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Review

Acoustic, Myoelectric, and Aerodynamic Parameters of Euphonic and Dysphonic Voices: A Systematic Review of Clinical Studies

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Abstract: Background: At present, there is no clinical consensus on the concept of normal and dysphonic voices. For many years, the establishment of a consensus on the terminology related to normal and pathological voices has been studied, in order to facilitate the communication between professionals in the field of the voice. Aim: systematically review the literature to compare and learn more precisely the measurable and objective characteristics of the acoustic, aerodynamic and surface electromyographic parameters of the normal and dysphonic voices. Methods: The PRISMA 2020 methodology was used as a review protocol together with the PICO procedure to answer the research question through six databases. Results: In total, 467 articles were found. After duplicate records were removed from the selection, the inclusion and exclusion criteria were applied and 19 articles were eligible. A qualitative synthesis of the included studies is presented in terms of their methodology and results. Conclusions: Studying the acoustic, aerodynamic, and electromyographic parameters with more precision, in both normal and dysphonic voices, will allow health professionals working in the field of voice (speech therapy, otorhinolaryngology, phoniatrics, etc.) to establish a diagnostic and detailed consensus of the vocal pathology, enhancing the communication and generalization of results worldwide.

Keywords: acoustic; aerodynamic; electromyography; dysphonia; voice disorders; voice quality

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1. Introduction

To enable rehabilitation that adapts to the needs of the patient, a functional evaluation of the voice is necessary, which requires an otorhinolaryngological medical diagnosis and a speech therapy evaluation [1].

Through the functional evaluation of the voice, the patients' vocal behavior should be observed by analyzing aspects related to anatomy and physiology and the negative vocal habits they present, thereby determining the severity of the disorder and establishing a prognosis and/or a diagnosis [2].

With regards to speech therapy, a detailed anamnesis of the vocal pathology and a postural examination should be carried out. In addition, a subjective assessment of the voice (i.e., auditory perceptual analysis) should be performed, preferably by a speech therapist trained in alterations of the voice; as a complementary evaluation to an objective assessment of the voice through acoustic, aerodynamic, and surface electromyographic analyses, among others.

For this reason, being able to perform an exhaustive evaluation of a majority of the parameters and structures that are related to vocal emission, helps and facilitates the professionals who work with it in a clinical manner (speech therapists, doctors, otolaryngologists . . .) to provide an adequate diagnosis of the vocal pathology.

When describing an individual's voice, there are terminological differences. For professionals working to develop, describe and/or rehabilitate human voices, it is necessary to be able to recognize and agree on terms and vocal parameters [3].

At present, there is no clinical consensus on the concept of normal voice and dysphonic voice. For many years, the establishment of a consensus on the terminology related to normal and pathological voices has been studied, in order to facilitate the communication between professionals in the field of the voice. Most recently, a comprehensive review of the worldwide healthy adult voice baseline parameters has been performed, in an attempt to address this lack of consensus [2].

When referring to the euphonic or "normal voice", Jackson-Menaldi [4] takes into account the presence of a pleasant vocal timbre, a volume which is appropriate to the vocal needs, and a tone which is appropriate to the sex and age of the patient.

In contrast, according to Lee [5], dysphonia appears when the quality of the voice, the tone, the volume, the resonance and/or the duration differ or are inappropriate for the age, gender, cultural background, or geographic location of a person.

During the last 40 years, the clinical application of acoustic analysis has been developing, but the acoustic differentiation between healthy and pathological voices is still inaccurate [6,7].

Accordingly, it appears relevant to describe the objective parameters of the normal and dysphonic voices. Taking this into consideration, the objective of the present systematic review was to evaluate the conditions for a normal and a dysphonic voice in adult patients from the measurement of acoustic, aerodynamic, and myoelectric characteristics of their voices.

2. Materials and Methods

The present systematic review was carried out following the PRISMA 2020 (Preferred Reporting Items for Systematic reviews and Meta-Analysis) statement guidelines [8].

2.1. Eligibility Criteria

The eligibility criteria were established by following the PICO model [9], as follows. population/problem (P): adult patients with or without vocal pathology (normal/dysphonic voice); intervention (I): procedures for the determination of the healthy/pathological state of the voice, comprising the evaluation of acoustic, myoelectric, and/or aerodynamic objective measures; comparison/control (C): comparison of such objective measures in the previously described population; outcome (O): measurable outcomes from voice diagnostic tests.

Clinical studies that addressed the aforementioned PICO parameters were eligible for the present systematic review. The date or language of the publications were not considered as inclusion/exclusion criteria.

The exclusion criteria were the following: descriptive, evaluation, or treatment studies of organic vocal pathology (except nodules and polyps); studies on therapy or rehabilitation in benign pathology of the vocal cords; articles on voice disorders not related to vocal overexertion (puberphonia, presbyphonia, head and neck cancer, laryngectomy, etc.); works on the voice in neurodegenerative diseases or feminization of the voice; voice rehabilitation techniques and/or methods; studies on evaluation and/or rehabilitation of the singing voice; childhood dysphonia; gastroesophageal reflux; phonosurgery; and systematic reviews.

Voice disorders derived from vocal muscle tension and organic pathology such as nodules and polyps were included, which are usually the most frequent in the vocal rehabilitation of the speech therapy clinic.

2.2. Search Strategy

The database search, study screening process, data extraction, and risk of bias analysis were performed by two independent researchers. In case of doubt or disagreement, a third investigator was consulted.

An advanced database search was performed in six electronic databases: Web of Science, Medline, Scopus, Embase, Cochrane Library, and SciELO on 19 December 2019, and last updated on 30 September 2020, without any language or year filters. The search strategy was designed by taking into account previously published studies within the field of the evaluation of voice parameters, and their most cited descriptors. Consequently, the following search terms were used: "voice", "normal voice", "euphonic voice", "voice quality", "dysphonia", "dysphonic", "pathologic voice", "voice pathology", "hyperfunctional dysphonia", "measure", "test", "analysis", "assessment", "quantification", "subglottic pressure", "subglottal pressure", "intensity", "pitch", "airflow", "parameter", "surface electromyography", "laryngeal muscle", "muscular", "larynx", "laryngeal", "acoustic analysis", "acoustic measurement of voice", and "acoustic parameters". The Boolean operators "AND" and "OR" were used to annex the search terms. The search strategy, divided by search fields, is illustrated in Figure 1.

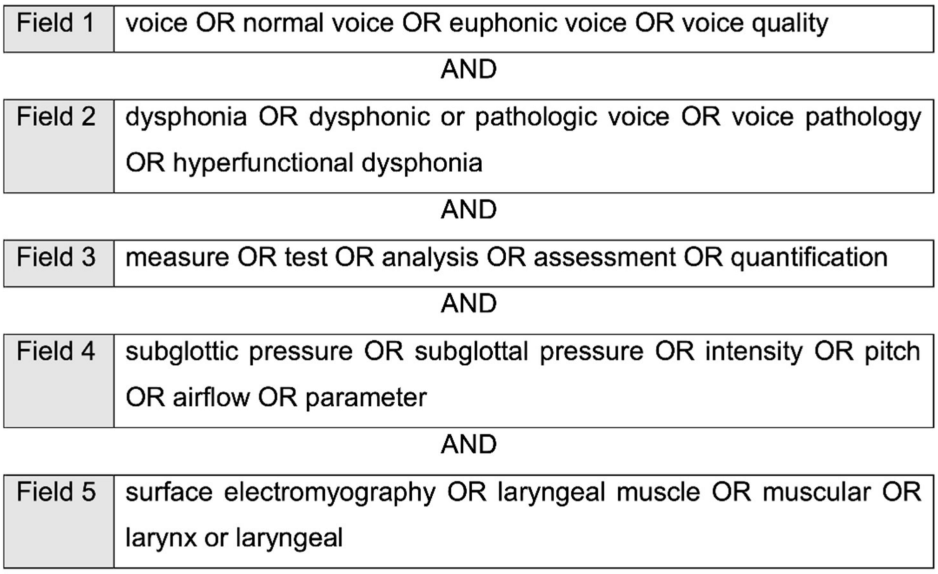

Figure 1. Search strategy illustration.

2.3. Study Selection Process

Study records resulting from the search process were exported to Mendeley Desktop 1.19.4 reference manager software (Elsevier, AMS, The Netherlands) to manually check for duplicates. After discarding duplicates, an initial screening of the reference titles and abstracts was performed, following the aforementioned inclusion and exclusion criteria. The studies that did not fulfill such criteria upon the screening of their title and abstract were discarded. Studies that did meet the criteria where subsequently assessed for eligibility by a full-text screening.

2.4. Data Extraction

The process of data extraction was divided into three categories: extraction of variables for study characteristics, methodology, and results. Variables for study characteristics comprised the authors and year of publication. Variables for study methodology were the sample size and its characteristics (vocal healthy/pathological state, gender, age), study type, technique/s for the registry and evaluation of vocal parameters, and statistical analysis. Lastly, results variables included acoustic measures, aerodynamic data, myoelectric activity registries, and comparisons performed.

2.5. Quality Assessment

For the quality assessment, "The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement" [10] was used for the included observational studies. To evaluate the quality of the case series included in the present review, the "Tool for evaluating the methodological quality of case reports and case series" from "Methodological quality and synthesis of case series and case reports" [11] was followed. The full texts of the studies were screened and evaluated for each of the parameters included in the quality assessment tools.

3. Results

3.1. Search Results and Study Selection

The study selection process is shown in Figure 2. The database searches identified 467 records: seven from Scopus, 66 from Cochrane Library, 178 from Medline, 188 from Web of Science, and 28 from Embase. The search performed in SciELO produced no results. Duplicates were discarded using the reference manager software, resulting in 384 records. From the resulting records, 367 were excluded upon screening of the title and abstract. Two additional eligible studies were found upon screening the references of the resulting studies. The resulting 19 papers were evaluated by full-text screening, and all of them were eligible for qualitative synthesis.

3.2. Study Methodology

Table 1 shows the summary of the methodology used in the 19 studies included in the review. In most of them, a sample made up of two groups was observed: an experimental group made up of people with vocal pathology and a control group made up of people without vocal pathology [12–25]. Another three were made up of a group of volunteers with vocal pathology [26–28] and two more were composed of volunteers without vocal pathology [29,30]. In all of the observational studies, the groups were established in a non-randomized controlled manner. The sample size of the included studies ranged from 10 [26] to 387 [15] participants, except for one study [20] which included a sample of 1410 participants due to the use of a previous database.

Regarding the parameters analyzed in the different studies (Table 2), three categories can be established: acoustic measurements, aerodynamic parameters, and parameters of myoelectric activity.

Within the section on acoustic measurements, a small section has been included referring to the auditory perceptual analysis assessment scales and instruments used in the different articles.

In seven studies, subjective and quasi-objective measures were used to assess voices: the Voice Problem Self-Assessment Scale (VPSS) [27], GRBAS scale [14,17,19,27], Visual Analog Scale evaluation (VAS) [19], Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) [21,25] and Voice-Related Quality of Life (V-RQOL) [25].

For the recording of objective voice measurements, software programs such as Multi-Dimensional Voice Program (MDVP) [16,18,27], FonoView 4.5 [28], Praat acoustic analysis program [21,23–25], Dr. Speech [23], Computerized Speech Lab (CSL) [29], among others were used. Phonatory Aerodynamic System 6000 was used by one study for aerodynamic analysis [18]. The Dysphonia Severity Index (DSI) was used by two studies [21,27].

In the studies where the aerodynamic parameters were evaluated, the repetition of the syllable [pa] [18,22,26,30] or the syllable [pi] [14,29] was used.

Regarding the instruments and materials used in the selected studies, a series of microphones, hardware, and software, both for the vocal register and for the aerodynamic register were used. This is summarized in Table 3.

Differences were also observed regarding the distance from the microphone to the mouth: 3 cm [19], 5 cm [16,17,23], 8 cm [29], 10 cm [14,21,24,25,28], 12 cm [30], and 15 cm [12,26].

3.3. Study Results

A summary of the results of the included studies in terms of acoustic and aerodynamic parameters is presented in Tables 4 and 5, respectively.

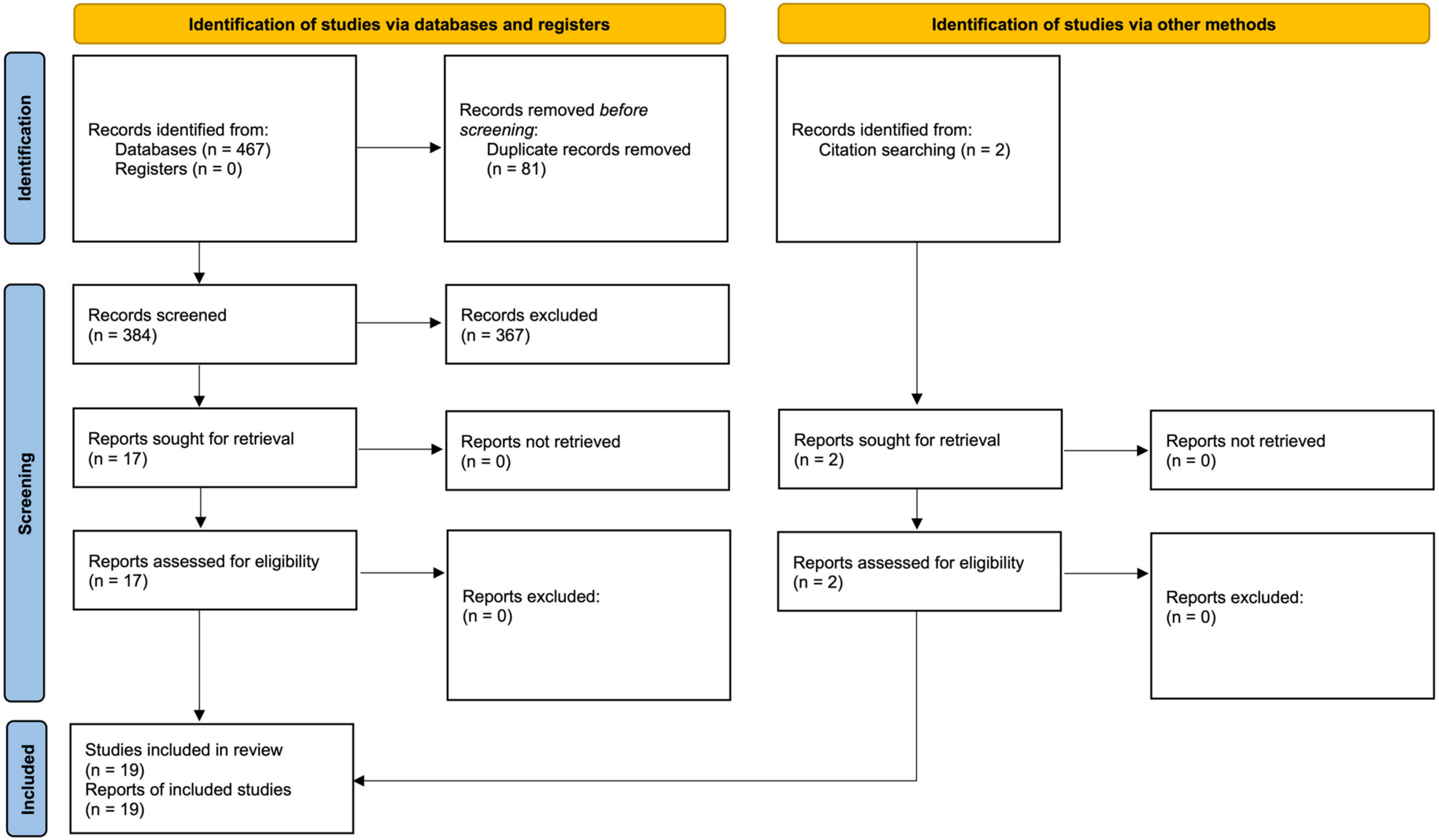

Figure 2. Schematic illustration of the study selection process. Based on PRISMA 2020 flow diagram.

Table 1. Summary of the methodology of the selected studies.

Authors	Year	Sample Characteristics	Sample Size	Age Range	Gender	Voice Evaluation Techniques
Aboras et al.	2010	Volunteers with vocal pathology (100)	100	25–55	–	VPSS; GRBAS Scale; MDVP; DSI; Aerophone II
Balata et al.	2015	Volunteers with (19) and without (22) vocal pathology	41	28–57	W: 36, M: 5	VAS; Surface electromiography Miotool 200®; Miograph 2.0; Sennheiser PC-20 Microphone; VoxMetria 4.7; GRBAS Scale
Björklund and Sundberg	2016	Volunteers without vocal pathology	31	W: 26–36 M: 25–47	W: 16, M: 15	Pressure transducer; Sound card; Pressure gauge; Headset microphone DPA 4066-C; Sound level meter
Brockmann-Bauser et al.	2019	Volunteers with vocal pathology (58) [vocal nodules (39), vocal polyps (5) and without muscle tension dysphonia (14)] and without vocal pathology (58)	116	18–64	W	V-RQOL, CAPE-V; Koufman y Isaacson Scheme, modified by Amaral Catani; Sennheiser MKE104 Microphone; Praat
Brockmann-Bauser et al.	2018	Volunteers with vocal pathology (58) [vocal nodules (39), vocal polyps (5) and muscle tension dysphonia (14)] and without vocal pathology (58)	116	18–64	W	Koufman and Isaacson Scheme, modified by Amaral Catani; Sennheiser MKE104 Microphone; Pneumotachograph; Preamplifier; Praat
Cantarella et al.	2011	Volunteers with vocal pathology (53) [vocal nodules (3), vocal polyps (24), cysts (15), Reinke's edema (11)] and without vocal pathology (39)	92	SG: 17–74 CG: 20–65	SG: (W: 36, M: 17) CG: (W: 19, M: 20)	GRBAS Scale; AKG B29L Microphone; EVA system; Pneumotachograph
Casado Morente et al.	2001	Volunteers with vocal pathology (60) [vocal nodules (30), vocal polyps (30)] and without vocal pathology (100)	160	SG: (Nodules: 25–38), (Polyps: 19–42) CG: 20–40	SG: (Nodules: W: 19, M: 11), (Polyps: W: 13, M: 17) CG: (W: 43, M: 57)	Telelaryngoscope; Fiberlaryngoscope; Stroboscope; Dr. Speech 3.0 Voice Assessment; Sound card; Professional microphone (600 ohms impedance)
Gilman et al.	2017	Volunteers with (192) and without (45) vocal pathology	237	SG: 19–86 CG: (W: 18–36, M: 17–30)	SG: (W: 133, M: 59) CG: (W: 20, M: 25)	PAS
Hemmerling et al.	2016	Volunteers with vocal pathology (705) [hyperfunctional dysphonia (213), vocal cord paralysis (213), other pathologies (279) and without vocal pathology (705)	1.410	–	SG: (W: 450, M: 255) CG: (W: 450, M: 255)	SVD
Holmberg et al.	2003	Volunteers with vocal pathology [vocal nodules (10)]	10	W: 19–35	W: 10	Microphone (Sony ECM 50); Pressure system (Glottal Enterprises)

Table 1. *Cont.*

Authors	Year	Sample Characteristics	Sample Size	Age Range	Gender	Voice Evaluation Techniques
Lopes et al.	2017	Volunteers with vocal pathology [vocal nodules (93 without structural alterations (64), vocal cyst (34), reflux vocal alteration (27), polyps (17), posterior hiatus (18), vocal paralysis (10), *sulcus vocalis* (8), Reinke's edema (8)]	279	W: 18–65	W: 279	FonoView 4.5; Sennheiser 835 Microphone; VoxMetria; Sound ForSG Pro 10.0; Matlab 7.9
Ma and Yiu	2006	Volunteers with (112) and without (41) vocal pathology	153	20–55	SG: (W: 93, M: 19) CG: (W: 35, M: 6)	CSL 4300B; MDVP; Shure Beta 87 Microphone; GRBAS Scale; Interobservers evaluation; Phog 1.0; Aerophone II
Nemr et al.	2006	Volunteers with (24) and without (42) vocal pathology	66	20–83	SG: (W: 17, M: 7) CG: (W: 25, M: 17)	Audacity®; AKG 520 Microphone; CAPE-V; Praat
Petrović-Lazić et al.	2011	Volunteers with (46 [vocal polyps]) and without (21) vocal pathology	67	SG: (W: 18–61) CG: (W: 21–61)	SG: (W: 46) CG: (W: 21)	MDVP; Sennheiser E825S Microphone; SPSS
Rachel et al.	2018	Volunteers with (10) and without (10) vocal pathology	20	–	–	Proton BOOM815 Recorder; Praat; Dr. Speech
Rosenthal et al.	2014	Volunteers without vocal pathology (18)	18	18–26	(W: 12, M: 6)	CAPE-V; CSL 4500; Glottal Enterprises MS100-A2; Microphone (Tascam DR-2d Linear PCM)
Vaziri et al.	2010	Volunteers with (329) and without (58) vocal pathology	387	–	SG: (W: 188, M: 141) CG: (W: 36, M: 22)	APQ; PPQ; CD; LLE; ApEn; FD; ZL
Yiu et al.	2004	Volunteers with vocal pathology [vocal hyperfunction (28): vocal edema (1); vocal polyp (2); vocal cord thickening (10); vocal nodules (16)] and without pathology (28)	56	20–50 SG: 33.25 ± 9.70 CG: 33.39 ± 9.43	SG: (W: 28) CG: (W: 28)	Aerophone II
Zheng et al.	2012	Volunteers with (26) –muscle tension dysphonia- and without (27) vocal pathology	53	SG: 18–56 CG: 20–56	SG: (W: 18, M: 8) CG: (W: 18, M: 9)	MDVP; PAS

Note: SG, Study Group; CG, Control Group; W, Women; M, Men; VPSS, Voice Problem Self-assessment Scale; MDVP, Multi-Dimensional Voice Program; DSI, Dysphonia Severity Index; VAS, Visual Analog Scale; RMS, Root Mean Square; V-RQOL, Voice-Related Quality of Life; CAPE-V, Consensus Auditory-Perceptual Evaluation of Voice; Praat, Software of acoustic analysis; PAS, Pentax Phonatory Aerodynamic System 6600; SRRS, Self-rating scale of stress; SVD, Saarbruecken Voice Database; CSL, The Computerized Speech Lab; Phog 1.0., Soundswell real-time computerized phonetogram; APQ, Amplitude Perturbation Quotient; PPQ, Pitch Perturbation Quotient; CD, Correlation Dimension; LLE, Largest Lyapunov Exponent; ApEn, Approximate Entropy; FD, Fractal Dimension; ZL, Ziv-Lempel complexity; ROC, Receiver Operating Characteristics.

Table 2. Summary of the acoustic parameters analyzed in the selected studies.

Authors	Year	Acoustic Measurements				Aerodynamic Parameters		Myoelectric Parameters		Phonatory Tasks
		SM	QOM	OM	AP	W/T	WO/T	OM	N° Channels	
Aboras et al.	2010	VPSS	GRBAS scale	MDVP; DSI	Shim; APQ; NHR	MPT	SGP	–	–	–
Balata et al.	2015	–	VAS; GRBAS scale	–	F_0; Intensity	–	–	Electrical potentials: SH and IH muscles	3	Maintained vowel /ε/ and counting numbers (20–30) with a comfortable and maximum intensities
Björklund and Sundberg	2016	–	–	–	F_0; Intensity	–	Intraoral pressure; SGP	–	–	Syllable [pa] repetition with different intensities and with the same frequency
Brockmann-Bauser et al.	2019	V-RQOL	CAPE-V	–	F_0; Intensities: minimum, maximum and normal; CPPS	–	–	–	–	Maintained vowel /a/ with comfortable minimum and maximum intensities
Brockmann-Bauser et al.	2018	–	–	–	F_0; Intensity; Jitter; Shim; HNR	–	–	–	–	Maintained vowel /a/ with comfortable minimum and maximum intensities
Cantarella et al.	2011	–	GRBAS scale	–	Jitter; Shim; CV F_0; CV I; HNR	MPT	SGP; OAF; OA CV; GL; GEI; LE; OAF*P	–	–	Maintained vowel /a/ with comfortable intensity and frequency. Words, sentences and conversations repeated
Casado Morente et al.	2001	–	–	–	Jitter; Shim; NNE (dB); HNR (dB); SNR (dB); F_0	–	–	–	–	Maintained vowel /a/ with comfortable intensity and frequency
Gilman et al.	2017	–	–	–	–	–	- MFR - Est-Pub	–	–	Maintained vowel /a/ (comfortable frequency and intensity; Syllable [pa]
Hemmerling et al.	2016	–	–	–	F_0; Jitter; Shim; 1st, 2nd, 3rd formants; MFCC	–	–	–	–	Maintained vowels /a/, /i/, /u/ with minimum, normal and maximum, frequency
Holmberg et al.	2003	–	–	–	Intensity; F_0; H1; H2; F1; F3	–	Intraoral air pressure; OAF; Transglottal air pressure; ACflow; Closed quotient; Speed quotient; Maximum flow declination rate	–	–	Maintained vowel /a/ and syllable [pa] with comfortable and maximum intensity

Table 2. *Cont.*

Authors	Year	Acoustic Measurements				Aerodynamic Parameters		Myoelectric Parameters		Phonatory Tasks
		SM	QOM	OM	AP	W/T	WO/T	OM	N° Channels	
Lopes et al.	2017	–	–	FonoView 4.5	F_0; Jitter; Shim; GNE	–	–	–	–	Maintained vowel /ε/ with comfortable frequency and intensity
Ma and Yiu	2006	-	GRBAS	Phonetogram	Minimum and maximum F_0; Maximum and minimum intensity; Jitter; Shim; NHR	MPT	Phonatory airflow Air pressure Intraoral pressure	–	–	Sentences with comfortable and maximum intensity; Maintained vowel /a/ with maximum and minimum intensity and frequency; Maintained vowels /i/, /u/ with comfortable frequency and intensity; Syllable [pi]
Nemr et al.	2016	–	CAPE-V	DSI	F_0 max; I min	–	–	–	–	Maintained vowel /a/ at comfortable and increasing F0; Maintained vowel /a/ at comfortable intensity and decreasing
Petrović-Lazić et al.	2011	–	–	MDVP	vF_0; Jitter; Shim; NHR; VTI; PPQ; APQ	–	–	–	–	Maintained vowel /a/ at comfortable frequency
Rachel et al.	2018	–	–	Praat; Dr. Speech	F_0; F_0 tremor; Jitter; Shim; HNR; SNR	–	–	–	–	Maintained vowel /a/
Rosenthal et al.	2014	–	CAPE-V	CSL	F_0	–	Oral air pressure; OAF; SGP; TLF; Translaryngeal resistance; MFDR	–	–	Syllable [pi] with different levels of vocal effort; Sentences
Vaziri et al.	2010	–	–	Vocal samples from Kay Elemetrics Corporation database (model 4337, v 1.03)	F_0; PPQ; APQ	–	–	–	–	Maintained vowel /a/; Lecture
Yiu et al.	2004	–	–	–	–	MPT	Intraoral pressure; SGP; Airflow rate	–	–	Long vowels (/a/, /i/, /u/) as many time as possible with comfortable tone and volume; Syllable [pi]; Sentences

Table 2. *Cont.*

Authors	Year	Acoustic Measurements				Aerodynamic Parameters		Myoelectric Parameters		Phonatory Tasks
		SM	QOM	OM	AP	W/T	WO/T	OM	N° Channels	
Zheng et al.	2012	–	–	MDVP model 5105	Jitter; Shim; PPQ; APQ	MPT	SGP; GR; MFR	–	–	Maintained vowel /a/ with comfortable frequency and intensity; Syllable [pa]

Note: SM, subjective measures; QOM, quasi-objective measures; OM, objective measures; AP, acoustic parameters; W/T, with tools, WO/T, without tools; F_0, Fundamental Frequency (Hz); F_0 max, Maximum Frequency (Hz); I min, Minimum intensity (dB); SGP, Subglottic Pressure (cm H20); VPSS, Voice Problem Self-Assessment Scale; CAPE-V, Consensus Auditory-Perceptual Evaluation of Voice; MDVP, Multi-Dimensional Voice Program; DSI, Dysphonia Severity Index; Shim, Shimmer (%); PPQ, Pitch Perturbation Quotient (%); APQ, Amplitude Perturbation Quotient (%); NHR, Noise-to-Harmonic Ratio (%); MPT, Maximum Phonation Time (seconds); VAS, Visual Analog Scale evaluation; SH, Suprahyoid muscles; IH, Infrahyoid muscles; CPPS, Smoothed Cepstral Peak Prominence (dB); V-RQOL, Voice-Related Quality of Life; CV F_0, Coefficient of variation of the fundamental frequency; CV I, Coefficient of Variation of the Intensity; HNR, Harmonics-to-Noise Ratio (%); OAF, Oral Airflow (cc/s); OA CV, Oral Airflow Coefficient Variation; GL, Glottic Leakage (cc* dB/s); GEI, Glottal Efficiency Index (dB/hPa); LE, Laryngeal Efficiency (dB* s/hPa*dm^3); OAF*P, Oral Airflow Power; MFR, Mean Airflow Rate (L/s); est-Pub, estimated subglottal pressure; EGG, Electroglottography; MFCC, Mel-frequency cepstrum coefficients; H1, First Harmonic; H2, Second Harmonic; F1, First Formant; F2, Second formant; GNE, Glottal to Noise Excitation; vF_0, Fundamental Frequency Variation; VTI, Voice Turbulence Index; SNR, Signal-to-noise ratio (%); NNE, Normalized Noise Energy (dB); MFDR, Maximum Flow Declination Rate (l/sec2); CSL, Computerized Speech Lab; TLF, Translaryngeal Airflow (mL/s); GR, Glottal Resistance (cm H2O/[L/s]); MTD, Muscular Tension Dysphonia.

Table 3. Summary of the tools and materials used in the selected studies.

Author	Year	Vocal Registry				Aerodynamic Registry		Electromyographic Registry		
		Microphone	MMD	Hardware	Software	Hardware and Tools	Software	Hardware	Software	Material
Aboras et al.	2010	–	–	–	MDVP	–	Aerophone II Model 6800	–	–	
Balata et al.	2015	Sennheiser PC-20	3 cm	Sony Vaio	VoxMetria 4.7h	–	–	Miotool 200®; SDS500 Sensors; LG notebook	Miograph 2.0; Windowa Vista Premium; Butterworth digital filter	MEDITRACE Pediatric electrodes
Björklund and Sundberg	2016	DPA 4066-C	12 cm	Symetrix SX202 Preamplifier; TEAC RD 200 PCM Sound card; Ono Sokki LA 210 Sound level meter	Soundswell program	Pressure transdiucer (Glottal Enterprises 162); TEAC RD 200 PMC Sound card; Pressure gauge	Soundswell program; Swellcal Module	–	–	–
Brockmann-Bauser et al.	2019	Sennheiser MKE104	10 cm	Symetrix SX302 Preamplifier; CyberAmp 380 electronic preconditioning; Voltage range: ±10V Digitada 1440A	Praat 5.4.1.4	Rothenberg's Mask	–	–	–	–

Table 3. *Cont.*

Author	Year	Vocal Registry				Aerodynamic Registry		Electromyographic Registry		
		Microphone	MMD	Hardware	Software	Hardware and Tools	Software	Hardware	Software	Material
Brockmann-Bauser et al.	2018	Sennheiser MKE104	10 cm	Symetrix SX302 Preamplifier; CyberAmp 380 electronic preconditioning; Voltage range: ±10V Digitada 1440A	Praat 5.4.1.4	–	–	–	–	–
Cantarella et al.	2011	AKG B29L	5 cm	–	EVA System	Rothenberg's Mask	–	–	–	–
Casado Morente et al.	2001	Professional microphonel (impedance: 600 ohms)	15 cm 45° angle	Richard Wolf de 70° Telelaringoscope; Machida ENT-30P-III Fibrolaringoscope; Fiegert Endotech CCD CD5131 Color camera; Super VHS; Richard Wolf 5012 Estrobosocope with cool light source; Pentium personal computer; Sound Blaster-Pro Sound car	"Voice Assessment" from Dr. Speech Science 3.0 software	–	–	–	–	–
Gilman et al.	2017	–	–	–	–	–	PAS	–	–	–
Hemmerling et al.	2016	–	–	–	Vocal database (SVD)	–	–	–	–	–
Holmberg et al.	2003	Sony ECM50	15 cm	–	–	–	–	–	–	–
Lopes et al.	2017	Sennheiser 835	10 cm	Dell all-in-one desktop; Preamplifierr U Phoria UMC 204	FonoView 4.5; VoxMetria 4.7h; Sound FOrge 10.0	–	–	–	–	–
Ma and Yiu	2006	Shure Beta 87	10 cm	–	MDVP CSL Phog 1.0	–	Aerophone II model 6800	–	–	–
Nemr et al.	2016	AKG 520	10 cm 30° angle	Desktop computer with USB 5.1 3D; Edirol UA-101 Sound card; Class B external digital amplifier; Sound level meter (Center model 322)	Audacity® Praat	–	–	–	–	–
Petrović-Lazić et al.	2011	Sennheiser E825S	5 cm	Laptop HACER ICK 70	MDVP CSL	–	–	–	–	–

Table 3. *Cont.*

Author	Year	Vocal Registry				Aerodynamic Registry		Electromyographic Registry		
		Microphone	MMD	Hardware	Software	Hardware and Tools	Software	Hardware	Software	Material
Rachel et al.	2018	BOOM815 Recorder; Microphone with NX Audio sound cable	5 cm	–	Praat 6.022 Dr. Speech 4 Matlab	–	–	–	–	–
Rosenthal et al.	2014	Micro condenser inside a Tascam DR-2d recorder	8 cm	Sound level meter	CSL	Rothenberg's Mask	Glottal Enterprises MS100-A2 with MCU-4 calibration Unit; TF32	–	–	–
Vaziri et al.	2010	DAT	–	–	Kay Elemetrics Corporation (model 4337, v 1.03)	–	–	–	–	–
Yiu et al.	2004	–	–	–	–	Rothenberg's Mask	Aerophone II model 6800	–	–	–
Zheng et al.	2012	–	–	–	–	Rothenberg's Mask	Kay Elemetrics Phonatory Aerodynamic System (model 6600	–	–	–

Note: MMD, Microphone-to-Mouth Distance; MDVP, Multi-Dimensional Voice Program; CSL, Computerized Speech Lab; PAS, Pentax Phonatory Aerodynamic System 6600; EGG, Electroglottography; SVD, Saarbruecken Voice Database by the Institute of Phonetics of the University of Saarland; MFDR, Maximum Flow Declination Rate; DAT, Digital Audio Tape.

Table 4. Summary of the results of the included studies in terms of acoustic parameters.

Author	Year	Group	Acoustic Parameters														
			Frequency			Intensity				Perturbation parameters							
			F_0	Max F_0	Min F_0	Intensity	Max I	Min I	CPPS	Jitt	Shim	HNR	NHR	VTI	PPQ	APQ	GNE
Aboras et al.	2010	SG	–	–	–	–	–	–	–	–	3.653	2.703	–	–	–	2.449	–
Balata et al.	2015	CG	194.66 ± 7.59	262.52 ± 12.48	–	68.74 ± 1.23	83.38 ± 0.94	–	–	-	–	–	–	-	-	-	-
		SG	195.08 ± 14.10	244.77 ± 10.88	–	64.20 ± 1.05	79.54 ± 1.36	–	–	-	-	-	-	-	-	-	-
Brockmann-Bauser et al.	2019	CG	249.2	266.6	244.1	87.7	95.8	81.1	16	–	–	–	–	–	-	–	–
		SG	243.3	253.4	248.4	88.0	95.9	79.5	15.6	–	–	–	–	–	–	–	–
Brockmann-Bauser et al.	2018	CG	249.2	266.6	244.1	87.7	95.8	81.1	–	Min: 0.38	2.66	25.1	–	–	-	–	–
										Comf: 0.30	1.65	27.7	–	–	–	–	–
										Max: 0.24	1.19	29.8	–	–	-	–	–
		SG	243.3	253.4	248.4	88.0	95.9	79.5	–	Min: 0.41	2.74	24.4	–	–	–	–	–
										Comf: 0.32	1.97	26.5					
										Max: 0.24	1.32	29.4					
Cantarella et al.	2011	CG	CV F_0: 0.79 ± 0.28			CV I: 0.92 ± 0.32			–	0.45 ± 0.22	0.26 ± 0.14	20.61 ± 2.96	–	–	–	–	–
		SG	CV F_0: 2.32 ±s 3.21			CV I: 1.20 ±0.50			–	2.15 ± 4.70	0.96 ± 0.92	14.62 ± 7.00	–	–	–	–	–

Table 4. *Cont.*

Author	Year	Group	Acoustic Parameters														
			Frequency			Intensity				Perturbation parameters							
			F_0	Max F_0	Min F_0	Intensity	Max I	Min I	CPPS	Jitt	Shim	HNR	NHR	VTI	PPQ	APQ	GNE
Holmberg et al.	2003	SG	207 ± 20.2	245 ± 29.6	–	83 ± 2.9	92 ± 3.2	–	–	-	–	–	–	–	–	–	–
Lopes et al.	2017	CG	201.87 ± 27.39	–	–	–	–	–	–	0.27± 0.16	5.22± 2.84	–	–	–	–	–	0.81± 0.18
		SG	194.24 ± 47.23	–	–	–	–	–	–	1.54± 2.58	8.22± 6.88	–	–	–	–	–	0.70± 0.20
Ma and Yiu	2006	CG	216.03 ± 34.09	1141.35 ± 311.38	40.08 ± 4.87	–	105.24 ±6.32	48.71 ±3.12	–	–	6.25± 7.58	–	0.24 ±0.04	–	–	0.98 ±0.38	–
		SG	196.72 ± 38.01	832.19 ± 266.51	120.04 ± 25.81	–	109.29 ±6.08	60.78 ±7.25	–	–	9.71± 3.66	–	0.24 ±0.07	–	–	1.81 ±0.99	–
Nemr et al.	2016	CG	452.9 ± 101.0	–	–	–	–	55.2 ± 4.4	–	0.38 ± 0.24	–	–	–	–	–	–	–
		SG	449.1 ± 90.2	–	–	–	–	58.4 ± 4.9	–	1.04 ± 0.84	–	–	–	–	–	–	–
Petrović-Lazić et al.	2011	CG	CV F_0: 1.117 ± 0.439			–	–	–	–	0.509 ± 0.168	1.845 ± 0.439	–	–	0.044 ± 0.014	0.319 ± 0.148	1.102 ± 0.365	–
		SG	CV F_0: 2.096 ± 1.241			–	–	–	–	1.986 ± 1.387	5.647 ± 2.457	–	–	0.065 ± 0.027	1.191 ± 0.850	4.156 ± 2.156	–
Rachel et al.	2018	CG	180.25 ± 62.99	–	–	–	–	–	–	0.463 ± 0.377	(in dB) 0.384 ± 0.443	20.34 ± 5.57	–	–	–	–	–
		SG	201.23 ± 67.9	–	–	–	–	–	–	0.64 ± 0.574	(in dB) 4.225 ± 3.24	20.51 ± 6.29	–	–	–	–	–
Vaziri et al.	2010	CG	–	–	–	–	–	–	–	–	–	–	–	–	0.3229 ± 0.0673	1.4698 ± 0.7359	–
		SG	–	–	–	–	–	–	–	–	–	–	–	–	1.3904 ± 4.2573	4.8993 ± 11.7756	–

Note: SG, Study Group; CG, Control Group; F0, Fundamental Frequency (Hz); F0 max, Maximum Frequency (Hz); F0 min, Minimum Frequency (Hz); I max, Maximum intensity (dB); I min, Minimum Intensity (dB); Comf, Comfortable; CV F0, Coefficient of Variation of the Fundamental Frequency (%); CV I, Coefficient of Variation of the Intensity (%); HNR, Harmonics-to-Noise Ratio; CPPS, Smoothed Cepstral Peak Prominence (dB); Jitt, Jitter (%) Shim, Shimmer (%); NHR, Noise-to-Harmonic Ratio (%); VTI, Voice Turbulence Index; PPQ, Pitch Perturbation Quotient (%); APQ, Amplitude Perturbation Quotient (%); GNE, Glottal to Noise Excitation.

Table 5. Summary of the results of the included studies in terms of aerodynamic parameters.

Author	Year	Group	Aerodynamic Parameters													
			MPT	SGP	OAF	OA CV	GL	TGI	LE	MFR	TGP	SQ	CQ	MFDR	TLF	GR
Aboras et al.	2010	SG	4.019	–	–	–	–	–	–	–	–	–	–	–	–	–
Björklund and Sundberg	2016	CG	–	W: 78.1 M: 80.0	–	–	–	–	–	–	–	–	–	–	–	–
Cantarella et al.	2011	CG	19.90 ± 6.93	12.05 ± 4.51	144.86 ± 58.36	6.64 ± 5.20	1.87 ± 0.78	10.62 ± 3.26	88.69 ± 84.05	–	–	–	–	–	–	–
		SG	11.52 ± 5.54	8.31 ± 2.64	213.70 ± 156.24	6.43 ± 6.66	2.85 ± 2.00	7.41 ± 2.62	43.76 ± 45.37	–	–	–	–	–	–	–
Gilman et al.	2017	CG	–	–	6.3 ± 1.4	–	–	–	–	0.19 ± 0.07	–	–	–	–	–	–
		SG	–	–	7.78 ± 3.17	–	–	–	–	0.17 ± 0.12	–	–	–	–	–	–
Holmberg et al.	2003	SG	–	–	–	–	–	–	–	0.31 ±0.09	11.0 ± 3.7	2.6 ± 0.4	40.4 ± 3.5	502 ±129	–	–
Ma and Yiu	2006	CG	[a]: 22.90 ±8.86 [i]: 24.45 ±8.79 [u]: 23.06± 9.05	[pi]: 9.75± 1.85 Sentence: 7.71± 1.72	–	–	–	–	–	[a]: 0.11 ± 0.04 [i]: 0.11 ± 0.04 [u]: 0.12 ± 0.05	–	–	–	–	–	–
		SG	[a]: 15.29 ± 7.79 [i]: 16.45 ± 7.64 [u]: 15.40 ± 6.67	[pi]: 16.95 ± 5.49 Sentence: 12.32 ± 4.13	–	–	–	–	–	[a]: 0.15 ± 0.08 [i]: 0.14 ± 0.08 [u]: 0.17 ± 0.09	–	–	–	–	–	–

Table 5. *Cont.*

Author	Year	Group	Aerodynamic Parameters													
			MPT	SGP	OAF	OA CV	GL	TGI	LE	MFR	TGP	SQ	CQ	MFDR	TLF	GR
Nemr et al.	2016	CG	17.4 ± 5.4	–	–	–	–	–	–	–	–	–	–	–	–	–
		SG	11.1 ± 5.5	–	–	–	–	–	–	–	–	–	–	–	–	–
Rosenthal et al.	2014	CG	Comfortable	7.03 ± 2.33	–	–	–	–	–	–	–	–	–	319.91 ± 194.30	174.87 ± 68.06	–
			Maximum	10.19 ± 4.55	–	–	–	–	–	–	–	–	–	540.96 ± 331.79	236.55 ± 60.00	–
			Minimum	5.37 ± 1.10	–	–	–	–	–	–	–	–	–	229.61 ± 115.18	202.72 ± 79.78	–
Zheng et al.	2012	CG	W: 23.36 ± 4.84	5.71 ± 1.49	–	–	–	–	–	0.08 ± 0.04	–	–	–	–	–	78.17 ± 58.50
			M: 25.74 ± 9 59	5.94 ± 1.26	–	–	–	–	–	0.11 ± 0.04	–	–	–	–	–	36.14 ± 22.15
		SG	W: 12.3 ± 4.61	10.47 ± 3.51	–	–	–	–	–	0.06 ± 0.04	–	–	–	–	–	180.85 ± 285.67
			M: 15.5 ± 6.47	10.25 ± 2.69	–	–	–	–	–	0.07 ± 0.04	–	–	–	–	–	63.98 ± 21.30

Note: SG, Study Group; CG, Control Group; W, Women; M, Men; MPT, Maximum Phonation Time (seconds); SGP, Subglottic Pressure (cm H20); OAF, Oral Airflow (cc/s); OA CV, Oral Airflow Coefficient Variation; GL, Glottic Leakage (cc* dB/s); GEI, Glottal Efficiency Index (dB/hPa); LE, Laryngeal Efficiency (dB* s/hPa*dm^3); MFR, Mean Airflow Rate (L/s); TGP, Transglottal Pressure (cm H2O); SQ, Speed Quotient (time opening/time closing); CQ, Closed Quotient -*100- (time closed/T); MFDR, Maximum Flow Declination Rate (l/sec2); TLF, Translaryngeal Airflow (mL/s); GR, Glottal Resistance (cm H2O/[L/s]).

With regards to the results obtained related to the acoustic parameters assessed in the selected studies, (Table 4), only those studies in which acoustic data appear (13 articles) have been included. In all of the studies, there are data on the average fundamental frequency (in Hz). In some, the maximum and minimum frequencies are also included. In two works [15,27] only disturbance parameters are studied: PPQ, APQ, and shimmer; and HNR and APQ, respectively.

Two studies [16,17] assessed the variation coefficient of the fundamental frequency (CV F_0), providing its values in % and not in Hz. The intensity is only studied in 7 of the 13 studies that analyze acoustic parameters.

The same happens with the acoustic disturbance parameters, which are studied in 9 of the 13 cases and the results are provided as a percentage, except in one of them [23] which reports shimmer results in dB.

Regarding the aerodynamic parameters assessed by the selected studies (Table 5), a great variability is observed. The most studied parameters were the maximum phonation time (MPT) in six of the nine articles and the subglottic pressure (SGP) in five of the nine studies.

In the only work included in the review which studied the relationship between acoustic and electromyographic parameters [19], data obtained in the different phonatory tasks (vowel /ε/ and counting at normal and maximum intensity) are reflected together with the different muscle groups studied: suprahyoid and infrahyoid muscles.

The aforementioned tables do not include data obtained in the subjective and quasi-objective assessment of the voice (VPSS, GRBAS scale, CAPE-V, V-RQOL, etc.), since the objective of this study was to assess the acoustic, aerodynamic, and electromyographic parameters.

3.4. Quality Assessment

The quality assessment of the observational studies included in the present review is presented in Tables 6 and 7. Overall, studies presented a clear structure, and the key data regarding the methodology and results were reported. Titles were appropriate, but often failed to indicate the study design. However, in all cases, the abstract presented an adequate summary of the methodology and main findings. Introductions presented a clear background and rationale for the investigation and indicated the specific aims of the studies. Generally, data regarding the methodology used was enough to allow for replication (i.e., inclusion criteria and variables were clearly defined, and statistical analyses were described), but none of the studies indicated how the sample size was calculated. With reference to the results, outcome data and the description of the main results were generally structured and clear, except data regarding the participants (i.e., characteristics, missing data, and drop-out rates, when applicable). Lastly, studies generally presented an adequate discussion: by describing, interpreting, and generalizing the main results, whilst addressing the possible limitations of the study design. Two other observational studies were included in the present review [15,20], but were not assessed using the STROBE statement, since they were based on voice recordings and not human subjects.

The last study included in the review [26] was a case series and was independently assessed for quality and risk of bias parameters using a specific tool for case series [11], as previously mentioned. Overall, the exposures and outcomes were adequately ascertained, and the cases were described with sufficient detail to allow for replication. However, the selection method for the participants was unclear.

Table 6. Quality assessment for observational studies: title, abstract, introduction and methodology.

Author	STROBE Checklist Items for Study Title, Abstract, Introduction and Methodology																	
	1a	1b	2	3	4	5	6a	6b	7	8	9	10	11	12a	12b	12c	12d	12e
Aboras et al., 2010	N	Y	Y	Y	Y	N	N	-	Y	Y	N	N	Y	Y	N	N	-	N
Balata et al., 2015	N	Y	Y	Y	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Björklund & Sundberg et al., 2016	N	Y	Y	Y	Y	N	N	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Brockmann-Bauser et al., 2019	Y	Y	Y	Y	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Brockmann-Bauser et al., 2018	Y	Y	Y	Y	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Cantarella et al., 2011	Y	Y	Y	Y	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Casado et al., 2001	Y	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Gillman et al., 2017	Y	Y	Y	Y	Y	Y	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Lopes et al., 2017	N	Y	Y	N	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	Y
Ma & Yiu et al., 2006	N	Y	Y	Y	Y	N	Y	-	Y	Y	Y	N	Y	Y	Y	N	-	N
Nemr et al., 2006	N	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Petrović-Lazić et al., 2011	N	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Rachel et al., 2018	Y	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	N	N	N	-	N
Rosenthal et al., 2014	Y	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Yiu et al., 2004	N	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N
Zheng et al., 2012	N	Y	Y	Y	Y	N	Y	-	Y	Y	N	N	Y	Y	Y	N	-	N

Y: reported (yes), N: not reported (no), -: non-applicable.

Table 7. Quality assessment for observational studies: results and discussion.

Author	STROBE Checklist Items for Study Results and Discussion															
	13a	13b	13c	14a	14b	14c	15	16a	16b	16c	17	18	19	20	21	22
Aboras et al., 2010	N	N	N	N	N	-	Y	Y	-	N	N	Y	N	Y	N	N
Balata et al., 2015	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Björklund & Sundberg et al., 2016	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Brockmann-Bauser et al., 2019	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Brockmann-Bauser et al., 2018	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Cantarella et al., 2011	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Casado et al., 2001	N	N	N	N	N	-	Y	Y	-	N	Y	Y	Y	Y	Y	Y
Gillman et al., 2017	N	N	N	N	N	-	Y	Y	-	N	Y	Y	Y	Y	Y	Y
Lopes et al., 2017	Y	Y	Y	N	N	-	Y	Y	-	N	Y	Y	Y	Y	Y	Y
Ma & Yiu et al., 2006	N	N	N	N	N	-	Y	Y	-	N	N	Y	N	Y	Y	Y
Nemr et al., 2006	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Petrović-Lazić et al., 2011	N	N	N	N	N	-	Y	Y	-	N	N	Y	N	Y	Y	Y
Rachel et al., 2018	N	N	N	N	N	-	Y	Y	-	N	N	Y	N	Y	Y	Y
Rosenthal et al., 2014	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Yiu et al., 2004	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y
Zheng et al., 2012	N	N	N	N	N	-	Y	Y	-	N	N	Y	Y	Y	Y	Y

Y: reported (yes), N: not reported (no), -: non-applicable.

4. Discussion

The multifactorial analysis of the voice, both objectively and subjectively, is of great interest for the study and evaluation of vocal disorders from a global perspective.

In studies where the sample was divided into two groups, only 10 specified the type of vocal pathology [12,13,16–18,20,24–26,28]. In addition, none of the studies specified how the calculation of the sample size or the sampling procedure was performed. Both the distribution by groups (gender and number) and the age ranges observed in the included studies were quite heterogeneous, except in two of the included works [24,25], where the same number of participants appeared in both groups. This heterogeneity may hinder the interpretation of the studies' results since both age and gender could act as factors influencing voice quality and its characteristics. Other factors such as ethno-cultural features or traits could also present a certain specificity in terms of the characteristics of the voice, as suggested by Lee et al. [31].

The voice evaluation techniques assessed in the different included studies are highly heterogeneous. In 10 of the studies [12,15,16,20,21,23–25,28] only acoustic parameters were registered, two included only aerodynamic parameters [13,22], and in seven [14–18,26,27,29,30] both parameters were recorded. Only one study assessed the acoustic parameters together with the myoelectric activity [19].

The most commonly analyzed acoustic parameters were the fundamental frequency [14–16,19–21,23–25,29,30], the intensity [14,19,21,24–26,28,30], the perturbation parameters of the frequency (jitter) [12,14,16–18,20,23,24,28], the perturbation parameters of the intensity (shimmer) [12,14,16–18,20,23,24,27,28], and the glottic noise (HNR, NHR, SNR . . .) [12,14,16,17,23,24,27].

In all of the included works, the phonatory tasks performed to evaluate the vocal register were indicated, except in one study [27]. The most commonly used was the emission of a sustained vowel /a/ at a comfortable frequency and intensity, although in some cases the minimum and maximum intensity possible was also requested. Other types of phonatory tasks that were carried out were: counting numbers (from 20 to 30) [19], repeating words [17], phrases [13,14,17,29], spontaneous conversation [17] and reading aloud [15]. In two works [19,28], the sustained vowel /ε/ was requested instead of /a/.

Most of the studies [12–16,18,21,23–26,28,29] reported on the characteristics of the space in which the samples were collected, these being silent or quiet rooms and soundproof rooms or cabins. However, only three of the analyzed studies specified the noise level in the room [14,21,28].

Regarding the results of the included studies in terms of acoustic parameters, the vocal disturbance parameters (jitter, shimmer, HNR, etc.) were higher and statistically significant differences were observed in people with pathological voices compared to people with healthy or non-dysphonic voices [12,16,23,24], the shimmer being one of the significant factors in the discrimination between subjects with and without vocal pathology [17].

On the other hand, the aerodynamic measurements reflected, to a higher degree, the presence of vocal pathology than the acoustic measurements [26]. Subglottic pressure has an important role in normal voice production and direct importance in the evaluation of laryngeal function [32].

Statistically significant differences were observed in subglottic pressure between the group with vocal pathology compared to the group without vocal pathology [22] and between genders [30]. Men with vocal pathology were also found to have higher subglottic pressure and glottic resistance compared to women with vocal pathology and shorter maximum phonation time [18].

In addition, one study indicated that the maximum phonation time and the glottic efficiency index are significant factors in the discrimination between subjects with and without vocal pathology [17].

According to another study [13], the use of aerodynamic measurements was a strong predictor to differentiate between groups with vocal pathology and without pathology. They also indicate that these should be used as an adjunct to therapy and not just as a diagnostic tool.

Analyzing the selected studies, a great variability was observed in almost all of the aspects observed, i.e., the sample size and characteristics, etc. However, what is most striking is the number of different protocols, hardware, and software used among the studies, hindering the generalization and establishment of acoustic, aerodynamic, and electromyographic normative parameters, as well as the comparison between the results obtained by the different studies and, in turn, defining what is understood by a normal voice and a pathological voice.

Nevertheless, an effort has been made to propose standardized protocols for the instrumental assessment of vocal function, such as the one presented by Patel et al. [33], developed by an American Speech-Language-Hearing Association expert panel. In this proposal, however the lack of evidence and consensus in the field is acknowledged, as described in the present manuscript.

5. Conclusions

In accordance with the objective of the present study, which aimed to evaluate the conditions of the normal and dysphonic voices in adults from acoustic, aerodynamic, and surface electromyographic parameters, it can be highlighted that the results from the included studies show differences between both voices.

The most studied acoustic parameters were frequency and intensity, which tend to decrease with the presence of dysphonia and disturbance parameters (jitter, shimmer, and HNR) that tend to increase in vocal pathology. Regarding the aerodynamic measurements, maximum phonation time (MPT) and subglottic pressure (SGP) were the most analyzed, with MPT being generally higher in people without vocal pathology and SGP higher in people with dysphonia. The existence of differences in surface electromyographic parameters cannot be determined due to the small number of articles that discuss this topic.

The small number of articles, the variability of the populations analyzed, the variety of instruments used, and aspects examined related to the voice, hinder the establishment of normative criteria to objectively define what is a normal voice and a dysphonic voice.

Studying the acoustic, aerodynamic, and electromyographic parameters with more precision, both of the normal and dysphonic voice, will allow health professionals working in the field of voice (speech therapy, otorhinolaryngology, phoniatrics, etc.) to establish a diagnostic and detailed consensus of the vocal pathology in question, favoring the communication and generalization of the results worldwide.

Therefore, more studies are needed to deepen the development and implementation of study protocols. This would favor the homogeneity of the records in order to be able to generate the necessary data to establish thresholds of normality and pathology, as well as allow the comparison of results between different study groups.

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References

1. Behlau, M. The 2016 G. Paul Moore Lecture. Lessons in Voice Rehabilitation: Journal of Voice and Clinical Practice. *J. Voice* **2019**, *33*, 669–681. [CrossRef] [PubMed]
2. Saggio, G.; Costantini, G. Worldwide Healthy Adult Voice Baseline Parameters: A Comprehensive Review. *J. Voice* **2020**, in press. [CrossRef] [PubMed]
3. Shewell, C. The effect of perceptual training on ability to use the vocal profile analysis scheme. *Int. J. Lang. Commun. Disord.* **1998**, *33*, 322–326. [CrossRef] [PubMed]
4. Jackson-Menaldi, M.C. Aspectos generales para tener en cuenta en la evaluación de la voz y organización del laboratorio de voz. In *La voz Normal y Patológica*; Médica Panamericana: Buenos Aires, Argentina, 2019; pp. 204–217.
5. Lee, L. Quick Screen for Voice and Supplementary Documents for Identifying Pediatric Voice Disorders. Language, Speech, and Hearing Services in Schools. *Lang. Speech Hear. Serv. Sch.* **2004**, *35*, 308–319. [CrossRef]
6. Awan, S.N.; Roy, N.; Zhang, D.; Cohen, S.M. Validation of the Cepstral Spectral Index of Dysphonia (CSID) as a Screening Tool for Voice Disorders: Development of Clinical Cutoff Scores. *J. Voice* **2016**, *30*, 130–144. [CrossRef]
7. Jannetts, S.; Schaeffler, F.; Beck, J.; Cowen, S. Assessing voice health using smartphones: Bias and random error of acoustic voice parameters captured by different smartphone types. *Int. J. Lang. Commun. Disord.* **2019**, *54*, 292–305. [CrossRef]
8. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ* **2021**, *372*, n71. [CrossRef]

9. Liberati, A.; Altman, D.G.; Tetzlaff, J.; Mulrow, C.; Gøtzsche, P.C.; Ioannidism, J.P.A.; Clarke, M.; Devereaux, P.J.; Kleijnen, J.; Moher, D. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *BMJ* **2009**, *339*, b2700. [CrossRef]
10. Von Elm, E.; Altman, D.G.; Egger, M.; Pocock, S.J.; Gøtzsche, P.C.; Vandenbroucke, J.P. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for reporting observational studies. *Int. J. Surg.* **2014**, *12*, 1495–1499. [CrossRef]
11. Murad, M.H.; Sultan, S.; Haffar, S.; Bazerbachi, F. Methodological quality and synthesis of case series and case reports. *BMJ Evid. Based Med.* **2018**, *23*, 60–63. [CrossRef]
12. Casado, J.C.; Adrián, J.A.; Conde, M. Estudio objetivo de la voz en población normal y en la disfonía por nódulos y pólipos vocales. *Acta Otorrinolaringol. Esp.* **2001**, *52*, 476–482. [CrossRef]
13. Yiu, E.M.L.; Yuen, Y.; Whitehill, T.; Winkworth, A. Reliability and applicability of aerodynamic measures in dysphonia assessment. *Clin. Linguist. Phon.* **2004**, *18*, 463–478. [CrossRef]
14. Ma, E.P.M.; Yiu, E.M.L. Multiparametric Evaluation of Dysphonic Severity. *J. Voice* **2006**, *20*, 380–390. [CrossRef] [PubMed]
15. Vaziri, G.; Almasganj, F.; Behroozmand, R. Pathological assessment of patients speech signals using nonlinear dynamical analysis. *Comput. Biol. Med.* **2010**, *40*, 54–63. [CrossRef] [PubMed]
16. Petrović-Lazić, M.; Babac, S.; Vuković, M.; Kosanović, R.; Ivanković, Z. Acoustic Voice Analysis of Patients with Vocal Fold Polyp. *J. Voice* **2011**, *25*, 94–97. [CrossRef] [PubMed]
17. Cantarella, G.; Baracca, G.; Pignataro, L.; Forti, S. Assessment of dysphonia due to benign vocal fold lesions by acoustic and aerodynamic indices: A multivariate analysis. *Logop. Phoniatr. Vocol.* **2011**, *36*, 21–27. [CrossRef] [PubMed]
18. Zheng, Y.Q.; Zhang, B.R.; Su, W.Y.; Gong, J.; Yuan, M.Q.; Ding, Y.L.; Rao, S.Q. Laryngeal Aerodynamic Analysis in Assisting With the Diagnosis of Muscle Tension Dysphonia. *J. Voice* **2012**, *26*, 177–181. [CrossRef]
19. Balata, P.M.M.; Silva, H.J.; Pernambuco, L.A.; Amorim, G.O.; Souto Maior Braga, R.; Fernandes Da Silva, E.G.; de Lima, L.M.; Arruda, S.R. Electrical Activity of Extrinsic Laryngeal Muscles in Subjects With and Without Dysphonia. *J. Voice* **2015**, *29*, 129.e9–129.e17. [CrossRef]
20. Hemmerling, D.; Skalski, A.; Gajda, J. Voice data mining for laryngeal pathology assessment. *Comput. Biol. Med.* **2016**, *69*, 270–276. [CrossRef]
21. Nemr, K.; Simões-Zenari, M.; De Souza, G.S.; Hachiya, A.; Tsuji, D.H. Correlation of the Dysphonia Severity Index (DSI), Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V), and Gender in Brazilians With and Without Voice Disorders. *J. Voice* **2016**, *30*, 765.e7–765.e11. [CrossRef]
22. Gilman, M.; Petty, B.; Maira, C.; Pethan, M.; Wang, L.; Hapner, E.R.; Johns, M.M., 3rd. Aerodynamic Patterns in Patients with Voice Disorders: A Retrospective Study. *J. Voice* **2017**, *31*, 545–549. [CrossRef]
23. Shamila Rachel, S.; Snekhalatha, U.; Vedhasorubini, K.; Balakrishnan, D. Spectral Analysis of Speech Signal Characteristics: A Comparison between Healthy Controls and Laryngeal Disorder. In *Advances in Intelligent Systems and Computing*; Springer: Berlin/Heidelberg, Germany, 2018; Volume 632, pp. 333–341. [CrossRef]
24. Brockmann-Bauser, M.; Bohlender, J.E.; Mehta, D.D. Acoustic Perturbation Measures Improve with Increasing Vocal Intensity in Individuals With and Without Voice Disorders. *J. Voice* **2018**, *32*, 162–168. [CrossRef]
25. Brockmann-Bauser, M.; Van Stan, J.H.; Carvalho Sampaio, M.; Bohlender, J.E.; Hillman, R.E.; Mehta, D.D. Effects of Vocal Intensity and Fundamental Frequency on Cepstral Peak Prominence in Patients with Voice Disorders and Vocally Healthy Controls. *J. Voice* **2019**, *35*, 411–417. [CrossRef] [PubMed]
26. Holmberg, E.B.; Doyle, P.; Perkell, J.S.; Hammarberg, B.; Hillman, R.E. Aerodynamic and acoustic voice measurements of patients with vocal nodules: Variation in baseline and changes across voice therapy. *J. Voice* **2003**, *17*, 269–282. [CrossRef]
27. Aboras, Y.; El-Banna, M.; El-Magraby, R.; Ibrahim, A. The relationship between subjective self-rating and objective voice assessment measures. *Logop. Phoniatr. Vocol.* **2010**, *35*, 34–38. [CrossRef]
28. Lopes, L.W.; Batista Simões, L.; Da Silva, D.J.; Da Silva Evangelista, D.; Da Nóbrega, A.C.; Oliveira Costa Silva, P.; Dias Vieira, V.J. Accuracy of Acoustic Analysis Measurements in the Evaluation of Patients With Different Laryngeal Diagnoses. *J. Voice* **2017**, *31*, 382.e15–382.e26. [CrossRef]
29. Rosenthal, A.L.; Lowell, S.Y.; Colton, R.H. Aerodynamic and Acoustic Features of Vocal Effort. *J. Voice* **2014**, *28*, 144–153. [CrossRef]
30. Björklund, S.; Sundberg, J. Relationship between Subglottal Pressure and Sound Pressure Level in Untrained Voices. *J. Voice* **2016**, *30*, 15–20. [CrossRef]
31. Lee, S.J.; Cho, Y.; Song, J.Y.; Lee, D.; Kim, Y.; Kim, H. Aging Effect on Korean Female Voice: Acoustic and Perceptual Examinations of Breathiness. *Folia Phoniatr. Logop.* **2015**, *67*, 300–307. [CrossRef]
32. Goozée, J.V.; Murdoch, B.E.; Theodoros, D.G.; Thompson, E.C. The effects of age and gender on laryngeal aerodynamics. *Int. J. Lang. Commun. Disord.* **2010**, *33*, 221–238. [CrossRef]
33. Patel, R.R.; Awan, S.N.; Barkmeier-Kraemer, J.; Courey, M.; Deliyski, D.; Eadie, T.; Paul, D.; Švec, J.G.; Hillman, R. Recommended Protocols for Instrumental Assessment of Voice: American Speech-Language-Hearing Association Expert Panel to Develop a Protocol for Instrumental Assessment of Vocal Function. *Am. J. Speech-Lang. Pathol.* **2018**, *27*, 887–905. [CrossRef] [PubMed]