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# Digit Ratio (2D:4D) and Relative Age Effect (RAE) in Physical Fitness Testing Performance on Male and Female Adolescences

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## ABSTRACT

The digit ratio (2D:4D), measure the prenatal testosterone and estrogen exposure, where a lower ratio suggests higher testosterone exposure that has been associated with masculine traits, including aggression and athletic performance. Simultaneously, the relative age effect (RAE) illustrates the advantages in physical performance and sports for individuals born closer to the selection cut-off dates. Despite these associations, research presents mixed findings on the impact of 2D:4D and RAE on physical fitness testing among adolescents, indicating a critical gap in understanding the dynamics between biological and chronological factors in youth fitness performance. Therefore, this study aims to explore the correlation between the role of 2D:4D and RAE with physical fitness performance in male and female adolescents. A cohort of 234 high school students, aged 13 to 17 years old, underwent measurements of height, weight, body mass index, waist-to-hip ratio, and 2D:4D participated in six physical fitness tests. Interestingly, the findings reveal no significant correlation between 2D:4D and RAE with physical fitness performance in males, whereas in females, certain associations were observed with 2D:4D correlated with SBJ and RAE are linked with RL-HGS ($p<0.05$). These results underscore the complexity of predicting athletic ability from biological and chronological markers and highlight the necessity for further research to dissect the intricacies influencing fitness outcomes among adolescents.

***Keywords:*** *prenatal testosterone, relative age effect, physical fitness, adolescences*

## INTRODUCTION

The digit ratio (2D:4D) emerges as a pivotal biological marker, offering profound insights into the realms of prenatal hormonal influences and their enduring impact on sexual dimorphism. This ratio, defined by the comparative lengths of the second (index) and fourth (ring) digits, has been extensively studied for its potential to reflect prenatal exposure to sex steroids, notably testosterone and estrogen. The prevailing scientific consensus suggests that males typically exhibit a lower 2D:4D than females, indicative of a longer fourth digit relative to the second, which is believed to signal greater prenatal testosterone exposure (Zheng & Cohn, 2011). In other study by Malas et al., (2006), they showed that the development of testosterone, estrogen, or a combination of both hormones during the embryonic stage influences whether a person exhibits more masculine or feminine characteristics. Additionally, they demonstrated that the 2D:4D is sexually dimorphic. This conclusion was further supported by Ernsten et al., (2021) and Galis et al., (2010) who linked the 2D:4D ratio with various physical and behavioral traits across genders. This biological nuance carries implications far beyond mere anatomical trivia, extending into domains such as athletic prowess (Kim & Kim, 2016; Pasanen et al., 2021), social behaviors (Nepomuceno et al., 2016; Richards et al., 2015), and even predispositions to certain sex-biased diseases (Hopp et al., 2014; Jeevanandam & Muthu, 2016).

Emerging from the foundational understanding of 2D:4D's biological underpinnings is a diverse body of research linking this 2D:4D to physical and athletic performance. Initial studies posited that a lower 2D:4D might serve as a proxy for heightened athletic ability, suggesting that individuals with a pronounced prenatal testosterone exposure—reflected through their 2D:4Ds—tend to excel in physical and sports-related endeavors. This association has been substantiated through various empirical inquiries, identifying significant correlations between lower 2D:4D and superior performance across a spectrum of physical fitness measures and sports disciplines (Disterhaupt et al., 2022; Eler & Eler, 2018; Gümüş & Tutkun, 2018; Kim & Kim, 2016; Ranson et al., 2015) However, some of these studies often rely on small sample sizes, much older subjects or primarily focus on one gender only. Focusing on physical fitness performance, Ranson et al., (2015) found that in Welsh children, a lower 2D:4D was oberseved with better aerobic capacity, speed, and power in males, but not in females. Despite these varied results, other studies have linked the 2D:4D ratio to upper body strength (Nanda & Samanta, 2017; Tomkinson & Tomkinson, 2017) and lower body power (Hsu et al., 2018; Nobari et al., 2021) .

However, the narrative surrounding 2D:4D and physical fitness performance is not without its complexities and contradictions. A segment of the scholarly community has presented evidence challenging the straightforward association between digit ratios and physical prowess. For example, Eghbali, (2016) did not observe any significant connection between 2D:4D and physical fitness tests in his study of Iranian male and female children. Manning and Hill, (2009) initially identified a significant correlation between a lower 2D:4D ratio and sprinting speed in young children, but subsequent analysis, considering covariances, revealed that this relationship was weak. In addition, in a study involving 359 primary schoolchildren, Azam et al., (2022) noticed that lower 2D:4D was associated with high scores in leg power and upper body strength among both male and female children. However that study merely focus on children, not on adolescent. These dissenting studies highlight the presence of mixed findings and argue against a universal applicability of 2D:4Ds as reliable predictors of athletic ability, underscoring the nuanced interplay of biological, environmental, and developmental factors in determining sports and fitness outcomes.

In parallel to the discourse on digit ratios, the relative age effect (RAE) has emerged as another lens through which disparities in athletic success and physical fitness can be examined. RAE delineates the developmental and experiential advantages accrued by individuals born closer to the cutoff dates used for age-group classification in sports. This temporal dimension of development posits that those born earlier in the selection year benefit from a relative maturity compared to their younger peers, potentially influencing their opportunities for success in athletic settings. A successful athlete needs to excel in both health-related and skill-related fitness components. In this context, RAE effect can significantly impact physical performance, particularly in cardiovascular fitness (endurance) and agility (Huertas et al., 2019). In addition to that, in an earlier review article by Cobley et al., (2009) shown that RAE is more prevalence in adolescent. Additionally, individuals who experience early exposure and rapid improvement in physical, physiological, and psychological aspects tend to have a performance edge over those who develop these attributes later (Jones et al., 2018; Joyner et al., 2020; Patel et al., 2019). While RAE's implications have been extensively explored among athletes, its impact on non-athletes, particularly adolescents, remains less understood. Existing research into RAE's gender-specific effects and its influence across different stages of education hints at a complex pattern that warrants further investigation, especially in relation to physical fitness performance among school-aged children (Nakata et al., 2017). Essentially, the past study of RAE is more focus on the performance of athlete in sport. Moreover, the study of RAE and fitness testing among adolescence is quite rare and difficult to obtained.

Given the outlined background, this study seeks to bridge the existing gaps in literature by examining the interplay between 2D:4D and RAE, and their collective impact on physical fitness testing performance among male and female adolescents. The endeavor aims to shed light on the nuanced relationships between 2D:4D and RAE, with a particular focus on correlating it with performance in physical fitness testing among adolescence. Through a comprehensive analysis of these variables, the study aspires to contribute valuable insights on 2D:4D and RAE, paving the way for more informed relationship of 2D:4D and RAE in physical fitness testing among adolescence..

## METHODOLOGY

The determination of the sample size was rigorously calculated using G*Power software version 3.1 with the effect size was set at medium 0.50 and power at 0.95 to ensure statistical validity and power for the research findings. The outcomes suggested minimum total sample size was 176 participants. This study encompasses a cohort of 234 secondary school students, comprised of 122 male and 112 female participants, whose ages range from 13 to 17 years old. Eligibility for participation required students to fall within the normal range for body mass index (BMI), and individuals with injuries, feeling sick were excluded, to maintain safety of the subjects. These selection criteria were meticulously established to mitigate any potential biases in the study's outcomes, aiming for a representative and equitable analysis. The ethical integrity of this research has been thoroughly vetted, receiving approval from the university's research ethics committee. Additionally, participation in the study is contingent upon obtaining informed consent from the subjects' parents or guardians, reinforcing the study's adherence to ethical standards and respect for participant welfare.

### *2D:4D Measurements*

The tools that are used in this study is by using photograph techniques. Before starting the assessment of the 2D:4D, the subjects were instructed to remove the watch, any accessories such as bracelets and rings and the subjects kneel down and aligned in straight position to have a comfortable position. Both of their palms facing upwards, fingers evenly spread but not excessively apart, and both of hands are pressed down on a foam, soft patching pad, and a sticker with the subject's id was placed on their palm. Later, by using a photograph technique, a phone camera was used to capture the photo. Both hands 2D:4D was coded as RL-2D:4D. The subjects are obligated to undertake this assessment for two attempts.

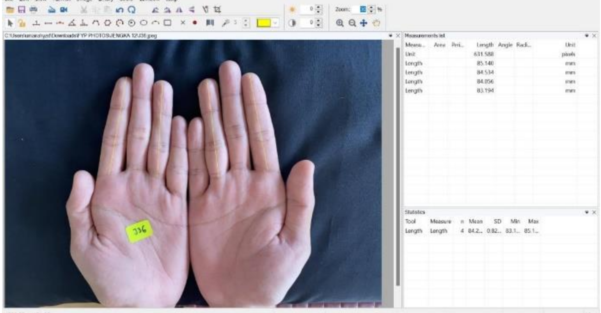

**Figure 1: Measurement to calculate the length of 2D:4D**

Figure 1 illustrates the methodology employed for calculating the 2D:4D on both hands, utilizing Digimizer Image Analysis software for this purpose. The selection of Digimizer over alternative options is predicated on its superior precision and accuracy in obtaining digit measurements, a critical factor in computer-assisted research methodologies. The advantages of using Digimizer include its capacity to deliver highly precise digit ratio readings, thereby significantly reducing the margin for human error inherent in manual measurements. This technological approach enhances the reliability and validity of the data collected by ensuring direct and meticulous measurement of digit lengths (Allaway et al., 2009; Kemper & Schwerdtfeger, 2009). To further safeguard the integrity of the measurement process, each photograph is calibrated prior to analysis, ensuring the utmost accuracy of the digit ratios by preventing any unintended alterations. In addition, participants weight, height, BMI and waist to hip ratio (WHR) was recorded earlier before commencing towards physical fitness testing.

***RAE Measurements***

For RAE, the birth month data were collected through form that are provided to the subjects. Classification of the quartiles are divided into four quartiles (Q1: January - March, Q2 – April - June, Q3: July - September and Q4: October - December).

***Physical Fitness Testing***

The physical fitness assessments conducted in this study encompass a comprehensive suite of tests designed to evaluate various dimensions of athletic capability, including the handgrip strength test for both right and left hand (RL-HGS), standing broad jump (SBJ), Illinois agility test (IAT), 20-meter sprint (ST), and the bleep test (VO2max). These tests collectively provide a holistic analysis of the participants' muscular strength (assessed through HGS), explosive power (evaluated by SBJ), agility (measured via IAT), speed (quantified with ST), and cardiovascular endurance (determined through VO2max). Prior to undergoing these fitness evaluations, subjects participated in a structured warm-up to prepare their bodies for the physical exertion and minimize the risk of injury. A thorough cooldown period followed the testing to facilitate recovery and reduce the risk of getting injury. Demonstrations of each test were provided to ensure participants fully understood the procedures and requirements, promoting accurate performance and data collection. Specifically, for the SBJ, peak power output (watts) was calculated utilizing the Sayers equation a method that transforms raw jump distance into a metric of explosive leg power (Sayers et al., 1999). The bleep test results were then converted into standardized norms, allowing for the comparison of cardiovascular fitness levels among the participants. This meticulous approach to pre-test preparation, instruction, and data analysis ensures the reliability and validity of the fitness assessments employed in this study.

$$Peak\ power\ (W)\ =\ 60.7 \times\ High\ jump\ (cm)\ + 45.3 \times weight\ (kg) - 2055$$

***Statistical analysis***

To ascertain the distributional properties of the data collected in this study, the Shapiro-Wilk test was employed, serving as a preliminary step to ensure the appropriateness of subsequent statistical analyses. In alignment with the research objectives delineated, two parametric tests were identified as suitable for this investigation: the Independent Samples T-Test and the Pearson Correlation Test. These analyses were meticulously executed using IBM SPSS Statistics (version 28.0), with a predetermined alpha level of significance established at $P < 0.05$, guiding the interpretation of results.

The independent samples t-test was applied to compare the mean values and standard deviations between male and female participants across two key variables: the 2D:4D digit ratio and RAE as they pertain to physical fitness performance among adolescents. Furthermore, the Pearson correlation test was utilized to explore the dynamics of the relationship between RAE and physical fitness testing performance within the adolescent. This test offers a quantitative measure of the degree to which RAE influences physical fitness levels, enabling a deeper understanding of how chronological age relative to peers may impact athletic performance.

## RESULTS AND DISCUSSION

### *Results*

**Table 1: Anthropometrics of on Male and Female Adolescences**

| | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|
| | **n** | **Min** | **Max** | **Mean±SD** | **n** | **Min** | **Max** | **Mean±SD** |
| **RL-2D:4D (mm)** | 122 | 0.835 | 1.053 | 0.957±0.38 | 112 | 0.891 | 1.046 | 0.970±0.032 |
| **Weight (kg)** | 122 | 32.50 | 113.80 | 60.00±15.72 | 112 | 36.85 | 112.20 | 53..01±13.09 |
| **Height (cm)** | 122 | 141.00 | 182.00 | 165.23±6.74 | 112 | 142.00 | 173.50 | 154.84±5.19 |
| **WHR** | 122 | 0.73 | 1.13 | 0.81±0.06 | 112 | 0.62 | 1.40 | 0.72±0.08 |
| **BMI (kg/min)** | 122 | 14.04 | 39.88 | 21.88±5.09 | 112 | 15.60 | 44.94 | 22.02±4.83 |

Table 1 showed descriptive data of anthropometrics and digit ratio of the subjects. Males had lower 2D:4D than females. RL-2D:4D or also known as total overall digit ratio, the lowest in male was 0.835mm and highest was 1.053mm (0.957±0.38). For RL-2D:4D (overall digit ratio), the lowest was 0.891mm and highest was 1.046mm (0.970±0.032).

**Table 2: RAE Frequency**

| | | Male | | Female | |
|---|---|---|---|---|---|
| | | **n (122)** | **%** | **n (112)** | **%** |
| **RAE** | Q1 | 28 | 23 | 30 | 26.8 |
| | Q2 | 34 | 27.9 | 24 | 21.4 |
| | Q3 | 31 | 25.4 | 28 | 25 |
| | Q4 | 29 | 23.8 | 30 | 26.8 |

Table 2 demonstrated RAE frequency of the male and female adolescences. In male, the highest of RAE frequency was in quartile 2 (n= 34), then followed by quartile 3 (n= 31), quartile 4 (n= 29) and the lowest was in quartile 1 (n= 28). As for female, the highest of RAE frequency was in quartile 4 and tied with quartile 1 (n= 30), followed by quartile 3 (n= 28) and the lowest was in quartile 2 (n= 24).

**Table 3: Physical Fitness and 2D:4D in Male**

| | 2D:4D Group | n | Mean±SD |
|---|---|---|---|
| **ST (s)** | High 2D:4D | 15 | 3.81±0.45 |
| | Low 2D:4D | 107 | 3.71±0.39 |
| **RL-HGS (kg)** | High 2D:4D | 15 | 67.04±9.00 |
| | Low 2D:4D | 107 | 68.60±13.70 |
| **IAT (s)** | High 2D:4D | 15 | 19.33±1.48 |

| | | | |
|---|---|---|---|
| | Low 2D:4D | 107 | 19.02±1.81 |
| **SBJ-PP (w)** | High 2D:4D | 15 | 12841.48±1939.68 |
| | Low 2D:4D | 107 | 12562.55±1748.29 |
| **VO2Max (ml/kg/min)** | High 2D:4D | 15 | 28.86±7.65 |
| | Low 2D:4D | 107 | 28.24±5.65 |

Table 3 showed Mean±SD value of male low and high 2D:4D group. A total of 122 subjects range from 13 years old to 17 years old participated. Based on the Table 4 above, low 2D :4D performed better than high 2D:4D in most of the physical fitness tests.

**Table 4: Physical Fitness and 2D:4D in Female**

| | **2D:4D Group** | **n** | **Mean±SD** |
|---|---|---|---|
| **ST (s)** | High 2D:4D | 19 | 4.50±.52 |
| | Low 2D:4D | 93 | 4.51±.54 |
| **RL-HGS (kg)** | High 2D:4D | 19 | 41.28±5.57 |
| | Low 2D:4D | 93 | 44.67±7.60 |
| **IAT (s)** | High 2D:4D | 19 | 23.19±1.93 |
| | Low 2D:4D | 93 | 22.52±1.95 |
| **SBJ-PP (w)** | High 2D:4D | 19 | 7480.77±1250.27 |
| | Low 2D:4D | 93 | 8194.99±1336.39 |
| **VO2Max (ml/kg/min)** | High 2D:4D | 19 | 20.12±1.81 |
| | Low 2D:4D | 93 | 20.32±2.40 |

Table 4 showed Mean±SD value of female low and high 2D:4D group. A total of 112 subjects range from 13 years old to 17 years old participated. Based on the Table 6 above, low 2D :4D performed better than high 2D:4Din most of the physical fitness tests.

**Table 5: Comparison of Low and High 2D:4D on Male Subjects**

| | **F** | **Sig.** | **t** | **df** | **Mean Diff** | **SE Diff** |
|---|---|---|---|---|---|---|
| **ST (s)** | 1.990 | 0.161 | 0.940 | 120 | 0.105 | 0.112 |
| | | | 0.839 | 17.031 | 0.105 | 0.125 |
| **RL-HGS (kg)** | 2.949 | 0.089 | -0.428 | 120 | -1.562 | 3.652 |
| | | | -0.584 | 24.241 | -1.562 | 2.676 |
| **IAT (s)** | 0.197 | 0.658 | 0.638 | 120 | 0.312 | 0.489 |
| | | | 0.740 | 20.311 | 0.312 | 0.422 |
| **SBJ-PP (w)** | 0.264 | 0.608 | 0.571 | 120 | 278.928 | 488.462 |
| | | | 0.528 | 17.341 | 278.928 | 528.574 |
| **VO2Max (ml/kg/min)** | 4.202 | 0.043 | 0.384 | 120 | 0.626 | 1.633 |
| | | | 0.306 | 16.212 | 0.626 | 2.050 |

Table 5 demonstrated comparison of low and high 2D:4D on male subjects using independent t-test and was set at significance level ($p < 0.05$). Based on the results above, there were no significant correlations between 2D:4D and all physical fitness tests in male adolescences ($p < 0.05$).

**Table 6: Comparison of Low and High 2D:4D on Female Subjects**

| | F | Sig. | t | df | Mean Diff | SE Diff |
|---|---|---|---|---|---|---|
| **ST (s)** | 0.003 | 0.958 | -0.068 | 110 | -0.009 | 0.136 |
| | | | -0.070 | 26.611 | -0.0093 | 0.132 |
| **RL-HGS (kg)** | 2.615 | 0.109 | -1.838 | 110 | -3.383 | 1.840 |
| | | | -2.251 | 33.319 | -3.383 | 1.503 |
| **IAT (s)** | 0.000 | 0.982 | 1.383 | 110 | 0.678 | 0.490 |
| | | | 1.393 | 26.073 | 0.678 | 0.487 |
| **SBJ-PP (w)** | 0.537 | 0.465 | -2.145 | 110 | -714.225 | 333.003 |
| | | | -2.242 | 27.095 | -714.225 | 318.555 |
| **VO2Max (ml/kg/min)** | 2.177 | 0.143 | -0.343 | 110 | -0.200 | 0.584 |
| | | | -0.413 | 32.489 | -0.200 | 0.485 |

Table 6 demonstrated comparison of low and high 2D:4D on female subjects using independent t-test andwas set at significance level ($p < 0.05$). based on the results above, there were no significant correlations between 2D:4D and all physical fitness tests except in SBJ in female adolescences. Female adolescence with low 2D:4D showed statistically significantly higher score in SBJ-PP test (8194.99±1336.39) than those who high 2D:4D(7480.77±1250.27), $t(110)=-2.145$, $p=0.034$.

**Table 7: Correlations Between RAE and Physical Fitness Tests in Male**

| | | RAE | ST (s) | RL-HGS (kg) | IAT (s) | SBP-PP (w) | VO2max (ml/kg/min) |
|---|---|---|---|---|---|---|---|
| **RAE** | Pearson correlation | 1 | 0.063 | -0.169 | 0.016 | -0.087 | -0.005 |
| | Sig. | | 0.492 | 0.063 | 0.864 | 0.338 | 0.953 |
| | n | 122 | 122 | 122 | 122 | 122 | 122 |
| **ST (s)** | Pearson correlation | 0.063 | 1 | -0.135 | 0.722** | -0.459** | -0.596** |
| | Sig. | 0.492 | | 0.138 | <0.001 | | <0.001 |
| | n | 122 | 122 | 122 | 122 | 122 | 122 |
| **RL-HGS (kg)** | Pearson correlation | -0.169 | -0.135 | 1 | -0.087 | 0.354** | -0.046 |
| | Sig. | 0.063 | 0.138 | | 0.340 | <0.001 | 0.611 |
| | n | 122 | 122 | 122 | 122 | 122 | 122 |
| **IAT (s)** | Pearson correlation | 0.016 | 0.722** | -0.087 | 1 | -0.492** | -0.560** |
| | Sig. | 0.864 | <0.011 | 0.340 | | <0.001 | <0.001 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | n | 122 | 122 | 122 | 122 | 122 | 122 |
| **SBP-PP (w)** | Pearson correlation | -0.087 | -0.459** | 0.354** | -0.492** | 1 | 0.476** |
| | Sig. | 0.338 | <0.001 | <0.001 | <0.001 | | <0.001 |
| | n | 122 | 122 | 122 | 122 | 122 | 122 |
| **VO2 max (ml/kg/min)** | Pearson correlation | -0.005 | -0.596** | -0.046 | -0.560** | -0.476** | 1 |
| | Sig. | 0.953 | <0.001 | 0.611 | <0.001 | <0.001 | |
| | n | 122 | 122 | 122 | 122 | 122 | 122 |

***. Correlation is significant at the 0.01 level (2-tailed).*

**Table 8: Correlations Between RAE and Physical Fitness Tests in Female**

| | | **RAE** | **ST (s)** | **RL-HGS (kg)** | **IAT (s)** | **SBP-PP (w)** | **VO2max (ml/kg/min)** |
|---|---|---|---|---|---|---|---|
| **RAE** | Pearson correlation | 1 | -0.086 | 0.198* | 0.028 | 0.069 | 0.051 |
| | Sig. | | 0.367 | 0.036 | 0.772 | 0.467 | 0.590 |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |
| **ST (s)** | Pearson correlation | -0.086 | 1 | -0.231* | 0.617** | -0.448** | -0.554** |
| | Sig. | 0.367 | | | <0.001 | <0.001 | <0.001 |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |
| **RL-HGS (kg)** | Pearson correlation | 0.198* | -0.231* | 1 | 0.236* | 0.423** | 0.036 |
| | Sig. | 0.367 | 0.014 | | 0.012 | <0.001 | 0.704 |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |
| **IAT (s)** | Pearson correlation | 0.028 | 0.617** | -0.236* | 1 | -0.495** | -0.594** |
| | Sig. | 0.772 | <0.001 | 0.012 | | <0.001 | <0.001 |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |
| **SBP-PP (w)** | Pearson correlation | 0.069 | -0.448** | 0.423** | -0.495** | 1 | 0.361** |
| | Sig. | 0.467 | <0.001 | <0.001 | <0.001 | | |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |
| **VO2 max (ml/kg/min)** | Pearson correlation | 0.051 | -0.554** | 0.036 | -0.594** | 0.361** | 1 |
| | Sig. | 0.590 | <0.001 | 0.704 | <0.001 | <0.001 | |
| | n | 112 | 112 | 112 | 112 | 112 | 112 |

Table 7 showed correlations between RAE and physical fitness tests in male using Pearson correlation test and was set at significance level ($p < 0.05$). Based on the results above, there were no significant correlations between 2D:4D and all physical fitness tests in male adolescences. For female in Table 8, there were no significant correlations between 2D:4D and all physical fitness tests in female adolescences except in RL-HGS. Female adolescence in quartile 4 showed statistically significantly higher score in RL-HGS test (8194.99±1336.39) than those in quartile 1 (7480.77±1250.27), (r = -0.198, n =112, p = 0.036).

***Discussion***

The study investigates the relationship between 2D:4D and RAE towards physical fitness tests in male and female adolescences. Based on the results, the data suggest that male that aged 13 to 17 years old have lower 2D:4D (0.957±0.38mm) compared to female (0.970±0.32). Female adolescences also had higher percentage of high 2D:4D compared to male. In addition, right and left hand of 2D:4D (RL-2D:4D) lowest reading for male was at 0.835mm and the highest reading was at 1.053mm while female subjects had the lowest reading at 0.891mm and the highest reading was at 1.046mm. For RAE, male has the highest on quartile 2 (27.9%) while female has the highest on quartile 1 and quartile 4 (26.8%). In conjunction with physical fitness tests, the statistical findings showed no significant correlation between 2D:4D and RAE towards all physical fitness tests for males, while for females, there is no significant correlation except 2D:4D and standing broad jump (SBJ-PP) as well as RAE and right and left handgrip strength test (RL-HGS). These findings aligned with previous research indicating no significant correlations between 2D:4D (Eghbali, 2016) and RAE (Folgado et al., 2021)towards physical fitness performance.

Both male and female groups display weak correlations with digit ratio towards handgrip strength test as similar results were also found in studies by Nanda and Samanta, (2017 and Pasanen et al., (2021). Further, this is also possible due to small sample size compared to other related studies (Pasanen et al., 2021). A study by Nicolay & Walker, (2005) suggested that muscular strength cannot be predicted solely by hand dimensions due to multifaceted influences (individual motivations, dietary state, tolerance to metabolic product buildup, biochemical, and tissue features of cells). The second component of physical fitness test, this study did not find a significant correlation between digit ratio and sprint tests. Manning & Hill, (2009) previously indicated that 2D:4D ratio is a stronger predictor of aerobic capacity and a relatively weak predictor of sprinting speed in boys. Similarly, Eghbali, (2016) and Gümüş and Tutkun, (2018) found no significant differences in sprint performance. The authors proposed that digit ratio and fitness performance might be associated with various motoric and functional dominance factors.

Meanwhile in Illinois agility test, this study did not find any links between digit ratio and the test outcomes. However, higher 2D:4D ratios were associated with better scores in the 5x10 meters shuttle run among Polish male students (Koziel et al., 2017). Conversely, Nobari et al., (2021) reported no significant correlations between digit ratio and change of direction (agility) in physical performance, suggesting that small sample size and maturational differences among participants might have influenced these results. In the following fitness components, there were no significant correlations between digit ratio and VO2Max in this study. As mentioned above, Nobari et al., (2021) also indicate that there were no linked between digit ratio and VO2max. The evidence showed that the 2D:4D ratio was not significant correlation with aerobic fitness in both groups (male and female). Possible reasons is due to high ventilatory threshold, which may be induced by a different muscle fiber type among individuals that mediates the association between high prenatal testosterone levels and better endurance running performance (Holzapfel et al., (2016). In other test, a study by Ranson et al., 2015 found that a lower digit ratio in males correlates with various physical fitness, but not with standing broad jump. However, this study found a significant correlation between digit ratio and standing broad jump in female and it is supported by a Azam et al., (2022) that comprises of primary school children aged 10 to 12 years old across the country, suggested that there was a significant correlation found between the digit ratio and standing broad jump. The author suggests that larger and more diverse age groups could have influenced physical performance due to factors like puberty changes and physique differences, potentially confounded by age, BMI, and maturation index.

Linking RAE with physical fitness performance, both genders' performance in physical fitness testing were not associated with RAE. In similar study, Folgado et al., (2021) mentioned that in both genders, age 14- to 16-year-old age group only shows minimal significant differences and a lack of pattern across quarters.

The author suggest that children who are born late were not physically active than children who are born in quartile 1 until 3 which are more physically active and eager to engage in sports. In a study by (Cupeiro et al., 2020), indicated that once the RAE difference diminishes, the physical effects also diminish. In contrast to the overall statistical data, (Nakata et al., 2017) revealed a significant RAE in males aged 7 to 15 years. This observation was supported by (Drenowatz et al., 2021) who found that RAE was prominent for fitness like strength, power, speed, agility, and object handling, particularly in males, while not significant for endurance. Recent research by (Mat-Rasid et al., 2022), supports the notion that children born earlier in the year experience a physical and physiological advantage. This could imply that adolescents with earlier birthdates have a maturational edge in their physical fitness outcomes, as indicated (Folgado et al., 2021; Hill et al., 2019), where students born earlier in the year, especially those who are sexually mature, tend to excel due to their advantageous developmental timing.

This study's findings suggest that the lack of association between RAE and most physical fitness tests in both genders, except for RL-HGS in females, could be due to differences in maturity levels and participation in physical activities/sports. The study doesn't consider puberty status, which might explain the absence of a connection between RAE and physical fitness, as maturity seems to influence RAE (Hill et al., 2020). Additionally, the lack of correlation between 2D:4D and most fitness tests could stem from the smaller sample size of 234 subjects used in this study compared to larger studies with up to 500 participants. Andrade, (2020) also supported this, noting that larger sample sizes yield more representative and accurate findings for the population. This mixed findings with past studies regarding 2D:4D and RAE towards physical fitness needed to be explained more in depth in the future.

## CONCLUSION

The study explored the relationship between 2D:4D and the RAE on physical fitness test performance in male and female adolescents. The findings suggest that there is no significant correlation between digit ratio and physical fitness test performance in male participants. Similarly, in female participants, there is no significant correlation between digit ratio and physical fitness test performance, except in the standing broad jump (SBJ-PP) test. Furthermore, the data indicates that there is no significant correlation between RAE and physical fitness test performance in male adolescents. Similarly, in female adolescents, the study found no significant correlation between RAE and physical fitness test performance, except in the right and left handgrip strength test (RL-HGS).

In conclusion, this study did not reveal a strong association between 2D:4D or RAE and physical fitness test performance in the participants. Future research, it is recommended that future researchers should consider larger sample sizes, including both genders and diverse ethnic backgrounds, to gain a more comprehensive understanding of the relationship between digit ratios and RAE in physical fitness. Additionally, focusing on maturity level could provide valuable insights, with a recommendation to examine the correlation between RAE in physical fitness exclusively among subjects who have reached puberty.

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## CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest in this research.

**AUTHORS CONTRIBUTIONS**

MZA is responsible for the overall direction of the grant, editing and finalizing the manuscript, and devised the project along with NDS. KAI, and NAMK almost all of the technical details, and arrangements for data collection. NAK worked out the statistical analysis and contributed to the interpretation of the results. UMY AND AKA assisted in data collection and drafting the manuscript.

**REFERENCES**


Allaway, H. C., Bloski, T. G., Pierson, R. A., & Lujan, M. E. (2009). Digit ratios (2D:4D) determined by computer-assisted analysis are more reliable than those using physical measurements, photocopies, and printed scans. *American Journal of Human Biology*, *21*(3), 365–370. https://doi.org/10.1002/ajhb.20892

Andrade, C. (2020). Learning Curve: Sample size and its importance in research. *Indian Journal of Psychological Medicine*, *42*(1), 138–143. https://doi.org/10.4103/IJPSYM.IJPSYM

Azam, Z., Zainuddin, Z. A., Kosni, N. A., & Sanuddin, N. D. (2022). Influence of digit ratio (2D:4D) on aerobic and anaerobic based fitness tests among primary schoolchildren. *Journal of Advances in Sports and Physical Education*, *5*(5), 96–103. https://doi.org/10.36348/jaspe.2022.v05i05.002

Cobley, S., Baker, J., Wattie, N., & McKenna, J. (2009). Annual age-grouping and athlete development. *Sports Medicine*, *39*(3), 235–256. https://doi.org/10.2165/00007256-200939030-00005

Disterhaupt, J. W., Fitzgerald, J. S., Rhoades, J. L., & Tomkinson, G. R. (2022). The relationship between the digit ratio (2D:4D) and vertical jump performance in young athletes. *American Journal of Human Biology*, *34*(3), 2–5. https://doi.org/10.1002/ajhb.23679

Eghbali, E. (2016). The relationship between digit ratio (2D:4D) and physical fitness in boys 7 to 13 years. *Physical Activity Review*, *4*, 154–162. https://doi.org/10.16926/par.2016.04.19

Eler, N., & Eler, S. (2018). 2D:4D , lateralization and strength in handball players. *6*(5), 170–178. https://doi.org/10.11114/jets.v6i5.3220

Ernsten, L., Körner, L. M., Heil, M., Richards, G., & Schaal, N. K. (2021). Investigating the reliability and sex differences of digit lengths, ratios, and hand measures in infants. *Scientific Reports*, *11*(1), 1–14. https://doi.org/10.1038/s41598-021-89590-w

Folgado, H., Bravo, J., Quintas, A., Raimundo, A., & Gonçalves, B. (2021). Relative age effect in physical fitness of south portugal students between 10 and 18 years old. *International Journal of Environmental Research and Public Health*, *18*(11). https://doi.org/10.3390/ijerph18116092

Galis, F., Ten Broek, C. M. A., Van Dongen, S., & Wijnaendts, L. C. D. (2010). Sexual dimorphism in the prenatal digit ratio (2D:4D). *Archives of Sexual Behavior*, *39*(1), 57–62. https://doi.org/10.1007/s10508-009-9485-7

Gümüş, M., & Tutkun, E. (2018). The relationship between physical fitness levels and digit ratio (2D:4D) of high school students engaged actively in sports. *Journal of Education and Training Studies*, *6*(10), 207. https://doi.org/10.11114/jets.v6i10.3613

Hill, M., Scott, S., Malina, R. M., McGee, D., & Cumming, S. P. (2020). Relative age and maturation selection biases in academy football. *Journal of Sports Sciences*, *38*(11–12), 1359–1367. https://doi.org/10.1080/02640414.2019.1649524

Holzapfel, S., Chomentowski III, P. J., Summers, L. A. M., & Sabin, M. J. (2016). The relationship between digit ratio (2D:4D), VO2max , ventilatory threshold , and running performance. *International Journal of Sports Sciences and Fitness*, *6*(1), 1–30.

Hopp, R. N., Caroline, N., Lima, S., Laurentino, J., Filho, F., Sena-filho, M., Samuel, R. O., Amaral, J. G., & Jorge, J. (2014). Digit Ratio (2D:4D ) and cancer : What is known so far ? Review Article Abstract. *International Journal of Cancer Therapy and Oncology*, 1–4.

Hsu, C. C., Fong, T. H., Chang, H. M., Su, B., Chi, C. P., Kan, N. W., & Hsu, M. C. (2018). Low Second-to-fourth digit ratio has high explosive power? A prepubertal study. *Journal of Strength and*

*Conditioning Research*, *32*(7), 2091–2095.

Huertas, F., Ballester, R., Gines, H. J., Hamidi, A. K., Moratal, C., & Lupiáñez, J. (2019). Relative age effect in the sport environment. Role of physical fitness and cognitive function in youth soccer players. *International Journal of Environmental Research and Public Health*, *16*(16), 1–19. https://doi.org/10.3390/ijerph16162837

Jeevanandam, S., & Muthu, P. K. (2016). 2D:4D ratio and its implications in medicine. *Journal of Clinical and Diagnostic Research*, *10*(12), CM01–CM03. https://doi.org/10.7860/JCDR/2016/21952.9000

Jones, B. D., Lawrence, G. P., & Hardy, L. (2018). New evidence of relative age effects in "super-elite" sportsmen: a case for the survival and evolution of the fittest. *Journal of Sports Sciences*, *36*(6), 697–703. https://doi.org/10.1080/02640414.2017.1332420

Joyner, P. W., Lewis, J. S., Dawood, R. S., Mallon, W. J., Kirkendall, D. T., & Garrett, W. E. (2020). Relative Age Effect: Beyond the youth phenomenon. *American Journal of Lifestyle Medicine*, *14*(4), 429–436. https://doi.org/10.1177/1559827617743423

Kemper, C. J., & Schwerdtfeger, A. (2009). Comparing indirect methods of digit ratio (2D:4D) measurement. *American Journal of Human Biology*, *21*(2), 188–191. https://doi.org/10.1002/ajhb.20843

Kim, T. B., & Kim, K. H. (2016). Why is digit ratio correlated to sports performance? *Journal of Exercise Rehabilitation*, *12*(6), 515–519. https://doi.org/10.12965/jer.1632862.431

Koziel, S., Kociuba Mail, M., Chakraborty, R., & Ignasiak, Z. (2017). Physical fitness and digit ratio (2D:4D) in male students from Wrocław, Poland. *Collegium Antropologicum*, *41*(1), 31–37.

Malas, M. A., Dogan, S., Hilal Evcil, E., & Desdicioglu, K. (2006). Fetal development of the hand, digits and digit ratio (2D:4D). In *Early Human Development* (Vol. 82, Issue 7, pp. 469–475). https://doi.org/10.1016/j.earlhumdev.2005.12.002

Manning, J. T., & Hill, M. R. (2009). Digit ratio (2D:4D) and sprinting speed in boys. *American Journal of Human Biology*, *21*, 210–213. https://doi.org/10.1002/ajhb.20855

Nakata, H., Akido, M., Naruse, K., & Fujiwara, M. (2017). Relative age effect in physical fitness among elementary and junior high school students. *Perceptual and Motor Skills*, *124*(5), 900–911. https://doi.org/10.1177/0031512517722284

Nanda, B., & Samanta, P. P. (2017). The second to fourth digit ratio: a measure of hand grip strength? *International Journal of Advances in Medicine*, *4*(5), 1250–1254. https://doi.org/10.18203/2349-3933.ijam20173712

Nepomuceno, M. V., Saad, G., Stenstrom, E., Mendenhall, Z., & Iglesias, F. (2016). Testosterone at your fingertips: Digit ratios (2D:4D and rel2) as predictors of courtship-related consumption intended to acquire and retain mates. *Journal of Consumer Psychology*, *26*(2), 231–244. https://doi.org/10.1016/j.jcps.2015.05.007

Nicolay, C. W., & Walker, A. L. (2005). Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender. *International Journal of Industrial Ergonomics*, *35*(7), 605–618. https://doi.org/10.1016/j.ergon.2005.01.007

Nobari, H., Alves, A. R., Clemente, F. M., & Pérez-Gómez, J. (2021). Influence of 2D:4D ratio on fitness parameters and accumulated training load in elite youth soccer players. *BMC Sports Science, Medicine and Rehabilitation*, *13*(1), 1–12. https://doi.org/10.1186/s13102-021-00354-5

Pasanen, B. E., Tomkinson, J. M., Dufner, T. J., Park, C. W., Fitzgerald, J. S., & Tomkinson, G. R. (2021). The relationship between digit ratio (2D:4D) and muscular fitness: A systematic review and meta-analysis. *American Journal of Human Biology*, *July*, 1–13. https://doi.org/10.1002/ajhb.23657

Patel, R., Nevill, A., Cloak, R., Smith, T., & Wyon, M. (2019). Relative age, maturation, anthropometry and physical performance characteristics of players within an Elite Youth Football Academy. *International Journal of Sports Science and Coaching*, *14*(6), 714–725. https://doi.org/10.1177/1747954119879348

Ranson, R., Stratton, G., & Taylor, S. R. (2015). Digit ratio (2D:4D) and physical fitness (Eurofit test battery) in school children. *Early Human Development*, *91*(5), 327–331.

https://doi.org/10.1016/j.earlhumdev.2015.03.005

Richards, G., Stewart-Williams, S., & Reed, P. (2015). Associations between digit ratio (2D:4D) and locus of control. *Personality and Individual Differences*, *83*, 102–105. https://doi.org/10.1016/j.paid.2015.03.047

Sayers, S. P., Harackiewicz, D. V., Harman, E. A., Frykman, P. N., & Rosenstein, M. T. (1999). Cross-validation of three jump power equations. *Medicine and Science in Sports and Exercise*, *31*(4), 572–577. https://doi.org/10.1097/00005768-199904000-00013

Tomkinson, J. M., & Tomkinson, G. R. (2017). Digit ratio (2D:4D) and muscular strength in adolescent boys. *Early Human Development*, *113*, 7–9. https://doi.org/10.1016/j.earlhumdev.2017.07.013

Zheng, Z., & Cohn, M. J. (2011). Developmental basis of sexually dimorphic digit ratios. *Proceedings of the National Academy of Sciences*. https://doi.org/10.1073/pnas.1108312108