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The usefulness of the acoustic and the capacity analysis of singing voice

Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

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ABSTRACT:

Introduction: The aim of the dissertation was to evaluate the parameters of acoustic and function analysis of the voice in patients with functional and organic dysphonia by using the DiagnoScope "Specjalista" computer program.

Material and methods: The study was performed in 131 people aged 21-82 years (the mean age was 48,34 years), including 75 women, at the age of 21–75 years and 56 men at the age of 22–82 years, all treated in the Clinic of Otolaryngology, Laryngological Oncology, Audiology and Phoniatrics of the Military Medical Academy Memorial University Hospital – Central Veterans' Hospital. The study participants were divided into 3 groups: I – 45 patients aged 22-82 years with functional dysphonia (hyperfunctional type dysphonia), II – 45 patients aged 28–80 years with chronic hypertrophic laryngitis (polyp of the vocal fold, hypertrophy of the vocal fold, Reinke-type edema-hypertrophic changes in the vocal folds), III – 41 individuals, including students of the Faculty of Military Medicine of the Medical University of Łódź, at the age of 21–70 years, without disease symptoms within the vocal organ. The following examinations were performed: a laryngological subject and object examination, a videolaryngoscopic and stroboscopic examination of the larynx (including the GRBAS scale), and a videolaryngostroboscopic-phoniatric examination, encompassing the following parameters: regularity of vibrations of the vocal folds, amplitude of vibrations, marginal shift, glottis closure, voice range, the way of creating the voice, voice reposition, time of phonation) and an acoustic and voice performance diagnostic analysis by the means of the DiagnoScope "Specjalista" program.

Results: The results obtained suggest that the differentiation of pathological voices from normal voices is statistically significant for parameters such as: Jitter, RAP, PPQ, AFO, SimpleQ, Shimmer, APQ, Q, APQ, HPQh, RHPQ, RHPQh, R2H, U2H, U2Hl, U2Hh, NHR, Yg. In the function analysis, statistically significant differences were found in all parameters.

Conclusions: The videolaryngostroboscopic examination, voice rating scales, and the objective analysis of the voice provide an appropriate set of tests that determine the nature of voice disorders. The acoustic and function analysis of the voice enables an early diagnosis of dysphonia, both functional and organic. The acoustic and function analysis is an objective method of assessment of the voice disorders which renders it possible to use it in judicature.

KEYWORDS: the acoustic and capacity analysis, functional and organic dysphonia

INTRODUCTION

At the beginning of the 20th century, the percentage of occupations requiring professional use of voice was as low as 10% compared to 90% of manual professions. Today, 90% of occupations require information being exchanged using voice and articulated speech. Mastering of appropriate voice emission techniques is therefore important not only for individuals for whom their voice is the natural tool of their trade, for example teachers, actors, or singers, but also for individuals of other professions [1–4].

Pruszewicz [5] presented a list of occupations associated with special burden on the voice organ classified according to the guidelines published by the Union of European Phoniatricians, and including:

- I – occupations requiring high-quality voice (singers, actors, radio and television speakers);
- II – occupations with significant requirements regarding the organ of voice (teachers and other educators, professional speakers, interpreters, call operators, politicians);
- III – occupations requiring more than average voice capacity and occupations performed in noisy environments (lawyers, justices, soldiers, individuals required to verbally communicate in noisy environment) [6].

Occupational voice disorders are an important problem particularly for professionals at risk of vocal exertion. They pose a significant challenge for numerous specialists, e.g. laryngologists, phoniatricians, occupational medicine specialists, etc., who provide care to the individuals at risk of extensive burden to their voice organ. The increasing number of individuals requiring voice as a tool of their trade necessitates optimization of voice disorder prevention efforts, particularly since the burden to the voice may be very high in certain professions [7–10]. The aim of this study was to evaluate the usefulness of the acoustic and the capacity analysis of singing voice using the DiagnoScope Specialist software.

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Tab. I. Descriptive statistics for fundamental frequency Fo (Hz) measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	316.46	311.54	276.26–345.64 (69.38)	46.78	9.97	295.72–337.21	228.32–394.99
	Male	165.09	151.28	114.56–233.71 (119.15)	59.21	13.96	135.64–194.53	87.46–252.35
	Total	248.34	269.05	159.67–321.38 (161.71)	92.32	14.60	218.82–277.87	87.46–394.99
Semi-professionals	Female	260.50	248.11	238.30–302.32 (64.02)	32.16	6.43	247.22–273.77	222.87–317.32
	Male	149.26	146.12	102.35–194.02 (91.67)	49.67	12.82	121.76–176.77	86.46–228.38
	Total	218.78	230.68	187.51–256.54 (69.03)	67.05	10.60	197.34–240.23	86.46–317.32
Reference group	Female	261.23	270.14	252.88–288.30 (35.42)	43.38	8.35	244.07–278.39	124.53–317.51
	Male	159.27	138.30	122.71–155.38 (32.67)	58.47	16.22	123.94–194.60	102.58–275.63
	Total	228.09	259.53	150.87–277.57 (126.70)	68.16	10.78	206.30–249.89	102.58–317.51
Total	Female	277.40	273.63	248.11–304.74 (56.63)	47.90	5.57	217.81–245.65	124.53–394.99
	Male	158.28	147.91	114.56–194.02 (79.46)	55.22	8.14	266.31–288.50	86.46–275.63
	Total	231.74	247.89	161.22–285.64 (124.42)	77.09	7.04	141.88–174.68	86.46–273.63

MATERIAL AND METHODS

The study was conducted in 120 adult subjects, including 74 women and 46 men aged 21–51 (average age of 26.3 years) diagnosed at the Clinic of Otolaryngology, Laryngological Oncology, Audiology, and Phoniatrics, Military Medical Academy Memorial Teaching Hospital in Lodz, divided into 3 groups:

- group I (treatment group) – professional singers (40 subjects, including 22 women and 18 men, aged 22–51, mean age of 29.1);
- group II (treatment group) – semi-professional singers (40 subjects, including 22 women and 15 men, aged 22–40, mean age of 25.5);
- group III (control group) – non-singers (40 subjects, including 27 women and 13 men, aged 21-28 mean age of 24.3, students of the Military Medical Faculty at Medical University of Lodz).

The research methodology included primary medical history, physical (otolaryngological) examination, videolaryngoscopic examination, GRBAS scale for subjective voice evaluation, diagnostic acoustic and capacity voice analysis using the DiagnoScope Specialist software (Diagnova Technologies, Poland) and a survey on basic lifestyle parameters and concomitant diseases which may affect voice quality (smoking, frequency of alcohol consumption, gastroesophageal reflux, mean duration of sleep, singing/non-singing status, years of singing experience and number of hours per week devoted to voice emission training). The results were then subjected to statistical analysis using the following significance tests: $\chi 2$ test of independence for 2x2 contingency tables, Shapiro-Wilk's W test for normality of distribution, and Levene's test for homogeneity of variances.

The results of the tests were considered statistically significant when the significance level was lower than 5 percentage points ($p < 0.05$). The research was approved by the Bioethics Committee at the Medical University of Lodz, decision no. RNN/117/16/KE dated 19 April 2016.

RESULTS

On the basis of survey questionnaires, history of nicotinism was confirmed by 12.5% of professionals, 25.0% of semi-professionals, and 10.0% of reference group subjects. Overall, smoking was declared by 15.83% of all study subjects. The differences between the groups were not statistically significant (P = 0.217).

The average alcohol consumption patterns were as follows: in the group of professionals, 50% of responders declared alcohol being consumed 1–2 times a month, 47.5% of responders declared alcohol being consumed 1–2 times a week, and 2.5% of responders declared alcohol being consumed more than 2 times a week; the respective values were 57.5%, 35.0%, and 7.5% in the semi-professional group and 77.5%, 20.0%, and 2.5% in the reference group. Overall, alcohol was consumed 1–2 times a month, by 61.6% of all subjects, 1-2 times a week by 34.17% of subjects, and more than 2 times a week by 4.17% of subjects. The differences between the groups were not statistically significant (P = 0.054).

Nocturnal sleep patterns were as follows: in the group of professionals, 25.0% of responders slept less than 6 hour a day, 75.0% of responders slept 7–8 hours a day, and 5% of responders slept more than 8 hours day; the respective values were 15.0%, 70.0% and 5.0% in the semi-professional group and 32.5%, 67,5%, and 0% in the reference group. The differences between the groups were not statistically significant (P = 0.465).

On the basis of survey questionnaires, history of gastroesophageal reflux disease was confirmed by 15.0% of professionals, 22.5% of semi-professionals, and 10.0% of reference group subjects. Overall, gastroesophageal reflux was reported by 12.5% of subjects. The differences between the groups were not statistically significant (P = 0.390).

The mean singing experience (i.e. regular voice emission training, choir rehearsals) in the group of professionals was 11.42 years and was nearly twice as high as that in the group of semi-professionals (7.57). Overall, the mean singing experience was 9.5 years. Differ-

Tab. II. Descriptive statistics for F1, F2, F3, and F4 formant measurements in study subjects in individual study groups.

GROUP	FORMANT	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	F1	838.91	845.67	721.86–949.51 (227.65)	131.44	20.78	796.87–88.94	265.17–1068.15
	F2	1379.32	1407.20	1209.03–1492.93 (283.90)	182.74	28.89	1320.88–1437.77	1065.41–1891.60
	F3	2828.82	2879.50	2670.30–3002.73 (332.43)	228.77	36.17	2755.65–2901.98	2232.42–3191.28
	F4	3772.80	3763.29	3681.64–3895.66 (214.02)	232.68	36.79	3698.39–3847.22	3118.98–4213.94
Semi-professionals	F1	780.79	770.34	698.45–873.26 (174.81)	111.81	17.68	745.03–816.55	429.60–943.32
	F2	1339.20	1374.34	1173.11–1472.73 (299.62)	162.64	25.72	1287.19–1391.22	1050.57–1620.95
	F3	2809.27	2803.68	2673.22–2942.48 (269.26)	200.35	31.68	2745.19–2873.35	2259.64–3185.68
	F4	3759.59	3759.39	3650.11–3990.39 (340.28)	292.89	46.31	3665.92–3853.26	3118.98–4263.70
Reference group	F1	826.67	797.72	732.81–914.95 (182.14)	113.76	17.99	790.29–863.05	609.53–1032.37
	F2	1332.87	1373.31	1182.25–1483.04 (300.79)	169.47	26.79	1278.67–1387.07	986.73–1577.87
	F3	2809.78	2795.18	2648.61–3004.92 (356.31)	238.14	37.65	2733.62–2885.94	2136.60–3211.52
	F4	3790.12	3810.40	3648.59–3892.40 (243.81)	230.66	36.47	3716.35–3863.89	3247.36–4333.30
Total	F1	815.46	827.47	720.77–905.36 (184.59)	120.96	11.04	793.59–837.32	429.60–1068.15
	F2	1350.47	1388.42	1197.77–905.36 (184.59)	171.62	15.67	1319.44–1381.49	986.73–1891.60
	F3	2815.96	2812.64	2663.19–2976.21 (313.02)	221.31	20.20	2775.95–2855.96	2136.60–3211.52
	F4	3774.17	3766.17	3653.69–3914.08 (260.39)	251.90	22.99	3728.64–3819.70	3118.98–4333.30

Tab. III. Descriptive statistics for voiced (%) phonation probability in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	161.65	167.67	108.26–198.17 (89.91)	66.93	14.27	131.98–191.32	65.04–288.96
	Male	105.79	99.22	71.01–130.78 (59.77)	47.61	11.22	82.11–129.46	38.97–207.10
	Total	136.51	119.94	93.32–184.99 (91.67)	64.75	10.24	115.80–157.22	38.97–288.96
Semi-professionals	Female	118.85	103.96	70.29–158.03 (87.74)	57.94	11.59	94.94–142.77	33.06–232.42
	Male	112.13	118.40	60.15–148.60 (88.45)	46.69	12.06	86.27–137.99	37.62–185.59
	Total	116.33	107.44	67.79–153.31 (85.52)	53.47	8.46	99.23–133.43	33.06–232.42
Reference group	Female	85.39	83.98	56.52–104.52 (48.00)	36.53	7.03	70.94–99.84	10.12–197.80
	Male	78.03	77.17	48.74–85.96 (37.22)	36.11	10.02	56.21–99.85	38.68–148.60
	Total	83.00	78.27	52.19–98.09 (45.90)	36.10	5.71	71.45–94.54	38.68–197.80
Total	Female	119.37	104.24	70.29–167.05 (96.76)	61.92	7.20	105.02–133.71	33.06–288.96
	Male	100.01	95.69	60.15–134.57 (74.42)	45.65	6.73	86.45–113.57	37.62–207.10
	Total	111.94	99.92	67.39–143.25 (75.86)	56.83	5.19	101.68–122.22	33.06–288.96

ences in the average singing experience differed significantly between the study groups (P = 0.026).

Mean phonation times were 15.44, 13.14, and 15.15 seconds in the groups of professional singers, semi-professional singers, and non-singers, respectively. Overall, the mean phonation time was 14.58 seconds. With regard to the mean phonation time, differences between the groups were not statistically significant (P = 0.813).

Genderwise, mean time of phonation was 15.34 seconds in females and 15.58 seconds in males within the group of professional singers, 13.78 seconds and 12.08 seconds, respectively, in the group of semi-professional singers, and 15.61 seconds and 14.19 seconds, respectively, in the reference group. Genderwise and groupwise, no statistically significant differences were observed in phonation times among professional singers (P = 0.918), semi-professionals (P = 0.128), and the reference group (P = 0.553).

Mean true phonation times were 15.30, 13.10, and 15.03 seconds in the groups of professional singers, semi-professional singers, and non-singers, respectively. Overall, the mean true phonation time was 14.48 seconds. With regard to the true phonation time, differences between the groups were not statistically significant (P = 0.819).

The average no phonation coefficient amounted to 0.011, 0.003, and 0.007 in the groups of professional singers, semi-professional singers, and non-singers respectively. Overall, the average no phonation coefficient was 0.07. Genderwise and groupwise, no statistically significant differences were observed in no phonation coefficients among professional singers (P = 0.834) and the reference

Tab. IV. Descriptive statistics for jitter (%) measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	0.30	0.27	0.22–0.33 (0.11)	0.11	0.02	0.25–0.35	0.15–0.59
	Male	0.54	0.39	0.26–0.81 (0.55)	0.37	0.09	0.36–0.73	0.19–1.37
	Total	0.41	0.32	0.24–0.42 (0.18)	0.29	0.04	0.32–0.50	0.15–1.37
Semi-professionals	Female	0.31	0.26	0.23–0.36 (0.13)	0.11	0.02	0.26–0.36	0.18–0.62
	Male	0.57	0.44	0.34–0.91 (0.57)	0.32	0.08	0.40–0.75	0.25–1.32
	Total	0.41	0.33	0.25–0.46 (0.21)	0.25	0.04	0.33–0.49	0.18–1.32
Reference group	Female	0.31	0.29	0.23–0.38 (0.15)	0.10	0.02	0.27–0.36	0.18–0.62
	Male	0.56	0.51	0.39–0.58 (0.19)	0.26	0.07	0.41–0.72	0.31–1.26
	Total	0.40	0.34	0.27–0.48 (0.21)	0.20	0.03	0.33–0.46	0.18–1.26
Total	Female	0.31	0.28	0.23–0.36 (0.13)	0.11	0.01	0.28–0.33	0.15–0.62
	Male	0.56	0.44	0.35–0.68 (0.33)	0.32	0.05	0.46–0.65	0.19–1.37
	Total	0.40	0.33	0.25–0.47 (0.22)	0.25	0.02	0.36–0.45	0.15–1.37

Tab. V. Descriptive statistics for PPQ (%) value measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	0.18	0.17	0.14–0.21 (0.07)	0.06	0.01	0.15–0.21	0.09–0.34
	Male	0.30	0.22	0.16–0.43 (0.27)	0.18	0.04	0.21–0.39	0.13–0.67
	Total	0.23	0.19	0.15–0.28 (0.13)	0.14	0.02	0.19–0.28	0.09–0.67
Semi-professionals	Female	0.18	0.16	0.14–0.24 (0.10)	0.06	0.01	0.16–0.21	0.11–0.31
	Male	0.31	0.26	0.18–0.43 (0.25)	0.15	0.04	0.23–0.40	0.15–0.66
	Total	0.23	0.18	0.15–0.28 (0.13)	0.12	0.02	0.19–0.27	0.11–0.66
Reference group	Female	0.19	0.17	0.14–0.23 (0.09)	0.06	0.01	0.16–0.21	0.10–0.33
	Male	0.34	0.31	0.24–0.40 (0.16)	0.14	0.04	0.25–0.43	0.18–0.68
	Total	0.24	0.21	0.16–0.28 (0.12)	0.12	0.02	0.20–0.28	0.10–0.68
Total	Female	0.18	0.17	0.14–0.22 (0.08)	0.06	0.01	0.17–0.20	0.09–0.34
	Male	0.32	0.27	0.19–0.43 (0.24)	0.16	0.02	0.27–0.36	0.13–0.68
	Total	0.23	0.19	0.15–0.28 (0.13)	0.13	0.01	0.21–0.26	0.09–0.68

group (P = 0.301) whereas statistical difference was observed in the group of semi-professionals (P = 0.019).

The average phonation break coefficient amounted to 0.00009, 0.00002, and 0.00013 in the groups of professional singers, semi-professional singers, and non-singers respectively. Overall, the average phonation break coefficient was 0.07. No statistically significant differences were observed in the no phonation coefficients between the study groups (P = 0.598).

The average vocal capacity coefficient amounted to 14.95, 13.65, and 13.78 in the groups of professional singers, semi-professional singers, and non-singers respectively. Overall, the average vocal capacity coefficient was 14.13. No statistically significant differences were observed in the vocal capacity coefficients between the study groups (P = 0.199).

The average medium quality phonation coefficient amounted to 1.049, 1.049, and 0.948 in the groups of professional singers, semi-professional singers, and non-singers respectively. Overall, the average medium quality phonation coefficient was 1.015. No statistically significant differences were observed in the medium quality phonation coefficients between the study groups (p = 0.096).

The average fundamental frequency F0 amounted to 248.34 Hz, 218.78 Hz, and 228.09 Hz in the groups of professional singers, semi-professional singers, and non-singers (Tab. I.). Statistically significant differences were observed with regard to the average fundamental frequency F0 between the study groups (P = 0.030).

The average fundamental frequency F0 in the group of professional singers amounted to 316.46 Hz in women and 165.09 Hz in men; the respective values were 260.50 Hz and 149.26 Hz among semi-professionals and 261.23 Hz and 159.27 Hz among non-singers, respectively. Genderwise and groupwise, statistical differences were observed in the fundamental frequency F0 in professionals (P < 0.001), semi-professionals (P < 0.001), and the reference group (P < 0.001). The average first-formant frequency F1 amounted to 838.91 Hz, 780.79 Hz, and 826.67 Hz in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. II.). No statistically

Tab. VI. Descriptive statistics for shimmer (%) measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	3.27	3.44	2.44–4.09 (1.65)	0.97	0.21	2.85–3.70	1.60–5.00
	Male	3.75	3.77	2.91–4.58 (1.67)	1.18	0.28	3.16–4.34	1.69–6.11
	Total	3.49	3.60	2.74–4.16 (1.42)	1.08	0.17	3.14–3.83	1.60–6.11
Semi-professionals	Female	3.46	3.26	2.89–3.85 (0.96)	0.87	0.17	3.10–3.82	2.31–5.56
	Male	3.77	3.11	2.40–4.34 (1.94)	1.81	0.47	2.77–4.77	2.06–8.42
	Total	3.58	3.26	2.70–4.06 (1.36)	1.29	0.20	3.16–3.99	2.06–8.42
Reference group	Female	4.33	4.33	3.83–4.99 (1.16)	1.02	0.20	3.93–4.73	2.77–6.73
	Male	4.39	4.39	3.69–4.90 (1.21)	1.07	0.30	3.74–5.03	2.06–6.26
	Total	4.35	4.11	3.78–4.95 (1.17)	1.02	0.16	4.02–4.68	2.06–6.73
Total	Female	3.72	3.64	2.96–4.40 (1.44)	1.05	0.12	3.48–3.97	1.60–6.73
	Male	3.94	3.77	2.92–4.72 (1.80)	1.39	0.20	3.52–4.35	1.69–8.42

Tab. VII. Descriptive statistics for APQ (%) value measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	2.31	2.35	1.64–2.87 (1.23)	0.77	0.16	1.97–2.65	1.18–3.89
	Male	3.14	2.99	2.42–3.44 (1.02)	1.21	0.29	2.54–3.75	1.38–6.15
	Total	2.68	2.73	2.04–3.14 (1.10)	1.07	0.17	2.34–3.03	1.18–6.15
Semi-professionals	Female	2.43	2.26	2.11–2.71 (0.60)	0.63	0.13	2.17–2.69	1.45–4.17
	Male	3.48	2.83	2.06–4.37 (2.31	1.94	0.50	2.41–4.56	1.56–8.10
	Total	2.82	2.47	2.09–3.06 (0.97)	1.36	0.22	2.39–3.26	1.45–8.10
Reference group	Female	3.11	3.01	2.54–3.40 (0.86)	0.72	0.14	2.83–3.39	1.80–4.71
	Male	4.05	3.75	3.12–4.99 (1.87)	1.19	0.33	3.33–4.77	2.61–5.85
	Total	3.41	3.13	2.79–3.94 (1.15)	0.99	0.16	3.10–3.73	1.80–5.85
Total	Female	2.64	2.62	2.15–3.12 (0.97)	0.79	0.09	2.46–2.82	1.18–4.71
	Male	3.51	3.15	2.50–4.37 (1.87)	1.50	0.22	3.07–3.95	1.38–8.10
	Total	2.97	2.80	2.24–3.33 (1.09)	1.19	0.11	2.76–3.19	1.18–8.10

Tab. VIII. Descriptive statistics for NHR (%) value measurements in study subjects divided according to study group and gender.

GROUP	GENDER	STATISTICAL PARAMETER						
		M	ME	Q_1–Q_3 (IQR)	SD	SE	95% CI	MIN.–MAKS.
Professionals	Female	3.28	3.07	2.52–4.08 (1.56)	0.94	0.20	2.87–3.70	2.05–4.86
	Male	6.00	4.89	3.78–7.80 (4.02)	3.73	0.88	4.15–7.76	2.74–18.52
	Total	4.51	3.98	2.76–4.85 (2.09)	2.90	0.46	3.58–5.43	2.05–18.52
Semi-professionals	Female	3.23	3.14	2.64–3.38 (0.74)	0.91	0.18	2.86–6.31	1.84–5.46
	Male	6.72	6.39	2.83–9.00 (6.17)	4.36	1.13	4.30–9.14	1.87–18.52
	Total	4.54	3.29	2.67–4.94 (2.27)	3.21	0.51	3.52–5.57	1.84–18.52
Reference group	Female	3.89	3.78	3.43–4.41 (0.98)	0.82	0.16	3.56–4.22	2.17–5.98
	Male	6.13	5.94	4.93–6.92 (1.99)	2.00	0.56	4.92–7.35	3.51–10.60
	Total	4.62	4.08	3.54–5.46 (1.92)	1.68	0.27	4.08–5.16	2.17–10.60
Total	Female	3.49	3.37	2.68–4.14 (1.46)	0.93	0.11	3.27–3.70	1.84–5.98
	Male	6.27	5.51	3.78–7.81 (4.03)	3.51	0.52	5.23–7.32	1.87–18.52
	Total	4.56	3.81	2.98–4.95 (1.97)	2.65	0.24	4.08–5.04	1.84–18.52

significant differences were observed with regard to the average first-formant frequency F1 between the study groups (P= 0.053).

The average second-formant frequency F2 amounted to 1379.32 Hz, 1339.20 Hz, and 1332.87 Hz in the groups of professional

singers, semi-professional singers, and non-singers, respectively. No statistically significant differences were observed with regard to the average second-formant frequency F2 between the study groups (P = 0.113).

The average third-formant frequency F3 amounted to 2828.82 Hz, 2809.27 Hz, and 2809.78 Hz in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. II.). No statistically significant differences were observed with regard to the average third-formant frequency F3 between the study groups (P = 0.185).

The average fourth-formant frequency F4 amounted to 3772.80, 3759.59 Hz, and 3790.12 Hz, in the groups of professional singers, semi-professional singers, and non-singers, respectively. No statistically significant differences were observed with regard to the average fourth-formant frequency F4 between the study groups (P = 0.726).

The average probability of Voiced phonation amounted to 136.51%, 116.33%, and 83.00% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. III.). Statistically significant differences were observed with regard to the probability of Voiced phonation between the study groups (P = 0.001). The average probability of Voiced phonation in the group of professional singers amounted to 161.65% in women and 105.79% in men; the respective values were 118.85% and 112.13%, among semi-professionals and 85.39% and 78.03% among non-singers. Genderwise and groupwise, statistical differences were observed in the probability of Voiced phonation in professionals (P < 0.005) whereas no statistical differences were observed in semi-professionals (P < 0.686), and the reference group (P < 0.441).

The average jitter value amounted to 0.41%, 0.41%, and 0.40% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. IV.). No statistically significant differences were observed in the jitter value between the study groups (P = 0.646). The average value of the jitter value in the group of professional singers amounted to 0.30% in women and 0.54% in men; the respective values were 0.31% and 0.57%, among semi-professionals and 0.31% and 0.56% among non-singers. Genderwise and groupwise, statistical differences were observed in the jitter value in professionals (P < 0.006), semi professionals (P < 0.001), and the reference group (P < 0.001).

The average PPQ values amounted to 0.23%, 0.23%, and 0.24% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. V.). No statistically significant differences were observed in the PPQ values between the study groups (P = 0.346). The average PPQ values in the group of professional singers amounted to 0.18% in women and 0.30% in men; the respective values were 0.18% and 0.31%, among semi-professionals and 0.19% and 0.34% among non-singers. Genderwise and groupwise, statistical differences were observed in the PPQ values in professionals (P = 0.004), semi professionals (P = 0.001), and the reference group (P < 0.001).

The average shimmer value amounted to 3.49%, 3.58%, and 4.35% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. VI.). No statistically significant differences were observed in the shimmer value between the study groups (P = 0.005). The average value of the shimmer value in the group of professional singers amounted to 3.27% in women and 3.75 % in men; the respective values were 3.46% and 3.77%, among semi-professionals and 4.33% and 4.39% among non-singers. Genderwise and groupwise, no statistical differences were observed in the shimmer value in professionals (P = 0.158), semi-professionals (P = 0.456), and the reference group (P < 0.981).

The average APQ values amounted to 2.68%, 2.82%, and 3.41% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. VII.). No statistically significant differences were observed in the APQ values between the study groups (P = 0.002).

The average value of the APQ index in the group of professional singers amounted to 2.31% in women and 3.14% in men; the respective values were 2.32% and 3.48%, among semi-professionals and 3.11% and 4.05% among non-singers. Genderwise and groupwise, statistical differences were observed in the APQ values in professionals (P = 0.008), semi-professionals (P = 0.001), and the reference group (p < 0.001).

The average NHR values amounted to 4.51%, 4.54%, and 4.62% in the groups of professional singers, semi-professional singers, and non-singers, respectively (Tab. VIII.). No statistically significant differences were observed in the NHR values between the study groups (P = 0.399).

The average value of the NHR index in the group of professional singers amounted to 3.28% in women and 6.00% in men; the respective values were 3.23% and 6.72%, among semi-professionals and 3.89% and 6.13% among non-singers. Genderwise and groupwise, statistical differences were observed in the NHR values in professionals (P = 0.002), semi-professionals (P = 0.002), and the reference group (P < 0.001).

DISCUSSION

The recent decade witnessed an increasing number of computer-based methods of acoustic analysis being used for objective assessment of the phonation function [11, 12]. This trend may be explained not only by the increase in the computational powers and the drop in the costs of computer systems, but also by the development of novel technologies for digital processing and analysis of signals. While the voice profile and acoustic parameters are specific for individual speakers or singers, they may change as the result of diseases or overload of the vocal organ.

Current European standards highlight the need for comprehensive assessment of voice disorders using objective methods as described by Dejonckere et al. [13].

The voice is a psychoacoustic phenomenon, and any disturbances are due to improper distribution of its components such as frequency, amplitude, intensity, duration, and timbre (harmonic

components). Most common acoustic and capacity vocal parameters as referred to in the literature include the fundamental frequency, the shimmer value which defines relative changes in amplitude between individual periods, the jitter value which defines relative percentage changes in the fundamental frequency between individual periods, noise-to-harmonic ration (NHR) value indicative of the vocal noise content, and the maximum phonation time [14, 15].

Studies aimed at determination of specific acoustic parameters in professional singers and non-professional singers can be found in the literature. Comparing these groups, Rothman et al. [16] observed lower jitter, shimmer, and NHR values, higher fundamental frequencies, and, surprisingly, shorter maximum phonation times among professional singers.

As shown by our study, the average fundamental frequency F0 in the group of professional singers were markedly higher than among the semi-professionals and reference group subjects. According to the DiagnoScope software, normal values are 221.5 Hz and 126.4 for female and male subjects, respectively.

Similar observations were reported by Mendes et al. [17] who conclude that it is due to the more frequent and regular vocal training which includes voice being modulated so as to reach higher pitches, consequently extending the audible fundamental frequency range.

Toran et al. [18], Wang et al. [19], Deqhan et al. [20], and Izadi et al. [21] also observed that F0 values were significantly higher in women, mainly due to the anatomical differences between both genders. In males, larynx is 40% larger than in females; in addition, male vocal folds are more massive than female ones.

At the same time, Vilkman et al. [8] conclude that the higher fundamental frequencies are caused by stronger vibrations in vocal cords per unit time and may constitute a marker of vocal overload. They suggest that they may provide a potentially sensitive indicator of vocal hyperfunction. In practice, the accuracy, vibrancy and precision of the singing voice depend on the stability of the fundamental frequency. Strong correlation exists between the perception of stress and the stability and accuracy of the fundamental frequency [22, 23].

In our study material, no significant differences were observed in the jitter group of parameters within individual study groups. Statistically significant differences were observed between the study groups and between subject of different genders. According to the DiagnoScope software, normal values are 0.4 and 0.95 for female and male subjects, respectively.

On the other hand, the mean PPQ value is lower in professionals as compared to the remaining groups. Statistically significant differences were observed in PPQ values between the study groups and between subjects of different genders. According to the DiagnoScope software, normal values are 0.22 and 0.57 for female and male subjects, respectively.

Similar results were obtained in a study by Teachey et al. [24] which compared a group of choir singers and a group of non-singers. Jitter values were higher in non-singers as compared to those in choir singers. Teixeira et al. [14] point out that the higher the jitter value, the lower the subject's ability to control the vibrations of their vocal folds. Similar results are observed in subjects with vocal fold pathologies.

In our studies, the mean shimmer values in professional singers were lower than in the other study groups while no statistically significant differences were observed between the study groups and between subjects of different genders. According to the DiagnoScope software, normal values are 4.87 and 6.84 for female and male subjects, respectively.

On the other hand, inter-group differences in average APQ values were statistically significant. According to the DiagnoScope software, normal values are 3.4 and 6.38 for female and male subjects, respectively.

Teixeira et al. [14] observed that the higher the shimmer value, the higher the likelihood of pathological lesions within the vocal folds disturbing correct subglottal pressure flows, contributing to laryngeal resistance, or preventing full phonation stop. As a result, the capacity of the vocal organ is reduced, the voice becomes breathy and phonation breaks can be heard. Our analysis of the NHR values revealed statistical differences between the study groups and between subject of different genders, with mean values being lower in professional singers as compared to other groups. According to the DiagnoScope software, normal values are 3.73 and 7.46 for female and male subjects, respectively.

Similar correlations were reported by Mendes et al. [17] who concluded that lower NHR values in professional singers are associated with better control of the phonation and breathing apparatus resulting in better voice quality as a result of long-term development of vocal habits among choir singers. The "singer's formant" has been described in the literature. It is defined as two or more formants reaching similar frequency values with higher amplitudes and formation of formant groups including F3, F4, and sometimes F5 [12, 25, 26]. This combination of formants is responsible for the characteristic piercing sound of singing voice. Professional singers are often capable of generating resonances at a level of ca. 3000 Hz, ranging from 2600 to 4000 Hz [27]. This is achieved by a vocal technique which facilitates laryngeal lowering and requires many years of training.

No statistically significant differences were observed in our study between individual study groups with regard to the average third-formant frequency F3. According to the DiagnoScope software, normal values are 2850.27 Hz and 2669.35 Hz for female and male subjects, respectively.

The mean fourth-formant frequency F4 in the study subjects fell within the singer's formant range. According to the DiagnoScope software, normal values are 3899.84 Hz and 3629.39 Hz for female and male subjects, respectively. Sundberg et al. [28] report that singer's formant is developed as a result of intentional lowering of the larynx leading to the enlargement of the pharyngeal space. Ekholm et al. [29] observed that just as in the case of vibration, the presence of

the singer's formant is strongly correlated with the voice being perceived as beautiful or pleasant to hear. Maximum phonation time is another parameter frequently used in vocal capacity assessments. The aforementioned studies reported maximum phonation times in healthy singers being shorter than the reference values; this was also confirmed by our study results. Zielińska-Bliźniewska et al. [30] also observed shorter phonation times in their healthy subjects. This is reported to be possibly associated with improperly developed ability to control one's breath which is a crucial prerequisite for proper, vibrant, and efficient phonation.

Other capacity parameters were much lower and the differences were not statistically significant. Voiced phonation parameter plays an important role in voice analysis as its value is indicative of the likelihood of phonation i.e. a speech sound being generated. Signals above the phonation threshold are considered speech signals. Statistically significant differences were observed in our study between individual study groups with regard to the probability of voiced phonation. According to the DiagnoScope software, normal values are 49.33 and 55.96 for female and male subjects, respectively. The parameter is particularly high in professionals due to the fact that extensive training has led to proper emission, with the voice being more vibrant and expressive. It is worth noting that slight irregularity is a natural characteristic of a healthy voice. Voice is dynamic, complex, and subject to various intonations and emotions. In many cases, even the strongest attempts to maintain phonation stability are insufficient to completely eliminate amplitude, frequency, or noise level fluctuations, as pointed out by Gelfer [31] following examination of a group of healthy patients.

CONCLUSIONS

1. Values of the parameters that measure the character of the voice, relative period-to-period fundamental frequency perturbations, relative period-to-period amplitude perturbations, and the level of buzzing, when supported by other methods, are of diagnostic and predictive value in early detection of voice disorders.

2. The capacity analysis of the singing voice revealed very low values of the following parameters: phonation time, true phonation time, no phonation coefficient, voice efficiency coefficient and voice capacity.

3. In everyday practice of phoniatrics, evaluation of the acoustic and capacity parameters of the singing voice facilitates the objective and noninvasive analysis of voice to complement subjective assessments and other diagnostic examinations and help in differentiating between healthy and ill individuals.

4. Otolaryngological examination, videolaryngoscopic and stroboscopic examination of the larynx along with the diagnostic acoustic and capacity voice assessment facilitate precise diagnosis, implementation of appropriate management, and monitoring of the treatment process.

5. Acoustic analysis and short-term capacity analysis of voice facilitate the assessment of the laryngeal phonation function and may be useful in the diagnostics of discrete, imperceptible voice disorders, including the diagnostics of professional voices.

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