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ORIGINAL RESEARCH

Efficacy of Phonosurgery, Logopedic Voice Treatment and Vocal Pedagogy in Common Voice Problems of Singers

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ABSTRACT

Introduction: Functional and organic impairments of the singing voice are common career-threatening problems of singers presenting in phoniatric and laryngological departments. The objective was to evaluate the efficacy of phonosurgery, logopedic voice treatment and vocal pedagogy in common organic and functional voice problems of singers, including investigation of the recently introduced parameter vocal extent measure (VEM).

Methods: In a prospective clinical study, the analysis of treatment outcome in 76 singers [57 female, 19 male; 38 ± 11 years (mean ± SD)] was based on pre- and post-therapeutic voice function diagnostics and videolaryngostroboscopy. Examination instruments included auditory-perceptual voice assessment, voice range profile (VRP), the VEM calculated from area and shape of the VRP, acoustic–aerodynamic analysis, and patients' self-assessment (e.g., Singing Voice Handicap Index).

Results: While 28% of all singers (21/76) presented with functional dysphonia, 72% (55/76) were diagnosed with organic vocal fold changes, of which marginal edema (n = 25), nodules (n = 9), and polyps (n = 8) were the most common pathologic changes. Of the 76 singers, 57% (43) received phonosurgery, 43% (33) had conservative pedagogic (14) and logopedic (19) treatment. Three months post-therapeutically, most parameters had significantly improved. The dysphonia severity index (DSI) increased on average from 6.1 ± 2.0 to 7.4 ± 1.8 ($p < 0.001$), and the VEM from 113 ± 20 to 124 ± 14 ($p < 0.001$). Both parameters correlated significantly with each other (r_s = 0.41). Phonosurgery had the largest impact on the improvement of vocal function. Conservative therapies provided smaller quantitative enhancements but also qualitative vocal restoration with recovered artistic capabilities.

Conclusions: Depending on individual medical indication, phonosurgery, logopedic treatment and voice teaching are all effective, objectively and subjectively satisfactory therapies to improve the impaired singing voice. The use of VEM in singers with functional and organic dysphonia objectifies and quantifies their vocal capacity as documented in the VRP. Complementing the established DSI, VEM introduction into practical objective voice diagnostics is

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appropriate and desirable especially for the treatment of singers.

Keywords: Logopedic voice treatment; Phonosurgery; Professional singers; Therapy efficacy; Vocal extent measure (VEM); Vocal pedagogy; Voice disorders

INTRODUCTION

Functional impairments of the singing voice and small organic pathologic changes of the vocal folds are common problems of singers presenting in phoniatric and laryngological departments [1, 2]. Non-organic voice disorders that result due to each individual's particular way of using their voice are classified with various nomenclatures, e.g., 'Functional Dysphonia', 'Muscle Tension Dysphonia', 'Vocal Hyperfunction', 'Muscle Misuse Dysphonia' and 'Muscle Imbalance Dysphonia' [3–5]. The term 'Dysodia' describes the functional problems of the trained singing voice and resembles functional symptoms that occur in the course of singing [6–8]. All of these functional disorders result mainly from inappropriate use of the muscles within the larynx during phonation [9, 10]. It can appear with overuse of the vocal and vestibular folds (hyperfunctional muscle effort and laryngeal constriction), with underuse (hypofunctional muscle effort causing weakness and insufficient glottal closure), and also with a combination of both hyper- and hypofunctionality, showing smooth transitions of clinical signs and symptoms.

In case of persisting organic findings, the most relevant and common benign vocal fold pathologies comprise marginal swellings, nodules and polyps [11–13]. Localized vocal fold swellings and nodules belong to the group of exudative lesions of Reinke's space [14, 15]. Marginal swellings are uni- or bilateral, while nodules are typically bilateral and symmetrical lesions [16]. They are usually broad-based and appear in the middle third of the membranous part of the vocal folds, the region in which the amplitude has its maximum during phonation [17, 18]. The findings contain different entities, ranging from soft swellings without fibrous duplication of the underlying stroma to hard keratinized nodules [19]. Polyps appear in most cases unilaterally at the free margin of the vocal folds [20]. They are extensions of the lamina propria, which can be clearly differentiated from the surrounding epithelium [21]. Polyps are usually located between the anterior and the middle third of the vocal fold, at the point of greatest mechanical stress during phonation [22]. Overstress results in a change of the microstructure of vocal fold mucosa [23]. Induced vessel trauma leads to hemorrhage, fibrin exudation, thrombosis and proliferation of capillaries [24]. Teleangiectatic, red-colored polyps are filled with a convolute of cavernous blood compartments with clots and can enlarge to pedunculated mobile findings [25]. Hyaline translucent polyps consist of lamina propria swellings, which are mostly broad-based and therefore sessile [26].

Acute phonotrauma as well as chronic excessive or inappropriate use of the voice has the greatest influence on the development of these organic vocal fold lesions [27–29]. Associated symptoms are hoarseness, breathiness, throat discomfort, and unstable voice when speaking or singing [30–32]. Even small pathologic changes are relevant if they cause persistent strain and higher pressure during singing. Singers often lose their high notes and are not able to sing softly in the high register [33]. Additionally, reduced voice volume, vocal fatigue, and breaks of pitch can occur. If these symptoms are not relieved by carefully applied technical exercises and gentle vocalizing, singers are well advised to consult a medical specialist in the field of phoniatrics or otorhinolaryngology.

The primary therapy is a conservative approach, with voice rest [34, 35], voice therapy [36, 37], and treatment of concomitant diseases such as gastroesophageal reflux and allergy [38, 39]. Surgery is indicated in persisting organic lesions with impaired artistic capabilities, if non-surgical methods prove to be ineffective [40–42]. However, there are few data regarding the specific extent to which different modalities of conservative and surgical interventions improve vocal function [19].

Conservative treatment recommendations usually comprise the following therapy

components compiled by Goffi-Fynn and Carroll [43]: (1) logopedic training goals including reducing extrinsic laryngeal tension, using a relaxed laryngeal posture, and effective abdominal–diaphragmatic support for all phonation events; particular attention has to be given to the balance of respiratory forces, laryngeal coordination, and optimal filtering of the source signal via resonance and articulatory awareness; and (2) singing training goals, including a lowered breathing pattern to decrease subglottic air pressure, a lower laryngeal position to enable a relaxed laryngeal position, a top–down singing approach to allow for a balanced registration and effective resonance, and the acquisition of sensory and auditory mode of singing monitoring and control.

We offer interdisciplinary voice team consultation hours for singers with functional and organic dysphonia to comprehensively understand and manage the individual singing problem, to safely diagnose and evaluate clinical signs and symptoms, and to initiate a differentiated therapy that corresponds to the singer's needs. However, there is a need for more research to confirm the superiority of this treatment approach, with implications for vocal health, occupational safety, and health policy.

The purpose of this study was to evaluate the specific outcome of vocal pedagogy (singing lessons), logopedic voice therapy or phonomicrosurgery in singers who suffer from various functional and organic voice problems. Particular attention has been given to the recently introduced parameter vocal extent measure (VEM), which objectively quantifies vocal performance [44, 45]. The intention has been to investigate VEM changes after therapy and to compare its performance to that of established vocal parameters including the dysphonia severity index (DSI).

METHODS

Study Design and Criteria

A total of 76 singers with voice problems underwent therapy in a clinical prospective study. All participants were consecutively presenting between April 2011 and March 2017 at our interdisciplinary singer consultation service of the Department of Audiology and Phoniatrics, Charité—University Medicine Berlin, Germany. The trial was conducted in accordance with the Declaration of Helsinki and on approval by the local ethical review board. Data were collected at the pre-therapeutic visit and 3 months after the intervention. In participants who missed this appointment, follow-up examination was set at a later date. Subsequently, singers were offered to have a check-up once per year. Selection criteria comprised: professional and semiprofessional singers, recognized amateurs, and singing teachers suffering from dysphonia and/or dysodia, lack of spontaneous remission, complete treatment documentation and informed consent.

Conservative and Phonosurgical Treatments

The singers received either singing lessons, voice therapy or phonomicrosurgical treatment, depending on the underlying pathology and the previous course of the disease. Singing lessons were given by experienced vocal pedagogues. Logopedic voice therapy was conducted by qualified speech therapists with expertise in the singing voice. Both conservative treatments included at least 30 sessions, with a frequency of 2 times per week, each session lasting 45 min. Surgical treatment was carried out by experienced senior phonosurgeons following pathology-related phonosurgical standards [46]. A total of 38 patients were operated via direct microlaryngoscopy in general anesthesia (TIVA with propofol/remifentanil). In 5 singers, small vocal fold pathologies were transorally removed via insertion of a rigid laryngoscope and a curved forceps under local anesthesia after oral premedication with midazolam (7.5 mg) and atropine (15 gtt.). For laryngeal local anesthesia, we used a cotton swab soaked in a solution of 10 ml tetracaine (1%), adrenaline (6 gtt.) and tacholiquine (6 gtt.). Postoperatively, patients were prescribed voice rest for 3 days, with subsequent careful vocal reestablishment and vocal

hygiene counseling. To prevent a blend of different therapies, all patients were told to stick exclusively to their specific treatment group, without applying additional therapies up to the follow-up appointment 3 months after beginning of the specific intervention.

Examination Instruments

Generally established objective and subjective examination instruments were applied to evaluate the treatment outcome. Digital videolaryngostroboscopy (VLS) was performed using a high-resolution rigid videolaryngoscope (10 mm; 70°) with integrated microphone (XION Medical, Berlin, Germany) [47]. Laryngoscopy served to discriminate between functional and organic dysphonia. Organic findings were initially classified according to their morphological appearance, which was confirmed postoperatively via comparison with the final histopathological diagnoses. During laryngeal examination, digital videostroboscopy was activated to visualize the vocal fold vibrations during phonation. Pathology-associated impairment was seen when the vocal folds showed reduced or absent mucosal wave propagation as well as in the case of reduced or eliminated phonatory vibration.

The DiVAS software (XION Medical) was used for standardized registration of the voice range profile (VRP) and acoustic–aerodynamic analyses to obtain objective quantitative measurements of the speaking and singing voice [19, 48]. Various parameters were recorded, such as lowest vocalization (I_min), highest tone (F_0_max), maximum phonation time (MPT) and Jitter. Based on the established weighted combination of these parameters, the DSI as a recognized core part of instrumental voice evaluation was calculated to classify the voice into non-dysphonic (≥ 4.2) versus mildly (< 4.2 to ≥ 1.8), moderately (< 1.8 to ≥ -1.2), or severely (< -1.2) dysphonic [49]. Additionally, the VEM as a recently introduced measure for objective assessment of vocal capacity was calculated as the relationship of the area and the perimeter of the VRP [44, 45]. The underlying idea is that the VRP should not show abrupt differences in the dynamic range of notes produced by the patients along their frequency range. A well-balanced dynamic extent approximates the VRP shape to a circle where the area is largest for a given perimeter compared to other geometric figures. In this ideal concept, the dynamic range is evenly distributed over the tonal extent. Each deviation from the circular shape indicates a decrease in vocal performance. Accordingly, the VEM multiplies the VRP area by the quotient of the VRP perimeter and the theoretical perimeter of a circle with the same area as the VRP itself. The mathematical derivation of the equation of this measure is presented in Fig. 1. The VEM quantifies the dynamic performance and frequency range of the voice by a unidimensional, interval-scaled value without a unit, mostly between 0 and 120. These limits may be exceeded on both sides ($VEM_{min} \geq -150$; $VEM_{max} \leq 150$), characterizing a small vocal capacity by a small VEM, and a large VRP by a high VEM.

The auditory–perceptual voice evaluation was assessed via the GRB-system when singers were reading the standardized text "The north wind and the sun" [50]. The perceived roughness (R), breathiness (B), and overall grade of hoarseness (G) of the voice were scored on a scale from 0 to 3 (0: not existing, 1: mild, 2: moderate, 3: severe) by one experienced phoniatric physician. To optimize evaluation objectivity, all 152 audio recordings were rated in one session after being shuffled and blinded regarding patient assignment and pre-/post-therapeutic status.

The Voice Handicap Index (VHI-9i) and the Singing Voice Handicap Index (sVHI) were applied for singer's subjective self-assessment of their own voice. Originally, the 30-item VHI was constructed to quantify the psychosocial consequences of vocal problems focusing on the speaking voice [51]. We used the time-saving 9-item version, VHI-9i, which had been created after item reduction based on factor analysis and test–retest validation [52]. The 36-item sVHI was constructed to assess the self-perceived handicap associated with singing problems [53]. The German version of the SVHI was used in this study, having previously been demonstrated to be reliable and valid in

1. The area (A) of a circle of radius r is defined as:

$$A_{circle} = \pi r^2$$

2. The perimeter (P) of a circle of radius r is defined as:

$$P_{circle} = 2 \pi r$$

3. Consequently, the perimeter of a circle with a known area is:

$$P_{circle} = 2 \pi \sqrt{\frac{A_{circle}}{\pi}}$$

4. The VEM is the product of the VRP area and the quotient of the actual VRP circumference and the perimeter of a circle with the VRP surface area:

$$VEM_{exp} = A_{VRP} \frac{P_{circle}}{P_{VRP}} = A_{VRP} \frac{2 \pi \sqrt{\frac{A_{circle}}{\pi}}}{P_{VRP}}$$

5. The resulting exponential characteristic is inconvenient for correlations with linear variables. To obtain a more manageable value, the natural logarithm, a coefficient and a subtrahend were applied:

$$VEM = 50 \ln \left(A_{VRP} \frac{2 \pi \sqrt{\frac{A_{circle}}{\pi}}}{P_{VRP}} \right) - 200$$

Fig. 1 Design and derivation of the VEM equation

German-speaking countries [54]. In both the questionnaires applied, study participants rated all questions on a scale from 0 to 4 (0: never, 1: almost never, 2: sometimes, 3: almost always, 4: always), followed by one question regarding the speaking or singing voice impairment at the present time (VHI_{self} and $sVHI_{self}$, respectively) on a scale from 0 to 3 (0: normal, 1: mild, 2: moderate, 3: severe).

Statistical Analysis

The outcome analysis for each treatment modality was based on pre- and post-therapeutic voice function diagnostics and VLS. Descriptive statistics were calculated for all vocal function parameters before and 3 months after intervention, as well as their changes. To compare distributions of pre- and post-therapeutic values, various graphical techniques such as boxplots, histograms and kernel densities were applied. Spearman's rank-order correlation (r_s) served to examine the strength and direction of association between pre- and post-therapeutically measured characteristics and their differences. The Mann–Whitney–Wilcoxon test was used to investigate whether vocal function parameters significantly improved due to the treatment. Mean values and 95% confidence intervals for these changes were calculated. All statistical tests and graphics were carried out with R v.3.2.5 (GNU project; Free Software Foundation, Boston, MA, USA). Significance was set at $p < 0.05$.

RESULTS

Pre-therapeutic Assessment

The study cohort ($n = 76$) included 57 female and 19 male singers. Their ages ranged from 17 to 64 years [3 ± 11 years (mean ± SD)]. Status categorization revealed 61 professional singers, 9 semiprofessionals, 2 amateurs, and 4 singing teachers. All common voice types were represented: 46 soprano, 11 alto, 7 tenor, 9 baritone, 3 bass. Taking into account different singing styles and performance abilities, study participants were classified according to the singer taxonomy proposed by Bunch and Chapman [55], as follows: 24 opera (2.1, 3.1, 4.1), 3 musical theater (2.3 and 3.3), 26 concert/oratorio/recital (2.4, 3.4, 5.4, 6.1), 7 pop (3.6, 4.6, 5.6), 3 rap (2.8, 3.8 and 5.8), 1 jazz (3.10), and 12 church and cathedral (3.15, 8).

While 28% of all singers (21/76) presented with functional dysphonia, 72% (55/76) were diagnosed with organic vocal fold changes. VLS allowed reliable distinction between both

entities and provided precise diagnoses, which were all postoperatively confirmed by final histopathological reports. With larger sizes of the organic findings, stroboscopy revealed increasingly disturbed or absent mucosal wave propagation and impaired glottal closure during phonation. Persisting marginal edema ($n = 25$; unilateral $n = 13$, bilateral $n = 12$), nodules ($n = 9$; all bilateral) and polyps ($n = 8$; all unilateral) were the most common vocal fold pathologies, followed by leukoplakia, contact granuloma, papillomatosis and varix cordis (each $n = 2$), and less frequent diagnoses such as sulcus vocalis, Reinke's edema, vocal fold cyst, laryngeal chondroma and dystonia (each $n = 1$). Singer characteristics, pathology classification according to Rosen and Murry [56] and a listing of all diagnoses are shown in Table 1.

Regarding pretherapeutic vocal state, auditory-perceptual GRB evaluation was assessed without impairment in 38 singers (G0 R0 B0), with mild impairment in 35 singers (G1 R0-1 B0-1), and at worst with moderate impairment in 3 singers (G2 R2 B1–2). The latter group included one female pop singer with keratinized nodules, one female jazz singer with Reinke's edema, and one male classical singer with papillomatosis of the vocal folds. Patients' subjective self-assessment of their own voice demonstrated mild to moderate impairment (VHI-9i 11 ± 8, VHI_{self} 1.5; sVHI 70 ± 29, $sVHI_{self}$ 1.8). The objective acoustic and aerodynamic parameters showed good results (e.g., DSI 6.1 ± 2.0; VEM 113 ± 20; MPT 17.9 ± 5.7 s) compared to normal standard values of healthy non-singers; however, most singers reported on mild to moderate objective impairment of their usual artistic capabilities due to their demanding top-level voice needs. The correlation analysis revealed that both DSI and VEM showed a positive linear relationship with MPT ($r_s = 0.42$ and $r_s = 0.40$) and with each other ($r_s = 0.41$), but negative linear relationships with the subjective parameters G ($r_s = -0.33$ and $r_s = -0.24$), R ($r_s = -0.36$ and $r_s = -0.22$), B ($r_s = -0.42$ and $r_s = -0.38$), as well as with VHI ($r_s = -0.22$ and $r_s = -0.26$) and sVHI ($r_s = -0.24$ and $r_s = -0.25$). VHI and sVHI correlated moderately with each other ($r_s = 0.53$), while G correlated strongly with B ($r_s = 0.67$) and nearly perfectly with R ($r_s = 0.92$).

Following comprehensive counseling related to clinical signs, symptoms, individual vocal requirements, abilities and medical history, the singers were assigned to a treatment group. Concerning subgroups, the mean pretherapeutic values of most objective and all subjective parameters were best in the vocal pedagogy group and worst in the phonosurgery group, showing increasingly poor voice parameters with higher grades of pathology. Between both of these subgroups, significant differences were found for the parameters VHI_{self} ($p < 0.001$), VHI, $sVHI_{self}$, and B (each $p < 0.01$), as well as for sVHI, G, and R (each $p < 0.05$). The preoperative data for the total patient group and all subgroups are presented in Table 2.

Post-therapeutic Assessment

57% (43/76) of the singers received careful phonosurgical excision of glottal pathologies; the remaining 43% (33/76) had conservative treatment with pedagogic voice training (14/33) and logopedic voice therapy (19/33). Both conservative treatment groups included a total of 12 singers with small organic findings, involving 8 patients with marginal edema, 2 with contact granuloma, 1 with vocal fold nodules and 1 with laryngeal dystonia. Posttherapeutically, the marginal edema was completely absent in 2 patients (1/4 in both groups) and significantly smaller in all remaining singers (3/4 in both groups). However, VLS showed unchanged findings after conservative treatment in contact granuloma, keratinized vocal fold nodules and laryngeal dystonia. In the phonosurgery group, all organic pathologies were successfully excised. Within the mean postoperative observation period of 291 ± 294 days (median, 168 days), no side effects or recurrences became apparent. VLS check-ups revealed scarless healing with stable epithelium on the preserved lamina propria. All operated patients showed straight vocal fold edges, complete glottal closure and recovered mucosal wave propagation during vocal fold oscillations. Figure 2 gives an impression of

Table 1 Singers characteristics: unless otherwise specified, data expressed as number of patients and percentage of group

Characteristics	No. of patients	% of total group (n = 76)	No. of male patients	% of male group (n = 19)	No. of female patients	% of female group (n = 57)
Gender						
Male	19	25.0%	–	–	–	–
Female	57	75.0%	–	–	–	–
Age						
Years (mean ± SD)	38 ± 11	–	39 ± 26	–	37 ± 4	–
Professional level						
Professional	61	80.2%	15	78.9%	46	80.7%
Semi-professional	9	11.8%	2	10.5%	7	12.2%
Amateur	2	2.6%	1	5.3%	1	1.8%
Singing teacher	4	5.4%	1	5.3%	3	5.3%
Voice type						
Soprano	46	60.5%	–	–	46	80.7%
Alto	11	14.6%	–	–	11	19.3%
Tenor	7	9.2%	7	37.0%	–	–
Baritone	9	11.8%	9	47.2%	–	–
Bass	3	3.9%	3	15.8%	–	–
Singing styles						
Opera	24	31.6%	6	31.4%	18	31.6%
Musical theater	3	3.9%	1	5.3%	2	3.5%
Concert/ oratorio	26	34.3%	3	15.8%	23	40.4%
Pop	7	9.2%	1	5.3%	6	10.5%
Rap	3	3.9%	3	15.8%	0	–
Jazz	1	1.3%	1	5.3%	0	–
Church and cathedral	12	15.8%	4	21.1%	8	14.0%
Pathology classification						
Functional dysphonia	21	27.6%	4	21.1%	17	29.8%

Table 1 continued

Characteristics	No. of patients	% of total group (n = 76)	No. of male patients	% of male group (n = 19)	No. of female patients	% of female group (n = 57)
Organic dysphonia	55	72.4%	15	78.9%	40	70.2%
Rosen I (epithelium)	4	5.4%	4	21.1%	0	–
Rosen II (LP)	46	60.5%	9	47.2%	37	64.9%
Rosen III (arytenoid)	2	2.6%	1	5.3%	1	1.8%
Rosen IV (other)	3	3.9%	1	5.3%	2	3.5%
Organic diagnosis						
Marginal edema	25	33.0%	3	15.8%	22	38.5%
Vocal fold nodules	9	11.8%	0	–	9	15.6%
Vocal fold polyp	8	10.7%	5	26.2%	3	5.3%
Leukoplakia	2	2.6%	2	10.5%	0	–
Contact granuloma	2	2.6%	1	5.3%	1	1.8%
Papillomatosis	2	2.6%	2	10.5%	0	–
Varix cordis	2	2.6%	1	5.3%	1	1.8%
Sulcus	1	1.3%	1	5.3%	0	–
Reinke's edema	1	1.3%	0	–	1	1.8%
Vocal fold cyst	1	1.3%	0	–	1	1.8%
Laryngeal chondroma	1	1.3%	0	–	1	1.8%
Dystonia	1	1.3%	0	–	1	1.8%

Pathology classification according to Rosen and Murry [56] i.e.: I: epithelium, e.g., leukoplakia, hyperkeratosis, CIS (= carcinoma in situ), carcinoma, papillomatosis; II: lamina propria, e.g., Reinke's edema, polyps, cysts, scars, vascular malformation; III: arytenoid, e.g., granuloma, infection; IV: other, including movement disorders, hypo-/atrophy, malformation, e.g., sulcus or glottal web

pre- and postoperative VLS findings in three patients with different organic pathologies.

Regarding vocal function in the total group of singers, all acoustic and aerodynamic parameters apart from the Jitter (n.s.) had significantly improved at the 0.1% level (i.e., $p < 0.001$; pre vs. post). For example, the MPT increased on average from 17.9 ± 5.7 to

Table 2 Pre- and post-therapeutic parameters of vocal function in all singers and each subgroup (mean ± SD), their mean therapeutic differences (*Diff*) and 95% confidence intervals (*CI*) for changes in vocal measures 3 months after treatment

Vocal measure	Therapeutic status	Total group of singers (n = 76)	Phonosurgery group (n = 43)	Logopedic treatment group (n = 19)	Vocal pedagogy group (n = 14)
I_min	Pre	48.8 ± 6.5	49.5 ± 7.6	46.3 ± 3.3	49.8 ± 5.5
	Post	46.0 ± 2.9	45.8 ± 2.1	45.2 ± 2.8	47.5 ± 4.4
	Diff (CI)	− 2.8 (− 4.3; − 1.3)	− 3.7 (− 6.1; − 1.4)	− 1.1 (− 2.9; 0.7)	− 2.3 (− 4.8; 0.3)
F_0_max	Pre	819.1 ± 257.2	799.1 ± 253.2	789.4 ± 270.8	921.0 ± 243.1
	Post	885.4 ± 257.4	875.5 ± 265.6	856.5 ± 235.9	955.2 ± 265.2
	Diff (CI)	66.3 (25.9; 106.6)	76.4 (20.3; 132.4)	67.1 (− 15.3; 149.5)	34.2 (− 66.8; 135.2)
MPT	Pre	17.9 ± 5.7	17.3 ± 5.9	18.5 ± 4.9	18.8 ± 6.3
	Post	21.5 ± 7.8	21.2 ± 8.0	20.7 ± 4.5	23.3 ± 10.7
	Diff (CI)	3.6 (2.3; 4.9)	3.9 (2.0; 5.9)	2.2 (0.3; 4.1)	4.5 (1.3; 7.7)
Jitter	Pre	0.4 ± 0.4	0.3 ± 0.3	0.5 ± 0.5	0.4 ± 0.3
	Post	0.5 ± 0.4	0.4 ± 0.3	0.6 ± 0.6	0.4 ± 0.3
	Diff (CI)	0.1 (0.0; 0.1)	0.1 (0.0; 0.1)	0.2 (− 0.1; 0.4)	0.0 (0.0; 0.1)
DSI	Pre	6.1 ± 2.0	5.9 ± 2.3	6.4 ± 1.8	6.4 ± 1.7
	Post	7.4 ± 1.8	7.4 ± 1.8	7.1 ± 1.6	7.8 ± 1.9
	Diff (CI)	1.3 (0.9; 1.7)	1.5 (0.9; 2.0)	0.8 (0.0; 1.5)	1.4 (0.6; 2.3)
VEM	Pre	113 ± 20	112 ± 18	110 ± 24	119 ± 19
	Post	124 ± 14	125 ± 16	122 ± 13	127 ± 10
	Diff (CI)	11 (8; 15)	13 (8; 17)	12 (3; 20)	8 (− 2; 18)
VHI	Pre	11 ± 8	13 ± 8	12 ± 8	7 ± 6
	Post	6 ± 5	5 ± 5	8 ± 5	5 ± 5
	Diff (CI)	− 5 (− 7; − 4)	− 8 (− 9; − 6)	− 4 (− 6; − 1)	− 2 (− 3; 0)
VHI_{self}	Pre	1.5 ± 0.8	1.8 ± 0.7	1.5 ± 0.8	0.6 ± 0.5
	Post	0.6 ± 0.6	0.5 ± 0.6	0.7 ± 0.6	0.6 ± 0.6
	Diff (CI)	− 0.9 (− 1.2; − 0.7)	− 1.3 (− 1.6; − 1.0)	− 0.8 (− 1.3; − 0.4)	0.1 (− 0.5; 0.7)
sVHI	Pre	70 ± 29	74 ± 27	71 ± 31	57 ± 29
	Post	30 ± 22	26 ± 22	35 ± 22	37 ± 24
	Diff (CI)	− 40 (− 47; − 34)	− 48 (− 56; − 40)	− 36 (− 49; − 23)	− 20 (− 35; − 6)

Table 2 continued

Vocal measure	Therapeutic status	Total group of singers (n = 76)	Phonosurgery group (n = 43)	Logopedic treatment group (n = 19)	Vocal pedagogy group (n = 14)
$sVHI_{self}$	Pre	1.8 ± 0.8	2.1 ± 0.7	1.7 ± 0.8	1.3 ± 0.9
	Post	0.7 ± 0.7	0.6 ± 0.7	1.0 ± 0.6	0.6 ± 0.7
	Diff (CI)	− 1.1 (− 1.4; − 0.9)	− 1.5 (− 1.8; − 1.3)	− 0.7 (− 1.0; − 0.4)	− 0.6 (− 1.5; 0.3)
R	Pre	0.5 ± 0.6	0.6 ± 0.6	0.5 ± 0.5	0.2 ± 0.4
	Post	0.0 ± 0.2	0 ± 0	0.1 ± 0.3	0 ± 0
	Diff (CI)	− 0.5 (− 0.6; − 0.3)	− 0.6 (− 0.8; − 0.4)	− 0.4 (− 0.6; − 0.1)	− 0.2 (− 0.5; 0.0)
B	Pre	0.3 ± 0.5	0.4 ± 0.5	0.3 ± 0.5	0 ± 0
	Post	0.0 ± 0.2	0 ± 0	0.1 ± 0.3	0 ± 0
	Diff (CI)	− 0.3 (− 0.4; − 0.2)	− 0.4 (− 0.6; − 0.2)	− 0.2 (− 0.3; 0.0)	0.0 (N/A)
G	Pre	0.5 ± 0.6	0.7 ± 0.6	0.5 ± 0.5	0.2 ± 0.4
	Post	0.0 ± 0.2	0 ± 0	0.2 ± 0.4	0 ± 0
	Diff (CI)	− 0.5 (− 0.6; − 0.4)	− 0.7 (− 0.9; − 0.5)	− 0.3 (− 0.6; − 0.1)	− 0.2 (− 0.5; 0.0)

I_min lowest vocalization, F_0*_max* highest tone, *MPT* maximum phonation time, *DSI* dysphonia severity index, *VEM* vocal extent measure, *VHI* Voice Handicap Index, VHI_{self} self-perceived impairment of speaking voice at the present time, *sVHI* Singing Voice Handicap Index, VHI_{self} self-perceived impairment of singing voice at the present time, *R* roughness, *B* breathiness, *G* overall grade of hoarseness, *N/A* not applicable

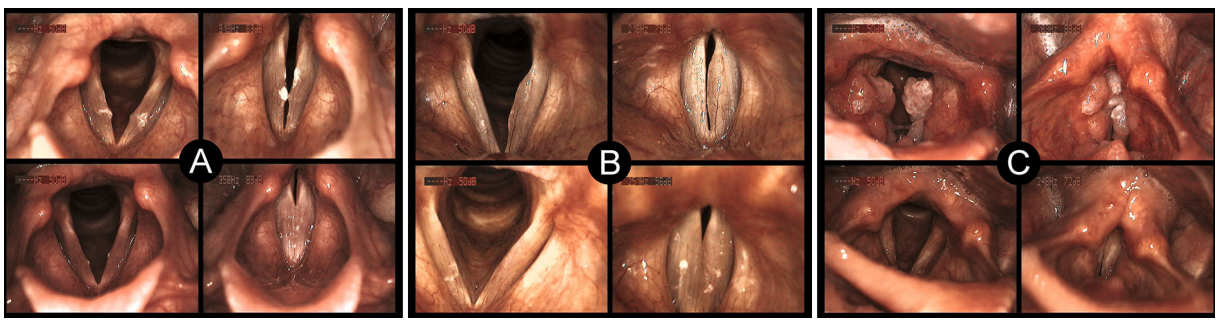

Fig. 2 Videolaryngostroboscopic pictures of preoperative (upper row) versus postoperative (lower row) vocal fold anatomy and function in three patients with organic dysphonia. **a** 23-year-old female pop singer with keratinized vocal fold nodules. **b** 48-year-old female jazz singer with unilateral Reinke's edema. **c** 39-year-old male classical singer with laryngeal papillomatosis. Findings 3 months postoperatively show: pathologies completely removed, healing process finished (scar-free), vocal folds have a straight margin, glottal closure is improved, normalized vocal fold oscillations

21.5 ± 7.8 s, the DSI improved from 6.1 ± 2.0 to 7.4 ± 1.8, and the VEM from 113 ± 20 to 124 ± 14. All subjective parameters also improved significantly at the 0.1% level. The mean sVHI (70 ± 29 to 30 ± 22) and VHI-9i (11 ± 8 to 6 ± 5) decreased, the self-perceived impairment of the speaking voice (VHI_{self}) and the singing voice ($sVHI_{self}$) reduced on average from moderately to mildly disturbed. Furthermore, the mean GRB-status exposed less roughness, breathiness and overall grade of hoarseness ($p < 0.001$).

Comparison of treatment groups revealed that phonosurgery had the largest impact on vocal function with higher numerical improvement of nearly all parameters. Selected objective and subjective parameters before and after therapy are graphically displayed in Fig. 3 for all subgroups. Inspection reveals convergence of treatment results, whereas the pretherapeutic status affects the post-therapeutic outcome. Age, gender, vocal register and singing style had no influence on the treatment outcome.

To evaluate the magnitude of improvement and thus the extent of the treatment-related benefit, Table 2 also includes the mean differences between pre- and post-therapeutic values of all parameters and the 95% confidence intervals for them. The numeric outcome of conservative therapies was smaller, but nevertheless they also resulted in the restoration of the artistic vocal capabilities of most singers.

DISCUSSION

According to common experience, it appears desirable when the treatment of singers is approached in a multidisciplinary setting with close cooperation between a phoniatrician or laryngologist, a speech language pathologist specialized in voice disorders among singers, and a vocal pedagogue/singing teacher trained in vocology. However, this study aimed at evaluating the specific efficacy of phonosurgery, logopedic treatment and vocal pedagogy in common organic and functional voice problems of singers, including investigation of the recently introduced parameter, VEM. Our results revealed that all three treatment modalities are effective, objectively and subjectively satisfactory therapies to improve the impaired singing voice. Phonosurgery had the largest numeric impact on improvement of vocal function. But even if logopedic voice therapy and vocal pedagogy lead to smaller numeric changes, the voice quality was restored and artistic capabilities recovered. This corresponds to other studies and systematic reviews which proved the effectiveness of phonosurgery in organic dysphonia and comprehensive conservative treatments in functional dysphonia.

Hazlett et al. [57] reviewed the literature to investigate the impact of voice training on the vocal quality of professional voice users. Most included studies revealed that voice training significantly improved at least one voice-related measure. Many patients in these trials reported that voice training improved the knowledge, awareness and quality of their voice. Ruotsalainen et al. [58] conducted a systematic review concerning the treatment of functional dysphonia and prevention of voice disorders in adults. As a result, the combination of direct and indirect voice therapy, compared with no intervention, improved self-reported, observer-rated and instrumentally assessed vocal functioning. However, there was no evidence of effectiveness of voice training in preventing voice disorders. Effective treatment options for functional dysphonia in singers comprise indirect therapy (i.e., vocal hygiene, patient education), direct therapy (e.g., voice therapy, circumlaryngeal manual therapy), medical treatment in case of associated laryngopharyngeal reflux or upper airway infections, and phonosurgery for secondary organic lesions [3, 59]. Comparable to our results, significantly improved objective, subjective and perceptual findings verify positive combined voice therapy effects in patients with functional dysphonia [60]. Further benefits may result when applying physical therapy or yoga as adjunct treatments [61, 62]. Yoga practices are not considered a substitute for comprehensive and integrated somatic retraining systems (e.g., Alexander Technique, Feldenkrais); however, by emphasizing kinaesthetic and proprioceptive awareness, singers can facilitate the learning of vocal

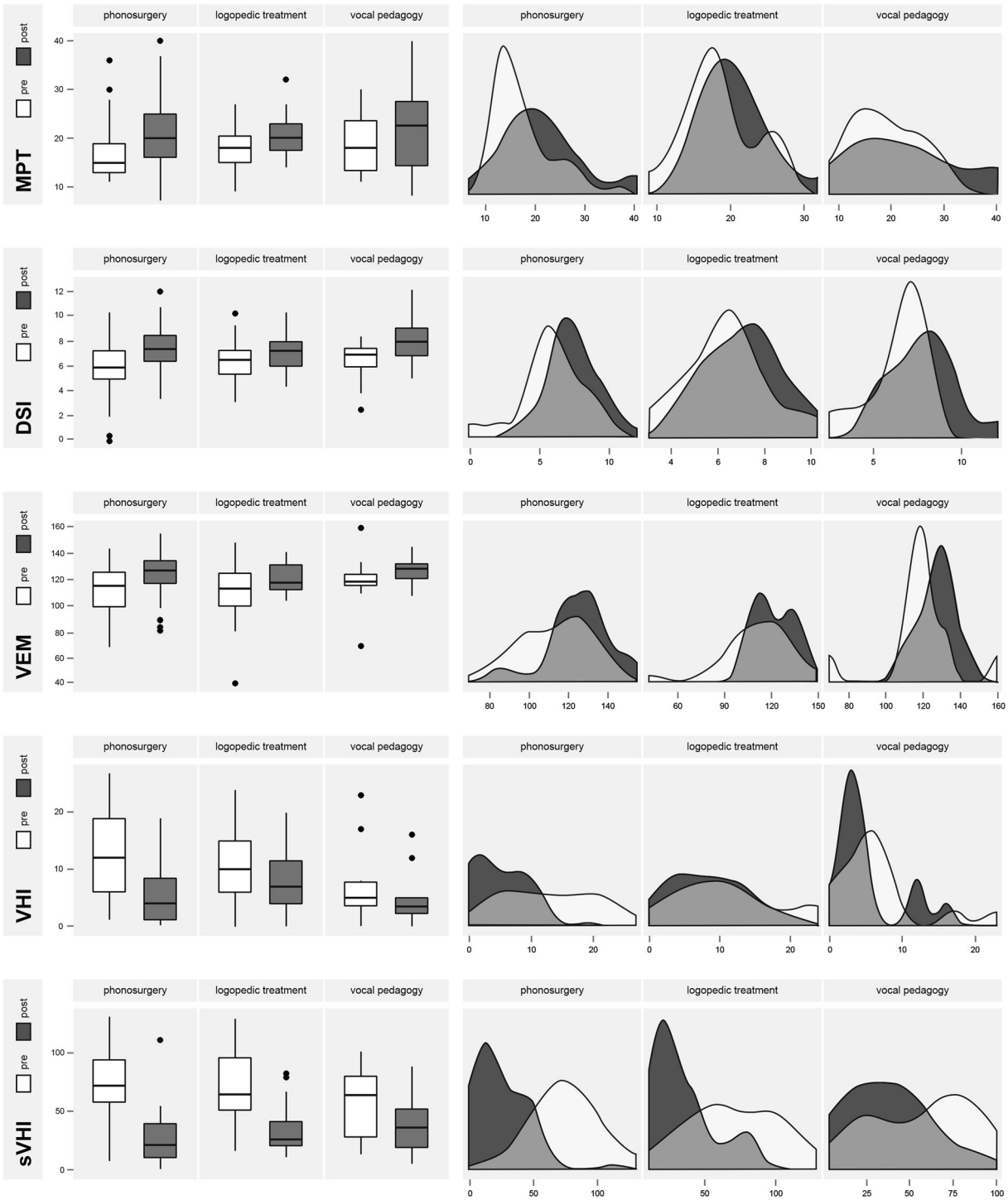

Fig. 3 Selected objective (MPT, DSI, VEM) and subjective parameters (VHI, sVHI) before and after phonosurgery, logopedic treatment, and vocal pedagogy. Left side: pre-/post-therapeutic comparison via boxplots, which display the median, quartiles, range of values covered by the data, and any outliers (single spots). Right side: pre-/post-therapeutic comparison via kernel density curves (Gaussian smoothing), in which histograms were shifted and overlaid with smooth density estimates to illustrate the different distributions

remediation techniques. Moreover, the influence of singing training on measures of voice quality is also well documented [63, 64]. Dastolfo-Hromack et al. [65] investigated singing voice outcomes following singing voice therapy in patients with functional and organic dysphonia. Post-therapeutically, sVHI scores decreased without significant differences between both groups. It is stated that voice care providers should partner with a singing voice therapist to provide optimal care for the singing voice.

In organic dysphonia, our study showed that conservative therapy might also be helpful in singers with small marginal edema, but seems not to be effective for restitution of other chronic findings such as keratinized vocal fold nodules or persistent contact granuloma. Our phonosurgical treatment indication and results are in line with published research data concluding that phonomicrosurgical resection is an adequate therapy to improve the voice in singers suffering from chronic benign glottal lesions [19, 42]. Comparable to the subgroup of operated patients in our investigation, Zeitels et al. [40] prospectively studied the outcome in 185 singers and performing artists who underwent phonomicrosurgical excision of different vocal fold lesions. Vocal function was evaluated by means of patient perception, VLS, and objective acoustic and aerodynamic measurements. Postsurgically, objective measurements fell within normal limits, and almost all patients also reported subjective improvement in their vocal function. All singers returned to full vocal activities. do Amaral Catani et al. [66] performed subjective and objective voice analyses before and 3 months after phonosurgery in 240 professional voice users with various benign vocal fold pathologies. All investigated parameters significantly improved after operation. Obviously, with a correct preoperative diagnosis, a competent and precise phonomicrosurgical procedure (e.g., protection of vocal fold margins, preservation of the lamina propria), a normal postoperative course with regular wound healing, and obeying voice counseling (e.g., 3 days of voice rest, careful vocal rehabilitation), the surgical excision of organic glottal pathologies is a safe, subjectively and objectively satisfactory therapy for the restoration of vocal function.

As a novelty, we examined in our study to which exact extent surgical resection influenced vocal parameters, in order to be able to advise singers about their expected benefit from phonomicrosurgery. The quantitative changes and thus the degree of improvement are indicated by the mean differences between pre- and post-therapeutic voice parameters and the 95% confidence intervals. The range of the increase of MPT (2.0–5.9 s), VEM (8–17) and DSI (0.9–2.0), as well as the decrease of VHI (− 9 to − 6) and sVHI (− 56 to − 40) could serve as reference range for subjective and objective expectation values. If further studies can reveal that the extension of this database with values of future singers enables more precise prognosis about vocal outcome, these values could be quantified for specific diagnosis-related subgroups and used for quality control after phonosurgery. In contrast, the Jitter failed to show a difference in our study. One reason might be the altered time of day during pre- and post-therapeutic voice recordings. According to the process of our clinical routine, most pre-therapeutic measurements were conducted around noon, when patients had time to use and stabilize their voice beforehand. Post-therapeutic check-ups after 3 months took place in the morning without a comparable vocal warm-up. In addition, we know from repeated measurements that the Jitter in general seems to be a rather sensitive parameter, resulting in different consecutive intra-individual values. According to our results, the Jitter as a measurement of irregularities in the frequency seems to be less appropriate to evaluate the success of surgical and conservative voice therapies compared to the other aforementioned parameters.

The recently introduced parameter, VEM, demonstrated significant changes with phonosurgery, logopedic treatment and vocal pedagogy in all singers. This confirmed the results of previous studies where the VEM proved to be a comprehensible and easy-to-use measure for objective evaluation of the VRP [19, 45]. The standardized VRP and the data thereby determined in order to calculate the DSI are core

elements in objective voice diagnostics [67]. However, the DSI quantifies dysphonia as a negative criterion and involves the risk of inaccurate results due to its multidimensional acquisition [49]. Additionally, previous studies revealed that the DSI is influenced by differences of measurements of the registration programs as well as by age or gender [68, 69]. Unimpaired by these interacting factors, we developed the unidimensional VEM for objective VRP evaluation and quantification of vocal performance. The VEM quantifies the subject's dynamic performance and frequency range, and is calculated as a relationship of the area and the perimeter of the VRP [44]. The VEM describes the vocal abilities and enables a classification of the voice performance as a positive criterion. Based on our results, this positive measure of vocal function seems to be a compelling diagnostic addition to other established voice measurements and suitable to objectively quantify the vocal performance in singers.

Some study limitations have to be discussed critically when drawing general conclusions. For example, our post-intervention period of 3 months was too short to allow statements about the long-term outcome. Although we did not register any deterioration or relevant recurrences within our follow up, further regular inspections are necessary to ascertain the success of conservative treatments and operations after several years, especially in singers with laryngeal papillomatosis. We advised our patients that the recurrence of vocal fold pathologies cannot be prevented by surgical removal, but that recurrence instead depends on the vocal load after healing, on the speaking and singing technique, and on individual disposition. In addition, the sample size of our study was too small to ensure an informative breakdown for all genres (e.g., musical theater, rap, jazz). Our results indicate a significant improvement for all singing styles; however, a larger pool of singers is required in order to conduct a comparative genre study. Furthermore, the investigated treatment modalities are often used in a combined mode to accelerate recovery and optimize vocal outcome in dysphonic singers. Although we told our patients to stick exclusively to their specific treatment group, we could not control whether they were receiving other, hidden, therapies. Additional singing lessons or logopedic treatment are easily accessible and could influence the results, especially in the recovery of operated patients. Additionally, some general and well-known factors influencing the VRP registration have to be taken into account, such as dependence on the experience of the examiner, the motivation of the singer and the absence of generally accepted specifications concerning the quantity of registered tones. Moreover, the size of the recorded tone intervals affects the VRP circumference. For instance, larger intervals can hide register changes with decreased vocal capability and thus wrongly enlarge the VRP. Most of these errors can be neglected in our study, since all VRPs were recorded by one experienced examiner under practically equal conditions.

CONCLUSIONS

Pedagogic voice teaching, logopedic voice treatment and phonosurgery are all effective, objectively and subjectively satisfactory therapies to improve the impaired singing voice. Specific treatment recommendation depends on phoniatric indication and should be based on comprehensive counseling related to clinical signs, symptoms, individual vocal requirements, abilities, and medical history. The use of the recently introduced parameter, VEM, in singers with functional and organic dysphonia objectifies and quantifies their vocal capacity as documented in the VRP. This useful, intelligible and user-friendly positive measure of vocal performance provides additional information about voice function. Complementing the established DSI, VEM introduction into practical objective voice diagnostics is appropriate and desirable, especially for the treatment of singers.

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Authorship Contributions. All authors participated in and contributed to study design, data collection and manuscript preparation. Statistical analysis was mainly performed by the author Tatiana Ermakova. Data analysis, interpretation and medical writing were primarily performed by the authors Maria del Mar Ropero Rendón and Philipp P. Caffier.

Disclosures. Maria del Mar Ropero Rendón, Tatiana Ermakova, Marie-Louise Freymann, Alina Ruschin, Tadeus Nawka and Philipp P. Caffier have nothing to disclose.

Compliance with Ethics Guidelines. All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Data Availability. The datasets generated and analyzed for this study are not publicly available, as they were obtained from a proprietary database via a licensing agreement.

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