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Using 2D: 4D digit ratios to determine motor skills in children

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Abstract. – In past few decades, there has an outburst of research surrounding second to fourth finger digit ratio (2D:4D) and its relation to prenatal sex steroids including both testosterone and estrogen. In utero, testosterone and estrogen are responsible for the differences in digit ratio between the genders. Recent research has tried to extend past the influence of steroids and look at the potential effect of digit ratios on fine and gross motor skills in children. We compiled the current understanding of the connection between sex hormones and the development of the 2D:4D ratio as well as the effect the ratio has on motor skills. There seems to be a significant positive correlation between 2D:4D digit ratio and precision of fine motor skill. In addition, there is a negative correlation between 2D:4D ratio and speed of fine motor activity. In this review, we will outline the use of 2D:4D ratio as a biomarker for prenatal sex steroids and through that, a proxy marker for fine and gross motor skills.

Key Words:
Second to fourth finger digit ratio, Index finger, Ring finger, Digit ratios, Gender, Sex steroids, Testosterone, Estrogen, Motor skill.

Introduction

A difference in the digit ratios between men and women was first established in 1875. In the last century, it has been very well recognized that the length of index-finger to finger-length ratio is different between the two sexes; it is sexually dimorphic. People show sexual differences in 2D:4D ratios as early in age as 2 years[1]. The 2D and 4D digits of females are generally about the same lengths. When the length of the index finger and the ring finger are the same length, the ratio is 1.00. The ratio would be greater than 1.00 if the index finger was longer than the ring finger and less than 1.00 than if the ring finger is longer than the index finger. For men, the index finger is typically about 96% of the length of the ring finger, which is a ratio of 0.96. Women have an average 2D:4D ratio of 1.00, which is termed "high digit ratio". Thus, the digit ratio of 2D:4D is significantly lower in men than in women[2].

Role of Sex Hormone in Digit Morphology

In past few decades, there has an outburst of research surrounding digit ratio (2D:4D) and its relation to prenatal sex steroids including both testosterone and estrogen. The cause of sexual dimorphism in 2D:4D digit ratios has been attributed to the effect of sex hormones during early fetal development. High levels of testosterone during a critical prenatal stage may facilitate the development of the ring finger while high levels of estrogen in females may lead to the growth of the index finger. Testosterone and estrogen are most likely responsible for the smaller 2D:4D digit ratios in men and for the larger 2D:4D digit ratios in women (Figure 1)[3,4].

Difference is Ratios Correlate with Certain Characteristics

Men with a lower 2D:4D ratio, possibly due to a greater fetal exposure to testosterone during the 1st trimester, lend to certain "hyper masculine" traits. This is called the sexual differentiation theory. These traits may include being more fer-

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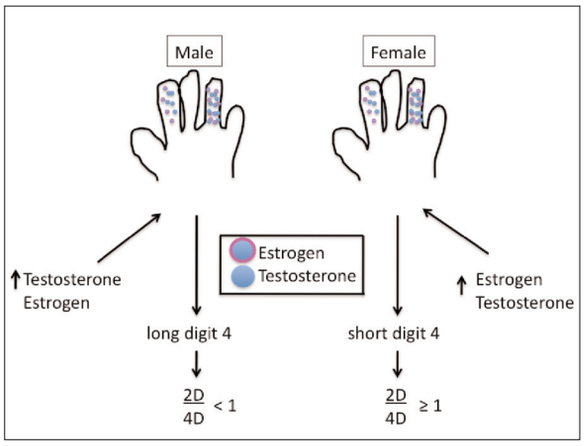

Figure 1. Diagrammatic representation of the effects of testosterone and estrogen on the 2D and 4D digit formation in male and females. These effects lead to a digit ratio of less than 1 in males and equal to or greater than 1 in females.

tile, having higher lifetime reproductive success, being more aggressive and assertive, having a greater tendency towards homosexuality and a higher aptitude for music and sports. Interestingly, a low 2D:4D ratio in women leads to a greater tendency towards homosexuality as well as more aggressive and assertive behavior. Women with a higher 2D:4D ratio, possibly due to a greater fetal exposure to estrogen in the 1st trimester, tend to have higher fertility, greater reproductive success and higher risk of breast cancer. Men with high 2D:4D ratio, on the other hand, may have a higher risk of early heart disease. Autistic children tend to have unusually long ring fingers in relation to their index fingers, which confirms the "extreme male theory" behind autism[5,6].

Molecular Mechanism

At a molecular level, the digit ratio is determined by allelic variation in androgen receptor sensitivity and dictated by a Hox gene. The primary target of action of prenatal sex hormones in utero is to act on specific receptors on a discrete set of neurons in the brain. The 2D:4D ratio covaries with the number of polyglutamine amino acid residues in exon 1 of androgen receptor genes. Alleles of the androgen receptor gene (AR) with low levels of CAG triplets (polyglutamine) respond to testosterone with high activity while high numbers of the polyglutamine repeats lead to increased insensitivity to testosterone. The AR structure manifests itself, phenotypically, as the 2D:4D ratio. 2D:4D right-hand ratio was positively correlated with polyglutamine number and people with low 2D:4D ratio on their right hand compared to the left hand were found to have low CAG repeats[7,8]. In addition, prenatal sex hormones *in utero* were investigated as having an effect on lateralization of the brain. The 'GBG' hypothesis addresses this issue and claims that high levels of fetal testosterone may have a negative effect on the development of the left cerebral hemisphere but a positive effect on the development of the right hemisphere, which dictates many of the motor skills[9].

More evidence has emerged regarding this theory by manipulating digit ratios in rodents. Zheng et al[10] reported that the 2D:4D ratio in mice is determined by the balance of testosterone to estrogen signaling during a small window in fetal development. AR and estrogen receptor (ER) activity is greater in digit 4 than digit 2 (Figure 1). Androgen and estrogen activate and actually regulate a network of genes that are involved in chondrocyte proliferation and leads to the growth of digit 4 in both genders. Inactivation of AR in mice population decreases the length of digit 4, which leads to an increased 2D:4D ratio. Inactivation of ER has the opposite effects and actually increases the growth of digit 4, which leads to a lower 2D:4D ratio.

Racial and Height Differences in Digit Ratio

There are significant racial differences when it comes to digit ratios across various ethnic populations. A comparison of digit ratios of Afro-Caribbean Jamaicans found that they tend to have lower mean 2D:4D digit ratios while white Caucasians populations tend to have higher mean 2D:4D ratios. The results surrounding any correlations between height and the 2D:4D finger-length ratio are inconsistent. Many researchers have found that there was no relation of body height with the 2D:4D digit ratio. Some researchers, however, reported a significant negative correlation between these two parameters, with negative coefficients of -0.49 and -0.25[11]. Gillam et al[2], on the other hand, found that there was a positive correlation between height and 2D:4D ratio, but only for women. Finally, Barut et al[12] recently reported that height was negatively correlated with left-hand digit ratios of men and the right-hand digit ratios of women.

Digit Ratio Difference Among Twins

Voracek et al[13] measured digit lengths and 2D:4D ratios of same-sex twins and found that the

mean average for male twins was 0.951 while the mean average for female twins was 0.968. This was expected and confirmed previous results done in other populations. For opposite-sex twins, however, the mean digit ratio for males was 0.961 and the mean 2D:4D ratio for females was 0.965. This slight difference may be attributed to the female embryo being exposed to the testosterone meant for the male embryos and vice versa with the estrogen exposure to the male embryo.

2D:4D Rratio in Children

Research has looked into determining whether age plays a factor in ratio determination. Trivers et al[14] have looked at populations from Caucasians of the Liverpool area, China and Afro-Caribbean populations to determine if digit ratio varies with age. None of the studies found any variation between right or left 2D:4D and age, Most of the current literature that is based on the 2D:4D ratio and physical activity revolves around its correlation with sporting skills such as running. In a sample of Afro-Caribbean Jamaican children, it was found that children with low 2D:4D ratio were linked to faster left-hand speed relative to right-hand speed. Furthermore, children with lower 2D:4D ratio in their right-hand relative to their left-hand were associated with faster left-hand speed relative to right-hand speed[11,13].

Fink et al[11] looked at determining whether digit ratio could be related to hand skill in right-handed children in a population of white Caucasian Austrians. Hand skill scores were found to be positively associated with higher 2D:4D digit ratios. In males, low prenatal testosterone was correlated with increased right-hand performance while high prenatal testosterone was associated with better left-hand performance. The correlation was stronger for the high prenatal testosterone/left-hand digit ratio than for the low testosterone/right-hand digit correlation. For females, hand skill performance was positively associated with 2D:4D left-hand ratio[14].

A subset of the Indian population was looked at by Mathangi et al[15] to determine whether there was a correlation between digit ratio and motor skill in children aged 8-12. The mean 2D:4D digit ratio for males was 0.979 and for females was 0.967 (Table I). The male population showed better performance when compared to the female subset on tests such as gross and fine motor speed. Females were better at the precision of fine motor skill. These correlations were supported by the GBG theory. The positive correlation between males and gross and fine motor speed was likely due to exposure to testosterone, which compromised the development of the right-hemisphere, causing left-hand performances to increase. The negative relationship between females and gross motor skills could be explained by the lack of exposure to testosterone. Gross motor skill was measured by a bounce test, fine motor skill was tested by doing a time trace of a butterfly. Speed was measured with a maze trace and precision was measured by a dotting circle over 30 seconds (Table II).

Conclusions

In the last decade, there has been a plethora of research surrounding the correlations between 2D:4D digit ratio and the potential exposure to sex hormones in utero. The digit ratio of 2D:4D is significantly lower in men than in women. The difference in the digit ratio between men and women are likely due to the presence of prenatal estrogen in utero for female embryos and prenatal testosterone exposure for male embryos. Men have a low 2D:4D ratio when compared to females, and men with lower digit ratios tend to have traits such as increased fertility, reproductive success, increased aggression and a greater ability for sports. Women with higher 2D:4D ratio also tend to have increased fertility, reproductive success and surprisingly, a higher risk of breast cancer. On a genetic level, a 2D:4D digit ratio is determined by the number of CAG repeats on exon 1 of androgen receptor genes[1,5,7,14].

In this review, we looked at the three separate studies done to determine if the 2D:4D digit ratio can be correlated to fine and gross motor skills in

Table I. Mean 2D:4D ratios in a population of 40 males and 40 females.

	2D:4D right hand ratio	2D:4D left hand ratio	Mean 2D:4D ratio
Female (n = 40)	0.979 ± 0.03	0.962 ± 0.05	0.970 ± 0.03
Male (n = 40)	0.967 ± 0.05	0.959 ± 0.05	0.963 ± 0.04

Table II. Gross and fine motor skill measurements for male and female children.

Parameter	Right Hand		Parameter	Left Hand	
	Female	Male		Female	Male
	0.979 ± 0.03	0.967 ± 0.05	2D:4D ratio	0.962 ± 0.05	0.959 ± 0.05
Gross motor skill	23.46 ± 4.90	25.44 ± 5.95	Gross motor skill	19.79 ± 4.64	23.31 ± 6.71
Fine motor skill	90.04 ± 28.25	104.77 ± 39.70	Fine motor skill	106.30 ± 35.26	120.25 ± 44.34
Speed	35.90 ± 8.80	29.73 ± 10.18	Speed	28.15 ± 9.37	21.21 ± 8.94
Precision	50.49 ± 7.98	47.97 ± 10.51	Precision	26.38 ± 7.41	26.31 ± 8.26

children. First, we looked at studies determining whether the digit ratio varies across ages. There was no significant relationship between 2D:4D digit variation and ages after 2 years[10-14]. Then, we examined research that correlated digit ratio in children and their motor skills. Research that looked at Afro-Caribbean Jamaican children found that those with reduced 2D:4D ratio had a faster left-hand speed relative to right-hand speed. Furthermore, Fink et al[11] found that in male children, low prenatal testosterone was correlated with better right-hand performance while high digit ratio in was linked to increased left-hand performance. Finally, Mathangi et al[15] looked at Indian children and determined that, due to the lower 2D:4D digit ratio in males, they are better at the gross and fine motor speed skills while those with higher 2D:4D ratio are better at precision of fine motor skills. This review suggests that looking at 2D:4D digit ratio as a proxy marker is viable for both prenatal sex hormone exposure and motor skills.

Conflict of Interest

The Authors declare that there are no conflicts of interest.

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