer Res 41(9 Part 2):3711–3717.

Kley HK, Edelmann P, Krüskemper HL. 1980. Relationship of plasma sex hormones to different parameters of obesity in male subjects. Metabolism 29(11):1041–1045

Kociuba M, Chakraborty R, Ignasiak Z, Koziel S. 2019. Digit ratio (2D:4D) moderates the change in handgrip strength on an aggressive stimulus: a study among Polish young adults. Early Hum Develop 128: 62–68.

Kociuba M, Kozieł S, Chakraborty R, Ignasiak Z. 2017. Sports Preference and Digit Ratio (2D:4D) Among Female Students in Wroclaw, Poland. Biosoc Sci 49(5):623–633.

Kociuba M, Kozieł S, Chakraborty R. 2015. Sex differences in digit ratio (2D:4D) among military and civil cohorts at a military academy in Wrocław, Poland. J Biosoc Sci 48(5):658–671.

Koziel S, Kociuba M, Chakraborty R, Sitek A, Ignasiak Z. 2018. Further evidence of association of low second-to-fourth digit ratio (2D:4D) with selection in uniformed services – a study among police personnel from Wroclaw, Poland. J Biosoc Sci 50(4): 527–539.

Kondo T, Zákány J, Innis JW, Duboule D. 1997. Of fingers, toes and penises. Nature 390(6655):29–29.

Kujala UM, Taimela S, Antti-Poika I, Orava S, Tuominen R, Myllynen P. 1995. Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. BMJ 311(7018):1465–1468.

Lichtenberg-Kokoszka E. 2016. Biomedyczne aspekty kształtowania płci somatycznej. Znaczenie prenatalnego okresu życia. Family Forum (6):45–58.

Lutchmaya S, Baron-Cohen S, Raggatt P, Knickmeyer R, Manning JT. 2004. 2nd to 4th digit ratios, fetal testosterone and estradiol. Early Him Develop 77(1–2):23–28.

Mailhos A, Buunk AP, Arca D del, Tutte V. 2016. Soccer players awarded one or more red cards exhibit lower 2D:4D ratios. Aggress Behav 42(5):417–426.

Malas MA, Dogan S, Hilal Evcil E, Desdicioglu K. 2006. Fetal development of the hand, digits and digit ratio (2D:4D). Early Hum Develop 82(7):469–475.

Manning JT. 2002. Digit Ratio: A Pointer to Fertility, Behavior and Health. New Brunswick: Rutger University Press.

Manning JT. 2011. Resolving the role of prenatal sex steroids in the development of digit ratio. PNAS 108(39):16143–16144.

Manning JT, Fink B. 2011. Digit ratio (2D:4D) and aggregate personality scores across nations: Data from the BBC internet study. Pers Individ Differ 51(4):387–391.

Manning JT, Fink B. 2020. Sex differences in the relationship between digit ratio (2D:4D) and national case fatality rates for COVID-19: A reply to Sahin (2020). Early Hum Develop 148:105–120.

Manning JT, Scutt D, Wilson J, Lewis-Jones DI. 1998. The ratio of 2nd to 4th digit length: a predictor of sperm numbers and concentrations of testosterone, luteinizing hormone and oestrogen. Hum Reprod 13(11):3000–3004.

Manning J, Kilduff L, Cook C, Crewther B, Fink B. 2014. Digit Ratio (2D:4D): A Biomarker for Prenatal Sex Steroids and Adult Sex Steroids in Challenge Situations. Front Endocrinol 30(5):9.

Manning JT, Wood S, Vang E, Walton J, Bundred PE, et al. 2004. Second to fourth digit ratio (2D:4D) and testosterone in men. Asian J Androl 6(3):211–215.

Millet K. 2011. An interactionist perspective on the relation between 2D:4D and behavior: An overview of (moderated) relationships between 2D:4D and economic decision making. Pers Individ Differ 51(4):397–401.

Millet K, Dewitte S. 2007. Digit ratio (2D:4D) moderates the impact of an aggressive music video on aggression. Pers Individ Differ 43(2):289–294.

Mitchell JH, Haskell W, Snell P, Van Camp SP. 2005. Task Force 8: Classification of sports. Journal of the American College of Cardiology 45(8):1364–1367.

Mularczyk M, Ziętek-Czeszak A, Ziętek Z. 2014. Ocena dymorfizmu płciowego wskaźnika długości palców (2D:4D). Rocz Pomor Akad Med 60(1):47–51.

Nelson TL, Vogler GP, Pedersen NL, Miles TP. 1999. Genetic and environmental influences on waist-to-hip ratio and waist circumference in an older Swedish twin population. IJO 23(5):449–455.

Perciavalle V, Di Corrado D, Petralia MC, Gurrisi L, Massimino S, Coco M. 2013. The second-to-fourth digit ratio correlates with aggressive behavior in professional soccer players. Molec Med Rep 7(6):1733–1738.

Putz DA, Gaulin SJC, Sporter RJ, McBurney DH. 2004. Sex hormones and finger length. Evol Hum Behav 25(3):182–199.

Rahman Q, Korhonen M, Aslam A. 2005. Sexually dimorphic 2D:4D ratio, height, weight, and their relation to number of sexual partners. Pers Individ Differ 39(1):83–92.

Reed S, Meggs J. 2017. Examining the effect of prenatal testosterone and aggression on sporting choice and sporting longevity. Pers Individ Differ 116:11–15.

Ribeiro E, Neave N, Morais RN, Kilduff L, Taylor SR, et al. 2016. Digit ratio (2D:4D), testosterone, cortisol, aggression, personality and hand-grip strength: Evidence for prenatal effects on strength. Early Hum Develop 100:21–25.

Schwerdtfeger A, Heims R, Heer J. 2010. Digit ratio (2D:4D) is associated with traffic violations for male frequent car drivers. Accid Anal Prev 42(1):269–274.

Soroka A. 2011. Charakterystyka wybranych modeli gry piłkarzy nożnych podczas Mistrzostw Świata – RPA 2010. Biała Podlaska: Państwowa Szkoła Wyższa im. Papieża Jana Pawła II.

Tamiya R, Lee SY, Ohtake F. 2012. Second to fourth digit ratio and the sporting success of sumo wrestlers. Evol Hum Behav 33(2):130–136.

Whitehouse AJO, Gilani SZ, Shafait F, Mian A, Tan DW, Maybery MT, et al. 2015. Prenatal testosterone exposure is related to sexually dimorphic facial morphology in adulthood. Proc R Soc B 282:20151351. 10.1098/rspb.2015.1351

Zaleska K, Kliś K, Suder A, Teul I, Wronka I. 2017. Dymorfizm płciowy i asymetria wskaźnika długości palców ręki (2D:4D) – badania pilotażowe. Pomeranian J Life Sci 62(1):31–34.

Złotkowska R, Skiba M, Mroczek A, Bilewicz-Wyrozumska T, Król K, et al. 2015. Negatywne skutki aktywności fizycznej oraz uprawiania sportu. Hygeia Public Health. 50(1):41–46.