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CORRELATIONS BETWEEN SPORTSMEN'S MORPHO-FUNCTIONAL MEASUREMENTS AND VOICE ACOUSTIC VARIABLES

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ABSTRACT
Purpose. Since human voice characteristics are specific to each individual, numerous anthropological studies have been oriented to find significant relationships between voice and morpho-functional features. The goal of this study was to identify the correlation between seven morpho-functional variables and six voice acoustic parameters in sportsmen. **Methods.** Following the protocols of the International Biological Program, seven morpho-functional variables and six voice acoustic parameters have been measured in 88 male professional athletes from Kosovo, aged 17–35 years, during the period of April–October 2013. The statistical analysis was accomplished through the SPSS program, version 20. The obtained data were analysed through descriptive parameters and with Spearman's method of correlation analysis. **Results.** Spearman's method of correlation showed significant negative correlations ($R = -0.215$ to -0.613; $p = 0.05$) between three voice acoustic variables of the fundamental frequency of the voice sample (Mean, Minimum, and Maximum Pitch) and six morpho-functional measures (Body Height, Body Weight, Margaria-Kalamen Power Test, Sargent Jump Test, Pull-up Test, and VO_{2max}.abs). **Conclusions.** The significant correlations imply that the people with higher stature have longer vocal cords and a lower voice. These results encourage investigations on predicting sportsmen's functional abilities on the basis of their voice acoustic parameters.

Key words: voice parameters, morpho-functional measures, professional soccer playe

Introduction

Vocal chords are part of the glottis, located horizontally across the middle part of the larynx. While their external edges are fixed to the larynx muscle, their inner edges are free, forming the *rima glottidis*. Any spoken short phrase requires movement collaboration of about 100 muscles. The complex human speech is controlled by two brain nuclei which are located in the left hemisphere of the cortex (Wernicke zone). The connection of this zone with the visual and auditory systems enables us to read, to hear and to understand what others say, as well as to answer [1]. The fact that human voice characteristics are specific to each individual has prompted numerous anthropological studies to find significant relationships between voice and morphometric characteristics.

According to Lieberman [2] and Ybarra [3], the voice frequency in humans depends on the dimensions of the vocal folds, such as thickness and size. Different groups of humans, e.g. males or females, adults or children, show, besides morpho-functional differences, significantly different vocal chords sizes and different acoustic variables of voice [4–7]. Several studies have reported strong significant correlation ($r = 0.926$, according to Fitch and Giedd) between the vocal tract length and the body size [7]. In contrast to these findings, the study by Hatano et al. shows that there is no relationship between the vocal tract length and the body size ($r = 0.08$) [8]. González has found a weak relationship between the formant frequencies and the body size in adult humans [9]. Additionally, Hatano et al. have observed a negative correlation ($r = -0.61$) between pitch frequency and body height, finding no significant correlation between vocal tract length and formant frequencies [8].

Avery and Liss, even though they have not found any significant correlation between formant frequencies and body characteristics, state that male speakers with less masculine characteristics have higher voice frequencies as compared with male speakers with more masculine characteristics [10]. Although it is believed that people with large morphometric dimensions should produce low frequency, deep voice, a study of Van Dommelen and Moxness overturns this concept. The two researchers have tried to predict the body size of male and female speakers on the basis of their voice. They have found significant correlations between estimated and actual height and weight of male speakers. Additionally, they have indicated that the speech rate of male speakers might be a reliable predictor for weight estimation [11].

A study by Poorjam et al. indicates the possibility to estimate human body height with speech signals using an i-vectors framework [12]. Evans et al. have found a significant negative relationship between fundamental frequency and measures of body shape and weight [13]. According to Jenkins, testosterone levels determine the length and thickness of the vocal chords, which are responsible for lowering the fundamental frequency, and thus for the deep voice in an adult male [14]. Taking into

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account the specificity of the individual vocal characteristics, Bahari and Van Hamme suggest the possibility to estimate age using speech signals based on i-vectors [15].

However, many studies in this field have identified strong correlations between body size and voice acoustic parameters. Research regarding the relation between voice acoustic parameters and morphometric parameters indicates that the human being functions as an undivided unit. Therefore, any scientific approach toward the human being should be carried out in a multidisciplinary anthropological way. Significant relations between different anthropometric parameters may encourage research related to predicting one dependent anthropometric variable on the basis of the values of different independent anthropometric variables.

Up till now, we have not found any study of voice acoustic parameters in the field of sports science; therefore, the goal of this study is to identify the correlation between seven morpho-functional variables and six voice acoustic parameters in sportsmen.

Since testing athletes' functional capabilities requires expensive equipment and is time-consuming, a possibility to predict these capabilities would be a scientific imperative.

Material and methods

The present study, as a part of 'The relation between anthropometrical and voice acoustic variables' project, was carried out at the Centre for Sport, Fitness and Nutrition 'Corpore Sano' in Prishtina, Kosovo, and received an approval from the Ethics Committee of the University Clinical Centre in Prishtina.

Following the protocols of the International Biological Program, the morpho-functional variables have been measured in 88 male athletes from Kosovo (soccer players, basketball players, and boxers), aged 17–35 years, during the period of April–October 2013. The morphometric measurements were taken by classic anthropometric measuring tools, such as an anthropometer, short anthropometer, digital weighing scale, milimetric tape, and skinfold caliper. Because stature and body weight show diurnal variation, the sports entities were measured in the morning (08.00–11.00 a.m.).

The following morpho-functional variables were measured:

– *Body Height* (m) – measured with a classical anthropometer.

– *Body Weight* (kg) – measured with a digital weighing scale.

– *Body Fat Mass* (kg) – estimated for each measured entity with a 4-Site Skinfold Equation by Jackson and Pollock.

– *Margaria-Kalamen Power Test* (kg/m/s) – a classic test of power of the lower extremities. The sportsman runs as fast as possible through nine steps. They start running 6 m from the bottom of the steps and then runs up them, three at a time (stepping on the 3^{rd}, 6^{th}, and 9^{th} steps). The interval between the athlete placing their foot on the 3^{rd} and 9^{th} step is recorded. The power (P) is calculated with the following formula: $P = g \times m \times h / t$ (where g – gravitational acceleration [9.81 m/s^2]; m – the athlete's mass; h – vertical height between the 3^{rd} and 9^{th} steps; t – time between stepping on the 3^{rd} and 9^{th} steps; the obtained power will be expressed in kgm/s).

– *Sargent Jump Test* (cm) – performed with a specialized apparatus called Vertec.

– *Pull-up Test* (reps./min) – widely used as a measure of upper body strength. The sportsman grasps an overhead bar using an underhand grip (palms facing toward body), with the arms fully extended. Then they raise their body until the chin clears the top of the bar, and lower again to the position with the arms fully extended. The pull-ups should be performed in a smooth motion.

– *VO_{2max}.abs.* (L/min) – *absolute* value of *maximal oxygen uptake measured according to the Astrand-Rhyming Cycle Ergometer Test*.

The measured voice acoustic variables were as follows:

– *Mean Pitch* (Hz) – average fundamental frequency of the voice sample.

– *St. Deviat.* (Hz) – standard deviation of the fundamental frequency.

– *Min. Pitch* (Hz) – the lowest fundamental frequency of the voice sample.

– *Max. Pitch* (Hz) – the highest fundamental frequency of the voice sample.

– *Jitter* (%) – jitter percentage gives an evaluation of the variability of the pitch period within the analysed voice sample. It represents the relative period-to-period variability of pitch in microseconds.

– *Shimmer* (dB) – gives an evaluation of the period-to-period variability of the peak-to-peak amplitude within the analysed voice sample.

– *Mean Harmonic/Noise* (dB) – noise to harmonic ratio is an average ratio of energy of the inharmonic components energy in the range of 1500–4500 Hz to the harmonic components energy in the range of 70–4500 Hz. It is a general evaluation of the noise presence in the analysed signal (such as amplitude and frequency variations, turbulence noise, sub-harmonic components, and/or voice breaks).

Voice acquisition environment

For the initial voice acquisition, a personal computer (PC) and Supercardioid Dynamic Vocal Microphone (AKG D5) were applied. The distance between the microphone and the subject's mouth equalled about 5 cm, and the main axis of the microphone cylinder was fixed in order to be parallel to the ground and perpendicular to the mouth. We used PRAAT4324_winsit – Cool Edit

96 as audio recording software and saved the voice files as a WAV files. To ensure high-quality recordings, the sampling frequency of 44.1 kHz was employed. Each subject, after a resting period of about 1 hour, was asked to talk naturally with operators without tension and taking care to maintain their usual volume and speed of voice. The test began with self-presentation of each tested entity, then continued with recording the pronounced vowels such as *a*, *e*, *i*, *o*, and *u* for 3 s, with 1s silence between them. After a further break of 1 s, the subject repeated the given words, such as *rrota* and *shota*, twice, with a 1s silence between them. At the end of the last word, the recording was stopped.

The statistical analysis was accomplished through the SPSS program, version 20. The obtained data were analysed through descriptive parameters (arithmetic means and standard deviation) and with Spearman's method of correlation analysis.

The Kolmogorov-Smirnov test was used to determine whether sample data (voice parameters) were normally distributed.

Results and discussion

Table 1 contains the descriptive data for each measured variable.

The mean values of the measured body size data in the study were compatible with standard data for the population of Kosovo. In turn, the low values of standard deviation indicate that the collected data tend to be close to the mean values [16].

Since the results of the Kolmogorov-Smirnov test (Table 2) indicated that almost all voice parameters (except Shimmer) were not normally distributed, Spearman's method of correlation analysis was applied to investigate the relationship between the voice parameters and the morpho-functional variables.

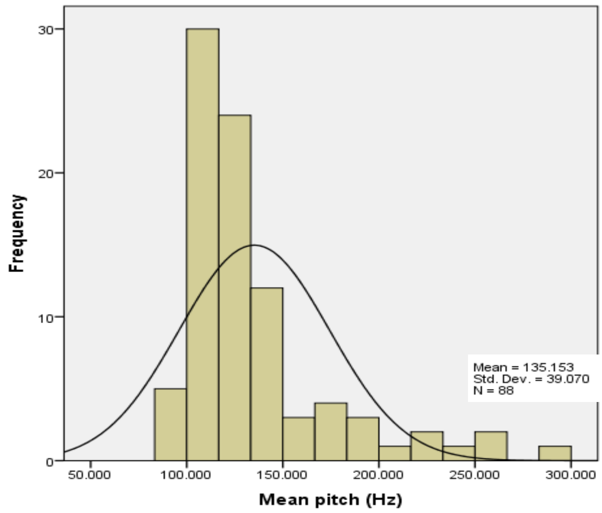

Figure 1. Graphical presentation of non-normal distribution of the Mean Pitch results

An example of a non-normal distribution of the Mean Pitch results is presented in Figure 1. Mean Pitch means the rate of vocal folds vibration. The Gaussian distribution of the results for this voice acoustic parameter shows that most testing entities have a low rate of vocal folds vibration per second, which denotes lower voice.

Table 3 shows the clustering of the voice acoustic parameters in two groups. Whereas the first group contains variables of voice frequencies (Mean Pitch, St. Deviat, Min. Pitch, and Max. Pitch), the other group consists of variables of voice perturbation (Jitter, Shimmer, and Mean Harmonic/Noise). The clustering of the measured voice acoustic variables indicates a similarity and close relationship between the clustered variables.

Table 4 shows the correlations between morphometric and functional variables. Since among the seven measured morpho-functional variables three are morphometric and the other four are functional, a clustering

Table 1. Descriptive parameters

	Minimum	Maximum	Mean	Standard deviation
Body Height	142.00	209.70	177.00	12.29
Body Weight	36.00	136.00	70.75	18.07
Body Fat Mass	0.60	37.70	6.86	7.09
Margaria-Kalamen Power Test	100.40	321.20	205.91	53.16
Sargent Jump Test	10.00	56.00	41.71	8.94
Pull-up Test	0.00	14.00	4.55	3.93
VO_{2max}.abs	2.70	4.60	3.75	0.42
Mean Pitch	96.46	288.19	135.15	39.07
St. Deviat.	0.08	2.59	0.60	0.41
Min. Pitch	95.53	286.03	134.07	38.79
Max. Pitch	97.42	289.67	136.21	39.31
Jitter	0.14	1.08	0.37	0.17
Shimmer	0.08	1.90	0.35	0.27
Mean Harmonic/Noise	4.75	26.65	16.72	4.15

Table 2. Kolmogorov-Smirnov test

	Mean Pitch	St. Deviat.	Min. Pitch	Max. Pitch	Jitter	Shimmer	Mean Harmonic/ Noise
Mean	135.15	0.6	134.07	136.21	0.37	0.35	16.72
Standard deviation	39.07	0.41	38.79	39.31	0.17	0.27	4.15
Absolute	0.24	0.19	0.24	0.24	0.12	0.18	0.09
Positive	0.24	0.19	0.24	0.24	0.12	0.18	0.03
Negative	–0.16	–0.11	–0.16	–0.16	–0.09	–0.16	–0.09
Kolmogorov-Smirnov *Z*	2.275*	2.28*	1.74*	2.29*	2.28*	1.14	1.66*
p	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.15	< 0.01

* Significant differences in relation to normally distributed ($p < 0.01$)

Table 3. Spearman's correlations between voice acoustic parameters

	Mean Pitch	St. Deviat.	Min. Pitch	Max. Pitch	Jitter	Shimmer	Mean Harmonic/ Noise
Mean Pitch	1.000						
St. Deviat.	0.324*	1.000					
Min. Pitch	0.999*	0.307*	1.000				
Max. Pitch	0.999*	0.348*	0.998*	1.000			
Jitter	–0.152	0.384*	–0.160	–0.137	1.000		
Shimmer	–0.066	–0.007	–0.061	–0.069	0.382*	1.000	
Mean Harmonic/Noise	0.275*	0.003	0.274*	0.274*	–0.559*	–0.751*	1.000

* Correlation significant at the 0.01 level (2-tailed)

Table 4. Spearman's correlations between morpho-functional variables

	Body Height	Body Weight	Body Fat Mass	Margaria-Kalamen Power Test	Sargent Jump Test	Pull-up Test	VO_{2max}.abs
Body Height	1.000						
Body Weight	0.687**	1.000					
Body Fat Mass	0.363**	0.805**	1.000				
Margaria-Kalamen Power Test	0.637**	0.853**	0.746**	1.000			
Sargent Jump Test	0.562**	0.408**	0.082	0.468**	1.000		
Pull-up Test	0.174	–0.001	–0.185	0.096	0.630**	1.000	
VO_{2max}.abs	0.461**	0.168	–0.132	0.348*	0.699**	0.551**	1.000

* Correlation significant at the 0.05 level (2-tailed)
** Correlation significant at the 0.01 level (2-tailed)

of these variables was expected. In accordance with the expectation, Table 4 presents clustering of these variables in two subgroups:

– the first subgroup contains three morphometric variables (Body Height, Body Weight, and Body Fat Mass) and one functional variable (Margaria-Kalamen Power Test);

– the second subgroup consists of three functional variables (Sargent Jump Test, Pull-up Test, and VO_{2max}.abs).

Similarly to the clustering of the voice acoustic variables (Table 4), the clustering of the morpho-functional variables may suggest the necessity to explore their latent structure.

Despite this clustering, the morpho-functional variables are also characterized by slight but significant mutual correlations.

The close mutual relationship between morpho-functional variables is compatible with the nature of the studied subjects. Since they were sportsmen, the improvement of their functional capabilities was directly dependent on developing their morphometric characteristics.

Table 5 shows Spearman's correlations among the morpho-functional and voice acoustic variables. These results are in agreement with previous studies [7, 8, 10, 11, 13]. Three measured voice acoustic variables of the fundamental frequency of the voice sample (Mean Pitch, Min. Pitch, and Max. Pitch) show significant correlations with almost all morpho-functional variables (except for Body Fat Mass). The other three voice acoustic variables (Jitter, Shimmer, and Mean Harmonic/Noise) have not turned out significantly correlated with the measured morpho-functional variables.

Table 5. Spearman's correlations among morpho-functional and voice acoustic variables

	Body Height	Body Weight	Body Fat Mass	Margaria-Kalamen Power Test	Sargent Jump Test	Pull-up Test	VO_{2max}.abs
Mean Pitch	–0.612**	–0.485**	–0.144	–0.554**	–0.597**	–0.386**	–0.453**
Min. Pitch	–0.333**	–0.320**	–0.121	–0.371*	–0.268	–0.048	–0.264*
Max. Pitch	–0.613**	–0.487**	–0.146	–0.552**	–0.597**	–0.385**	–0.452**
Jitter	–0.086	–0.009	0.161	0.077	–0.158	–0.060	–0.215*
Shimmer	–0.056	–0.076	–0.030	0.149	–0.002	–0.067	0.016
Mean Harmonic/Noise	0.101	0.051	–0.049	–0.203	0.089	–0.033	0.128

* Correlation significant at the 0.05 level (2-tailed)
** Correlation significant at the 0.01 level (2-tailed)

Significant negative correlations between three voice acoustic variables of the voice sample fundamental frequency (Mean Pitch, Min. Pitch, and Max. Pitch) and morpho-functional measures (Body Height, Body Weight, Margaria-Kalamen Power Test, Sargent Jump Test, Pull-up Test, and VO_{2max}.abs) mean that people with higher stature have longer vocal cords (vocal tract length) and lower voice [2, 3, 7].

Conclusions

The present study indicates significant correlations between measured voice acoustic and morpho-functional parameters.

In the cybernetic aspect, the human organism operates as a multidimensional system comprising many subsystems, strongly interrelated with each other. Good or weak function of one subsystem interferes with the functioning of other subsystems. This strong correlation between the subsystems of an organism has encouraged scientists to predict, on the basis of some morpho-functional parameters, the respective morpho-functional variables, such as body height, VO_{2max} (maximal oxygen uptake), explosive power, age, puberty stages, etc.

Significant correlations between three voice acoustic parameters (Mean Pitch, Min. Pitch, and Max. Pitch) and morpho-functional variables (Body Height, Body Weight, Margaria-Kalamen Power Test, Sargent Jump Test, Pull-up Test, and VO_{2max}.abs) hypothetically allow to explore the possibilities to predict the criterion (dependent) variables. In the case of this research, the criterion (dependent) variable may be one of the variables that present explosive power, such as Margaria-Kalamen Power Test or Sargent Jump Test.

The results of the present study may determine the goals of upcoming research:

– Investigation is encouraged of the possibility to predict sportsmen's functional abilities on the basis of their voice acoustic parameters.

– The clustering of the measured variables will motivate the study of their latent structure.

– In order to gain more information on the relationship between voice acoustic features and morpho-functional features it is required to expand the list of measured variables and include the following:

– Voice Turbulence Index (VTI), or the relative energy level of high frequency noise.

– Soft Phonation Index (SPI), or the ratio of the harmonic energy in the range of 70–1600 Hz to the harmonic energy in the range of 1600–4500 Hz.

• *Tremor parameters*:

– Fo-Tremor Frequency (Fftr) (Hz), or the frequency of the most intensive Fo-modulating component of tremor;

– Amplitude Tremor Frequency (Fatr) (Hz), or the frequency of the most intensive amplitude-modulating component of tremor;

– Frequency Tremor Intensity Index (FTRI) (%), or the ratio of the Fo-tremor to the total frequency magnitude of the voice sample;

– Amplitude Tremor Intensity Index (ATRI) (%), or the ratio of the amplitude tremor to the total amplitude of the voice sample.

• *Parameters of subharmonic components*:

– Number of Subharmonic Segments (NSH);

– Degree of Subharmonics (DSH) (%), or relative evaluation of subharmonic to Fo components in the voice sample.

• *Parameters of voice irregularities*:

– Number of Unvoiced Segments (NUV);

– Degree of Voiceless (DUV) (%), or relative evaluation of non-harmonic areas in the voice sample [17].

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