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RESEARCH ARTICLE

Pinna anthropometry in sex estimation: a machine learning-based approach

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ABSTRACT

Aim: The pinna, the hearing organ, also contributes to the aesthetic appearance of the face. We aimed to investigate the feasibility of sex prediction using anthropometric measurements of the pinna in machine learning.

Methods: The study included two hundred healthy individuals (104 women and 96 men). The pinna of these individuals were measured in eight different parts using a digital calliper. The data, which differed by sex, were processed in eight different machine-learning algorithms.

Results: Seven different measurements, such as pinna length, width and lobule length, were greater in men than in women ($p<0.05$). The K-Nearest Neighbor model showed the best success in sex prediction with an accuracy of 0.825 and a ROC value of 0.882.

Conclusions: Pinna's anthropometric measurement values can be used in machine learning to predict sex with a high success rate. Our study shows that ear prints may have potential use in forensic identification.

Keywords: anthropometry, machine learning, pinna, sex estimation

INTRODUCTION

The external ear consists of the pinna and the external ear canal. While the pinna captures the sound wave, the outer ear canal transmits the sound wave to the middle ear. In addition to hearing, the outer ear helps diagnose congenital anomalies and syndromes (1). Changes in the shape and size of the auricle and its position on the head help to identify anomalies and syndromes. While the pinna is large in individuals with Apert and Crouzon syndromes, the pinna is small in individuals with Down syndrome and cleft palate/lip (1). Additionally, pinna deformities can be seen in trisomy 13 and 18 (2).

The appearance of the pinna, its symmetry and harmony with age, sex and face are important for

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facial aesthetics. Any deformity in the size, shape or position of the pinna, small size (microtia) or absence (anotia) of the pinna can be corrected by aesthetic and plastic surgery. For all of these surgical corrections and the creation of artificial ear prostheses, normative dimensions of the auricle are required (3). In addition, these dimensions are also crucial for the ergonomic production of hearing aids/cochlear implants used in hearing (re)habilitation.

Anthropometry refers to the study of the dimensions of different parts of the body. Due to its position relative to the head and its many indentations and protrusions, the auricle can be measured using direct or indirect anthropometric methods. Direct measurements use calipers or tape measures to measure the features of the pinna, such as width and length. In indirect measurements, measurements are obtained from various radiologic images and photographs (4). These anthropometric measurements of the pinna may vary between ethnic groups and sexes (1,5). Although the size of the pinna increases with age, the ratio between their sizes remains constant (4). Additionally, pinna measurements (indirect) require less spatial resolution and are less affected by light changes. For these reasons, pinna measurements perform better than facial measurements in terms of diagnosis and sex prediction (6). The Forensic Ear Identification Project is working to use earprints to identify criminals and suspects, similar to fingerprints, retinas and DNA (7). For this reason, it is believed that the pinna, which has distinct, permanent, and unpredictable biometric features, will be widely used for identification and verification purposes in forensic medicine.

Some studies have investigated the anthropometric characteristics of the pinna in the Turkish society (6,8,9). However, there are limited studies using anthropometric measurements of the pinna in machine learning for sex prediction (6). This study aims to investigate the feasibility of sex prediction with machine learning using anthropometric measurements of the pinna in Turkish people. The relationship between pinna and age, height, weight and body mass index (BMI) was also investigated.

MATERIAL AND METHOD

Permission was received from the ethics committee of Karabük University for this prospective study (2023/3 Decision no: 25). Written and verbal informed consent was obtained from all individuals included in the study.

Two hundred healthy individuals were included in the study. The study excluded participants with any pinna anomalies, deformities, microtia or anotia. The age, sex, height and weight information of these individuals were recorded. Participants were divided into two groups based on sex (Female: 104, Male 96). The participants' pinnae were measured in millimetres from 8 measurement points using a digital caliper (Figure 1). These measurement points are labeled a, b, c, d, e, f, g and h. The boundaries of the measurement points were created as stated by Petrescu et al. (10).

[a]: Superaurale- Subaurale
[b]: Protragion- Helix (Distance from tragus to helix) (11)
[c]: Incisura intertragica inferior- Postaurale
[d]: Incisura intertragica inferior- Otobasion inferior
[e]: Lobule anterior- Lobule posterior
[f]: Protragion- Strongest anthelical curvature
[g]: Incisura anterior auris posterior- Postaurale
[h]: Incisura anterior auris posterior- Stobasion superior

Figure 1. Measurement points taken on the pinna.

Statistical analysis and machine learning models

Statistical analysis was performed to determine the attributes to build machine learning models. Statistical analysis was carried out using the SPSS 21 IBM program. Shapiro-Wilk test was used to check the normality of the data. Student's t-test was used to analyze normally distributed data, and Mann-Whitney U tests were used to analyze non-normally distributed data. The statistical significance level was accepted as $p<0.05$. The significant data between the groups were used as input (feature) in machine learning models. Python (Version 3.7) programming language was used for machine learning models. Machine learning consists of supervised, unsupervised, and reinforcement learning types. Supervised learning algorithms are often used for classification and regression problems in medical and health sciences. In our study, K-Nearest Neighbor (KNN), Decision Trees (DT), Random Forest (RF), Support Vector Machine (SVM), Logistic Regression (LR), XGBoost, and Artificial Neural Network (ANN) were used as machine learning algorithms. We determined the best set of hyperparameters using the Grid Search method. While modeling the algorithms, 96 (80%) of the data were used in the training process, and the remaining 24 (20%) were used in the testing process. The success of the models was evaluated according to the accuracy in the testing phase and the area under the ROC curve (AUC).

RESULTS

The average age of the 104 women included in the study was 20.63±3.30 (range 18-35) years, and the mean age of the 96 men was 21.41±4.05 (range 17-40) years. There was no difference in age between the groups (p:0.137).

The values obtained from the measurement points of the right and left pinna based on sex are presented in Table 1. The number of pinnae (n: 400) was used to compare pinna measurements based on sex and to investigate the relationship between pinna measurements and age, height, weight, and body mass index (BMI). There was a positive correlation between age and lengths of [b], [c], [g] and [h]; a positive correlation between height and lengths of [a], [b], [c], [d], [f], [g] and [h]; a positive correlation between weight and lengths of [a], [b], [c], [d], [e], [f], [g] and [h]; and a positive correlation between BMI and lengths of [a], [b], [c], [d], [e], [g] and [h] ($p<0.05$). The relationship between pinna measurements and height, weight, and BMI is presented in Table 2. The lengths of [a], [b], [c], [d], [f], [g] and [h] were greater in men than in women ($p<0.05$). However, there was no difference in [e] length between the sexes ($p>0.05$). Pinna lengths by sex are presented in Figure 2.

Table 1. Values measured in the right and left pinna according to sex

	Female			Male		
	Right	Left	Mean	Right	Left	Mean
[a] mm	59.68±3.78	59.58±3.79	59.63±3.77	63.80±4.51	63.81±4.31	63.80±4.40
[b] mm	25.11±3.29	25.79±3.60	25.45±3.45	26.86±2.20	27.23±2.53	27.05±2.37
[c] mm	43.80±3.69	44.24±3.02	44.02±3.37	47.70±3.24	47.80±3.51	47.75±3.37
[d] mm	17.09±2.59	17.12±2.97	17.11±2.77	17.85±2.49	18.00±2.49	17.93±2.48
[e] mm	16.14±3.50	17.13±3.50	16.64±3.53	16.78±3.66	17.31±3.31	17.05±3.49
[f] mm	17.81±2.52	18.17±2.53	17.99±2.54	18.65±2.78	18.80±2.27	18.72±2.53
[g] mm	31.50±3.58	31.48±4.09	31.49±3.83	33.03±2.88	33.08±3.83	33.07±3.38
[h] mm	20.58±3.15	20.69±3.12	20.63±3.13	21.42±2.53	21.69±2.52	21.55±2.52

Table 2. Relationship between pinna measurement points and height, weight and BMI

		Age (year)	Height (cm)	Weight (kg)	BMI
	Mean±Sd	21.00±3.68	170.27±9.13	66.81±14.71	22.86±3.74
		Correlation coefficient (p value)			
[a] mm	61.63±4.58	0.6 (0.264)	4.6 (<0.001)	5.2 (<0.001)	3.8 (<0.001)
[b] mm	26.22±3.09	1.0 (0.047)	2.9 (<0.001)	3.1 (<0.001)	1.9 (<0.001)
[c] mm	45.81±3.78	1.9 (<0.001)	4.3 (<0.001)	5.0 (<0.001)	3.7 (<0.001)
[d] mm	17.50±2.66	0.1 (0.736)	2.0 (<0.001)	3.7 (<0.001)	3.6 (<0.001)
[e] mm	16.83±3.51	-0.7 (0.147)	0.8 (0.093)	2.0 (<0.001)	2.1 (<0.001)
[f] mm	18.34±2.56	0.5 (0.281)	1.0 (0.042)	1.2 (0.015)	0.7 (0.115)
[g] mm	32.25±3.70	1.3 (0.007)	2.4 (<0.001)	3.2 (<0.001)	2.5 (<0.001)
[h] mm	21.08±2.89	1.2 (0.011)	2.4 (<0.001)	2.6 (<0.001)	2.0 (<0.001)

BMI: Body Mass Index, Spearman Correlation Test

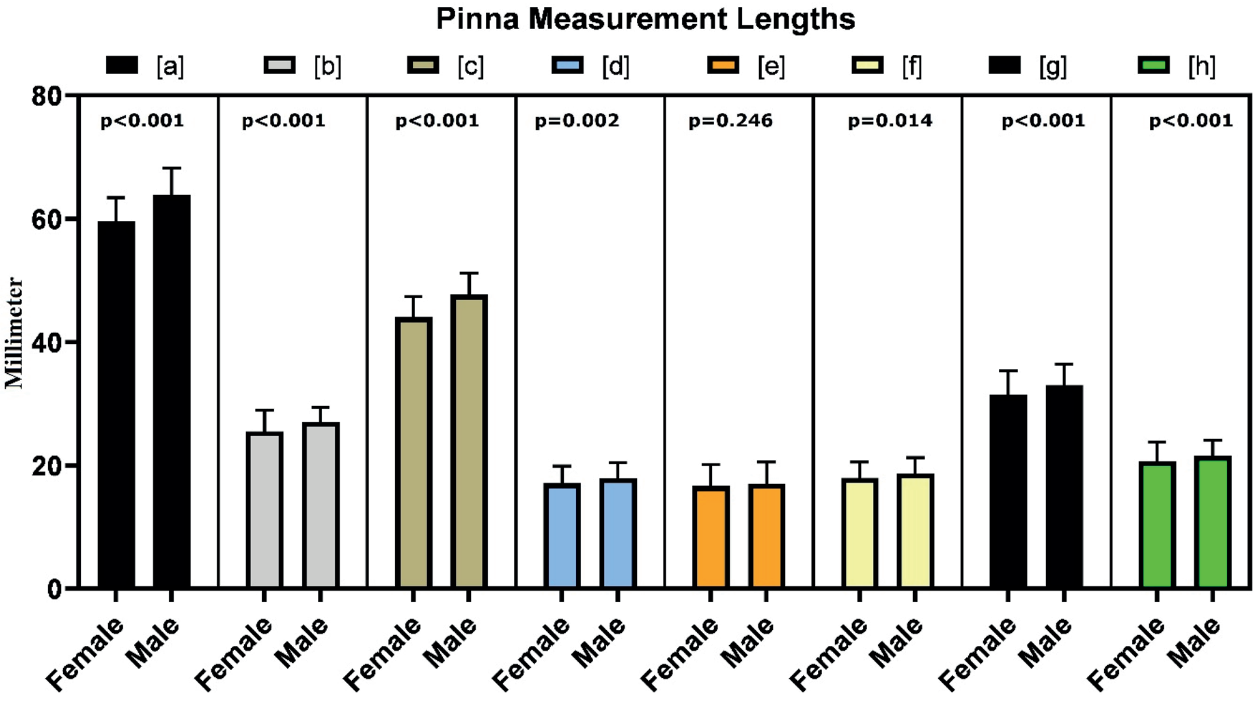

Figure 2. Measurement lengths by sex.

The lengths of [a], [b], [c], [d], [f], [g] and [h], which were found to be statistically significant, were used as features to build machine learning models. The heat map of the correlation matrix between the used features and the sex is presented in Figure 3A. KNN achieved the highest success rate among the created models with an accuracy value of 82.5% (Supplemental 1). The confusion matrix and ROC curve of the KNN algorithm are presented in Figures 3B and 3C. The performance of the eight algorithms used was shown in Table 3.

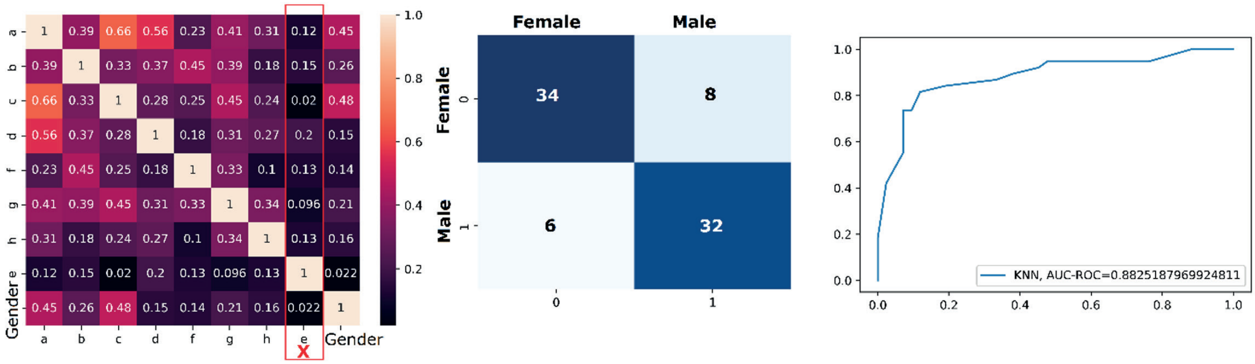

Figure 3. A: Heat map of the correlation matrix of features, [e] was not statistically significant between sexes. B: Confusion matrix of the K-Nearest Neighbor algorithm. C: ROC curve of the K-Nearest Neighbor algorithm.

Table 3. Success rates of the models

Algorithms	Precision	Recall	F1-score	Accuracy	ROC- AUC
K-Nearest Neighbor	0.80	0.84	0.82	0.8250	0.882
Naive Bayes	0.81	0.76	0.78	0.8000	0.827
Decision Tree	0.71	0.79	0.75	0.7375	0.741
Random Forest	0.84	0.84	0.84	0.7500	0.869
Support Vector Machine	0.72	0.76	0.74	0.7500	0.808
Logistic Regression	0.73	0.79	0.76	0.7625	0.808
XGBoost	0.72	0.74	0.73	0.7375	0.825
Artificial Neural Networks	0.73	0.87	0.80	0.7975	0.791

DISCUSSION

In addition to its functionality in providing hearing, the pinna also adds aesthetics to the face. Individuals want a normal and aesthetically pleasing auricle for social acceptance and self-confidence. We did not focus on the hearing benefit of the pinna and its aesthetics. We used seven pinna measurements, which were found to be longer in men than in women, in 8 different machine learning algorithms and aimed to predict sex with these features. The K-Nearest Neighbor model performed best with an accuracy of 0.825 and an AUC of 0.882.

Studies in the literature have shown differences in the pinna between ethnic groups and sexes. In a study conducted on Indians (11), the pinna length in males was 60.4 mm, with a width of 24.3 mm, while in females, the pinna length was 57.6 mm, and the pinna width was 23.3 mm. The researchers reported a difference between the sexes in all measured pinna qualities except lobule length. In a study conducted on Sudanese (2), the pinna length in males was 62.9 mm, with a width of 29.5 mm, while the pinna length in females was 60.9 mm, with a width of 28.8 mm. Researchers reported that the auricle length, width, base, and turbinate length of males are larger than those of females, while the width of the lobes and turbinates are similar. In a study conducted on Koreans (12), the pinna length in males was 62.2 mm and the pinna width was 46.3 mm, while the pinna length in females was 59.30 mm and the pinna width was 44.3 mm. In our study, the pinna length in males was 63.80 mm and the pinna width was 27.05 mm; the pinna length in females was 59.63 mm and the pinna width was 25.45 mm. In our study, all the measurements except the lobule width were larger in males than in females. In comparison with other ethnic groups, the pinna length of Turks in our study was larger than that of Indians, smaller than that of Sudanese, and similar to that of Koreans. Pinna width was greater than that of Indians and smaller than that of Sudanese and Koreans. The differences in auricle length between societies or ethnic groups may be due to genetic, environmental, and nutritional factors.

The findings of studies investigating the relationship between pinna measurements and height, weight, and BMI are contradictory. Acar analyzed the pinna morphometry of 246 university students using the photo analysis method and examined its relationship with height, weight, and BMI (4). The authors reported that pinna length and width had a strong positive relationship with height, but not with BMI. Laxman reported that there is a positive correlation between pinna morphometric measurements and height and that the pinna can be used to estimate height ($r=0.728$, $p<0.001$ in girls; $r=0.815$, $p<0.001$ in boys) (13). In another study pinna and lobule length and width were associated with higher weight and BMI, but not with height (14). In our study, in contrast to the studies in the literature, a positive relationship was found between auricle anthropometric measurements and all three (BMI, height and weight) (4,13,14).

Maturation of the pinna cartilage is completed at the age of 13 in men and at the age of 12 in women (15). The legal system often requires two different types of corroborating evidence for identification. There are many structures on the pinna, and the distances of these structures from each other can be easily measured. Therefore, pinna anthropometry can be used for identification in forensic medicine and medicolegal cases. Sezgin et al. estimated sex using pinna measurements, height, and weight of 350 individuals in a binary logistic regression analysis (16). The researchers achieved a 68% success rate with the model created using only anthropometric measurements of the pinna, they achieved 88% success in the model developed using height, weight, and pinna measurements. Akyol et al. reported that the success rate with ANN in sex prediction using front face, side face, and age information in machine learning algorithms was 82.6% (6). It was reported that when pinna anthropometric measurements were added, this rate increased to 92.2%. Murgod et al. performed discriminant function analysis with pinna parameters and reported that these parameters accurately predicted sex at a rate of 68–71% (17). In our study, we used only anthropometric measurements of the pinna in machine learning and achieved an accuracy rate of 82.5% with the KNN model. To avoid going beyond our purpose, we did not include attributes such as height and weight in machine learning models. To the best of our knowledge, this study is the first to achieve the highest accuracy in sex prediction using machine learning based on pinna anthropometry. Machine learning-based mobile software can be developed in future studies, and sex prediction can be made with high accuracy.

We used eight different machine learning algorithms in our study. The performances of machine learning algorithms vary depending on data structures, problems, and application scenarios. The strengths and weaknesses of each algorithm depend on the specific problem context, dataset characteristics, and use cases. The discriminant function analysis used by Murgod et al. is a traditional statistical method (17). Although binary logistic regression is considered a machine learning algorithm, it is more suitable for situations where linear distinctions are evident, and its performance decreases in non-linear situations. In our findings, the accuracy of the logistic regression model was lower (76.25%). Unlike logistic regression, KNN can successfully solve non-linear classification problems and can be adapted to various data set structures. Moreover, KNN is also effective on multi-class and multi-dimensional datasets. This flexibility is especially advantageous for complex classification problems and large data sets (18). Therefore, the high success we achieved in our study by using only pinna morphometry is due to the use of many machine learning algorithms.

Our study presents anthropometric measurements of the pinna, the hearing organ, in Turkish people. Our data can serve as a database for otolaryngologists/plastic surgeons interested in pinna reconstruction. It can guide the ergonomic production of newly developed models of hearing aids/cochlear implants (19). As a contribution to the literature, we propose that the pinna can be utilized with high accuracy for sex estimation, in addition to its primary functions of hearing and aesthetic appearance. By providing adequate infrastructure, creating data collection tools and standardizing measurement points, pinna anthropometry (ear print) can also be used in forensic identification.

This study has several limitations. The sample group in our study consists mainly of young adults. The pinna undergoes physical changes with ageng. Therefore, our machine learning model may produce different results in middle-aged and older individuals. In future studies, pinna anthropometric measurements from individuals in more homogeneous age groups or diverse age groups can be used in machine learning. In this way, models with higher accuracy rates can be developed.

CONCLUSION

Sexual dimorphism in pinna size is reflected in higher anthropometric measurements in males than in females. Pinna's anthropometric measurements can be used in machine learning to predict sex with a high success rate. Our study shows that ear prints may have potential use in forensic identification.

Ethical approval

This study has been approved by the Karabük University (approval date 29/03/2023, number 25). Written informed consent was obtained from the participants.

Author contribution

Surgical and Medical Practices: ES; Concept: ES; Design: ES, STY; Data Collection or Processing: ES; Analysis or Interpretation: STY, ES; Literature Search: ES, STY; Writing: ES, STY. All authors reviewed the results and approved the final version of the article.

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Conflict of interest

The authors declare that there is no conflict of interest.

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