

The relationship among the digit ratio (2D:4D), physical activity, aggression and sensation seeking in mature and immature boys

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Article Info	Abstract
<p>Original Article</p> <p>Article history: Received: 22 July 2021 Revised: 29 July 2021 Accepted: 01 August 2021 Published online: 02 December 2021</p> <p>Keywords: aggression, physical activity, prenatal androgen, puberty, sensation seeking.</p>	<p>Background: Digit ratio (2D:4D) is a marker of prenatal androgen exposure that has been associated with behavioral parameters. Individuals with low 2D:4D are more aggressive and tend to engage in more physical activity.</p> <p>Aim: We examined the relationship between 2D:4D and physical activity, sensation seeking and aggression in mature and immature boys.</p> <p>Materials and Methods: The study population consisted of Mazandaran male students aged 9 to 17 years in 2019-2020. The sample was 218 healthy, cluster randomly selected boys (13.77 ± 2.4 y/o) from three schools with no health issues. 2D:4D digit ratio, physical activity, aggression, sensation seeking were measured. Pearson correlation analyzed variable associations. Significance was considered at $P \leq 0.05$.</p> <p>Results: Low 2D:4D ratio was associated with higher physical activity ($r \approx -0.27$), sensation seeking ($r \approx -0.3$), and aggression ($r \approx -0.21$), during childhood and adolescence ($P < 0.05$). These relationships among right and left hand 2D:4D ratios with physical activity and sensation seeking remained consistent across maturity levels ($P < 0.05$). Only immature boys had a significant association between 2D:4D ratios and aggression ($r \approx -0.29$, $P < 0.05$). Physical activity was positively associated with sensation seeking ($r \approx 0.25$, $P < 0.05$), but not aggression in mature and immature boys.</p> <p>Conclusion: Prenatal testosterone organizes boys' physical activity and behavioral parameters, influencing the later development of sensation-seeking and aggression and greater participation in physical activity. The study has limitations such as a small sample size and a self-report method for assessing aggression. Future research should focus on behavioral observation methods with larger sample sizes.</p>

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1. Introduction

The ratio of the second to the fourth digit (2D:4D ratio) is calculated by dividing the length of the second digit (index) by the length of the fourth digit (ring) and becomes relatively established during the early years of life [1]. There is evidence that this ratio is a sex-specific characteristic, with lower averages for men than for women. Such a difference has been observed in children under the age of two, and even in other species of animals. This ratio appears to be determined in utero around the 14th week of pregnancy and may be influenced by the prenatal hormonal environment.

A high testosterone to estrogen (T/E) ratio is thought to result in a low 2D:4D ratio (male-typical) and a high estrogen to testosterone (E/T) ratio is believed to result in a high 2D:4D ratio (female-typical) [2]. Therefore, one of the non-invasive methods to study prenatal levels of androgens is to use the 2D:4D ratio [1].

Lutchmaya et al. (2004) were the first to show a relationship between the concentration of fetal testosterone and estradiol in the amniotic fluid and the 2D:4D ratio; this relationship became significant only when the ratio was measured in the right hand [3].

Ventura et al. (2013) also found an association between amniotic testosterone and the 2D:4D ratio that was statistically significant only in girls [4].

Finally, some researchers found no association between the 2D:4D ratio and prenatal sex hormone levels [5, 6].

One possible mechanism for the association between the 2D:4D ratio and sex hormone levels is probably through the action of the Hox genes that differentiate the digits, testes, and ovaries. The joint action of these genes may underlie the relationship between gonadal function

(production of estrogen to testosterone) and digit growth [2]. The primary role of sex hormones during early development is to produce morphological and neurological sex differences that provide a basis for sex differences in behavior [7]. Sexual differentiation of the brain appears to follow a similar pattern to morphological traits, with tissue being masculinized by testosterone or feminized by its absence.

There are also several cases of gender differences in personality that are often associated with sex steroids [2]. For example, men score higher than women on psychopathy and various scales of aggression. A negative correlation has been found between testosterone levels and neuroticism in men. In addition, men are more involved in risk-taking and sensation-seeking, and a positive relationship has been reported between sensation-seeking and testosterone levels in men. On the other hand, women have been found to score higher than men on neuroticism and various measures of depression, and to have higher scores on conscientiousness and neuroticism [2, 8]. Perez et al. (2022) reported an inverse relationship between the 2D:4D ratio and psychopathic traits such as narcissism in humans, especially males [9].

One of the most important psychopathic traits related to the 2D:4D ratio is aggression. Aggressiveness, or the tendency to react in an angry way, is one of the most common antisocial behaviors that can create an unsafe environment for those around them and predict issues like delinquency, depression, substance abuse, and academic failure in those who exhibit aggressive behaviors. Studies conducted in Iran have reported 30% to 50% of aggression in children and adolescents [10]. Aggressive behavior has multiple causes, and biological, social, and cultural factors

continually interact with it. Regarding biological factors, previous research has focused on the role of hormones, especially testosterone and cortisol, in two developmental periods, before birth and during adolescence [11]. During these two periods, the nervous system is more sensitive to these hormones and causes structural changes that may affect future behavior. Therefore, a relationship between prenatal testosterone markers, such as the 2D:4D ratio, and some behavioral traits, such as aggression, seems likely. Several studies have shown such an association in young men [12], black men and women [13], children and adolescents [14], and pre-adolescent boys [15]. Also, the meta-analysis results of Turanovic et al. (2017) reported a weak but significant association between fetal testosterone, 2D:4D ratio, and aggressive behavior [16]. However, some other studies did not find an association between prenatal testosterone and aggressive behavior [17, 18].

Maturity is characterized by biological, psychological and behavioral changes in people. Regarding the relationship between testosterone levels during maturity and aggressive behavior, different studies have found varying results. Some studies have found that high testosterone levels are linked to increased aggression in mature individuals. Higher testosterone may raise proactive or instrumental aggression at this stage. However, testosterone alone does not completely explain aggression during maturity as other social and environmental factors also shape aggressive behavior to a large extent.

Sensation seeking is another important biosocial dimension of personality that includes sensation seeking and adventure (such as sports and risky activities), lack of inhibition (such as alcohol abuse, gambling,

and promiscuous sex), experience seeking (through the mind and senses and gaining new experiences), and boredom (restlessness and aversion to any kind of repetitive experience) [19]. There is evidence that prenatal testosterone levels are positively associated with sensation seeking. However, the evidence is conflicting [19].

Previous findings show a positive relationship between serum testosterone and lack of inhibition, as well as a positive relationship between free androgen index and the Zuckerman Sensation Seeking Scale [20]. However, other studies have reported no relationship between salivary and serum testosterone and sensation seeking [21]. These conflicting results may reflect the potential indirect effects of androgens on sensation seeking [20]. The presence of a positive relationship between 2D:4D and sensation seeking may be a sign of this indirect relationship. This may be due to the effect of the DRD4 dopamine gene variation, which involves the dopaminergic system in sensation seeking behavior; Because testosterone can affect the release of dopamine from dopaminergic neurons and its reward system [20].

On the other hand, the benefits of regular participation in physical activity during childhood are well documented. In recent years, however, an increase in sedentary behavior and a significant decline in aerobic fitness have been observed in the child population [22]. It appears that prenatal testosterone levels may have a potential effect on the amount of physical activity and subsequent physical fitness in humans.

Hönekopp et al. (2006) concluded that the 2D:4D ratio is negatively correlated with physical fitness in both men and women. They showed that the relationship

between physical fitness and 2D:4D ratio in men is mediated by the relationship with physical activity level. Therefore, a higher 2D:4D ratio in men may lead to a decrease in physical activity and provide a background for a sedentary lifestyle and a decrease in physical fitness [23]. This was also confirmed in the study by Ranson et al. (2015). They suggested that a lower 2D:4D ratio, which is associated with high testosterone and low estrogen before birth, plays a role in speed, endurance and handgrip strength in boys [22].

Crewther et al. (2022) also concluded that the 2D:4D ratio and testosterone were joint predictors of jump performance with different timing, speed and direction in male athletes, confirming that testosterone can activate and organize physical fitness in boys through multiple pathways [24]. However, Peeters et al. (2013) found no relationship between 2D:4D ratio and elements of physical fitness [25].

Koziel et al. (2017) also showed that there is an association between a lower 2D:4D ratio and improvements in sports and physical performance, which is at least partially due to prenatal testosterone function [26].

In a review study, Pasanen et al. (2022) found a weak negative correlation between the 2D:4D ratio and hoof strength, with significant heterogeneity between studies that could not be adjusted for sex and age. They suggested further studies on the mechanism of this association [27].

In this vein, the main purpose of the current study is to examine the relationship between the ratio of the second to fourth digits of the right and left hands, as a marker of prenatal testosterone levels, with aggression, sensation seeking, and physical activity in boys, and to examine the role of maturity in this relationship. It appears that

the 2D:4D ratio can potentially predict athletic success, physical health, and the need for individuals to consult with psychologists to control aggression and sensation seeking without the need for costly laboratory measurements. In this way, some of the maladjustments and misbehaviors observed in the boys at home and at school are significantly reduced.

2. Materials and Methods

The current research is a cross-sectional correlational study. In this research, the researchers intended to obtain relevant information about get a detailed assessment of the relationship between the ratio of the second to the fourth digit (2D:4D ratio) and psychological variables such as aggression and sensation seeking as well as physical activity in boys during before and after the stages of maturity. We confirm that all relevant ethical guidelines have been followed and that the Human Research Ethics Committee of Yazd University (Yazd, Iran) has approved the study protocol.

2.1. Participation

The statistical population of this research included all 9- to 17-year-old male students in Noor at various levels of primary and secondary schools. Using G-Power software for correlational research, the sample size consisted of 218 student boys. The sample size was deemed adequate based on the results of the sample size calculation. A sample size of at least 218 participants was needed for a correlational study with an anticipated effect size of 0.24, statistical power of 0.8, and a 0.05 level of significance [28]. The final sample in the study met the required sample size criteria. The sample was selected using cluster random sampling, wherein all primary

schools and secondary schools in Noor were considered as clusters. From each cluster, a random sample of students within the age range of 9 to 12 years for primary schools and 13-17 for secondary schools were selected.

2.2. Procedure

In this study, a cluster-randomization sampling method (based on the education level and region) was implemented from schools in Noor. Initially, the necessary permission for implementing research at schools was taken from the education office. Then, after meeting the schools authorities, invitation letters were sent to the students' parents to participate in the research. According to the statements of the parents, these people had no history of neuromuscular, cardiovascular, or any disease that would limit or prohibit physical activity. Their daily lives did not include any events that indicated deteriorating mental or physical health. They had clean bills of health with respect to all ailments limiting mobility and psychological wellbeing. Also, these people had no history of hospitalization due to psychiatric problems.

Participants with any diagnosed psychological or neurological disorders were excluded from the study. Only those participants who assented to participate and

whose parents provided written informed consent were included in the final sample. Based on the schedule, after filling the medical information questionnaire, the selected students were invited to the Ayatollah Khamenei Indoor Sports Hall in Noor city for evaluation. All selected students who assented to participate in the study were included in the final sample for conducting the research study.

2D:4D ratio. 2D:4D ratio: The length of the digits was measured using the indirect measurement technique [29]. For this purpose, a trained examiner performed the measurements twice for each subject (after performing multiple measurement techniques and reproducing the results). To perform the measurement, the subject was first asked to sit in a comfortable chair and place his hands on the grid paper on the table with the digits extended (in full abduction). In this situation, the shape of the digits was drawn by the examiner using a pencil placed completely vertically on the paper. From the above figure, the length of the digits was measured using a caliper with an accuracy of 0.1 cm [29]. The measurement procedure is shown in Figure 1.

The length of the second digit (2D). From the fold of the wrist that is as tangential as possible to the horizontal line of the grid paper to the tip of the index digit.



Figure 1. Measuring the length of the second and fourth digits

The length of the fourth digit (4D). From the fold of the wrist that is as tangential as possible to the horizontal line of the grid paper to the tip of the ring digit.

The second to fourth digit ratio (2D:4D ratio) was calculated by dividing the average length of the second to fourth digit by two measurements. Using the intraclass correlation coefficient (ICC) to estimate this ratio in two measurements, the reliability of this measurement technique was reported to be 0.95 for the dominant hand and 0.94 for the nondominant hand.

2.3. Instrument

Assessment of maturity status. The Iranian version of the Maturity Self-Rating Questionnaire was used to determine the degree of maturity [30]. This questionnaire included two series of images of genital growth and body hair growth patterns, which were self-reported by the subjects. Maturity was diagnosed clinically based on Tanner's stages, which classifies maturation in boys into five stages based on primary and secondary sexual development, including changes in the penis and growth of pubic and axillary hair. In the previous studies, this questionnaire had an acceptable coefficient of reliability [30]. The English version of this questionnaire has acceptable validity, and can be sufficiently accurate for a simple distinction between prepuberty and puberty for epidemiologic studies [30]. To ensure the accuracy of the results of the questionnaire, the subjects were also examined by a general practitioner.

Aggression. The standardized Buss-Perry Aggression Questionnaire (BPAQ) was used as a self-report measure of aggression in this study. This questionnaire has 29 items in which the subject evaluates his or her situation on a five-point Likert

scale. On this scale, people whose score is lower than the mean have low aggression and those whose score is higher than the mean have higher aggression. The Buss-Perry Aggression Questionnaire (BPAQ) has a high internal consistency. In the previous studies in the Iranian context, the Cronbach's reliability alpha coefficient for the total score of the questionnaire was reported to be 0.88, and for the subscales of physical aggression, verbal aggression, anger, and hostility between 0.72 and 0.84 [31]. The test-retest coefficient of the questionnaire was also reported as 0.8 in the previous studies [31]. In this study, the Cronbach's reliability alpha coefficient for the entire questionnaire was 0.85. The structural validity of this questionnaire has already been confirmed in Iranian children and adolescents [31].

Sensation seeking. Regarding the age of the subjects, Alizadeh's Sensation Seeking Scale (ASSI) was used to measure sensation seeking. This scale contains 24 4-point Likert-type items, which were designed according to the personality and behavioral characteristics and cultural and social context of Iranian society. In the previous studies, the test-retest reliability of this scale was reported as 0.77 and its Cronbach's reliability alpha coefficient was 0.86. The criterion validity of this questionnaire has been confirmed based on the criteria of Arnet's Sensation Seeking Questionnaire, Minnesota Scale, and Eysenck's Personality Questionnaire [32]. The total score of the test varies between 24 and 96, and a higher score indicates more sensation seeking. In the present study, the Cronbach's alpha coefficient of reliability of this questionnaire was calculated to be 0.85.

Physical activity. In this study, the Physical Activity Questionnaire of Children and Adolescents (PAQ-C) was used to

measure the amount of physical activity. The original version of the PAQ-C is appropriate for elementary and middle school-aged children (approximately 8-14 years of age), but this questionnaire has also been used in Iranian children aged 12-16 years [33]. This questionnaire includes 9 five-point Likert items developed by Kowalski et al. The score of this questionnaire varies between 1 and 5, with 1 indicating the lowest amount of physical activity and 5 indicating the highest amount of physical activity [33]. The internal consistency of this test was reported to be 0.79 to 0.89 by Cronbach's alpha coefficient of reliability; also, using the test-retest method, the reliability was obtained to be 0.75 to 0.82. The criterion validity of this questionnaire shows favorable values with other similar questionnaires [34].

2.4. Statistical analysis

Descriptive statistics, including mean and standard deviation, were used to classify and summarize the data. The distribution of each variable was checked prior to analysis. There was no gross violation of normality (all skewness and kurtosis values were within ± 2). Due to the normality of the data distribution, Pearson's correlation coefficient and linear regression were used to examine the relationship between the research variables. SPSS 26.0 was used for statistical analysis. A p-value less than 0.05 was considered statistically significant.

3. Results

Descriptive statistics of the data related to the research variables in all subjects in terms of maturity status are shown in Table 1.

Table 1. Descriptive statistics of the research variables in terms of the immature and mature groups

Variable	Group	Number	Mean	SD
2D:4D (Right hand)	Immature	109	0.9923	0.01233
	Mature	109	0.9926	0.01261
	Total	218	0.9925	0.01244
2D:4D (Left hand)	Immature	109	0.9924	0.01218
	Mature	109	0.9931	0.01264
	Total	218	0.9928	0.01239
Sensation seeking	Immature	109	64.3303	11.01855
	Mature	109	67.9174	10.43687
	Total	218	66.1239	10.85677
Aggression	Immature	109	71.3303	10.85515
	Mature	109	74.3394	12.67340
	Total	218	72.8349	11.86834
Physical activity	Immature	109	2.8426	0.69778
	Mature	109	2.9290	0.78868
	Total	218	2.8858	0.74416

The results show that the mean 2D:4D ratio of the right hand is slightly lower than that of the left hand. The level of sensation seeking in the mature group was slightly higher than in the immature group (3%). The level of aggression in the mature group

was also slightly higher than in the immature group (4.2%). The amount of physical activity based on cut points [3] was not favorable and most of the subjects were in the inactive category.

The general results of the correlation

between the ratio of the second to the fourth digit of the right and left hand and

psychological variables and physical activity are presented in Table 2.

Table 2. The results of the Pearson correlation coefficient in examining the relationship between the variables in all subjects

Variable	Index	2D:4D L	2D:4D R	Physical activity	Aggerssion	Sensation seeking
2D:4D L	r	1	0.991**	-0.272**	-0.213**	-0.299**
	sig.		0.000	0.000	0.002	0.000
	N	218	218	218	218	218
2D:4D R	r		1	-0.268**	-0.215**	-0.317**
	sig.			0.000	0.001	0.000
	N		218	218	218	218
Physical activity	r			1	0.065	0.251**
	sig.				0.343	0.000
	N			218	218	218
Aggression	r				1	0.099
	sig.					0.145
	N				218	218

*significant at 0.05 level

r: Pearson correlation coefficient; sig.: significant level; 2D:4D L: the ratio of the second to the fourth digit of the left hand; 2D:4D R: the ratio of the second to the fourth digit of the right hand

The results show that there is a high correlation between the ratio of the second to the fourth digit of the right and left hand with each other ($r=0.99$).

Also, there is a significant and inverse relationship between the ratio of the second to the fourth digit of the left and right hand with the level of physical activity ($r=-0.272$ for the left hand and $r=-0.268$ for the right hand). There is also a significant and negative relationship between psychological variables (sensation seeking and aggression) and the ratio of the second to the fourth digit of the left and right hand in boys (sensation seeking: $r=-0.299$ for the left hand and $r=-0.317$ for the right hand; aggression: $r=-0.213$ for the left hand and $r=-0.215$ for the right hand).

The results of the Pearson correlation coefficient also show that there is no significant correlation between physical activity and aggression ($r=0.065$). However, a significant correlation was

observed between physical activity and sensation seeking ($r=0.251$). The relationship between sensation seeking and aggression was also not significant ($r=0.099$).

Table 3 shows the results of the relationship between the research variables in terms of the maturity status of the subjects. These results show that there is a direct and high relationship between the ratio of the second to the fourth digit of the right and left hand in both groups ($r=0.993$ for the immature group and $r=0.990$ for the mature group).

Also, there is a significant and inverse relationship between the 2D:4D ratio in both hands and the level of physical activity in both groups, and this relationship is slightly higher in the mature group (in the immature group, $r=-0.215$ for the left hand and $r=-0.219$ for the right hand, and in the mature group, $r=-0.325$ for the left hand and $r=-0.314$ for the right hand).

Table 3. Results of the Pearson correlation coefficient in examining the relationship between the research variables in terms of maturity status

Variable	Index	Immature					Mature				
		2D:4D L	2D:4D R	Physical activity	Aggression	Sensation seeking	2D:4D L	2D:4D R	Physical activity	Aggression	Sensation seeking
2D:4D L	r	1	0.993**	-0.215*	-0.287**	-0.256**	1	0.990**	-0.325**	-0.161	-0.361**
	sig.		0.000	0.025	0.002	0.007		0.000	0.001	0.094	0.000
	N	109	109	109	109	109	109	109	109	109	109
2D:4D R	r		1	-0.219*	-0.289**	-0.273**		1	-0.314**	-0.161	-0.376**
	sig.			0.022	0.002	0.004			0.001	0.094	0.000
	N		109	109	109	109		109	109	109	109
Physical activity	r			1	0.057	0.272**			1	0.058	0.221*
	sig.				0.556	0.004				0.548	0.021
	N			109	109	109			109	109	109
Aggression	r				1	-0.003				1	0.155
	sig.					0.975					0.106
	N				109	109				109	109

*significant at 0.05 level

r: Pearson correlation coefficient; sig.: significant level; 2D:4D L: the ratio of the second to the fourth digit of the left hand; 2D:4D R: the ratio of the second to the fourth digit of the right hand

The correlations between sensation seeking and the ratio of the second to the fourth digit of the left and right hand in boys are also shown in Table 3 in terms of maturity status. These results show that there is a significant and inverse relationship between sensation seeking and the ratio of the second to the fourth digit of the left and right hand in the mature and immature groups (in the immature group, $r=-0.256$ for the left hand and $r=-0.273$ for the right hand, and in the mature group, $r=-0.361$ for the left hand and $r=-0.376$ for the right hand).

Also, there is a significant and inverse relationship between this ratio in both hands and the level of aggression only in the immature group (in the immature group, $r=-0.287$ for the left hand and $r=-0.289$ for the right hand, and in the mature group, $r=-0.161$ for the left and right hands).

The results of the Pearson's correlation coefficient in examining the relationship between physical activity level and sensation seeking in the two mature and immature groups show the existence of a significant and direct relationship in both groups. However, this correlation is significantly higher in the immature group ($r=0.272$ in the immature group and $r=0.221$ in the mature group).

Also, regarding the relationship between the level of physical activity and aggression, the results indicate that there is no significant relationship between these two variables in both the mature and immature groups ($r=0.057$ in the immature group and $r=0.058$ in the mature group).

Finally, the Pearson correlation coefficient between the two variables of sensation seeking and aggression shows the absence of a significant relationship

between these two variables in both the mature and immature groups (the correlation coefficient in the immature group $r=-0.003$ and in the mature group $r=0.155$).

In order to show the relationship between the ratio of the second to fourth

digits of the right hand (Figure 2) and the left hand (Figure 3) with the variables of physical activity, sensation seeking and aggression in both the mature and immature groups, a scatterplot diagram was used. The regression coefficient (R^2) between the two variables is shown in the figures.

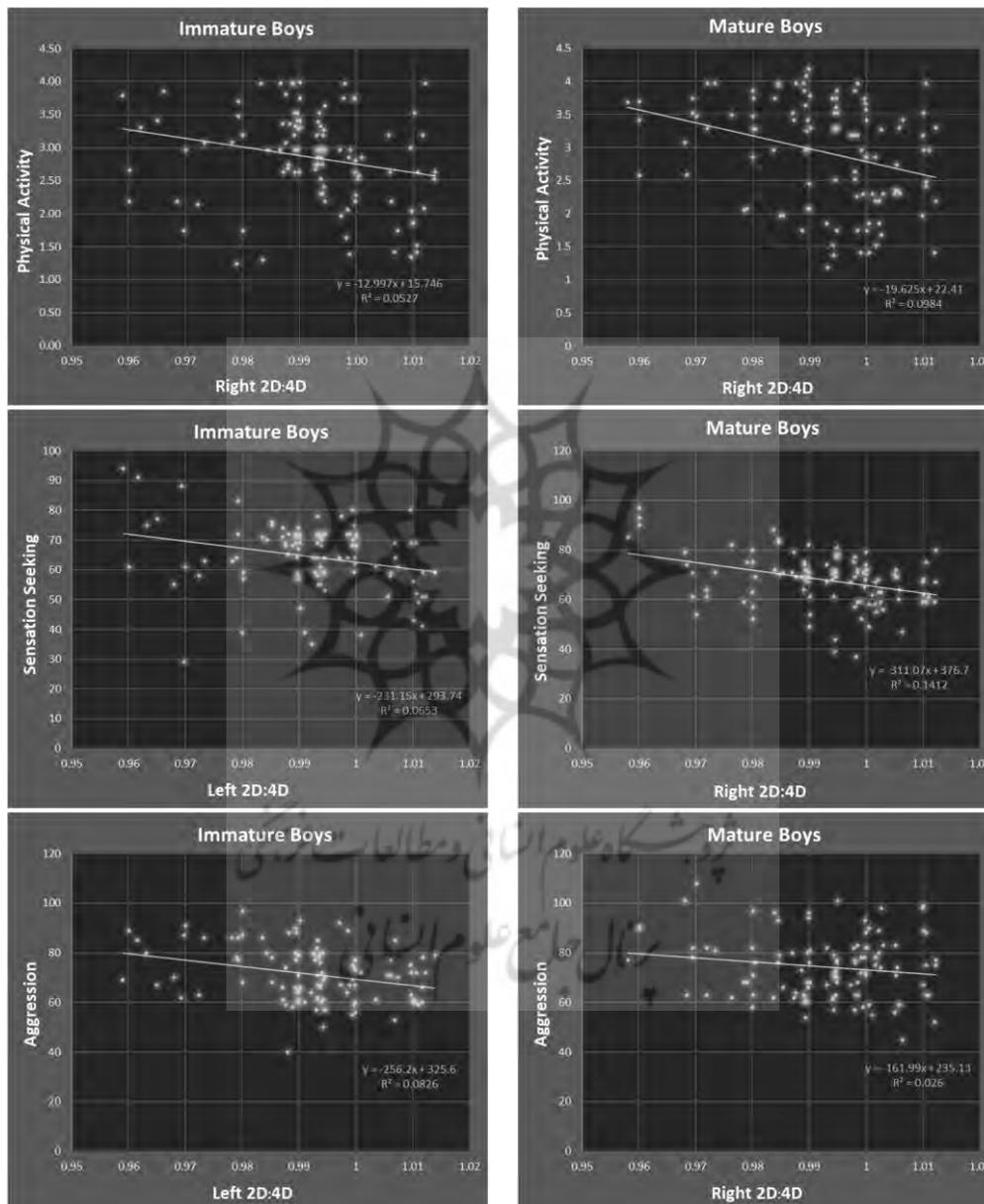


Figure 2. Scatter charts of the relationship among Digit ratio (2D:4D) of the right hand with the dependent variables in mature and immature boys

Figure 2 shows that the regression coefficient of the level of physical activity by the ratio of the second to the fourth digit

of the right hand is 5.3% for the immature group and 9.8% for the mature group; also the regression coefficient of the level of

sensation seeking by the ratio of the second to the fourth digit of the right hand is 7.4% for the immature group and 14.1% for the mature group. Furthermore, the regression coefficient of aggression by the ratio of the second to the fourth digit of the right hand is 8.3% for the immature group and 2.6% for the mature group.

Figure 3 shows that the regression coefficient of the level of physical activity by the ratio of the second to the fourth digit

of the left hand is 4.6% for the immature group and 10.6% for the mature group; also the regression coefficient of the level of sensation seeking by the ratio of the second to the fourth digit of the left hand is 6.5% for the immature group and 13% for the mature group. Furthermore, the regression coefficient of the level of aggression by the ratio of the second to the fourth digit of the left hand is 8.3% for the immature group and 2.6% for the mature group.

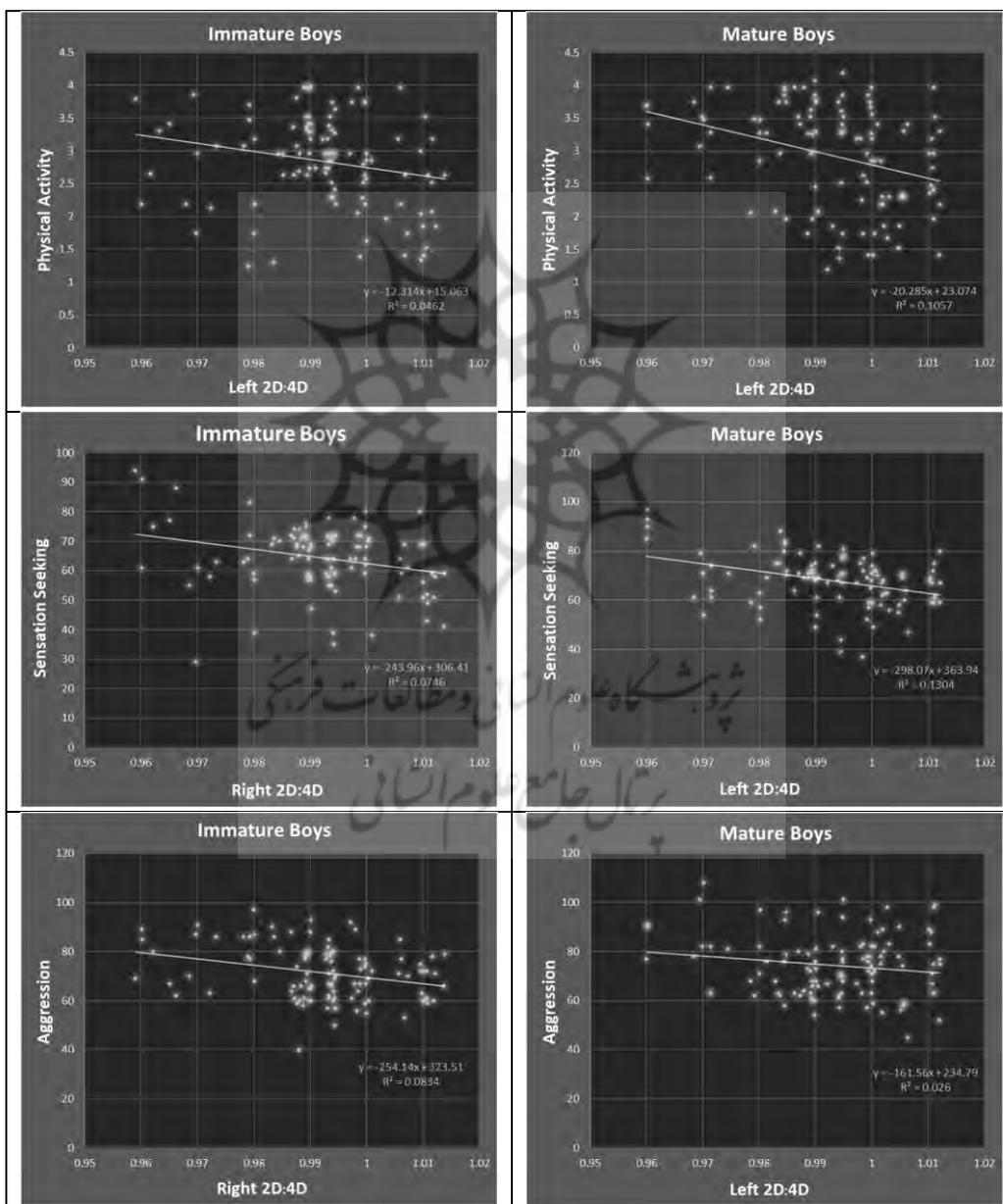


Figure 3. Scatter charts of the relationship among Digit ratio (2D:4D) of the left hand with the dependent variables in mature and immature boys

4. Discussion

The ratio of the length of the second digit to the length of the fourth digit is one of the anthropometric traits that is thought to be related to functional and psychological changes. A lower ratio of this marker indicates a higher level of prenatal testosterone, whose effects on human performance and behavior are well known. Therefore, the aim of this research was to examine the relationship between this marker and some psychological elements, such as aggression and sensation seeking, and the level of physical activity in boys before and after maturity.

The results of this research show that there is a high correlation between the ratio of the second to the fourth digit of the right and left hand in boys. This issue has been similarly reported in many previous studies. The correlation between the ratio of the second to the fourth digit of the right hand and the left hand in the previous researches was generally more than 0.9. However, the small difference between these two ratios can be related to physical, mental, and psychological characteristics, and even justify the difference in some results of previous research.

For example, Hönekopp and Schuster (2010) reported that contrary to popular belief, the second to fourth digit ratio of neither hand has the same correlation with athletic performance as the other hand, which means that researchers should always measure the second to fourth digit ratio in both hands. The result of their research showed that some physical and psychological variables are likely to be better predicted by the second to fourth digit ratio of the left hand and others by the second to fourth digit ratio of the right hand [35].

The relationship between the ratio of

the second to the fourth digit of the right hand to the left hand, $D(r-l)$, has also been confirmed as a criterion for diagnosing and predicting right-handedness or left-handedness. Interestingly, these results can be interpreted as a reason why left-handers are exposed to higher levels of testosterone in the womb [36].

The results of this research also show that there was a significant and inverse relationship between the ratio of the second to the fourth digit of the left and right hand with physical activity. In the past, there have been few and contradictory studies on this topic.

The results of the meta-analysis study by Pasanen et al. (2022) show that prenatal testosterone (the ratio of the second to the fourth digit) may be a long-term predictor of health by improving the amount of physical activity and increasing strength. It is likely that prenatal testosterone affects the regulation of several skeletogenic genes responsible for the growth and development of several body systems (e.g., musculoskeletal), leading to potential increases in strength. Prenatal testosterone may also affect muscle strength by influencing physical activity behavior [27].

Koziel et al. (2017), who compared the 2D:4D ratio between inactive healthy young men and team and individual athletes, reported that inactive young men had the highest 2D:4D ratio compared to the other two groups. Their results showed that individual athletes had a significantly lower 2D:4D ratio compared to team athletes and non-athletes [26].

Tomkinson and Tomkinson (2017) reported a significant relationship between 2D:4D ratio and grip strength, controlling for weight, age and BMI. They suggested that the physical activity level of the subjects was likely influential in this

relationship [37].

Ranson et al. (2015) reported a significant and inverse relationship between 2D:4D ratio and physical fitness test scores in boys. They suggested that physical fitness levels, especially aerobic fitness, are likely to be lower because of the decrease in physical activity levels of the subjects due to the decrease in sex hormone levels [22].

Hönekopp et al. (2006) also reported that the inverse relationship between second to fourth toe ratio and physical fitness in men was mediated by increased physical activity and sports participation. This shows that prenatal exposure to testosterone affects motivation to exercise, which in turn affects levels of physical fitness. Interestingly, this issue was only true for men, and in women, despite the existence of a relationship between physical fitness and a lower 2D:4D ratio, no relationship with physical activity was observed. According to them, high levels of testosterone in men may be a motivation for physical activity and training and success in a sport by satisfying the sense of competitiveness. This issue is consistent with the results of the present study that there is an association between more physical activity and a lower 2D:4D ratio [23].

Also, previous studies have shown that the voluntary choice of the type of sport activity is also related to the 2D:4D ratio, which may lead to higher sensation seeking in people with a smaller ratio of the second to the fourth digit [38]. Interestingly, a significant relationship between sensation seeking and physical activity was also observed in the current study, which supports the truth of this issue.

The results of Ramos et al. (2022) also showed that the 2D:4D ratio can be used to help identify and select talent and make decisions about training programs in sports,

especially ball sports [39].

However, a recent study in adolescents showed no significant relationship between the amount of physical activity and the 2D:4D ratio [40].

These conflicting findings may be related to other factors involved in sports participation in different cultures. On the other hand, the comparison of this relationship between mature and immature people shows a slight difference between them, indicating the lack of influence of maturity in this relationship.

The results of this study showed a significant relationship between the second to fourth digit ratio and psychological variables. In general, there was a significant and inverse relationship between arousal and aggression with the ratio of the second to the fourth digit of the left and right hand. This relationship was maintained with respect to sensation seeking and the 2D:4D ratio when maturity was taken into account (in both mature and immature groups). But in the case of aggression, only in the immature group, there was a significant and inverse relationship with the ratio of the second to fourth digit of the left and right hand. Previous research has investigated the relationship between personality traits and the 2D:4D ratio, and their findings indicate the existence of a correlation between some personality traits, such as the five main factors of personality, and the ratio of the second to fourth digit [9]. It is likely that this relationship is caused by the effect of the sex hormone system associated with the lower 2D:4D ratio on personality traits. It is possible that exposure to testosterone either prenatally or postnatally can cause behavioral changes in both humans and animals, excitability and aggression being two of them.

Previous studies on the relationship

between sensation seeking and 2D:4D ratio have reported conflicting results. The results of Fink et al. (2006) show that there is a significant relationship between a lower 2D:4D ratio and sensation seeking in men, but not in women [2]. However, Austin et al. (2002) reported a significant relationship between a lower 2D:4D ratio and sensation seeking in women but not in men [41].

The results of the meta-analysis by Voracek et al. (2009) did not report a significant relationship between the 2D:4D ratio of the left hand and sensation seeking in either sex. However, there was a significant relationship for the right hand [19].

These differences may be due to cultural or sample differences. However, other factors such as family relationships, media, and lifestyle patterns that may affect the level of sensation seeking were not examined in this study or in previous research. The time at which sensation seeking is measured may also be effective in this area. Previous findings have shown higher levels of sensation seeking in the evening than in the morning. In the present study, all measurements were taken in the morning, which may be effective in the relationship between 2D:4D ratio and sensation seeking. Sensation seeking appears to be related not only to androgens, but also to estrogens such as estradiol and estrone in men. Low levels of cortisol and endorphins, low levels of thyroid stimulating hormone and monoamine oxidase, and a serotonergic system along with a strong and controlled dopamine system in men are also associated with higher levels of sensation seeking. Therefore, other hormones related to sensation seeking may influence and reduce the variance of the relationship between 2D:4D ratio and sensation seeking [19].

On the other hand, Weisman et al. (2015) found a significant association between the oxytocin receptor gene (OXTR) with a lower 2D:4D ratio and psycho-emotional traits such as sensation seeking in humans [42]. However, changes in sensation seeking and its stability at different stages of life and age may also be effective in this context.

Previous studies show that for some people, sensation seeking is a more stable trait and has a stable pattern throughout life. However, more than half of adolescents show an increase in sensation seeking over time. Interestingly, adolescents with high sensation seeking and stability reported high levels of aggression and delinquency as they aged [43]. It appears that the effect of prenatal testosterone on people's arousal may change under the influence of puberty. Therefore, caution should be used in classifying sensation seeking in prepubertal children. A thorough understanding of the contextual and individual factors that distinguish more stable groups of sensation seekers may be useful in understanding the role of sensation seeking in relation to growth and maturation in other adolescent problem behaviors.

Another important finding of this study is the relationship between physical activity and sensation seeking in children and adolescents. The results of previous studies show that there is a significant and direct relationship between higher sensation seeking and engagement in physical activity [44, 45].

Minkwitz et al. (2016) reported a significant relationship between total daily energy expenditure and sensation seeking. They state that the preferred activity pattern of individuals with high arousal seeking is to engage in more intense activities rather than to engage in new activities [45].

Wilkinson et al. (2013) link the existence of sensation seeking with physical activity to the existence of possible genetic reasons for sensation seeking. One of these sensation-seeking genes is ACE, which is associated with physical activity in both children and professional athletes. There are other genes in TPH2 and SNAP25 that have been previously identified as being associated with gambling and smoking behavior. These four physical activity-related SNPs have distinct neural processing and/or metabolic functions [44].

These findings are also consistent with previous research investigating the social reasons for youth sports participation. Among elementary school boys, sports participation is directly related to higher social status [46]. Wilkinson et al. (2013) suggest that higher levels of sensation seeking may be a potential genetic factor for problem behaviors in childhood and adolescence, and that participation in sports activities may be an important moderator of this relationship [44].

One of the goals of modern criminology is to use physical indicators to predict the occurrence of crimes in people who are potentially prone to committing crimes. The results of the present study showed that there is a significant and inverse relationship between the ratio of the second to the fourth digit and aggression. Further investigation revealed that this relationship is significant only in the group of immature boys. The relationship between a lower 2D:4D ratio and aggression is consistent with many psychological and criminological theories. Previous research has shown that there is a significant relationship between physical aggression and a lower 2D:4D ratio in males, but not in females. Bailey and Hurd (2005) suggest that this may be due to the role of prenatal

testosterone as an organizer of physical aggression in men [12]. This organizing role has been confirmed in research on hyperactive preschool children.

The results of the meta-analysis also show the existence of a relationship between the two in men, but not in women. However, the correlation between 2D:4D ratio and many other physical and physiological factors, such as low heart rate and maternal smoking during pregnancy, is less with aggression [47].

On the other hand, puberty may influence aggression as an important factor by affecting sex hormone levels and modulating other physiological and psychological factors. Therefore, aggression after puberty seems to be less affected by factors such as prenatal testosterone. However, the relationship between prenatal testosterone and aggression may be strengthened in some situations.

Kilduff et al. (2013) played a violent video to men and found that those with a lower 2D:4D ratio showed more aggressive behavior after watching the video. Interestingly, testosterone levels increased more in men with a lower 2D:4D ratio than in men with a higher 2D:4D ratio after watching a violent video [48].

Ribeiro et al. (2016) observed a significant increase in strength and a moderate increase in testosterone levels, emotional stability, and physical aggression after showing violent tackles to 89 young men. This increase was correlated with a lower 2D:4D ratio in the subjects. Interestingly, there was no significant correlation between these indicators and the 2D:4D ratio after viewing an ineffective movie (blank screen) [49].

Probably, the relationship between these two variables may be due to exposure

to prenatal testosterone and self-control mechanism, which can be considered as primary factors of aggression. The lack of measurement of other factors related to aggression such as family, antisocial attitudes and their mutual effects may be one of the limitations of the present findings.

Finally, the results of the present study did not show a significant relationship between physical activity and aggression, while this issue has been investigated in some previous studies.

Fite and Vitulano's study (2011) shows a significant and inverse relationship between instrumental aggression and physical activity, but physical activity was not related to reactive aggression. In addition, physical activity moderated the relationship between active aggression and peer delinquency, such that at high levels of physical activity, instrumental aggression was not related to peer delinquency, but at low levels of physical activity, active aggression was positively related to peer delinquency. Therefore, physical activity may be an important factor in moderating the relationship between aggression and other problem behaviors [50].

A recent study of college students also shows how physical activity and emotional intelligence help reduce aggressive behavior. Emotional intelligence with greater ability to control emotions creates greater control over aggressive behaviors, which means fewer problems associated with aggressive behaviors. This study also shows that the higher the intensity of physical activity, the lower the markers of aggression. Physical activity should be emphasized not only to improve or maintain physical health, but also to improve behavior because it releases accumulated stress [51]. This may be particularly

important in some provinces of the country where crimes related to physical aggression are statistically high.

We do recognise the study limitations such as the small sample size, the pooling of physical activity, sensation seeking, and aggression data across each session and the combining of challenges to induce a behavioral parameters change. Thus, we are unable to determine the relative contribution of each stimulus to the observed behavioral profiles such as sensation seeking and aggression. Using self-report questionnaires to assess aggression can be difficult, as participants may underreport the extent of their aggressive behaviors and tendencies. Self-reported aggression measures are prone to social desirability biases where respondents aim to present themselves in a favorable light. Future research should focus on behavioral observation methods for measuring aggression using larger samples.

5. Conclusion

The results of this study show that boys with a lower ratio of second to fourth digits have higher levels of sensation seeking and aggression. At the same time, these individuals have higher levels of physical activity, which can potentially play an important role in modulating risky and stressful behaviors (especially in societies where this gives them a higher social status). Therefore, paying attention to individuals with a lower 2D:4D ratio as a target group for training can be considered very crucial for changing attitudes and social values.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. This research was approved by the ethics committee of Yazd university. (Ethical code: IR.YAZD.REC.1402.002).

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

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