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Stroboscopic Evaluation of the Vocal Folds' Morphometric Characteristics, between the Different Voice Categories on Professional Singers

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Abstract

Objective(s): The aim of this study is to explore if there is a correlation between the typical voice classification and the morphometric characteristics of the vocal folds, using video laryngeal stroboscopy, on professional singers in Greece. **Methods:** 70 professional singers, 50% men (35 men) and 50% women (35 women), were recruited for this study. A stroboscopic evaluation was prepared for every participant. Additionally, the voice classification and features of individuals were correlated statistically. **Results:** Statistically significant difference were observed between the voice categories and the size of stomatopharynx, the shape of the hard palate, the length of the vocal folds, the width and thickness of the vocal folds, as well as the tone of speech, in male singers. Statistically significant differences were also observed between the voice categories and all the variables except the shape of epiglottis, the color of speech and the shape of the vocal folds, in female singers. **Conclusions:** There is correlation between the morphometric characteristics of the vocal folds and the voice categories.

1. Introduction

Considering voice as the generator of voiced sound, it can be functionally separated into three units: the lungs that provide the power supplies, the vocal folds that use as oscillators and the vocal tract, which works as a resonator [1]. The singing voice production depends on many parameters, such as developmental, physical, psychological, environmental and the vocal training [2] [3] [4] [5] [6]. Singing voice has prevailed to be classified into groups, based on the frequency range of each singer, as follows: male voices belong to one of the categories basso, tenor, baritone, while female voices belong to one of the categories contralto, mezzo-soprano, and soprano [7] [8] [9] [10]. Many researchers have attempted to quantify the factors that influence and form phonation and singing, providing special methods of examination. So, radiological methods, such as the x-ray imaging, the computed tomography, the magnetic tomography, as well as the ultrasound-imaging test have been used as methods for the examination of larynx, over the years [11]-[16]. Most of the studies correlate the classical categories with body type, improving that low-frequency voices (such as bass male singers) tend to correlate with taller people, while high-frequency voices (such as tenor male singers and soprano female singers) correlate with shorter people [17]. Furthermore, other studies have suggested that there is a relationship between laryngeal size (length, shape and thickness of the vocal folds) and qualitative vocal characteristics (pitch, loudness and timbre), as they are observed clinically by vocal coaches and ENT doctors. The morphological characteristics of the vocal folds seem to differ between voice categories, and affect the voice production while singing [18] [19] [20] [21]. Our purpose was to evaluate the vocal folds' characteristics, using the examination method of stroboscopy.

2. Materials and Methods

2.1. Participants

Seventy (70) healthy singers (male: 35; female: 35), aged from 18 to 70, were included in this study. All of the participants were professional singers that practice voice in specialized centers, in Ioannina, Greece. Especially, all of the participants belong to the choirs of the municipality or practice in any of the conservatories in Ioannina city. The thirty-five males were classified as follows: 1) 16 basses, 2) 11 baritones, and 3) 8 tenors. Likewise, the thirty-five females were classified as: 1) 7 contraltos, 2) 12 mezzo-sopranos and 3) 16 sopranos. All subjects were classified into singing groups by an experienced vocal coach. Specific

included and excluded criteria were used to determine the final sample. All singers with a medical history of head and neck surgery or neck radiation were not included in this study [22] [23] [24] [25]. Additionally, subjects who had presented during the previous weeks laryngeal/vocal complaints, symptoms of gastro re-flux (GERD), or laryngopharyngeal reflux (LRP) disease, were excluded from this study [26] [27] [28] [29] [30]. Finally, subjects with a medical history of voice disorders in the past, of abuses (e.g. alcohol, drugs), smokers, were also excluded from the study [31]-[37]. Finally, female participants that were pregnant were also excluded from the study, because their receiving any radioactive substance would have been impermissible [38] [39]. This study was approved by the Ethical Committee of the Medical School, University of Ioannina.

2.2. Collection of Data

The above data were obtained through a specific history form used in the ENT clinic of the University Hospital of Ioannina. The sample was evaluated at the ENT clinic of the University Hospital of Ioannina, Greece. Each subject was informed of the research purposes and gave a written consent. We used a video laryngeal stroboscopy for each participant, for the evaluation of the vocal folds.

2.3. Video Laryngeal Stroboscopy

Each professional singer was submitted to a stroboscopic evaluation of the larynx. The choice of this endoscopic method was held because of some specific advantages. It is a non-invasive method of introspection of vocal folds that provides the opportunity of detailed imaging of the vocal folds' mobility and movement of the mucosal wave [40]-[45]. During stroboscopy, each singer was asked to produce an /e/ sound at a frequency of tessitura. Tessitura refers to the the most comfortable modal singing voice range for the professional singer [46] [47] [48]. Through the laryngeal stroboscopy, we selected specific information about: the shape of the vocal folds (round shaped, striped shaped), the shape of the epiglottis (flat, omega shaped), the length of the vocal folds (short, medium, long), the width of the vocal folds (narrow, wide, medium), the thickness of the vocal folds(thin, coarse, medium). We used a rigid transoral Storz Stroboscope for the examination of subjects.

2.4. Nasal-Sinus and Clinical Evaluation

A clinical evaluation of all participants was also performed from an ENT doctor to record the size of the oral cavity (small, medium, large) and the shape of the hard palate (oval, arched, flat). Through a subjective clinical examination we also observed the color of the voice (light, dark) and the tone of speech (acute, medium, heavy), of every participant, as qualitative data. An anterior rhinoscopy, using a small-sized Killian's Nasal Speculum and a headlight, was finally used to evaluate the transparency of the nasal cavity (good, reduced) [49].

2.5. Statistical Analysis

The distribution of variables was tested using the Kolmogorov-Smirnov and Shapiro-Wilk tests. All skewed variables are expressed as the medians and the inter-quartile range, and all normally distributed variables are expressed as the means and standard deviations (SD). Spearman's rank correlation coefficient was used to correlate the vocal category of the participants and the permeability of nasal cavity, oral pharyngeal size, shape of the hard palate, epiglottis, length of the vocal chords, shape of the vocal chords, width of the vocal chords, thickness of the vocal chords, tone/tonicity of the speech, vocal timbre. All reported p-values were two-tailed, and the statistical significance was set at the value of $p < 0.05$. The analysis was performed with SPSS statistical software (version 19.0, Armonk, NY, USA).

3. Results

Subsection

Through the examination of gender percentages, the participants are divided into: 50% men (35 men) and 50% women (35 women). Regarding the voice category to which the participants belong, the analysis showed that 16 singers (22.9%) belong in the bass category, 11 singers (15.7%) are baritones and 8 (11.4%) are tenors. 7 singers (10%) are contralto, 12 (17.1%) are mezzo-soprano and 16 singers (22.9) are soprano. The mean age of the total sample was 38.64 years (SD = 16.52) with the mean age of males at 36.51 (SD = 14.34) and the mean age of females at 40.77 years (SD = 18.41). The mean height of the total sample was 1.73 meters (SD = 0.08) with that for males being 1.76 (SD = 0.06) and for females 1.70 (SD = 0.08). The mean body weight of the total sample was 72.46 kg (SD = 10.88) with male mean body weight of 76.71 (SD = 9.96) and female mean body weight 68.20 kg (SD = 10.19). The mean years of vocal training for the total sample was 9.26 years (SD = 7.13) with mean male vocal training at 9.63 (SD = 7.74) and female mean vocal training at 8.89 years (SD = 6.95).

In an additional analysis, we correlated the weight and the age with the voice category. A non-statistically significant difference was observed for the age [p = 0.465]. A statistically significant difference was observed for the height [F = 35.22, p = 0.000] and the difference was between the bass and baritone [p = 0.000] and between the bass and the tenor [p = 0.000]. Statistically significant differences were also observed between the weight [F = 28.76, p = 0.000] and the difference was between bass and baritone [p = 0.001], bass and tenor [p = 0.000] and between baritone and tenor [p = 0.009]. Regarding the female voice categories, the same statistical analysis was followed. A non-statistically significant difference was observed for the age [p = 0.826]. A statistically significant difference was observed for the average height in centimeters [p = 0.000] with the difference being between contralto and mezzo-soprano [p = 0.000] and between mezzo-soprano and soprano [p = 0.048]. Statistically significant differences were also observed between the average weight [p = 0.000] with the difference being be-

tween loud and acute loud [p = 0.000].

The objective examination showed that 9 basso, 5 baritones and 6 tenors of the group of male singers had good transparency of the nasal cavity, while 7 basso, 6 baritones and 2 tenors had reduced transparency. All of 16 basso singers appeared large stomatopharynx. 1 baritone appeared small stomatopharynx, 9 baritones appeared mean size, while 1 appeared large stomatopharynx. All of 8 tenors appeared small stomatopharynx (Table 1).

The shape of hard palate was evaluated next. 13 basso singers appeared an oval-shaped palate, 3 basso presented arched palate and no one appeared flat hard palate. 5 baritones appeared an oval-shaped palate, 4 baritones presented arched palate and 2 appeared flat hard palate. 2 tenors appeared an oval-shaped palate, 1 presented arched palate and 5 appeared flat hard palate. Regarding the shape of the epiglottis, 7 basso, 6 tenors and had a high-rising epiglottis, while 5 basso, 5 baritones and 2 tenors had a lower-lying epiglottis (Table 2).

Concerning the length of vocal folds, in male singers, all of tenors appeared short vocal folds, while all basso appeared long vocal folds. Finally, 9 baritones appeared meddle length of vocal folds, while 2 baritones appeared long vocal folds. In terms of the shape of the vocal folds in male singers, 9 basso appeared rounded shape and 7 basso appeared elongated. 5 baritones appeared rounded and 6 appeared elongated vocal folds. Finally, 5 tenors appeared rounded and 3 appeared elongated vocal folds (Table 3).

Concerning the width of the vocal folds of the male singers, all of 15 basso appeared wide vocal fold. 2 baritones appeared wide vocal folds, 9 baritones appeared medium size vocal folds and 8 baritones appeared narrow vocal folds. The thickness of the vocal folds was found to be thin in 2 basso singers and 8 tenors. 14 basso, 2 baritones appeared thick vocal folds and 9 baritones appeared average thickness (Table 4).

The tone of speech was heavy in all of the 16 basso and in 2 baritones. 9 baritones appeared average tone of speech. All of the 8 tenors appeared acute tone of

Table 1. Statistical analysis results: correlation between male singers and the variables; reliability of the nasal cavity, size of stomatopharynx.

voice category	reliability of nasal cavity			size of stomatopharynx			
	good	reduced	total	small	Mean	large	total
basso	9	7	16	0	0	16	16
	56.30%	43.80%	100%	0%	0.00%	100%	100%
baritones	5	6	11	1	9	1	11
	45.50%	54.50%	100%	9.10%	81.80%	9.10%	100%
tenors	6	2	8	8	0	0	8
	75%	25%	100%	100%	0%	0%	100%
Pearson Chi-square		1.661			58.22		
p-level		0.436			0		

Table 2. Statistical analysis results: correlation between male singers and the variables; shape of hard palate, shape of epiglottis.

voice category	shape of hard palate				shape of epiglottis		
	oval	arched	flat	total	high	lower	total
basso	13	3	0	16	7	9	16
	81.30%	18.80%	0%	100%	48%	56.30%	100%
baritones	5	4	2	11	6	5	11
	45.50%	36.40%	18.20%	100.00%	55%	45.50%	100%
tenors	2	1	5	8	6	2	8
	25%	13%	63%	100%	70%	25%	100%
Pearson Chi-square	15.15				2.09		
p-level	0.004				0.35		

Table 3. Statistical analysis results: correlation between male singers and the variables; length of vocal folds, shape of vocal folds.

voice category	length of vocal folds				shape of vocal folds		
	short	meddle	long	total	Rounded	elongated	total
basso	0	0	16	16	9	7	16
	0%	0%	100%	100%	56.30%	43.80%	100%
baritones	0	9	2	11	5	6	11
	0%	81.80%	18.20%	100%	45.50%	54.50%	100%
tenors	8	0	0	8	5	3	8
	100%	0%	0%	100%	62.50%	37.50%	100%
Pearson Chi-square	60.45				0.58		
p-level	0				0.745		

Table 4. Statistical analysis results: correlation between male singers and the variables; width of vocal folds, thickness of vocal folds.

voice category	width of vocal folds				thickness of vocal folds			
	wide	meddle	narrow	total	thin	average	thick	total
basso	15	0	1	16	2	0	14	16
	93.80%	0%	6.30%	100%	12.50%	0%	87.50%	100%
baritones	2	9	0	11	0	9	2	11
	18.20%	81.80%	0%	100%	0%	81.80%	18.20%	100%
tenors	0	0	8	8	8	0	0	8
	0%	0%	100%	100%	100%	0%	0%	100%
Pearson Chi-square	54.69				50.1			
p-level	0				0			

speech. Finally, in observing the color of each participant's speech, it was found that 11 basso, 5 baritones and 4 tenors exhibited deep voice color. 5 basso, 6 ba-

ritones and 4 tenors appeared high-tone voice color (Table 5).

The objective examination based on stroboscopy clinical findings in female singers, showed that: 2 contralto, 4 mezzo-soprano and 14 soprano had good transparency of the nasal cavity, while 5 contralto, 8 mezzo-soprano and 3 soprano had reduced transparency. All of 7 contralto singers appeared large stomatopharynx, all of 12 mezzo-soprano singers appeared mean size of stomatopharynx, while all of the 16 soprano singers appeared large stomatopharynx (Table 6).

The shape of hard palate in female singers was evaluated next. 5 contralto appeared an oval-shaped palate and 2 contralto had flat hard palate. 3 mezzo-soprano appeared oval-shaped palate, 7 mezzo-soprano appeared arched palate and 2 appeared flat hard palate. 2 soprano appeared an oval-shaped palate, 5 presented arched palate and 9 soprano appeared flat hard palate. Regarding the shape of the epiglottis, 1 contralto, 8 mezzo-soprano and 10 soprano had a high-rising epiglottis. 5 basso, 5 6 contralto, 4 mezzo-soprano and 4 soprano had a lower-lying epiglottis (Table 7).

Concerning the length of vocal folds, in female singers, all of contralto appeared long vocal folds. All of the mezzo-soprano appeared meddle length of vocal folds, while all the soprano appeared short vocal folds. Finally, 9 baritones appeared meddle length of vocal folds, while 2 baritones appeared long vocal folds. In terms of the shape of the vocal folds in female singers, 1 contralto, 5 mezzo-soprano and 4 soprano appeared rounded shape of vocal folds. 6 contralto, 7 mezzo-soprano and 12 soprano appeared elongated vocal folds (Table 8).

Concerning the width of the vocal folds of the male singers, all of the contralto appeared wide vocal fold, all of the mezzo-soprano appeared medium size vocal folds and 8 all of the soprano appeared narrow vocal folds. The thickness of the vocal folds was found to be thin in all of the soprano. All of the mezzo-soprano appeared average thickness of the vocal folds and all of the contralto appeared thick vocal folds (Table 9).

Table 5. Statistical analysis results: correlation between male singers and the variables; tone of speech and color of speech.

voice category	tone of speech				color of speech		
	heavy	average	acute	total	Deep	high-toned	total
basso	16	0	0	16	3	4	7
	100%	0%	0%	100%	42.90%	57.10%	100%
batitones	2	9	0	11	4	8	12
	18.20%	81.20%	0%	100%	33.30%	66.70%	100%
tenors	0	0	8	8	6	10	16
	0%	0%	100%	100%	37.50%	62.50%	100%
Pearson Chi-square		60.45				0.173	
p-level		0				0.917	

Table 6. Statistical analysis results: correlation between female singers and the variables; reliability of the nasal cavity, size of stomatopharynx.

voice category	reliability of nasal cavity			size of stomatopharynx			
	good	reduced	total	small	mean	large	total
contralto	2	5	7	0	0	7	7
	28.60%	71.40%	100%	0%	0%	100%	100%
mezzosoprano	4	8	12	0	12	0	12
	33.30%	66.70%	100%	0%	100%	0%	100%
soprano	13	3	16	16	0	0	16
	81%	19%	100%	100%	0%	0%	100%
Pearson Chi-square	8.67			70			
p-level	0.013			0			

Table 7. Statistical analysis results: correlation between female singers and the variables; shape of hard palate, shape of epiglottis.

voice category	shape of hard palate				shape of epiglottis		
	oval	arched	flat	total	high	lower	total
contralto	5	0	2	7	1	6	7
	71%	0%	29%	100%	14%	86%	100%
mezzosoprano	3	7	2	12	8	4	12
	25%	58%	17%	100%	67%	33%	100%
soprano	2	5	9	16	10	6	16
	13%	31%	56%	100%	63%	37%	100%
Pearson Chi-square	13.53				5.68		
p-level	0.009				0.058		

Table 8. Statistical analysis results: correlation between female singers and the variables; length of vocal folds, shape of vocal folds.

voice category	length of vocal folds				shape of vocal folds		
	short	meedle	long	total	rounded	enlogated	total
contralto	0	0	7	7	1	6	7
	0%	0%	100%	100%	14.30%	85.70%	100%
mezzosoprano	0	12	0	12	5	7	12
	0%	100%	0%	100%	41.70%	58.30%	100%
soprano	16	0	0	16	4	12	16
	100%	0%	0%	100%	25.00%	75.00%	100%
Pearson Chi-square	70				1.8		
p-level	0				0.405		

The tone of speech was heavy in all of the contralto. Average tone of speech appeared all of the mezzo-soprano, while all of the soprano appeared acute tone

of speech. Finally, in observing the color of each participant's speech, it was found that 3 contralto, 4 mezzo-soprano and 6 soprano appeared deep voice color. 4 contralto, 8 mezzo-soprano and 10 soprano appeared high-tone voice color (Table 10).

4. Discussion

This study attempted to correlate the vocal category of professional singers with vocal folds characteristics, morphometrically, using video laryngeal stroboscopy, on professional singers. This was achieved through the collection between these characteristics and the voice categories of 70 healthy singers. The male singers included basses, baritones and tenors and the female singers were contraltos, mezzo-sopranos and soprano. We observe a relation between the size of stoma-topharynx and the voice category. In particular, we observe that as the frequency of the voice in males singers increases, the size of the oropharynx decreases. This relation is inversely proportional, in female singers.

Table 9. Statistical analysis results: correlation between female singers and the variables; width of vocal folds, thickness of vocal folds.

voice category	width of vocal folds				thikness of vocaal folds			
	wide	meedle	narrow	total	thin	average	thick	total
contralto	0	7	0	7	0	7	0	7
	0.00%	100%	0.00%	100%	0.00%	100%	0.00%	100%
mezzosoprano	0	0	12	12	0	0	12	12
	0.00%	0.00%	100%	100%	0%	0.00%	100.00%	100%
soprano	16	0	0	16	16	0	0	16
	100%	0%	0%	100%	100%	0%	0%	100%
Pearson Chi-square	54.69				70			
p-level	0				0			

Table 10. Statistical analysis results: correlation between female singers and the variables; tone of speech and color of speech.

voice category	tone of speech				colour of speech		
	heavy	average	acute	total	deep	high-toned	total
contralto	7	0	0	7	3	4	7
	100%	0%	0%	100%	42.90%	57.10%	100%
mezzosoprano	0	12	0	11	4	8	12
	0.00%	100.00%	0%	100%	33.30%	66.70%	100%
soprano	0	0	16	8	6	10	16
	0%	0%	100%	100%	37.50%	62.50%	100%
Pearson Chi-square	70				0.173		
p-level	0				0.917		

We also observe that the basso singers mostly appeared oval-shapes hard palate, while most tenors appeared flat hard palate. So, the low frequency male vocal categories relate with oval-shape hard palate, while the high frequency male voices relate with flat shape of hard palate.

We concluded that as the frequency of the male voice increases, the width of the vocal cords decreases.

In addition, as the frequency of the voice increases, the thickness of the vocal cords also increases, both in male and female singers. Therefore, we concluded that as the frequency of the singing voice increases, the tone of voice change in a proportional way.

There is an obvious correlation between the length of the vocal cords and the frequency of the voice in male and female singers. In particular, the frequency of the voice increases as the length of the vocal cords increases. Our results provide support to other studies reporting that statistically significant correlations occur between voice category and the length of the vocal folds.

Moreover, in this study, a statistically significant difference was observed between male singers and the body height. Specifically, basso singers appeared the highest average body height, followed by the tenors and finally the baritones, reinforcing the results of other researchers. Furthermore, we correlated the average body mass with voice category. Statistically significant differences were observed between the weight [F = 28.76, p = 0.000] and the difference was between bass and baritone [p = 0.001], bass and tenor [p = 0.000] and between baritone and tenor [p = 0.009]. Our result comes to an agreement with other studies reporting similar conclusions [17] [50] [51].

Sample size may was a limitation in this study. Due to the pandemic COVID-19 restriction laws, it was not available to recruit more participants. Video laryngeal stroboscopy, considered being a subjective evaluation method, for the assessment of larynx. Using a more objective evaluation method, that requires specific measurements of the dimensions of the vocal folds, would probably be more appropriate to deliver clear and concrete results. Nevertheless, the quality characteristics of voice and larynx, such as the tone of speech, the color of speech as well as the shape of epiglottis, remain features that need the subjective evaluation of the examiner. Taking into account these effect method limitations, the results of this study are good but more objective methods would increase their validity.

Conflicts of Interest

All authors declare no conflicts of interest in this manuscript.

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