Review Article

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Use of surface electromyography in phonation studies: an integrative review

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Summary

Introduction: Surface electromyography has been used to assess the extrinsic laryngeal muscles during chewing and swallowing, but there have been few studies assessing these muscles during phonation.
Objective: To investigate the current state of knowledge regarding the use of surface electromyography for evaluation of the electrical activity of the extrinsic muscles of the larynx during phonation by means of an integrative review.
Method: We searched for articles and other papers in the PubMed, Medline/Bireme, and Scielo databases that were published between 1980 and 2012, by using the following descriptors: surface electromyography and voice, surface electromyography and phonation, and surface electromyography and dysphonia. The articles were selectedon the basis ofinclusion and exclusion criteria.
Data Synthesis: This was carried out with a cross critical matrix. We selected 27 papers,i.e., 24 articles and 3 theses. The studies differed methodologically with regards to sample size and investigation techniques, making it difficult to compare them, but showed differences in electrical activity between the studied groups (dysphonicsubjects, non-dysphonicsubjects, singers, and others).
Conclusion: Electromyography has clinical applicability when technical precautions with respect to application and analysis are obeyed. However, it is necessary to adopt a universal system of assessment tasks and related measurement techniques to allow comparisons between studies.
Keywords: Electromyography; Phonation; Dysphonia; Laryngeal Muscles.

Introduction

The increased use of surface electromyography (SEMG) in speech and language pathology, not only in the literature but also in clinical practice, makes it important to investigate the current state of knowledge regarding this technique. This is true especially in the area of orofacial motricity, where SEMG is used as a tool for assessment and treatment. SEMG is also utilized in studies on the voice. When assessing the current knowledge regarding a particular subject area, it is important to identify and document the best evidence produced by quantitative and qualitative research on the topic in question. Then, through integrative review, it is possible to inventory gaps in the current knowledge that may constitute new challenges to the scientific community.

Electromyography is a technique that measures the electrical activity (EA) of several muscles in the body in order to diagnose movement disorders, and can also contribute to the assessment of prognosis in motor alterations. It has been employed in the fields of neurology, orthopedics, physical therapy, and otorhinolaryngology. There are 2 types of electromyographic examinations. Insertion electromyography (EMG) evaluates the action potentials of the motor units of deeper muscles; it is invasive and characterized by the use of needle electrodes fixed to the muscles under investigation. SEMG uses electrodes attached to the dermis to capture the myoelectric signals from muscles or muscle groups closer to the skin surface.

In speech and language pathology, SEMG is used to aid in diagnosis and therapy, especially for the orofacial functions of chewing and swallowing. These functions have a close relationship with movement of the larynx; the main function of the larynx is protection of the upper airways during the act of swallowing. To understand the activity of the intrinsic muscles of the larynx, the field of otorhinolaryngology has used EMG mainly for investigating neurological voice disorders. However, there has been little research on the extrinsic laryngeal muscles. These muscles have their origin in extra-laryngeal structures, but modify phonation indirectly by either raising or lowering the larynx via the basic function of the suprahyoid (SH) muscles and infrahyoid (IH) muscles, respectively. The evaluation of these muscles by SEMG is a procedure considered feasible for clinical examination.

The objective of this study was to investigate the current state of knowledge regarding the use of SEMG in assessing the EA of the SH and IH extrinsic muscles during phonation in order to help in understanding the complex phonatory phenomenon and its disorders, as well as to certify the use of this tool in vocal clinics.

Method

The integrative review is a method that belongs to the systematic review technique which, in turn, is focused on experimental studies that are preferably randomized with rigorous control of variables. This allows the safe development of evidence-based practice (1). As an alternative to narrative and systematic reviews, the integrative review involves a broader approach that allows the inclusion of studies which are not only experimental but also quasi-experimental or non-experimental. The process involved systematically follows pre-defined steps and allows a greater scope of theoretical and empirical sampling through a rigorous examination process.

The following steps comprised the present study: (1) preparation of the guiding question; (2) literature search for the definition of descriptors; (3) selection of articles according to the criteria for inclusion and exclusion; (4) collection, data extraction, reading, and critical analysis; (5) interpretation and discussion of results; (6) knowledge synthesis and review presentation.

Step 1) Preparation of the guiding question: the guiding question "what is the current state of knowledge regarding the use of SEMG in studies on the voice?" was defined from the theoretical and practical knowledge of the authors, with regards to the fact that SEMG is being increasingly used in studies on the area of speech and the voice, especially in Brazil.

Step 2) Literature search for the definition of descriptors: articles were searched for on the Pubmed, Medline, and Scielo databases using the following descriptors: surface electromyography and voice, surface electromyography and phonation, and surface electromyography and dysphonia.

Step 3) Selection of articles according to the criteria for inclusion and exclusion: articles and theses produced between 1980 and 2012 that complied with the criteria for inclusion and exclusion (Table 1) were included. Initially, we identified 48 articles on PubMed, 40 articles on Medline/Bireme, and 2 articles on Scielo using the descriptor surface electromyography and phonation. Due to the quantitative difference between Pubmed and Medline/Bireme, a new search with the same descriptors was performed on the Pubmed Central database. This time, 114 publications were found with the first descriptor surface electromyography and voice. With the other descriptors, the amount of publications found was lower, and all other articles had already been identified in the initial search (Figure 1).

Step 4) Collection, data extraction, reading, and critical analysis: these steps resulted in the development of an analytical matrix consisting of the following: article title, authors, country of origin, year of publication, type of study, study objective, sample, method (including vocal tasks and SEMG procedures), and conclusions (Table 2).These variables were considered to respond to the objective of the current review.

Steps 5) and 6) Interpretation and discussion of results and knowledge synthesis and review presentation:

Table 1. Inclusion and exclusion criteria for study selection

Inclusion criteria	Exclusion criteria
Articles and theses produced between 1980 to 2012 in English, Portuguese, and Spanish	Studies involving functions other than phonation
Experimental studies, quasi-experimental studies, or non-experimental studies	Studies restricted to description and evaluation of the technical characteristics of equipment
Studies addressing the use of SEMG as an assessment tool for normal and abnormal human voice	Studies addressing the use of SEMG as a training tool (biofeedback)
Studies evaluating the extrinsic muscles of the larynx and cervical muscles during vocal tasks	Studies on patients with alterations that prevent phonation

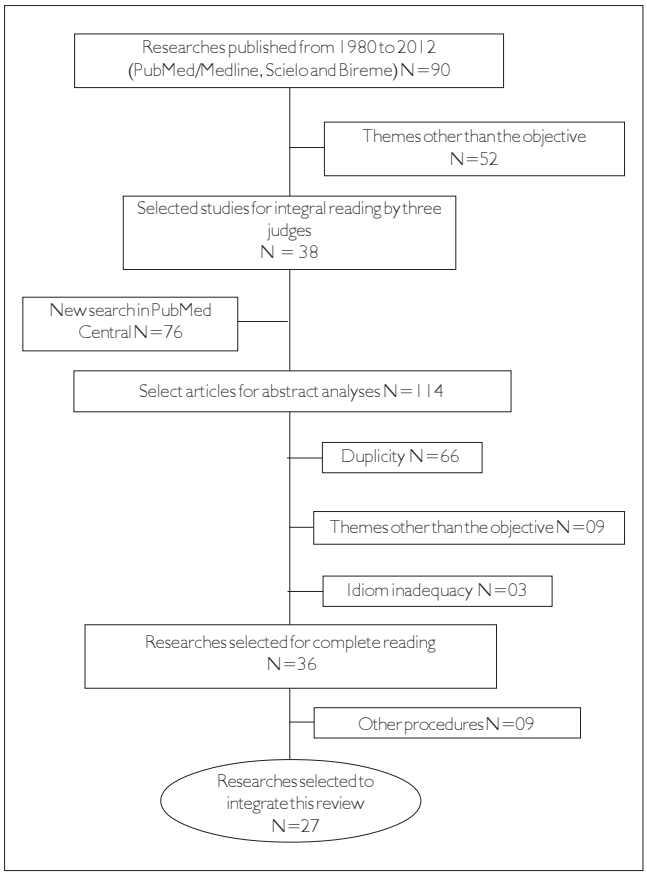

Figure 1. Scheme for searching and selection of works according to the inclusion and exclusion criteria.

analysis and discussion of the results were performed descriptively and integratively. This was followed by the sixth step that consisted of the synthesis of knowledge and review presentation.

Results and Discussion

The final selection of studies using the inclusion and exclusion criteria resulted in 24 articles and 3 theses being included for review; the theses consisted of a dissertation and 2 doctoral theses. Most studies included in this review originated from the United States (14 studies), followed by 5 articles from Brazil, 6 articles from European countries, and 1 article from Australia. This indicates the decentralization of interest in the use of SEMG technology to aid in understanding of the phonation phenomenon (Table 2).

While the use of SEMG in studies on voice began in the 1980s (2 studies), the number of studies increased in the 1990s (5studies) and from the year 2000 onwards (20 studies). From 2004, publications in this field had an annual frequency. This shows the growing interest of the scientific community in contributing more quantitative data on vocal assessment, which in turn has conferred greater objectivity to the parameters of this function, with the aim of understanding the behavior of the extrinsic muscles in various situations of phonation through the use of SEMG.

The studies investigated had diverse methodology, which made it difficult to compare them. The studies differed with respect to the muscle groups investigated, the tasks performed, and the sample size. There were often less than 40 subjects distributed between cases and controls (n = 25) (2-11), and some studies did not include comparison groups (n = 15) (12-25). However, controlled studies did show differences between the EA of muscles evaluated in case and control groups, and attested to the quality of SEMG as a tool for clinical evaluation of the voice.

Regarding the main objectives of the articles, there was a high frequency of articles studying hyperfunctional dysphonia (n = 7) (6,8,10,11,13,14,26), probably as a result of the muscle tension present in these frameworks and the need to bring greater objectivity to the assessment of these disorders. Other types of functional dysphonia, such as nodules and glottic chinks, were the subject of interest in 5 studies (4,7,9,16,27), and laryngectomized patients were subject of 3 studies (5,15,21). The muscle activity involved in singing was also a subject of interest (n = 4) (4,17,19,24). SEMG was used in the cervical and extrinsic laryngeal muscles, and the findings were related to the evaluation of various phonatory tasks such as usual phonation in the emission of vowels, connected speech and reading, simulated phonation in hyperfunction and whisper, singing voice, and the voice at rest.

Concerning electrode allocation, there was no normalization in the articles selected. Electrode allocation differed as a result of the objective of each study and the lack of an institutional recommendation regarding research procedures, especially for the muscles of small caliber that make up the SH, IH, and orofacial muscles (such as the lips orbicular (LO) and masseter (MA) muscle). Scientific organizations such as the *International Society of Electrophysiology and Kinesiology* (ISEK) and the group *Surface EMG for the Non-Invasive Assessment of Muscles* (SENIAM) integrate the basic research conducted in this area and enable exchange of data and experience with SEMG. These organizations have established appropriate criteria on electrode allocation and methods for captured signal processing, but make no reference to the muscle groups involved in phonation such as the SH and IH muscles.

The reason for election of unilateral electrode allocation in 12 studies is not clear (4,6,10,12-15,18,19,21,22,25), especially when the equipment used had channels to support bilateral investigation of muscle

activity. Bilateral evaluation of muscle activity may have identified possible asymmetries, although it does not always produce clear findings, as shown by the results of 8 studies (5,7,9,16,20,23,24,26). Therefore, the recommendation made in the study by Stepp (28) regarding compliance with the appropriate use of bipolar electrodes, which stated that they should be used in the body of the muscle of interest and never bilaterally, is apt.

Among the studies aimed at understanding hyperfunctional behavior, most (n = 4) evaluated both the IH and SH groups, and regarded the cervical muscles as the sternocleidomastoid (SCM), scalene (SC), and trapezius (TR) muscles. Some works (n = 2) evaluated the thoracic respiratory muscles, including the rectus abdominis (RA) and major pectoralis (MP) (17,19),during singing, detecting differences in EA according to the tasks performed. Muscles of the orofacial region, such as the MA and LO, were also evaluated (8,15,25).

It is interesting to mention that not all studies jointly assessed the SH and IH muscles, and investigators sometimes elected one or the other group for reasons that were not clarified in the methodology. However, investigation of the traction functions that such antagonistic muscles exert on the larynx during phonation and swallowing could extend the scope of projects studying the biomechanics of these functions. In addition, given the diversity of the tasks performed (emission of vowels, speaking, reading, and singing, with all of these tasks sometimes being requested in the same study), the reports investigated were too succinct in describing the occurrence of possible mechanical artifacts caused by the dynamics of emissions or difficulties associated with sustaining the electrodes in place during execution of these tasks.

The first classical studies (10,11) using SEMG to assess phonation in people with dysphonia, as well as the findings of Silvério (7),Hocevar-Boltezar, Janko, andZargi (8), and Neli (27), showed differences in the EA of muscles between dysphonic and non-dysphonic subjects, with activity being higher in dysphonia. This indicates that dysphonic and non-dysphonic subjects actually differ in their muscular activities. However, the results of more recent studies (13,26) contraindicate the use of SEMG as a tool to assess vocal hyperfunction and indicate that it may not be used for diagnosis of muscle tension dysphonia (MTD).Even if SEMG has no sensitivity or predictive value for the diagnosis of hyperfunction, study results suggesting different responses among different groups, including dysphonic subjects, singers and laryngectomized patients (2,3,7-11,15-21,23,25,27), suggest that this procedure has the ability to evaluate behavior in an inter- and intra-subject manner, and may be used as a benchmark for clinical outcomes.

Despite the methodological limitations of the studies analyzed, the technical evolution of SEMG measurement has involved some important factors that deserve consideration. For example, signal normalization is a technical recommendation that was used by 11 (40.7%) of the 27 studies included in this review. During SEMG, it is recommended to use a benchmark of muscle contraction from each person evaluated; this is known as signal normalization and reduces inter- and intra-subject variability. There are several ways to normalize a SEMG signal: by using the maximum peak of electrical activity, by using the maximal voluntary contraction (MVC) or submaximal voluntary contraction (SMC), and through the mean EA. When evaluating muscles of low caliber such as the SH, IH,SC, LO, or MA muscles, the occurrence of crosstalk (i.e., interference by signals from adjacent muscles) must be minimized to allow greater reliability in the capture and normalization of signals.

The articles studied in the current review used several methods of normalization, including maximal voluntary activation (MVA) or MVC (9,10,12,13,15,18,20), SMC (2,10), peak activity (14),and activity at rest (11). MVC was the most frequently used method. This was accomplished in most studies by means of manual counter-resistance or resistance against a static object (with platform to support the chin), and aimed to provide maximum activation of the SH, IH, SC, and SCM muscles. The extensive work of Stepp (28), which characterizes the clinical use of SEMG in studies on speech and swallowing, proposes the standardization of the methodological steps for use of this tool. Stepp also reports the use of normalization through MVC by various maneuvers, emphasizing manual counter-resistance (4,6,12,15,28).Despite the evidence provided by these articles, it is pertinent to note that the use of manual counter-resistance or resistance against an object may introduce a possible bias, given the possibility of recruitment of muscles adjacent to those of interest and thus the unwanted occurrence of crosstalk. This possibility gains strength when antagonistic muscle groups are being evaluated, as in the case of the SH and IH muscles. According to the studies mentioned above, the same maneuver was used to normalize the signals of different muscles. However, the use of the same maneuver to normalize all muscles being tested should be questioned. If, for example, the SCM has greater EA because it is larger and more robust, using the same normalizing maneuver for smaller muscles may result in the possibility that the SCM and perhaps the SC are also recruited for the normalization task. One measure that could minimize this potential bias would be to seek the maximum activation of specific muscle groups; since specific muscle groups have distinct and physiologically defined functions, this seems feasible. For the SCM, this would only be reliably achieved through some kind of biofeedback control that ensured the level of

contraction performed was within the desired threshold (50% less than the maximum level), a precaution that was taken in 2 previous studies (2,10).

Regarding normalization by the peak in speech emissions (reading, sentences, singing, and automatic sequences), this peak may be presented during the episode of respiratory pause and thus may not characterize the maximum phonation peak. In some situations, it may not even be present, as in the occurrence of an abrupt vocal attack for example.

The studies investigated came to the conclusion that normality standards for the EA of the muscles involved in speech phonation could be established, but these standards were not identified in any of the studies.At first, the definition of these parameters of normality seemed to be important for consistency among studies, in order to allow safe evaluation of similar cases and even evaluation of those with different etiology. However, SEMG does not seem to allow the definition of such standards, as this type of electrophysiological evaluation of phonation is subject to individual variables such as muscle conditioning, fat, sagging dermis, and teeth arch conditions. These variables are better controlled through the use of proper normalization, whereby the subject becomes an internal reference.

Although it has been advocated that the advent of high-density SEMG has contributed to the study of the action potentials of motor units, which was only possible previously using the invasive method of EMG, SEMG is not yet considered to be a tool for clinical implementation (29).Even so, it should be noted that despite the fact that methodological differences between studies hinder comparisons, the most recent studies, which are also the most numerous, use MVA normalization, which indicates a consistency in adopting this method. However, it should be assumed that normalization still constitutes a limitation of SEMG, since the maneuvers used for normalization did not differ between the muscles evaluated, which seems to create an important bias.

The current review identifies key gaps in the knowledge regarding use of SEMG for evaluation of phonation, and highlights the following challenges for future studies: normalization of electrode allocation by region and laterality; establishment of maneuvers for MVA to allow normalization by muscle (for antagonists in particular); and more robust studies with randomized control groups. However, the studies investigated point to a promising future regarding SEMG use. There is a mandatory requirement for the definition and adoption of an international system of assessment that establishes criteria for technical characteristics such as sites of electrode allocation, tasks to be performed, forms of assessment, signal treatment and analysis, and especially the most appropriate method of normalization. Finally, while acknowledging that SEMG has limitations and requires technical care during its application and analysis, we believe that this is a procedure that provides quantitative information for vocal assessment and allows objective paradigms for understanding the muscles involved in this function.

Conclusion

The current state of knowledge regarding the use of SEMG for the assessment of phonation confirms the clinical applicability of this tool, as published studies demonstrate differences in EA between groups. However, SEMG appears to have no predictive value as a diagnostic test. The standardization of assessment techniques should be established in order to enable comparisons among future studies.

Acknowledgements

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Table 2. Analysis matrix of the included studies.

Author(s)/year/country	Type of study	Objective	Sample	Vocal tasks	SEMG procedures	Conclusion(s)
Stepp(28)2012, USA	Review/ tutorial	To establish a consensus on the methodology of surface electromyography (SEMG) use for speech and swallowing	86 references	Not listed	-Electrode allocation in the orofacial, cervical, and infrahyoid (IH) regions - Normalization by maximal voluntary activation (MVA)of the cervical and mandible muscles in particular for 5 sec, 3 times	When proper care is taken for its use, SMEG has the potential for clinical use and research on speech and swallowing
Dietrich, Verdolini, Abbott(2)2011, USA	Non-experimental	To evaluate the influence of introversion in the vocal and extra-laryngeal behavior of vocally normal individuals as compared with extroverted subjects	2 groups: 27 introverted normal subjects and 2 extroverted normal subjects	Vowel emission, reading, public speaking, and rest	- Allocation of 2 electrodes in the submental (n = 1) and IH (n = 1) regions, unilaterally - Normalization by submaximal contraction (SMC) against resistive isometric depression (manual) of the mandible for 5 sec, 3 times	Introverted subjects had higher electrical activity (EA) of the IH muscles in different speaking situations
Van Houtte, Claeys, D'haeseleer, Wuyts, Van Lierde(26)2011, Belgium	Non-experimental	To evaluate SEMG as a diagnostic tool for muscle tension dysphonia (MTD)	2 groups: 18 subjects with MTD and 44 normal subjects	Vowel emission, reading, and spontaneous speech	- Allocation of 3 electrodes in the submental (n = 1), IH (n = 1), and cervical sternocleidomastoid(SCM) (n= 1) regions, bilaterally - Normalization by MVA with chin resistance against a chin platform and neck flexion for 10 sec, 3 times	There were no differences among the groups in muscle tension evaluated by SEMG, contraindicating this method for MTD diagnosis
Tamplinet al.(3)2011, Australia	Non-experimental	To evaluate the impairment of vocal function by respiratory failure caused by spinal injury	2 groups: 6 subjects with quadriplegia and 6 normal subjects	Vowel emission (high and soft loudness), reading (with and without masking), singing, and talking	- Electrode allocation in the cervical regions of the SCM and trapezius (TR), as well as the diaphragm - No normalization due to the physical limitations of the subjects	Respiratory deficiencies in quadriplegic subjects impaired vocal function, requiring recruitment of accessory muscles
Steppet al.(4)2011, USA	Non-experimental	To evaluate differences in the morphology of vocal nodules and impact on vocal function between singers and non-singers	3 groups: 10 singers with nodules, 8 non-singers with vocal nodules, and 10 normal subjects	Vowel emission, reading, and spontaneous speech	- Allocation of 3 electrodes in the cervical SCM region (n = 1) and IH region (n = 2; divided between thethyrohyoid (TH), omohyoid (OH),sternohyoid (SH),cricothyroid (CT), and sternothyroid (STH) muscles), unilaterally -Normalization by MVA (not specific for muscle)	SEMG did not differentiate between singers and non-singers with nodules, showing no specificity for the presence of nodules
Stepp, Hillman, Heaton(12)2011, USA	Non-experimental	To evaluate the inter-muscular beta coherence of the neck regarding modulation by means of SEMG	1 group: 10 normal subjects	Spontaneous speech, intelligible speech, speech with divided attention, singing, and hyperfunctionalspeech	- Allocation of 2 electrodes in the anterior neck region, 1 in the upper region of the neck (TH and OH) and another below (CT, SH, and STH), unilaterally-Normalization by MVA of the neck against manual counter-resistance and use of a dynamometer to maintain the strength of tongue retraction	The measurement of inter-muscular beta coherence differed between the speech tasks and hyperfunctional speech, resembling results found in patients with vocal nodules

Stepp et al.(13)2011, USA	Non-experimental	To compare the current classification systems of neck palpation	1 group: 16 subjects with hyperfunctional dysphonia	Vowel emission, reading, spontaneous speech, and rest	- Allocation of 3 electrodes in the IH region (n = 2; divided between the TH, OH, and SH muscles and the SH and CT muscles) and the cervical SCM region (n = 1), unilaterally-Normalization by MVA of the neck against manual counter-resistance	The inter-rater reliability was low for capture of tension in the neck
Stepp, Hillman, Heaton(5)2010, USA	Non-experimental	To evaluate the inter-muscular beta coherence of the neck muscles as an indicator of hyperfunctio-nal dysphonia	2 groups: 18 subjects with vocal nodules and 18 normal subjects	Spontaneous speech andreading	- Allocation of 2 electrodes in the anterior IH region (right and left), divided between the TH, OH, and STH muscles and the CT and SH muscles, unilaterally- Normalization not referred to	Measurement of beta coherencein the neck muscles with SEMG can be an indicator of vocal hyperfunction
Stepp et al.(6)2010, USA	Non-experimental	To determine the sensitivity of SEMG for identifying changes in the degree of vocal hyper-function	1 group: 13 subjects with hyperfunctional dysphonia	Vowel emission, spe-aking, reading, and sniff maneuver	- Allocation of 3 electrodes in the IH region (n = 2; divided between the TH, OH, and SH muscles and the SH and CT muscles) and the cervical SCM region (n =1), unilaterally-Normalization by MVA with manual counter-resistance	The significance of SEMG data was not sufficient to enable the use of this tool in assessing vocal hyperfunction
Santos, Caria, Tosello, Bérzin(14)2010, Brazil	Non-experimental	To evaluate the effects of type of esophageal voice and use of an electronic larynx on the cervical muscles	3 groups: 5 subjects with an electronic larynx, 5 subjects with esophageal speech, and 7 normal subjects	Spontaneous speech andreading	- Electrode allocation in the SCM and cervical paraspinal muscles, bilaterally-Standardization by the EA peak of the SCM and paraspinal muscles	Type of voice did not affect the pattern of muscle activity
Stepp, Heaton, Rolland, Hillman(15)2009, USA	Non-experimental	To check for electronic larynx control with SEMG	1 group: 8 laryngectomi-zedsubjects	Spontaneous speech and sequence of phrases	- Allocation of 7 electrodes in the submental region (n = 1), the upper portion of the neck (n = 1), above the stoma (n = 2), the oral rima (n = 1), the masseter muscle (n = 1), and the SCM muscle (n = 1), unilaterally- Normalization not referred to	Electrodes placed in the submental and upper neck regions provided the best signals for electronic hands-free larynx control
Guirro et al.(16)2008, Brazil	Non-experimental	To evaluate the EA of the suprahyoid (SH), SCM, and TR muscles as well as pain and voice after transcutaneous electrical nerve stimulation (TENS) in dysphonic subjects	1 group: 10 dysphonic subjects	Vowel emission, sponta-neous speech, and rest	- Allocation of electrodes in the SH, SCM, and TR regions, bilaterally - Number of electrodes not referred to - Normalization not referred to	There was reduction of EA in the muscles investigated, as well as pain reduction and improvement in vocal quality
Nelli(27)2006, Brazil	Non-experimental	To analyze body posture in patients with dys-phonia	2 groups: 23 dysphonic subjects and 20 normal subjects	Vowel emission, senten-ce repetition, counting, and rest	- Allocation of electrodes in the SH, IH, and SCM regions, unilaterally - Normalization not referred to	There was a positive correlation between dysphonia and postural change

Mendes, Brown, Sapienza, Rothman(17)2006, Portugal	Non-experimental	To determine if vocal training improves respiratory kinematics and muscle activity during singing	1 group: 4 singingstudents	Singing	- Allocation of electrodes in the respiratory region of the pectoralis major (PM), rectus abdominis (RA), and external oblique (EO) muscles - Number of electrodes not referred to - Normalization not referred to	Vocal training improved the force generated in the muscles evaluated
Pettersen, Bjørkøy, Torp, Westgaard(18)2005, Norway	Non-experimental	To investigate the intra-subject pattern activity of the SCM, scalene (SC), and upper TR muscles during the variation of loudness and pitch	1 group: 8 singing students	Vowel emission during gliding in a comfortable or high tone, speech in a loud or comfortable tone, and singing	- Allocation of electrodes in the respiratory region of the TR muscle and the cervical region (SCM, SC), unilaterally - Normalization by MVA with lateral flexion of the neck	The SCM and SC musclesdisplayedopposing forces in the chest at high pitch and during speech rather than upon inspiration
Pettersen, Westgaard(19)2005, Norway	Non-experimental	To characterize the activity patterns of the neck muscles during classical singing	1 group: 5 singers	Singing voice emission in different intensities	- Allocation of electrodes in the cervical region of the SCM and SC muscles, the posterior neck region, and the thoracic region (TX), unilaterally - Normalization by MVA with lateral flexion of the neck and head extension	Activity of the SCM, SC, and posterior region of the neck was correlated during inspiration and phonation in singers
Loucks et al.(20)2005, USA		To evaluate whether vocal changes resulting from mechanical disturbance are due to quick responses of the intrinsic muscles of the larynx	1 group: 10 normal subjects	Vowel emission with pitch variation, spontaneous speech, rest, whisper, and phonation with effort	- Allocation of electrodes in the thyroid region (STH) and the medial region of the cricoid to the SCM, bilaterally - Normalization by MVA with effort on the chin	There were changes in fundamental frequencies due to STH muscle response but not intrinsic muscles
Heaton et al.(21)2004, USA	Experimental	To systematically evaluate the use of SEMG for control of hands-free electronic larynxes	1 group: 8 laryngectomized subjects	Vowel emission, connected speech, and reading	- Allocation of electrodes in the neck, unilaterally - Normalization not referred to, but laryngeal contraction tasks through the retracted tongue were performed	SEMG can be an effective source for electronic larynx activation and control of voice modulation
Silvério(7)2002, Brazil	Non-experimental	To evaluate voice and the EA of the SCM and SH muscles in subjects with temporomandibular disorders (TMD)	2 groups: 10 dysphonic subjects and 10 normal subjects	Vowel emission, connected speech, spontaneous speech, and rest	- Allocation of electrodes in the submandibular region of the SH muscles and the SCM region, bilaterally - Normalizationofmean envelope	The EA of the SCM was higher in subjects with MTD

Sapir, Baker, Larson, Ramig(22)2000, USA	Non-experimental	To evaluate variations in fundamental frequency (F0) and EA induced by mechanical disturbance of the larynx	1 group: 19 normal subjects	Vowel emission	- Allocation of electrodes in the laryngeal region (CT), SH-digastric anterior and geniohyoid region, and IH-posterior region of the cricoid, unilaterally - Normalization not referred to	Sudden and mechanical disruption varied F0 according to the direction of the stimulus and increased the EA latency
Hocevar-Boltezar, Janko, Zargi(8)1998,Slovenia	Non-experimental	To determine the electromyographic characteristics of the muscles of the perioral and anterior neck regions during phonation	2 groups: 11 subjects with hyperfunctional dysphonia and 5 normal subjects	Vowel emission and rest	- Allocation of 9 electrodes in the perioral (upper and lower lips, chin), laryngeal (TH and CT), and cervical (SCM) regions, bilaterally - Normalization not referred to	There was increased EA of the muscles investigated during phonation and silence in dysphonic subjects
Silvério(9)1998, Brazil	Non-experimental	To evaluate the EA of the SCM and TR muscles in dysphonic subjects	2 groups: 10 dysphonic subjects and 10 normal subjects	Vowel emission, fricatives, connected speech, spontaneous speech, and rest	- Allocation of electrodes in the cervical region (SCM and TR), bilaterally - Normalization by MVA with neck flexion for the SCM and elevated shoulders for the TR	There was increased EA of the muscles investigated in dysphonic subjects
Laukkanen, Lindholm, Vilkman, Haataja, Alku(23)1996, Finland	Non-experimental	To evaluate the larynx and glottal source before and during the exercise of voiced bilabial fricative	1 group: 6 normal subjects	Vowel emission	- Allocation of 2 pairs of electrodes in the thyroid region, bilaterally - Normalization not referred to	The SEMG signal of laryngeal muscles proved to be reduced after exercise, indicating a lower EA and greater vocal economy
Larson, Sapir(24)1995, USA	Non-experimental	To evaluate the response of laryngeal and perioral reflexes to changes in affective state	1 group: 24 soprano singers	Continuous emission	- Allocation of electrodes in the orbicularis region, bilaterally - Normalization not referred to	There were no significant changes in orolaryngeal reflexes in response to changes in affective states
Sapir, Larson(25)1993, USA	Non-experimental	To evaluate the role of the SH muscles in vibrato control	1 group: 4 soprano singers		- Allocation of electrodes in the SH, thyroid cartilage, mandibular branch, and upper lip regions, unilaterally	There was involvement of the SH and extra-laryngeal muscles in vibrato control
Redenbaugh, Reich(10)1989, USA	Non-experimental	To evaluate absolute and relative SEMG signals in the anterior neck muscles of normal subjects and subjects with hyperfunctional dysphonia	2 groups: 7 normal subjects and 7 subjects with hyperfunctional dysphonia	Vowel emission and reading	- Allocation of electrodes in the laryngeal region (TH), unilaterally - Standardization of MVC and SMC with chin resistance against a platform	There were significant differences in the absolute values of the tasks, with values being higher in dysphonic subjects
Milutinoviæ, Lastovka, Vohradník, Janoseviæ(11) 1988, Czechoslovakia	Non-experimental	To evaluate the EA of the laryngeal, thoracic, and abdominal muscles during hyperkinetic phonation	2 groups: 5 normal subjects and 6 subjects with hyperfunctional dysphonia	Vowel emission, reading, and spontaneous speech in a comfortable/relaxing or loud pitch	- Allocation of electrodes in the thyroid lamina, chest, and abdomen - Normalization by rest	SEMG showed increased EA of the muscles of the larynx, thorax, and abdomen in subjects with hyperkinetic dysphonia

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