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Original Article / Özgün Araştırma

The ratio of second and fourth finger lengths (2D:4D) can determine handedness

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Abstract

Objective: The human body exhibits both structural and functional asymmetry. One measure of this asymmetry is the ratio of 2D:4D, which is the proportion of measurements of the 2nd (2D) and 4th finger (4D). In this research, our objective is to investigate the potential association between the ratio of 2D:4D and handedness with voluntary individuals.

Methods: A total of 312 individuals volunteered to take part in the research, where their left and right hand's 4th and 2nd finger lengths were measured using a precise digital caliper. The "Edinburgh Handedness Inventory" was used to determine hand lateralization. To determine the significance between the two independent groups, the Mann Whitney U Test was used. On the other hand, to determine the significance between the two dependent groups, the Wilcoxon Signed Rank Test was utilized.

Results: Of the participants, 154 were male and 158 were female (age range 18-55, mean age=28.34). According to the Edinburgh Handedness Inventory, 275 individuals were right handed, 18 were left handed, and 19 were bimanual. The Mann Whitney U Test showed a significant result in the ratio of right hand 2D:4D between male and female participants who were right handed (z =-1.979, p = 0.048). Additionally, the Wilcoxon Signed Ranks Test demonstrated a difference between the right and the left hand ratio of 2D:4D for all participants which was significant (z = -2.822, p = 0.005), as well as for participants who were right handed (z = -2.850, p = 0.004).

Conclusion: The ratio of 2D:4D finger lengths could be a significant indicator of hand preference in both male and female healthy individuals. The ratio of 2D:4D holds potential as an indicator and research tool in understanding human emotions, thoughts, and behaviors.

Keywords: Finger, Handedness, Finger Length Ratio, Testosterone, Estrogen

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İkinci ve dördüncü parmak uzunluklarının oranı (2D:4D) el tercihini belirleyebilir

Öz

Amaç: İnsan vücudu hem yapısal hem de fonksiyonel asimetri sergilemektedir. Bu asimetrinin bir ölçüsü ise elin ikinci (2D) ve dördüncü parmak (4D) ölçümlerinin oranı olan 2D:4D oranıdır. Bu araştırmada amacımız sağlıklı bireylerde 2D:4D oranı ile el tercihi arasındaki potansiyel ilişkiyi araştırmaktır.

Yöntemler: Toplam 312 kişinin gönüllü olarak katıldığı araştırmaya katılanların sağ ve sol el ikinci ve dördüncü parmak uzunlukları hassas dijital kumpas kullanılarak ölçüldü. El lateralizasyonunu belirlemek için "Edinburgh El Tercihi Envanteri" kullanıldı. İki bağımsız grup arasındaki farklılıkların incelenmesi için Mann Whitney U testi kullanıldı. İki bağımlı grup arasındaki farklılıkların incelenmesi için ise Wilcoxon İşaretli Sıralar Testi kullanıldı.

Bulgular: Katılımcıların 154'ü erkek, 158'i kadındı (yaş aralığı 18-55, ortalama yaş=28,34). Edinburg El Kullanımı Envanteri'ne göre 275 kişi sağ elini tercih eden, 18'i sol elini tercih eden ve 19'u bimanualdi. Mann Whitney U testi sonucu doğrultusunda sağ elini kullanan erkek ve kadın katılımcılar arasında sağ el 2D:4D oranında istatiksel olarak anlamlı bir fark bulundu (z= -1,979, p = 0,048). Ek olarak, Wilcoxon İşaretli Sıralar Testi sonucu doğrultusunda tüm katılımcılar için (z= -2,822, p = 0,005) ve sağ elini kullanan katılımcılar için (z= -2,850, p = 0,004) sağ ve sol el oranı arasında 2D:4D oranında istatiksel olarak anlamlı bir fark bulundu.

Sonuç: 2D:4D parmak uzunluklarının oranı hem erkek hem de kadın sağlıklı bireylerde el tercihinin önemli bir göstergesi olabilir. 2D:4D oranı, insanın duygu, düşünce ve davranışlarını anlamada bir gösterge ve araştırma aracı olabilir.

Anahtar kelimeler: Parmak, El Tercihi, Parmak Uzunluğu Oranı, Testosteron, Östrojen.

INTRODUCTION

The human body is characterized by both morphological and functional asymmetry even though it appears to possess a symmetrical structure with respect to the mid-sagittal plane. This asymmetrical organization entails dimensional and structural asymmetries concerning bilateral features such as eyes, eyebrows, and ears, as well as dimensional and structural asymmetry within internal organs like kidneys, lungs, and liver, despite their bilateral nature. Within the human brain, comprising the most intricate structure known in the universe, there are inherent structural and functional asymmetries that arise from the division into two hemispheres. Handedness preferences can provide insight into the anatomical and functional processes of the brain.

The ratio of 2D:4D is the ratio of the lengths of the 2nd and 4th digits on a hand. This topic has become a subject of interest in popular neuroanatomical studies, as it is associated with prenatal exposure to testosterone and estrogen hormones[1-3]. This ratio is linked to features that are altered by fetal sex hormones. The determination of an individual's preference for their left or right hand continues to be a topic of debate. While some scientists argue for a genetic basis for handedness, others propose environmental influences[4-8]. Among the significant factors influencing handedness, the effects of fetal testosterone and estrogen play a crucial role. The literature suggests that fetal testosterone, due to its involvement in early cerebral lateralization during early pregnancy, influences handedness[9-11]. The human hand's ratio of 2D:4D is sexually dimorphic and forms during the first trimester. Gender differences emerge early in pregnancy and remain stable during the 2nd trimester and beyond[12,13].

The ratio of 2D:4D has been researched on both healthy individuals and various disease groups, for instance, epilepsy, attention deficit hyperactivity disorder (ADHD), and autism spectrum disorder (ASD). The association between the ratio of 2D:4D and psychological assessment tests has been investigated in

healthy individuals[14]. In the study, individuals with a longer index finger than the ring finger were identified as having a dominant estrogen profile, while those with a shorter index finger than the ring finger were identified as having a dominant testosterone profile. The ratio of the left and right hand 2D:4D and the testosterone-dominated group had significantly higher scores for careful decision-making, organized, analytical thinking, and sensitivity compared to the estrogen-dominated group. Akdeniz et al. showed that the ratio of left hand 2D:4D was significantly lower in the epilepsy group compared to the group of healthy individuals, while the ratio of right hand 2D:4D was significantly higher in the epilepsy group. As a result, the ratio of 2D:4D was suggested to potentially serve as an indicator to differentiate epilepsy patients from healthy individuals[15]. Other studies comparing children with ASD to healthy children demonstrated a significantly lower ratio of 2D:4D in the former group, suggesting a significant difference compared to neurotypical development [16-18]. These findings were interpreted as the ratio of 2D:4D potentially influencing fundamental cognitive, motor, and social skills development in children with ASD. Furthermore, it was proposed that it could support early diagnosis and treatment. A study by Demirci and Öztop examined the ratio of right hand 2D:4D in 40 males with ADHD and 40 healthy individuals. The study compared the ratio of 2D:4D with levels of aggressiveness affecting social functionality. The results indicated a negative correlation between aggressiveness and the ratio of 2D:4D in ADHD individuals. This result suggested that prenatal testosterone exposure affects aggression levels in males with ADHD[19].

The existing body of literature on the relationship between the ratio of 2D:4D and hand preference is relatively scarce. Therefore, this study aims to explore the potential association between the ratio of 2D:4D and handedness preference in individuals who are in good health.

METHODS

The study included 312 participants (154 males, 158 females) with an age range of 18 to 55 years (mean age=28.34). The participant number was calculated with the G*Power 3.1 Program. It was determined that at least 300 people should be included in the study, with a power of 95% and $\alpha = 0.05$. Preventing possible data loss, 12 more people were added. Measurement was done on the lengths of participants' right and left hands' 4th and 2nd fingers, based on anatomical landmarks and using a precision measuring digital caliper from the Asimeto brand (Figure 1). During this procedure, the participants held their hands with the palm facing upwards, keeping the thumb separate and the four fingers in a closed position. The distance between the midpoint of the proximal line separating the finger root from the palm and the fingertip was measured. Measurements were taken twice for each participant. The ratio of 2D:4D was calculated by proportioning the second finger to the fourth finger in terms of length. Healthy volunteers with hand trauma, edema, swelling, or abscesses were excluded from the study.

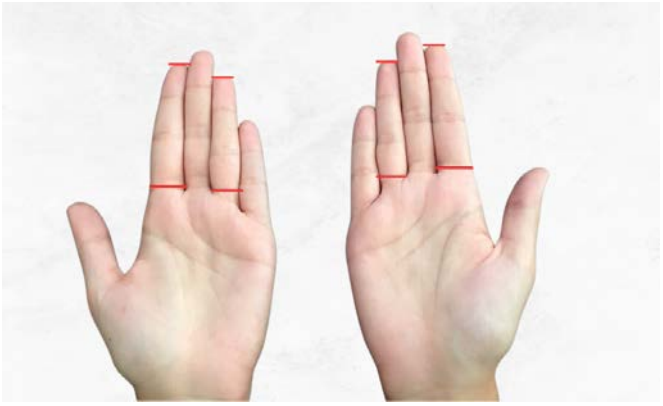

Figure 1: Anatomical measurement of 2D:4D finger lengths.

The Turkish version of the "Edinburgh Handedness Inventory" was applied to determine the participants' hand lateralization[20]. The Edinburgh Handedness Inventory included questions regarding hand preference for activities such as brushing teeth, drawing, writing, throwing, using a knife or spoon, using scissors, upper hand preference while sweeping, opening a jar lid, and striking a match. Based on the responses to the Edinburgh Handedness Inventory, a Geshwind score was obtained, and the degree of hand dominance was calculated. The study received ethical approval from the Scientific Research Ethics Committee (12/10-335).

Statistical Analysis

The statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS), Chicago IL Version 17 computer software. Kolmogorov-Smirnov test, Mann Whitney U test, and the Wilcoxon signed rank test were used to determine the normal distribution, comparing two independent groups, and comparing two dependent groups, respectively. For this study, a significance level of $p<0.05$ was used to determine statistical significance.

RESULTS

According to the Edinburgh Handedness Inventory results we found that 275 individuals exhibited right hand dominance, 18 individuals displayed left hand dominance, and 19 individuals were bimanual. Table 1 displays demographic information from the participants, including mean, standard deviation, and percentage values. It also shows the ratio of 2D:4D and The Edinburgh hand dominance scores. The median and interquartile range (IQR) values are included to reflect handedness preference.

Table I: Demographic information of the participants

Variables	N	Median	IQR	Age (Mean ± SD)
The number of participants	312			18-55 (28,34 ± 13,06)
Female	157			
Male	155			
Right Hand Preference	275			
Left Hand Preference	18			
Bimanual	19			
Edinburgh Right	275	1,0000	0,20	
Edinburgh Left	18	0,9000	0,25	
Edinburgh Bimanual	19	0,4000	0,05	
Right Female 2D:4D Ratio	157	0,9800	0,6	
Right Male 2D:4D Ratio	155	0,9700	0,6	
Left Female 2D:4D Ratio	157	0,9700	0,6	
Left Male 2D:4D Ratio	155	0,9800	0,5	

N: Number, IQR: Interquartile Range, SD: Standart Deviation

To the outcomes of the Mann-Whitney U Test, a remarkable difference was found between right handed male and female participants in the ratio of 2D:4D of the right handedness ($z = -1.979$, $p = 0.048$). But, no noteworthy differentiation was detected in the ratio of 2D:4D of left hand among male and female participants with left handedness ($z = -0.502$, $p = 0.616$) (Table 2).

Table II: Right and left hand 2D:4D ratios of right and left-handed participants

Variables	Group	N	Average Rank	U	Z	p
Right-Handed Participants' Right 2D:4D Ratio	Woman	133	147,78	8142,500	-1,979	,048*
	Male	142	128,84			
Right-Handed Participants' Left 2D:4D Ratio						
Left-Handed Participants' Left 2D:4D Ratio	Woman	133	141,42	8987,500	-,693	,488
	Male	142	134,79			
	Woman	11	10,00	33,000	-,502	,616
	Male	7	8,71			
Left-Handed Participants' Right 2D:4D Ratio	Woman	11	8,55	28,000	-,959	,338
	Male	7	11,00			

**p<0,05, Mann-Whitney U test, N: Number*

The outcomes of the Wilcoxon signed ranks test revealed a noteworthy distinction between the

ratio of 2D:4D of the right hand and that of the left hand across all participants (z = -2.822, p = 0.005) (Figure 2), as well as among participants for the right handedness (z = -2.850, p = 0.004) (Table 3). The comparison of the ratios of 2D:4D for right and left hands among participants with right handedness was illustrated in Figure 3. Furthermore, a notable difference in the ratios of 2D:4D between right and left hands in relation to age was detected for the entire participant (H(2) = 8.588, p = 0.014) (Figure 4).

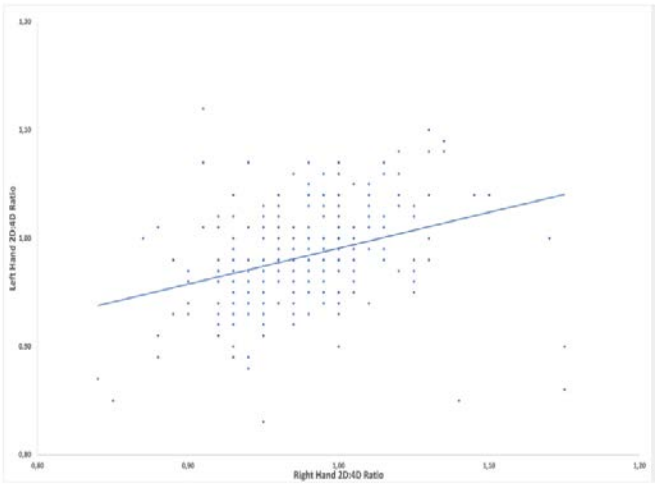

Figure 2: Comparison of participants' right and left hand 2D:4D ratios

Table III: Right and left hand 2D:4D ratios of right-handed participants and right and left hand 2D:4D ratios of all participants

Variables	Arr.	Average Sequence	Sum of Ranks	Z	p
Right 2D:4D - Left 2D:4D	Negative	121,92	12680,00	-2,822	,005*
Right 2D:4D - Left 2D:4D	Positive	129,72	19198,00		
Right Hand/ Right 2D:4D	Negative	114,42	11099,00	-2,850	,004*
Right Hand/ Left 2D:4D	Positive	122,17	17104,00		

*p<0,05, Wilcoxon signed ranks test, Arr.: Arrangement

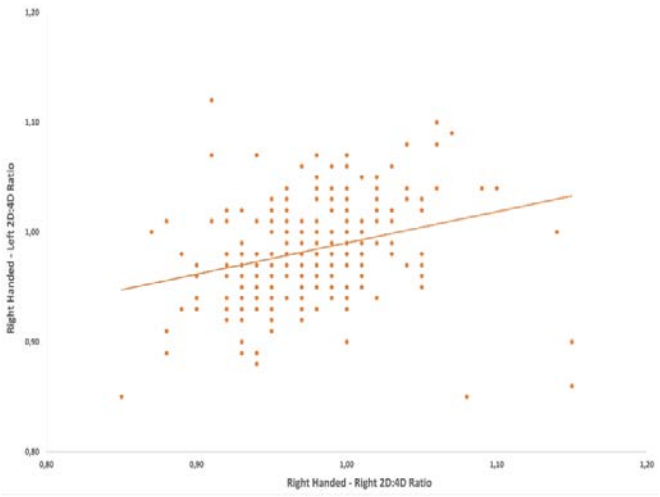

Figure 3: Comparison of right and left hand 2D:4D ratios of right-handed participants

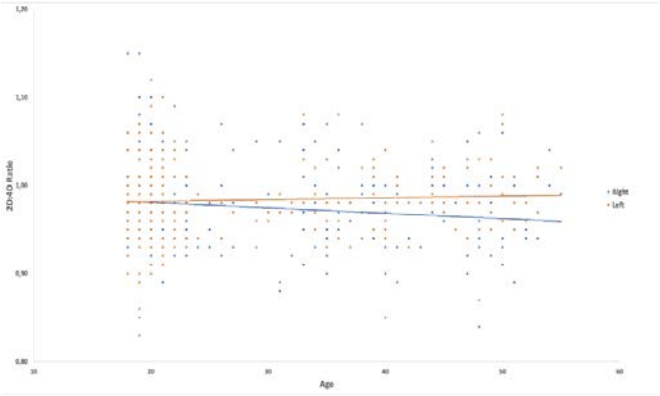

Figure 4: Comparison of right and left hand 2D:4D ratios by age

DISCUSSION

Our study determined the relationship between structure processes and asymmetries in the hand. The most significant finding of this study is that the finger length ratio shown in healthy individuals serves as a crucial indicator for right handedness in both males and females.

Studies have indicated that an individual's handedness preference serves as an indicator of brain lateralization. Research has demonstrated a link between elevated fetal testosterone levels and increased brain dominance[10,11]. According to previous studies, there is evidence suggesting a negative association between fetal

testosterone levels and the ratio of 2D:4D[2,3,21]. Considering all this information, this study reveals the potential for determining brain dominance through the ratio of 2D:4D, based on individuals' handedness preferences. The ratio of right 2D:4D was found significant in right handed individuals, whereas the ratio of left 2D:4D was not significant. Interestingly, in left handed individuals, both the ratio of left 2D:4D and the ratio of right 2D:4D were statistically insignificant. This situation raises questions about whether fetal testosterone, which is linked to both brain lateralization and the ratio of 2D:4D, affects dominant hand preference differently. Studies have shown that the ratio of finger lengths to each other remains unchanged during adolescence and adulthood after being established in the early fetal period[2].

We observed a significant difference in the ratio of right hand 2D:4D among right handed individuals, as opposed to the non-significant ratio of left 2D:4D for left handed. This situation may be linked to environmental factors that are separate from the impact of fetal testosterone exposure. The variability in individuals' innate dominant hand preference could have been altered over time, leading to changes in brain lateralization. This interpretation suggests that the established innate hand dominance could undergo variation and potentially modify brain lateralization over the course of time.

A statistically significant distinction was evident in the ratio of right 2D:4D between male and female participants displaying right handedness. Females displayed comparatively higher ratios of right 2D:4D than males. This outcome is congruent with Ventura et al.'s investigation, which indicated a lower ratio of 2D:4D among males relative to females[22]. This outcome implies that gender potentially may have an influence on finger ratios. Nevertheless, the absence of hormone data is a limitation of this study. Consequently, further exploration into the mechanisms underpinning the relationship between gender and the ratio of 2D:4D is warranted. The Wilcoxon signed ranks test reveals a significant disparity in the ratios of 2D:4D between the left and right hands among all the subjects. Unlike our study, in Protopapas, no substantial distinction was identified between hand preference and the ratio of 2D:4D[23]. The significant difference between right and left 2D:4D ratios in our findings suggests that hand preference might indeed have an impact on finger ratios.

Testosterone and estrogen hormones begin to be secreted during the 2nd and third months of pregnancy in the fetus, leading to sexual differentiation due to these hormones. Recent publications have reported that in males, the 4th finger is associated with prenatal testosterone hormone exposure, while in females, the 2nd finger is linked to estrogen hormone exposure[24]. In our study, we found that the ratio of 2D:4D was larger in the left hand in females, which is consistent with the literature[25-27].

In a study comprising a group of 800 individuals ranging in age from 2 to 25, it was found that the ratio of 2D:4D was different among females and males, which was higher in females, with both right and left hands[3]. This ratio was reported to remain constant with age in that study. In our study, the age range of the population is between 18 to 55 years old. Nonetheless, it is worth noting that age differences may not necessarily affect handedness related to the functional aspects. Sexual dimorphism could potentially influence hormones in early life stages. In a research conducted at a fertility center, involving 131 participants (69 males), it was observed that individuals with a higher ratio of 2D:4D exhibited lower sperm count and higher estrogen levels[1]. The 2D:4D sexual dimorphism is influenced by the proportions of testosterone and estrogen at the time of prenatal development. Our study stands out from existing studies on the ratio of 2D:4D in the

literature by studying the association between the ratio of 2D:4D and handedness in adult individuals.

Neuroscientists often attempt to measure individuals' dominant brain lateralization by using their handedness preference when investigating human behavior and emotion. In our study, we employed the Edinburgh Handedness Inventory, a reliable measurement test in the literature. Cherbuin and Brinkman demonstrated in their study that participants using their right hand have a significant determinant of hemispheric transfer processes and hemispheric interaction[28]. Furthermore, they found that individuals using their left hand have more effective hemispheric interaction compared to right handed individuals, which could be attributed to hand preference effects. The relationship between hand preference and asymmetrical hemispheres in the brain has been described by Serrien et al. suggesting that this could vary based on the relative activation of hemispheres and functional considerations[29]. Cabinio et al. have suggested that when given the same task, the varying degrees of asymmetry in the brain can change depending on individuals' performance differences. This has shown that it could change in connection with the Edinburgh score in terms of hand preference[30].

Our research revealed a noteworthy relationship between the ratios of 2D:4D of the left and right hands among right handed individuals, as determined by the Edinburgh Handedness Inventory. In contrast, we did not observe a significant correlation between the ratios of 2D:4D of the left and right hands in individuals who self-identified as left handed. This phenomenon has been interpreted as potentially stemming from the limited number of individuals in our study who exhibited left handed. Protopapas' study indicated that hand preference or hand performance level does not lead to changes in the ratio of 2D:4D[23]. Considering these findings along with our results, it raises questions about whether fetal testosterone, associated brain lateralization, and the ratio of 2D:4D, are indeed affected or not. Given the limitation of lacking fetal testosterone and estrogen values among participants in our study, further research should be conducted to address this issue.

Ethics Committee Approval: The study received ethical approval from the Scientific Research Ethics Committee (12/10-335).

Conflict of Interest: The authors declared no conflicts of interest.

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