Research Article / Araştırma Makalesi

Gender Estimation from 2D:4D Ratio and Hand Morphometry by Using Machine Learning Algorithms

Makine Öğrenimi Algoritmalarını Kullanarak 2D:4D Oranından ve El Morfometrisinden Cinsiyet Tahmini

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Abstract

Background: The present study was conducted to estimate gender from 2D:4D ratio and hand morphometry taken from participants by using machine learning (ML) algorithms.
Materials and Methods: The study was conducted retrospectively on 88 men and 96 women between the ages of 18 and 30 who did not have any pathology, deformity or surgical interventions on their hands. Hand width (HW), hand length (HL), second digit length (2D), and fourth digit length (4D) of the individuals were measured as the right (R) and left (L) side by using digital calliper and recorded in Excel. In addition, the ratio between the second digit and fourth digit (2D:4D) of each individual was also recorded.
Results: As a result of ML modelling, 0.92 accuracy was obtained with Random forest (RF) algorithm. With RF algorithm, all of the 16 women and 18 of the 21 men in the test set were estimated accurately. With SHAP analyzer of RF algorithm, HW-L parameter was found to have the highest contribution in estimating gender. The accuracy rates of the other ML models used in the study were found to vary between 0.78 and 0.89.
Conclusions: It was found that 2D:4D ratio and hand morphometry measurements, which are frequently preferred in gender determination, have higher accuracy rate when examined with ML algorithms. In our study, we concluded that using 2D:4D ratio and hand morphometry in estimating gender provides accurate and reliable data.

Key Words: 2D:4D ratio, Hand morphometry, Machine learning algorithms, Gender estimation

Öz

Amaç: Bu çalışma, makine öğrenimi (ML) algoritmaları kullanılarak katılımcılardan alınan 2D:4D oranından ve el morfometrisinden cinsiyet tahmini yapmak amacıyla gerçekleştirilmiştir.
Materyal ve Metod: Çalışma, ellerinde herhangi bir patoloji, deformite veya cerrahi müdahale bulunmayan, yaşları 18-30 arasında değişen 88 erkek ve 96 kadın üzerinde retrospektif olarak gerçekleştirildi. Bireylerin el genişliği (HW), el uzunluğu (HL), ikinci parmak uzunluğu (2D) ve dördüncü parmak uzunluğu (4D) dijital kumpas kullanılarak sağ (R) ve sol (L) taraf olarak ölçüldü ve kayıt altına alındı. Ayrıca her bireyin ikinci parmağı ile dördüncü parmağı arasındaki oran (2D:4D) de kaydedildi. ML modellerinin girişinde elde edilen ölçümler kullanılarak cinsiyet tahmini yapılmıştır.
Bulgular: ML modelleme sonucunda Random Forest (RF) algoritması ile 0,92 doğruluk elde edildi. RF algoritması ile test setindeki 16 kadın ve 21 erkekten 18'inin tamamı doğru tahmin edilmiştir. RF algoritmasının SHAP analizörü ile cinsiyet tahmininde en yüksek katkıyı HW-L parametresinin sağladığı görülmüştür.
Sonuç: Cinsiyet belirlemede sıklıkla tercih edilen 2D:4D oranı ve el morfometri ölçümlerinin ML algoritmaları ile incelendiğinde doğruluk oranının daha yüksek olduğu tespit edildi. Çalışmamızda cinsiyet tahmininde 2D:4D oranı ve el morfometrisinin kullanılmasının doğru ve güvenilir veri sağladığı sonucuna vardık.

Anahtar Kelimeler: 2D:4D oranı, El morfometrisi, Makine öğrenme algoritmaları, Cinsiyet tahmini

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Introduction

Gender has long been one of the leading topics of research for forensic anthropology. Determination of gender is critical in identifying a body that is not complete (1). While researching for reports of mission persons for an identification process, gender estimation has been found to reduce the parameters to be searched approximately by 50% (2). Accuracy and reliability of forensic medicine studies is critical for the evaluation of forensic cases. The first step in identifying bodies is determining gender. For this reason, it is important for the method used in identifying gender to be practical and reliable (3). While DNA analysis and recently machine learning (ML) algorithms have been used in gender determination, new methods based on hand morphology have also become a source of interest (4).

The ratio of second-fourth digit length (2D:4D ratio) is determined during the fetal period and becomes constant throughout life starting from the age of 2 (5). It can be seen that 2D:4D ratio is used in many different research areas, especially in areas where gender discrimination can be observed (6). There is a consistent relationship between 2D:4D ratios between men and women and between prenatal testosterone concentrations and 2D:4D ratios (7, 8). As a result of fetal testosterone exposure, 2D:4D ratio has a dimorphic feature and while it is lower in men, it is higher in women (9). 2D:4D ratio, which is one of the main analysis factors in gender analysis, occurs after birth. It does not change in adolescence and stays the same during the individual's life. For this reason, it does not change with growth and age (10).

While it has been known for more than a century that men's ring fingers are longer than their index fingers, this sexual sign was not a subject of interest to researchers until the last quarter of the last century (11). According to researchers, testosterone has an effect on the development of fourth finger, while oestrogen has an effect on the development of the second finger (12).

These days, machine learning (ML) algorithms are employed not only in the domains of engineering and health but also in crucial anthropological definitions like height, age, and gender estimate. ML categorizes algorithms into three groups: reinforcement learning, unsupervised learning, and supervision. Unsupervised learning matches the characteristics of data about which there is no knowledge, whereas supervised learning matches the link between input and output. Algorithms for reinforcement learning match input data with desired attributes (13).

The aim of our study is to make gender estimation with ML algorithms by using the 2D:4D ratios and hand morphometry of the participants.

Materials and Methods

Between the ages of 18 and 30, 88 men and 96 women who had no pathology, deformity, or surgical intervention in their hands participated in the study. Using a digital calli per, the subjects' hand width (HW), hand length (HL), second digit length (2D), and fourth digit length (4D) were measured on the right (R) and left (L) sides and entered into Excel. Furthermore, every person's 2D:4D ratio—the ratio between their second and fourth digits—was noted. By the Gaziantep Islam Science and Technology University Non-Interventional Clinical Research Ethics Committee 2024/384, the study was given approval. Furthermore, the study was carried out on volunteers in compliance with the Declaration of Helsinki's tenets.

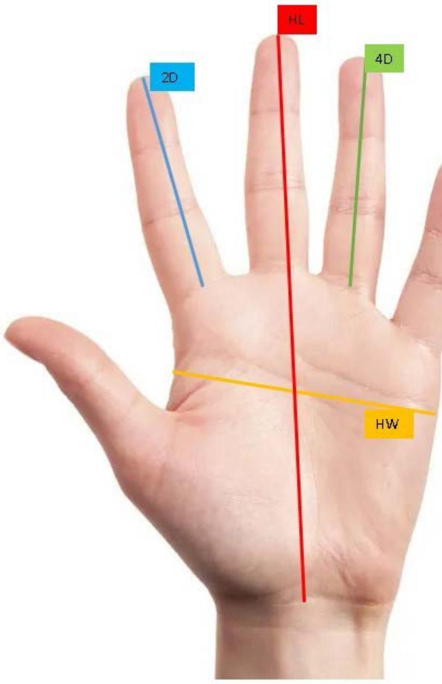


Figure 1. Measurements taken with a digital calliper

Machine Learning Algorithms Modelling

The study's favored machine learning models were K-Nearest Neighbors (k-NN), Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Decision Tree (DT), Extra Tree Classifier (ETC), Random Forest (RF), and Gaussian Naive Bayes (GaussianNB). 20% was used as a test set and 80% was used for training the models. A PC running the i5 operating system and equipped with 8GB of RAM was used to create the models. The RF algorithm's SHAP analyzer was chosen to display how each parameter affected the final outcome. In the study, K-Fold Cross Validation method was used to evaluate the performance of the model and to increase its generalisability.

As a result, the average accuracy score for gender prediction was calculated as approximately 89.18% with a standard deviation of 5.27%. The outputs of Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), and F1 score (F1) were obtained in order to assess the models' power. The following formulae were used to determine the True Positive (TP), False Positive (FP), True Negative (TN), and False Negative (FN) values from the data in the confusion matrix.

$$Acc = \frac{TP}{TP+FN+FP+TN}$$
$$\text{Sen} = \frac{TP}{TP+FN}$$
$$\text{Spe} = \frac{TN}{TN+FP}$$
$$\text{F1} = 2\frac{Precision \times Recall}{Precision + Recall}$$

Equation 1.

In our study, in which gender was estimated from hand measurements, the data cleaning process was carried out in the following steps: Firstly, the general characteristics of the dataset were analyzed, and missing data were identified. Missing data were filled by using the mean or mode value of the relevant features. Erroneous or illogical values were identified and removed from the data set. Outliers were identified using the Z-score method and managed appropriately so that these values do not adversely affect the accuracy of the model. Inconsistent data formats and units were standardized and all data were converted into formats suitable for analysis and modeling. These data cleaning steps were meticulously implemented to improve the accuracy.

Statistical Analysis

p<0.05 was considered significant in statistical analyses and Minitab 17, SPSS 21 package programs were used. Normality of data was tested with Anderson Darling test. Mean±standard deviation was used in normally distributed descriptive statistics, while median (minimum-maximum) values were used in descriptive statistics that were not normally distributed. In gender comparisons, Two Simple T test was used for normally distributed data, while Mann Whitney-U test was used for data that were not normally distributed. The correlation between parameters and the degree of correlation were tested with Spearman rho correlation test for data that were not normally distributed. ROC analysis was conducted to find out the contribution of each parameter. Non-Interventional Clinical Research/2021/9/3).

Results

In this study which was conducted by using the hand measurements of 88 men and 96 women between the ages of 18 and 30, mean age of female and male participants was found as 19 (18-30). As a result of the Anderson Darling test, it was found that 2D-R parameter was normally distributed, while all the other parameters were not normally distributed. 2D-R parameter was found to be 72.659±4.808 mm in men and 66.660±3.511 mm in women. 2D-R parameter was found to be longer in men when compared with women (p=.000). Significance and descriptive statistics of non-normally distributed parameters in terms of gender is shown in Table 1. All parameters except for 2D:4D-R, 2D:4D-L parameters were found to be statistically higher in men (p=.000).

Table 1. Comparison of non-normally distributed parameters in terms of gender

Parameters	Gender	Median (Min.-Max.)	P value**
Age (Years)	Male	19 (18-30)	.770
	Female	19 (18-30)	
HW-R (mm)	Male	86.350 (73.300-94.900)	**.000**
	Female	75.250 (64.600-86.500)	
HW-L (mm)	Male	85.150 (72.000-99.100)	**.000**
	Female	73.950 (65.600-85.100)	
HL-R (mm)	Male	190.000 (161.500-214.000)	**.000**
	Female	174.000 (148.000-192.800)	
HL-L (mm)	Male	190.000 (160.000-215.000)	**.000**
	Female	172.650 (149.600-194.000)	
4D-R (mm)	Male	73.150 (60.300-85.200)	**.000**
	Female	66.350 (59.000-83.800)	
2D:4D-R	Male	0.986 (0.856-1.135)	.054
	Female	0.997 (0.858-1.124)	
2D-L (mm)	Male	72.350 (62.500-82.100)	**.000**
	Female	65.950 (58.200-86.700)	
4D-L (mm)	Male	73.600 (60.800-85.100)	**.000**
	Female	66.100 (58.400-84.900)	
2D:4D-L	Male	0.976 (0.917-1.098)	**.003**
	Female	0.991 (0.931-1.145)	

***Mann Whitney-U test*

The correlation and degree of correlation between non-normally distributed data are shown in Table 2. Very high positive and significant correlation was found between HW-L and HW-R and HL-L and HL-R parameters (p<0.05).

Table 2. Spearman rho correlation table

Parameters	r/p	Age	HW-R	HW-L	HL-R	HL-L	4D-R	2D:4D-R	2D-L	4D-L	2D:4D-L
Age	r	1									
	p										
HW-R	r	.158[a]	1								
	p	**.032**									
HW-L	r	.124	.926[e]	1							
	p	.094	**.000**								
HL-R	r	.144	.757[d]	.770[d]	1						
	p	.051	**.000**	**.000**							
HL-L	r	.138	.774[d]	.787[d]	.952[e]	1					
	p	.062	**.000**	**.000**	**.000**						
4D-R	r	.141	.703[d]	.699[c]	.846[d]	.872[d]	1				
	p	.057	**.000**	**.000**	**.000**	**.000**					
2D:4D-R	r	-.078	-.159[a]	-.172[a]	-.233[a]	-.216[a]	-.358[b]	1			
	p	.291	**.032**	**.019**	**.001**	**.003**	**.000**				
2D-L	r	.158[a]	.695[c]	.707[d]	.805[d]	.828[d]	.865[d]	-.083	1		
	p	**.032**	**.000**	**.000**	**.000**	**.000**	**.000**	.265			
4D-L	r	.146[a]	.727[d]	.741[d]	.862[d]	.883[d]	.930[e]	-.238[a]	.899[d]	1	
	p	**.048**	**.000**	**.000**	**.000**	**.000**	**.000**	**.001**	**.000**		
2D:4D-L	r	.039	-.223[a]	-.226[a]	-.284[b]	-.288[b]	-.307[b]	.427[b]	.004[a]	-.372[b]	1
	p	.601	**.002**	**.002**	**.000**	**.000**	**.000**	**.000**	.954	**.000**	

a: Very weak correlation, b: Weak correlation, c: Moderate correlation, d: High correlation, e: Very high correlation

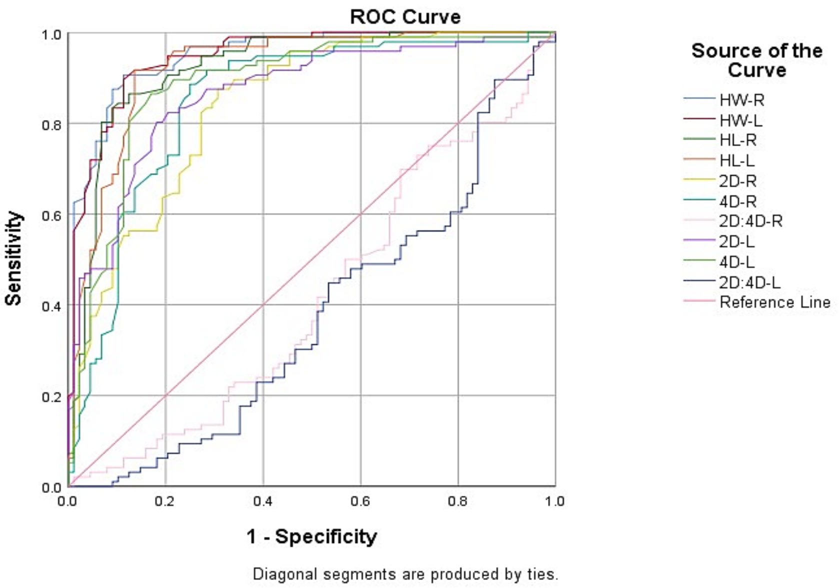


Figure 2. ROC graph

As a result of ROC analysis, HW-R parameter was found to have the highest contribution in the determination of gender (Figure 2).

Table 3 shows the performance criteria obtained as a result of ROC curve. The two parameters with the highest contribution to gender estimation were found as HW-R and HW-L.

As a result of the ML algorithms used to estimate gender, the highest Acc rate was found as 0.92 with RF algorithm. Acc rate of other algorithms were between 0.78 and 0.89 (Table 4).

As a result of RF algorithm, only 3 of the 21 men in the test set were estimated incorrectly, while all of the women were estimated correctly (Table 5).

The effect of parameters on the overall result was also examined with SHAP analyser of RF algorithm and the highest

3 contributes were provided by HW-L, HL-L and HL-R, respectively (Figure 3).

Table 3. ROC curve performance scores

Parameters	AUC (95%)	Cut off	p	Sen	Spe
HW-R	0.949 (0.919-0.979)	80.65	.000	88.5	88.6
HW-L	0.948 (0.917-0.978)	78.45	.000	88.5	88.6
HL-R	0.924 (0.883-0.964)	178.75	.000	86.5	87.5
HL-L	0.924 (0.884-0.964)	178.55	.000	85.4	86.4
2D-R	0.839 (0.782-0.896)	69.05	.000	72.9	72.7
4D-R	0.849 (0.790-0.908)	69.25	.000	78.1	77.3
2D:4D-R	0.418 (0.335-0.501)	0.99	.054	45.8	45.5
2D-L	0.866 (0.813-0.918)	68.45	.000	80.2	80.7
RD-L	0.886 (0.835-0.936)	68.9	.000	84.4	84.1
2D:4D-L	0.375 (0.294-0.456)	0.98	.003	44.8	44.3

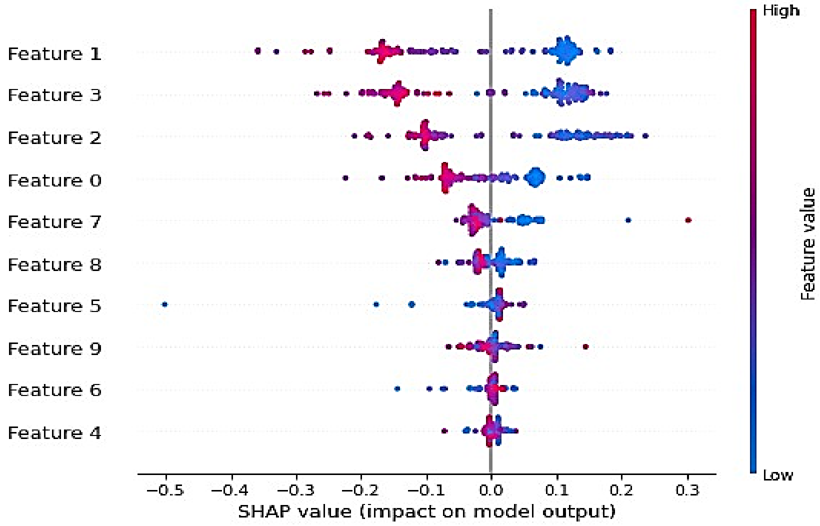
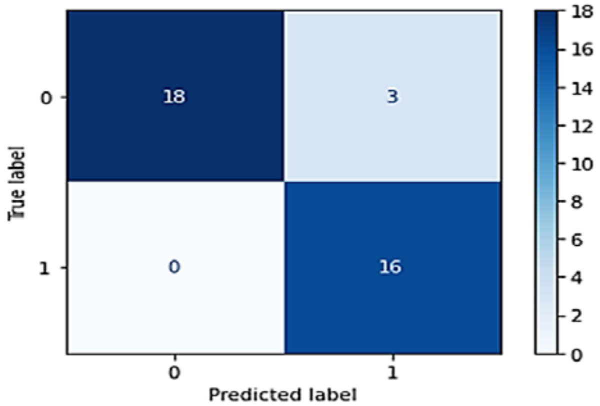


Figure 3. SHAP analyser of RF algorithm (Feature 0: HW-R, Feature 1: HW-L, Feature 2: HL-R, Feature 3: HL-L, Feature 4: 2D-R, Feature 5: 4D-4, Feature 6: 2D:4D-R, Feature 7: 2D-L, Feature 8: 4D-L, Feature 9: 2D:4D-L).

Table 4. Values of machine learning models

Algorithms	Acc	Spe	Sen	F1
LDA	0.86	0.90	0.86	0.86
QDA	0.78	0.78	0.78	0.78
LR	0.89	0.91	0.89	0.89
ETC	0.89	0.91	0.89	0.89
DT	0.81	0.87	0.81	0.81
RF	0.92	0.93	0.92	0.92
GaussianNB	0.89	0.91	0.89	0.89
k-NN	0.89	0.91	0.89	0.89

Table 5. Confusion matrix table of Random Forest algorithm



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Discussion

In the present study in which gender was estimated by using ML algorithms with parameters obtained from 2D:4D digit ratio and hand morphometry, the highest Acc rate was found as 0.92 with RF algorithm. Acc rate of other algorithms were between 0.78 and 0.89. In the test set of RF algorithm which had the highest rate of accuracy, 18 of 21 males were estimated correctly, while all 16 females were estimated correctly. In addition, the contribution of the parameters used in estimating gender was evaluated with SHAP analyser of RF algorithm and it was found that HW-L parameter had the highest contribution to determine gender. This was also evaluated with basic ROC analysis and HW-L parameter was found to have the second highest contribution and there was a difference of 0.001 AUC (95%) with the parameter that had the highest contribution. 2D:4D ratio was found to be higher in women, as in literature.

2D:4D ratio is a matter of scientific curiosity and it has been examined in literature in a wide spectrum including sports activities, gender dysphoria, hand preference, visual, auditory and verbal abilities, schizophrenia, diabetes, motor skills, hyperactivity, attention deficit, purchase attitudes and gender, with remarkable results (14-21). Gender related change in 2D:4D ratio is thought to be due to gender hormones prenatal testosterone and oestrogen. It is thought that prenatal high oestrogen causes the individual to gain feminine features in the postnatal period, while high testosterone causes the individual to gain masculine features (22, 23).

In a study they examined the 2D:4D ratio of women and men between the ages of 19 and 25, Sivakumar et al. found that 2D-R, 2D-L, 4D-R, 4D-L values were higher in men, while 2D:4D-R and 2D:4D-L values were higher in women and they reported that all parameters showed significant difference in terms of gender ($p<0.05$) (24). In a study Sağlam et al. conducted on 99 individuals with sexual dysphoria and 116 individuals without sexual dysphoria, they found that 2D:4D-L and 2D:4D-R values of women in the group without sexual dysphoria was higher than those of men. They also examined 2D:4D ratio on the right and left side in terms of gender and found that it was statistically significant ($p<0.05$) (20). In a study they conducted on 400 individuals with Type 2 diabetes (200 women, 200 men) and 400 healthy individuals (200 women, 200 men) between the ages of 20 and 80, Özkan et al. found that HW-R, HW-L, HL-R and HL-L parameters in the healthy group were higher in men when compared with women (21). In the present study, we found that 2D-R, 2D-L, 4D-R, 4D-L, HW-R, HW-L, HL-R and HL-L parameters were higher in men, while 2D:4D-R, 2D:4D-L parameters were higher in women. It was also found that all parameters except 2D:4D-R showed statistical difference in terms of gender. We think that the difference here may be due to population, number of differences or gender dysphoria undefined by the individual.

ML algorithms are engineering based algorithms and they have recently begun to be seen in the field of medicine (in forensic medicine, forensic anthropology, anatomy, surgical and clinical sciences). In studies conducted on different bones and bone pieces, it has been reported that ML algorithms give results with higher accuracy and reliability since some of the data are evaluated as test set and they are computer based (25-29). ML algorithms were preferred in our study to get reliable and highly accurate gender estimation results and a high Acc rate of 0.92 was found with the parameters obtained.

In the present study which we set out with the hypothesis that gender estimation can be made from 2D:4D ratio and hand morphometry by using ML algorithms, when the high Acc rate that was found with the parameters we determined by using RF algorithm is considered, we believe that the present study will contribute to and strengthen studies conducted on gender estimation.

Ethical Approval: Gaziantep Islam Science and Technology University Non-Interventional Clinical Research Ethics Committee 2024/384.

Author Contributions:
Concept: A.K., R.C.
Literature Review: A.K., R.C.
Design : A.K., R.C.
Data acquisition: A.K., R.C.
Analysis and interpretation: A.K., R.C.
Writing manuscript: A.K., R.C.
Critical revision of manuscript: A.K., R.C.
Conflict of Interest: *The authors have no conflicts of interest to declare.*
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