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Influence of Digit Ratio (2D:4D) on Aerobic and Anaerobic Based Fitness Tests among Primary Schoolchildren

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Abstract

As digit ratio (2D:4D) factor corresponds with high level of performances, fine-tune skills and immense ability were evidently found, but however the impact of 2D:4D on aerobic and anaerobic fitness components among younger subjects has yet to be fully understood. Thus, the main objective of this study is to examine the role of 2D:4D towards performance in physical fitness tests comprising of both aerobic-based and anaerobic-based elements. Results were collected from six physical fitness tests involving 594 primary schoolchildren (aged 10 to 12 years old) of both genders. Fingers images were taken through hand scanning method and the ratios were measured and calculated. Priorly, effect of covariances (age and body mass index) was found to have no effect on the fitness tests. For male students, the low 2D:4D of both hands showed various significant relationship with non-anaerobic based tests acquiring lower R^2 below 10%. Both genders reported to have higher percentage of variability of dependant variables detected at anaerobic based tests with the highest was found at standing broad jump test. Meanwhile, for the female subjects mixed results were found with all aerobic based tests scored lower R^2 below 10%. Overall, low digit ratio was much prominent in anaerobic-based tests in both male and female subjects. This study suggests that 2D:4D thrives more in anaerobic based events/tests among younger subjects and with thorough research, it is possible to implement 2D:4D as additional instrument in identifying sports talents and categorizing potential athletes according to the related fitness components.

Keywords: Digit ratio, aerobic, anaerobic, prenatal testosterone, children.

INTRODUCTION

Digit ratio (2D:4D) is a part of anthropometric marker that is currently being research worldwide due to its predictive capacity in certain fields such as in psychology, cancers, health, behaviours and others. In brief, 2D:4D consists of the index finger (2D) and the ring finger (4D), and most researchers are convinced that the distinction between the two fingers' lengths indicates the level of testosterone introduction in the womb (Voracek & Loibl, 2009; Zheng & Cohn, 2011). The more extended the ring finger contrasted with the forefinger, the reasoning goes, the higher the testosterone concentration level. Higher exposure towards prenatal testosterone received is reflected as low 2D:4D and vice versa for high 2D:4D. As can be seen in current studies, low 2D:4D is significantly related towards high performances in sports and physical fitness, high attainment and mostly visible among elite athletes rather than high 2D:4D.

There is an understanding with those discoveries, and this bolster the likelihood that a relationship between low 2D:4D and sports performance comes about in any event to a limited extent from the activity of prenatal testosterone on such accomplishment. The reason for that achievement is the relationship between prenatal testosterone and human body that it directly enhances the effectiveness of the cardiovascular framework and muscle fibres (Manning, Morris & Caswell., 2007), and additionally it might impact practices which affects the sports accomplishment (Bescós *et al.*, 2009; Hönekopp & Schuster, 2010; Kim & Kim, 2016). Directing towards the functions of testosterone on muscular system, it does contribute in assisting muscle growth, strength,

and power, as well as reducing fat mass and other impacts on the muscular system, such as increasing muscle protein anabolism and increasing the number of motor neurons and androgen receptors (Herbst & Bhasin, 2004). Low 2D:4D with high testosterone concentrations influences the development of the cardiovascular system, muscular physiology and foetal testosterone influences the cardiovascular system's defence mechanism (Kyriakidis *et al.*, 2010; Manning *et al*., 2007). As a result, those with a strong cardiovascular and muscular system have the better chance to be better athletes. Furthermore, success in sports likewise has appeared to be related with prenatal testosterone in men such as in rugby, football, rowing sumo and wrestling (Bennett *et al*., 2010; Hull *et al*., 2015; Keshavarz *et al*., 2017; Manning & Taylor, 2001; Tamiya *et al*., 2012), along with extensive review by Kim and Kim, (2016) on 2D:4D towards performance in various type of sports. In fact, previous studies have confirmed that 2D:4D has significant effect on differentiating the status of the athlete itself, with low 2D:4D is associated with elite athletes (Adamczyk *et al*., 2021; Keshavarz *et al*., 2017; Pokrywka *et al*., 2005; Tamiya *et al*., 2012)

Lots of similar studies relating 2D:4D towards performance on physical fitness were conducted in past few years. Research by Ranson *et al*., (2015) did find correlation between low 2D:4D on aerobic capacity, speed and power in a large population of Welsh boys but not girls. Linking to muscular strength, study by Tomkinson and Tomkinson, (2017) discovered a moderate age and body mass index-adjusted negative connection between 2D:4D and handgrip strength in adolescent male subjects. Furthermore, in recent study by Hsu *et al.*, (2018) found that low 2D:4D is significantly associated with jumping power among children. Those studies go on explaining that the result is most likely attributable to prenatal testosterone's long-term organizational benefits. Nonetheless, Eghbali, (2016) reported 2D:4D has no significant impact on all physical fitness tests conducted on children. Previously, Manning and Hill, (2009) suggested low 2D:4D was more associated with endurance running rather than sprinting. Those mixed findings regarding 2D:4D on various fitness components provides the pathway to further examine it especially on younger subjects. Therefore, this study hope to address those issues by focusing on both hands 2D:4D towards performance on both aerobic based tests and anaerobic based tests among primary schoolchildren of both genders.

MATERIAL & METHODS

Participants

A total of 594 subjects of male (n=359) and female (n=234) aged 10 to 12 years old were involved in this study. Sample size was determined earlier by using power analysis of G*Power analysis software version 3.1.7. Subjects came from primary schools in various demographic zones (central, east coast, southern, northern and west coast) in Malaysia. Selection criteria of the subjects were set to did not participate in any sports at school or representing school or outside school sport's organization in any tournament. Another selection criterion was that the subjects must be in normal category of body mass index (BMI). This is to ensure the outcome of the data is not bias, for example, an obese subject may have trouble in performing standing broad jump test, or difficulty in performing push-up and sit and reach test or may gain high score in hand grip strength test due to larger hand/palm. If the subjects have any injuries, diseases and/or illnesses, they are not permitted to participate in the testing. Subjects are asked to not engage in any vigorous physical activity at least two days prior to the testing day in order to ensure they are in good condition to participate. Letter of consent were obtained from the parent/custodian of the children, along with getting permission from the state education department and the schools involved. Any subject that failed to provide signed consent letter by their parent/custodian is excluded immediately for safety and liability purposes. This research was carried out with approval from the Ethics Committee, School of Postgraduate Studies, Universiti Teknologi Malaysia.

Digit ratio measurement

This study opted the indirect measurement method by using the scanner machine (Canon CanoScan LiDE 120 with a resolution of 2400x4800dpi). This method was chosen due to the high number of subjects involved in this study and taking into consideration the measuring features in the viewing software. Subjects were required to clean their hands thoroughly from any dirt/dust, and remove any accessories (watch, ring, bracelet, or anything that may hinder the scanning process and image quality). Both palms of right and left were faced downwards on the scanner with fingers spread evenly but not too wide. The palms were then gently put on the scanner for the scanning to commence. Later, the image of the scanned hands was saved into a specific folder on the laptop and were coded accordingly. Those saved hand images were opened in MicroDicom viewer software version 2.7.9 for measuring the digits and calculating the ratios.

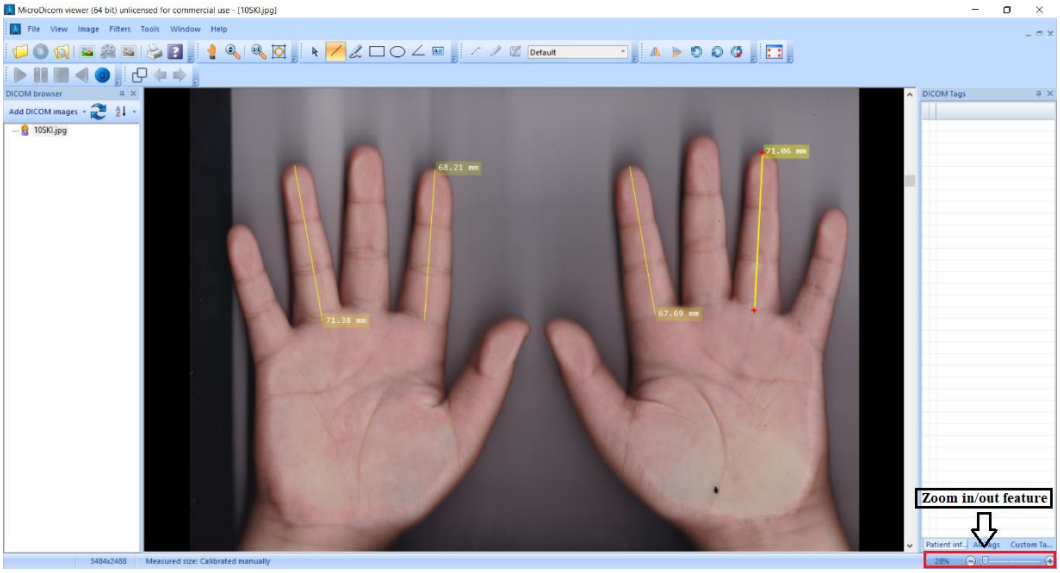

Figure 1: Zoom-in/out feature in MicroDicom viewer version 2.7.9 software

Figure 1 above showed the zoom-in/out function that is available in the software MicroDicom viewer version 2.7.9 which provided better accuracy in measuring the finger length. The hand image can be zoomed-in and out for a better view without compromising the image quality, thus ensuring measurement precision. Before running the measurement, the calibration process was run using the calibration function that is available in the software to ensure reliability and validity of the ratio is not affected.

Regarding the intra-rater repeatability analysis on single assessor on taking measurement of the 2D:4D, this study conducted intercorrelation coefficient (ICC) analysis with two-way mixed-effect model (Model 3) based on single measure (Form 1) and type absolute agreement was selected. The result from ICC (3,1) demonstrated excellent reliability (0.999) for both right hand 2D:4D and left hand 2D:4D measurement on male subjects. The same can also be found in female subjects with right hand 2D:4D (0.997) and left hand 2D:4D (0.999), thus it is acceptable to be used as a basis for further analysis.

Physical fitness testing

In this study, the selected physical fitness tests involved were 1-minute step test, sit and reach test, 1-minute abdominal test and push up test which are part of Malaysia's National Physical Fitness Standard Test (SEGAK). Additionally, two more fitness tests were added which were the standing broad jump (SBJ) test and hand grip strength (HGS) test. Based on the nature of those tests themselves, they can be categorized into their dominance fitness component starting with cardiovascular endurance (1-minute step test), flexibility (sit and reach test), muscular endurance (1-minute abdominal test), push up test (strength) and power (standing broad jump test and hand grip strength test). For ease of the testing session and safety of the subjects, they were divided into groups and were required to do proper warm up before commencing on the testing and cooling down after the testing. The arrangement of the testing was start with the least exhausting and ended with the most exhausting test

Statistical analysis

For normality testing, this study used the Shapiro-Wilk test and used the Grubbs test for detecting any extreme outliers. In examining the influence of covariances (age and BMI), Pearson correlation analysis was conducted to find any effect of those covariances might have towards the 2D:4D, thus the result can reflect the true meaning of performances in the fitness tests. As for the main objective, multiple linear regression analysis was chosen to explore the relationship of explanatory variables (both hands 2D:4D) towards the performance in the fitness tests. Values were shown as Mean±SD, and significance level was set at 0.05. In order to run all of the analyses above, XLSTAT Premium version 2021.2.2 software was chosen as the main platform.

RESULTS

To ensure any effect of covariances (age and BMI) affecting the scores in the fitness tests, Pearson correlation analysis was conducted. Table 1 below showed both variables of age ($r(357) = -0.03$, $p = .506$) and BMI ($r(357) = .09$, $p = .606$) did not have any significant relationship on the performances for male subjects in the fitness tests. The same finding was also detected for the female subjects with both covariances were not significantly correlated with age, $r(232) = -0.08$, $p = .217$, and BMI $r(232) = .02$, $p = .725$. The results concluded that covariances of age and BMI did not affect the performance of the subjects in the fitness tests.

Table 1: Effect of covariances (age and BMI) towards both hands 2D:4D

Male (N=359)		**Both hands 2D:4D**	**Age**	**BMI**
Both hands 2D:4D (mm)	Pearson correlation	1	-0.03	0.09
	Sig. (2-tailed)		0.506	0.606
Age	Pearson correlation	-0.03	1	0.299
	Sig. (2-tailed)	0.506		< 0.0001
BMI	Pearson correlation	0.09	0.299	1
	Sig. (2-tailed)	0.606	< 0.0001	
Female (N=234)		Both hands 2D:4D	Age	BMI
Both hands 2D:4D (mm)	Pearson correlation	1	-0.043	0.02
	Sig. (2-tailed)		0.510	0.778
Age	Pearson correlation	-0.043	1	0.046
	Sig. (2-tailed)	0.510		0.488
BMI	Pearson correlation	0.02	0.046	1
	Sig. (2-tailed)	0.778	0.488	
**Correlation is significant at the 0.01 level (2-tailed)				

Table 2 demonstrated descriptive data on the anthropometric and digit ratio of the subjects. Male subjects were found to have much lower 2D:4D in all categories compared to their female counterpart. Both hands 2D:4D were found lowest at 0.868mm in male subjects, while female subjects recorded 0.878mm. In right hand 2D:4D, male also demonstrated lower reading at 0.840mm whilst female shown 0.847mm. In addition, 0.868mm at left hand 2D:4D were found lower among male subjects and female recorded a little bit high reading at 0.900mm.

Table 2: Anthropometric and digit ratio descriptive values of the subjects

Gender	**Variables**	**Min.**	**Max.**	**Mean±SD**
Male (N=359)	Both hands 2D:4D (mm)	0.868	1.069	0.969±0.044
	Right 2D:4D (mm)	0.840	1.060	0.967±0.041
	Left 2D:4D (mm)	0.868	1.069	0.969±0.044
	Weight (kg)	18.00	71.00	32.67±7.89
	Height (m)	1.16	1.68	1.39±0.09
	BMI (kg/m^2)	10.76	31.93	16.65±2.55
Female (N=234)	Both hands 2D:4D (mm)	0.878	1.060	0.983±0.041
	Right 2D:4D (mm)	0.847	1.067	0.983±0.044
	Left 2D:4D (mm)	0.900	1.069	0.982±0.043
	Weight (kg)	21.00	58.00	33.41±6.77
	Height (m)	1.22	1.62	1.41±0.08
	BMI (kg/m^2)	11.71	27.97	16.75±2.19

Table 3: Both hands 2D:4D goodness of fit (% of performance) for MLR standard mode

Male (N=359)						
	Step test	Sit & reach	1-min abs	Push-up	RL-HGS	SBJ
DF	357	357	357	357	357	357
R^2	0.07	0.06	0.04	0.15	0.14	0.19
Adjusted R^2	0.07	0.06	0.04	0.15	0.13	0.18
RMSE	20.17	5.93	8.11	9.82	8.51	0.27
Female (N=234)						
	Step test	Sit & reach	1-min abs	Push-up	RL-HGS	SBJ
DF	234	234	234	234	234	234
R^2	0.01	0.01	0.03	0.11	0.12	0.28
Adjusted R^2	0.01	0.01	0.03	0.11	0.12	0.28
RMSE	23.45	6.43	6.96	8.06	7.09	0.23

Table 3 demonstrated the outcome from the MLR standard mode analysis for both male and female subjects on both hands 2D:4D towards six physical fitness tests. Results showed relationship with non-anaerobic based tests acquiring lower R^2 below 10% in both subjects especially at step test, sit and reach test and 1-min abs test. Higher percentage of variability of dependant variables were detected at anaerobic based test as the RL-HGS (R^2 = 14%), push-up (R^2 = 15%), and highest at SBJ (R^2 = 19%) for male subjects. The

same also goes to female subjects with RL-HGS (R^2 = 12%), push-up (R^2 = 11%), and highest at SBJ (R^2 = 28%).

As for female, which can be seen in Table 3, it revealed mixed results with all non-anaerobic based tests acquiring lower R2 below 10% (step test = 1%, and 1-min abs = 3%,). In addition to that, both step test (p = .065) and 1-min abs test (p = .134) were found not significant. Higher percentage of variability of dependant variables were detected at anaerobic based test as the push-up (R2 = 11%), RL-HGS (R2 = 12%), and highest at SBJ (R2 = 28%).

Table 4: Both hands 2D:4D model parameters for MLR standard mode on male subjects

Male (N=359)							
Fitness tests	Source	Value	SE	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Push-up	Intercept	109.81	11.43	9.60	< 0.0001	87.32	132.30
	Both hands 2D:4D	-93.22	11.79	-7.91	< 0.0001	-116.41	-70.04
Step test	Intercept	-12.23	23.48	-0.52	0.603	-58.40	33.94
	Both hands 2D:4D	0.27	0.05	5.24	< 0.0001	0.17	0.37
1-min abs	Intercept	57.16	9.45	6.05	< 0.0001	38.59	75.74
	Both hands 2D:4D	-0.21	0.05	-3.98	< 0.0001	-0.31	-0.10
RL-HGS	Intercept	104.70	9.90	10.57	< 0.0001	85.22	124.17
	Both hands 2D:4D	-0.37	0.05	-7.54	< 0.0001	-0.47	-0.27
SBJ	Intercept	4.24	0.31	13.64	< 0.0001	3.63	4.86
	Both hands 2D:4D	-0.43	0.05	-9.01	< 0.0001	-0.52	-0.34
Female (N=234)							
Fitness tests	Source	Value	SE	t	Pr > |t|	Lower bound (95%)	Upper bound (95%)
Push-up	Intercept	85.83	12.57	6.83	< 0.0001	61.07	110.59
	Both hands 2D:4D	-0.33	0.06	-5.33	< 0.0001	-0.45	-0.21
Step test	Intercept	40.05	36.55	1.10	0.274	-31.97	112.06
	Both hands 2D:4D	0.12	0.07	1.85	0.065	-0.01	0.25
1-min abs	Intercept	39.59	10.02	3.95	0.0001	19.84	59.33
	Both hands 2D:4D	-0.10	0.07	-1.50	0.134	-0.23	0.03
RL-HGS	Intercept	43.20	5.55	7.78	< 0.0001	32.26	54.14
	Both hands 2D:4D	-0.33	0.06	-5.27	< 0.0001	-0.45	-0.20
SBJ	Intercept	91.59	11.05	8.29	< 0.0001	69.82	113.36
	Both hands 2D:4D	-0.35	0.06	-5.70	< 0.0001	-0.47	-0.23

Table 4 provide the p-value of the F statistics computed in ANOVA yielded significance level of 5% (p < .001) for all six physical fitness tests for male subjects. Therefore, those given information derived from the results above brought by the explanatory variable (both hands 2D:4D) is significantly better than what a basic mean would bring. As for female subjects, the p-value of the F statistics computed in ANOVA and yielded significance level of 5% for five physical fitness tests, except for step test (p >.065) that resulted in not significant.

DISCUSSION

The findings from the analyses above explained various results regarding role of 2D:4D in affecting the performance in aerobic and anaerobic based fitness tests among the primary school children. Earlier, descriptive analysis showed that male subjects appeared to possess much lower 2D:4D in all both hands 2D:4D, right hand 2D:4D and left hand 2D:4D compared to female subjects. This finding suggests that digit ratio is sexually dimorphic as agreed by other studies, with male having higher prenatal testosterone and displaying lower 2D:4D than their female counterpart. Manning, one of the leading researchers in this field mentioned that the amount of androgen secretion while in mother's womb can lead to the formation of 2D:4D and thus can determine the status of 2D:4D (Manning *et al.*, (2000). As an example, in this study, the male subjects had shown lower 2D:4D (0.969±0.044mm) in both hands 2D:4D compared to the female subjects that demonstrated higher reading of 0.983±0.041mm. In addition, the lowest reading of 2D:4D was found in right hand for male at 0.840mm, and lowest 2D:4D was recorded at 0.847mm, also at the right hand, while female subjects expressed higher reading for all three 2D:4D measurements.

Linking this with performance in fitness tests, male subjects appeared to perform considerably better compared to female subjects, with all fitness tests were statistically significant towards both hands 2D:4D. Whilst in female, performance in step test and 1-min abs test were found to not have any association with both hands 2D:4D. Generally, step test can be categorised as aerobic fitness, and even though the 1-min abs test do have the element of strength fitness, it is more prone towards aerobic/endurance fitness, as the test requires individuals to do continuous repetitions of abdominal crunches for one minute. As shown from the

multiple regression analysis, it was also found that R^2 scores for step test and 1-min abs test were much lower than other fitness tests in both male and female participants. Moreover, the R^2 scores especially for the anaerobic-based fitness test (SBJ test and RL-HGS test) was higher than aerobic-based fitness tests. The same was also found in previous study on explosive power and 2D:4D by Hsu *et al.*, (2018). Interestingly, higher R^2 score was detected at push-up test. It is well-known that the SBJ test and RL-HGS test are anaerobically dominant tests, but as for the push-up test, it requires both cardiovascular efficiency and strength output to perform well. These findings appear to suggest that digit ratio does relate to performance in both aerobic and anaerobic-based fitness tests, with slight tendency towards anaerobic-based fitness tests.

When it comes to linking 2D:4D with performance in physical fitness testing, the presence of prenatal testosterone was found in most studies to be correlating with high performance or scores in those tests for low 2D:4D subjects. This is most noticeable in a study by Ranson *et al.*, (2015) who conducted Eurofit test on school children in which they managed to correlate low 2D:4D male school children on several fitness components such as sprinting, endurance, flexibility except on leg power by standing broad jump. The same was also found in this study for both male and female school children from all age groups (10-12 years old) where high scores were achieved by low 2D:4D subjects on hand grip strength and push-up tests.

In contrast to the finding by Ranson, this study did find a correlation between low 2D:4D subjects (male and female) and standing broad jump which is a test for power component. Interestingly, this study found an obvious link between prenatal testosterone on anaerobic fitness component rather than aerobic fitness component. This can be seen as there were no significant differences found between low and high 2D:4D subjects (male and female) from all age groups on step test, sit and reach and 1-minute abdominal test. The low performance/scores in those fitness components which was cardiovascular endurance and muscular endurance in this study were also correlating to a similar study on young children (7-13 years old) by Eghbali, (2016). His study involving 316 children did not manage to find any evidence linking 2D:4D and performance in both aerobic and anaerobic fitness tests conducted after considering interferer factor of puberty. The finding from that study contradicted with the review by Hönekopp *et al*., (2007) mentioning that 2D:4D was not affected by the onset of puberty. On the other hand, the sampling analysis was disputed as the age range of the sample is enormous, ranging from 7 to 13 years old. This identical scenario was also observed in a study conducted by Manning and Hill, (2009). They found that low 2D:4D was a weak predictor of sprinting speed in young male subjects. This was after they considered other affecting factors of age, BMI and maturational index. But it is understandable as in both studies mentioned above, they included a wider range of age groups from 7 to 13 years old and 10 to 17 years old which differ from this study with smaller age range (10-12 years old). The wider age groups create higher probability in affecting physical performance especially by the effect of puberty changes and gap in physique among older subjects through confounding variables of age, BMI and maturation index.

As years go by, there were more studies that managed to find significant correlation on variety of fitness components, achievements and high performances in various types of sports as shown in a review by Kim & Kim, (2016). The reason for that is when the subjects are under competitive situation, sudden surge of testosterone occurred and affected the performance in sports and scores in physical fitness testing Kilduff *et al.*, (2013). This is similar to this study when the subjects were encouraged by the teachers and the researcher at the same time, thus created the sense of competitiveness for them to perform at their best during the physical fitness testing. It is also important to review from the findings preferring low 2D:4D towards performances in anaerobic based test. It is mostly due to the effects of prenatal testosterone on the human muscles. It is well known that testosterone does affect the muscular growth through various mechanism focusing on the mesenchymal stem cells (Herbst & Bhasin, 2004). Thus, as a result of these prenatal testosterone mechanism, it improves the muscular strength and power. Through the years, there are mixed findings relating 2D:4D towards anaerobic based event/sports. Pasanen *et al.*, (2021) discussed in their article suggesting that 2D:4D has a weak relationship towards muscular strength specifically the hand grip strength in adult's population, but not in younger population. In attempt to further strengthen the connection of prenatal testosterone on anaerobic fitness component, a past study by Halil *et al*., (2013) which tested on muscle mass and muscle strength, they found that lower 2D:4D was associated with bigger muscle mass and stronger force generated from hand grip strength test. The same also can be seen on studies by Manning and Hill, (2009) and Ranson *et al.*, (2015) suggesting that younger subjects are more prone to anaerobic based tests. Past studies also indicated that 2D:4D is correlated with high performance in various sports such as rugby, fencing, football, wrestling and sumo. Those sports also contain anaerobic components such as speed, strength and power which is equally important to have in order to be able to play that sport competitively, not depending entirely on aerobic fitness component. This explained that prenatal testosterone does affect the development of the muscles, and affecting the capability to generate higher strength. Related to this study, the low 2D:4D school children did perform reasonably good in push-up, standing broad jump and hand grip strength test.

The conflicting findings especially regarding the relationship of 2D:4D and muscular strength among adults and children is definitely interesting. Therefore, this situation is worth to be investigated regarding the related factors that might contribute to the mixed results. Nonetheless, most of the previous studies suggested that 2D:4D could predict sports performance. Thus, with further in-depth research, 2D:4D has the potential to be included as supporting tool in talent identification system.

CONCLUSIONS

The result showed that 2D:4D is sexually dimorphic with male subjects expressing lower 2D:4D readings compared to female subjects. Thus, it agrees with most studies that higher secretion of prenatal testosterone was mostly visible in male subjects with female subjects receiving lower testosterone and higher oestrogen. On the other part, low 2D:4D was more correlated with performance in anaerobic-based fitness tests in both genders. It was more evident in male subjects as they are much more associated with high performances in standing broad jump test, hand-grip strength test, push-up test and 1-min abs test. Compared to their female counterpart, 2D;4D of female subjects were significant with all tests except for step test and 1-min abs test.

Those important results reflect new perspective in understanding the role of prenatal testosterone towards the development and influence in the aerobic and anaerobic physiologically in human. Rather than most studies which stated that prenatal testosterone is more prone towards influencing the growth of cardiovascular system, it is also highly possible that prenatal testosterone also plays bigger role in muscle development and energy system pathways of aerobic and anaerobic. For future studies, it is recommended to look into the role of 2D:4D in affecting the energy system pathways and include subjects from variety of age groups, and proceeds accordingly by also investigating other possible related factors.

Conflicts of interest: The authors report no conflict of interest.

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