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Electropalatography and its correlation to tongue movement ultrasonography in speech analysis

Eletropalatografia e sua correlação à ultrassonografia do movimento de língua nas análises da fala

ABSTRACT

Purpose: To analyze the use of electropalatography and ultrasonography regarding speech therapy through literature narrative review. **Research strategies:** A literature review was conducted at PubMed and Scielo databases, using descriptors as electropalatography, electropalatography AND evaluation, electropalatography AND therapy, electropalatography AND ultrasonography, electropalatography AND speech. **Selection criteria:** The research criteria selected in the database were: studies in the past five years and studies in humans. In the pre-selection, studies that were duplicate, not fully available, and have shown no direct relation with electropalatography in speech-language therapy were discarded. **Data analysis:** Data analysis was performed descriptively, following subdivisions: title, area, year, subject, implementation, and conclusion of the study. **Results:** Twenty one papers were selected, eight of them using the term electropalatography, two with the keywords electropalatography AND evaluation, six with the keywords electropalatography AND therapy, three of them with the keywords electropalatography AND ultrasonography, and two papers with the keywords electropalatography AND speech. **Conclusion:** Different types of research involving the use of electropalatography in the field of speech-language therapy were found and analyzed. Few researches have concomitantly used electropalatography and ultrasonography.

RESUMO

Objetivo: Analisar o uso da eletropalatografia e ultrassonografia na área da Fonoaudiologia por meio de revisão narrativa de literatura. **Estratégia de pesquisa:** Foi realizada pesquisa bibliográfica nas bases de dados PubMed e Scielo, utilizando como descritores *electropalatography*, *electropalatography AND evaluation*, *electropalatography AND therapy*, *electropalatography AND ultrasonography*, *electropalatography AND speech*. **Crítérios de seleção:** Como critério da pesquisa em base de dados, foram selecionados: estudos dos últimos cinco anos e estudos em humanos. Na pré-seleção, foram descartados estudos duplicados, não disponibilizados na íntegra e que não apresentassem relação direta da eletropalatografia para a área da Fonoaudiologia. **Análise dos dados:** A análise de dados foi realizada de forma descritiva, seguindo as subdivisões: título, área, ano, tema, aplicação e conclusão do estudo. **Resultados:** Foram selecionados vinte e um artigos, oito deles utilizando o termo *electropalatography*, dois com os descritores *electropalatography AND evaluation*, seis artigos com os descritores *electropalatography AND therapy*, três artigos com os descritores *electropalatography AND ultrasonography* e dois artigos com os descritores *electropalatography AND speech*. **Conclusão:** Foram encontrados e analisados diferentes tipos de pesquisas envolvendo o uso da eletropalatografia na área da Fonoaudiologia. Poucas pesquisas utilizaram concomitantemente a eletropalatografia e a ultrassonografia.

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INTRODUCTION

Speech is one of the most complex communication skills of human behavior, being a result of synchrony among orofacial, pharynx, larynx, and chest cavity muscles. Any change in any of these production levels can impair speech intelligibility. It is known that subjective perceptual evaluations are not enough for an accurate diagnosis and appropriate treatment. Objective clinical assessments are necessary to accurately check the level of production that is changed and provide ways for the Speech Language Pathologist (SLP) to intervene in the treatment.

In order to provide better evaluation conditions such as biofeedback for speech therapy, instrumental techniques such as ultrasonography (US) and electropalatography (EPG) have emerged. The use of objective instruments in the research and clinical speech therapy allows objective assessment of speech⁽¹⁻³⁾ and provides biofeedback to change speech production⁽⁴⁾.

US is applied to the field of speech/language, voice and swallowing, allowing a direct visualization of tongue movements, providing information about the processes involved in speech, also enabling the learning of perception and production parameters during speech therapy, which provides relevant information on this function when associated with the use of EPG.

Regarding the use of EPG in speech therapy, studies⁽⁵⁾ show that this instrument allows the therapist to observe the way the contacts between tongue and palate are, through palatogram configuration, which consists of the images of the contacts between tongue and palate provided by the percentage of contacts recorded for each phoneme. EPG can be applied in many areas of study of speech therapy, especially orofacial motor skills for the analysis of phonetic and phonological changes, as well as other language disorders. In addition, there are reports of the application of this technique in dentistry and ortodontics⁽⁶⁾, being positive its use combined with ultrasonography.

In Brazil, studies on the application of instrumental analysis are still scarce. Thus, this research proposes to present a literature review on the use of electropalatographic analysis alone and/or combined with speech ultrasonography in different areas of speech therapy.

METHODS

This review study was based on the following initial question: "How does the use of electropalatography isolated and/or with ultrasonography analysis of tongue movements can contribute to research and clinical speech therapy?" The objective of this review was to determine whether the use of electropalatography brings real benefits to research in speech therapy, as well as to point the application of this technique in clinical treatments, isolated and/or with the use of speech ultrasonography.

Papers have been selected based on searches at PubMed and Scielo databases aiming to answer the question, with the criteria as follows: apply electropalatography or its analysis associated with ultrasonography as an instrument for obtaining data; relate electropalatographic or ultrasonographical information to some of the areas of interest of speech therapy – such as speech, phonetics, voice, orofacial motricity, and/or swallowing; to

be fully available at PubMed, Scielo, or CAPES databases. The filters used in the search were: five years of studies and studies in humans.

Thus, 21 abstracts were found, being analyzed concerning their applicability.

The keywords were selected and combined as follows: electropalatography, electropalatography AND evaluation, electropalatography AND therapy, electropalatography AND ultrasonography, electropalatography AND speech.

The analysis of papers for the results was presented following the subdivisions for Charts in authors, year, study type, country, area, subject, and application, as well as title, objectives, results, and conclusion.

RESULTS

In Charts 1, 2, 3, 4, and 5, the papers found at PubMed and Scielo platforms will be presented, as well as the number of papers according to the following terms searched: electropalatography; electropalatography AND evaluation; electropalatography AND therapy; electropalatography AND ultrasonography; and electropalatography AND Speech. These Charts describe the type of study, the country, the area, the subject, and the application.

Regarding the eight (8) papers found at PubMed platform with the term electropalatography, two (2) were case-control studies, two (2) were prospective and qualitative, one (1) was a prospective, quantitative, and qualitative case-control, one (1) was a quantitative prospective paper, and the other one (1), was an exploratory case study. As for the study area, the speech was part of all the studies, followed by linguistics, which was observed in three (3) papers, the rest of the studies was divided into areas such as hearing habilitation and rehabilitation, orthodontics, voice, and neurology. Aside from a study that applied EPG combined with Electromagnetic Articulography (EMA), all studies investigated the isolated use of EPG. In addition, two (2) studies dedicated exclusively to EPG in speech therapy and the other ones only EPG as a clinical assessment tool.

Only two (2) papers were found at PubMed platform with the term and descriptor electropalatography AND evaluation, one (1) exploratory and the other one (1) quantitative prospective research. Regarding the area of study, both researched the isolated use of EPG in speech exclusively in SLP assessment.

Through the search at PubMed platform with the term and descriptor electropalatography AND therapy, six (06) papers were found, of which only one (1) was a prospective quantitative one, the other paper (1) was a randomized and the (4) other ones were descriptive papers. Regarding the study area, all the papers approached speech, being one of them related to the use of EPG in speech and neurology. Half of the studies showed the application of EPG in speech clinical assessment and the other half showed the use of this technique in therapy.

Concerning the search at PubMed platform with the term and descriptor electropalatography AND ultrasonography, three (3) papers were found, two (2) prospective qualitative quantitative papers, and one (1) descriptive. Regarding the study area, all referred to speech, and one incorporated neurology in its research. All studies put together EPG and US, and one of

Chart 1. Results found at PubMed platform with the term electropalatography

Study	Authors/ Year of Publication	Study Design	Country	Area	Subject	Application
1	Öller Darelid M, Hartelius L, Lohmander A (2015) ⁽⁷⁾	Case control	Sweden	Speech / Hearing	EPG	Therapy
2	Lee A, Gibbon FE, Oebels J (2015) ⁽⁸⁾	Prospective, qualitative	Scotland	Speech / Linguistics	EPG	Evaluation
3	Mantie-Kozlowsky A, Pitt K (2014) ⁽⁹⁾	Case control	USA	Speech / Orthodontics	EPG	Therapy
4	Lee A, Gibbon FA, Kearney E, Murphy D (2015) ⁽¹⁰⁾	Prospective, qualitative	Scotland	Speech / Linguistics	EPG	Evaluation
5	Weirich M, Fuchs S (2013) ⁽¹¹⁾	Case control Prospective, quantitative, and qualitative	Germany	Speech / Linguistics	EPG EMA	Evaluation
6	Timmins C, Hardcastle WJ, Wood S, Cleland J (2011) ⁽¹²⁾	Prospective quantitative qualitative	Scotland	Speech	EPG	Evaluation
7	Koenig LL, Fuchs S, Lucero JC (2011) ⁽¹³⁾	Prospective quantitative	Germany	Speech / Voice	EPG	Evaluation
8	Folker JE, Murdoch BE, Cahill LM, Rosen KM, Delatycki MB, Corben LA et al. (2010) ⁽¹⁴⁾	Exploratory research - Case Study	Australia	Speech / Neurology	EPG	Evaluation

Caption: EPG - Eletropalatografia; EME - Electromyographic evaluation

Chart 2. Results found at PubMed platform with the term and descriptor electropalatography AND evaluation

Study	Authors / Year of Publication	Study Design	Country	Area	Subject	Application
9	Mantie-Kozlowski A, Pitt K (2013) ⁽⁴⁾	Exploratory research - Case Study	USA	Speech	EPG	Evaluation
10	McLeod S (2011) ⁽⁶⁾	Prospective quantitative	Australia	Speech	EPG	Evaluation

Caption: EPG - Electropalatography

Chart 3. Results found at PubMed platform with the term and descriptor electropalatography AND therapy

Study	Authors / Year of Publication	Study Design	Country	Area	Subject	Application
11	Ballard KJ, Smith HD, Paramatmuni D, McCabe P, Theodoros DG, Murdoch BE (2012) ⁽¹⁵⁾	Prospective quantitative	Australia	Speech	EPG	Therapy
12	Murdoch BE, Kuruvilla MS, Goozée JV (2012) ⁽¹⁶⁾	Descriptive study	Australia	Speech	EPG EME	Evaluation
13	Gibbon FE, Lee A (2011) ⁽¹⁷⁾	Descriptive study	Ireland	Speech	EPG	Evaluation
14	Nordberg A, Carlsson G, Lohmander A (2011) ⁽¹⁸⁾	Descriptive study	Sweden	Speech	EPG	
15	Harteringer M, Tripoliti E, Hardcastle WJ, Limousin P (2011) ⁽¹⁹⁾	Quantitative randomized study	United Kingdom	Speech / Neurology	EPG	Evaluation
16	Lohmander A, Henriksson C, Havstam C (2010) ⁽²⁰⁾	Descriptive study	Sweden	Speech	EPG	Therapy

Caption: EPG - Electropalatography; EME - Electromyographic evaluation

Chart 4. Results found at PubMed platform with the term and descriptor electropalatography AND ultrasonography

Study	Authors / Year of Publication	Study Design	Country	Area	Subject	Application
17	Bacsfalvi P, Bernhard PM (2011) ⁽²¹⁾	Prospective qualitative quantitative	USA	Speech	US EPG	Evaluation
18	Murdoch BE (2011) ⁽²²⁾	Descriptive study	Australia	Speech / Neurology	EPG / EPG pressure sensitive / EME / US	Evaluation
19	McMillan CT, Corley M (2010) ⁽²³⁾	Prospective quantitative qualitative	Scotland	Speech	EPG US	Evaluation

Caption: EPG - Electropalatography; US - Ultrasonography; EMA - Electromyographic assessment

Chart 5. Results found at Scielo platform with the term and descriptor electropalatography AND speech

Study	Authors / Year of Publication	Study Design	Country	Area	Subject	Application
20	Jesus MS, Reis C (2012) ⁽²⁴⁾	Case study	Brazil	Speech	EPG	Evaluation
21	Jesus MS, Reis C (2012) ⁽⁵⁾	Case study	Brazil	Speech	EPG	Evaluation / Description

Caption: EPG - Electropalatography

Chart 6. Analysis of the selected studies

Study	Title	Objective	Results	Conclusion
1	Generalized EPG treatment effect in the cochlear implant user maintained after 2 years.	Assess the progress of therapy of a cochlear implant user with hearing impairment who had persistent errors of speech, applying EPG as visual feedback.	Improved production of the treatment target /g/ in simple words, sentences, connected speech, and texts reading after four months of treatment. Furthermore, results were maintained up to 24 months after intervention.	EPG seems to be a very effective method in the treatment of disorders in speech associated with hearing impairment since it can be used at home to monitor speech.
2	Lateral bracing of the tongue during the onset phase of alveolar stops: an EPG study.	Investigate the dynamic characteristics of the lateral contact of the tongue with the palate at the beginning of alveolar occlusion of phonemes /t/, /d/, and /n/ in typical adults, with the use of EPG.	The configuration of the tongue and its position were different between nasal and oral occlusive, being speculative the rate of contact for /t/ and /d/ in comparison with /n/, to the increased intraoral pressure in the oral plosives and the different positions of the jaw and shapes of the tongue for both types of sounds (oral x nasal).	EPG can be used to describe the articulators in phonemes that have the palate as a passive point, such as /t/, /d/, and /n/. This study showed that there is more contact with the palate in the oral plosives than the nasal.
3	Treating myofunctional disorders: a multiple-baseline study of a new treatment using electropalatography.	Evaluate the benefits of EPG in the treatment of patients with orofacial myofunctional disorders.	The therapy involving activation phases helps the targets of contact of the tongue with the palate. <i>The feedback</i> obtained by EPG enables more effective responses from the intervention with the use of this instrument when compared to the treatment without it.	EPG can be used to treat miofunctional speech disorders, being a valuable tool that provides the clinician and patient information to assist the individual therapy planning.
4	Tongue-palate contact during selected vowels in children with speech sound disorders.	a) check whether there has been full contact of the tongue on the palate in children with disorders in speech sounds and typical speech development; b) characterize the patterns of these complete contacts, if present.	None of the typical children had full contact of the tongue with the palate in any of the investigated vowels. This pattern is not unique to children with anatomical abnormalities in the vocal tract. Typical children had no full contact of the tongue with the palate in any investigated vowels.	Atypical children showed complete contact tongue-palate for at least part of the production of some vowels. The results suggest that the full contact of the tongue on the palate is a characteristic of the atypical speech development.
5	Palatal morphology can influence speaker-specific realizations of phonemic contrasts.	Investigate whether the tactile information of the tongue in contact with the palate affects the production and especially the distinction of sibilants in terms of their articulation position.	The morphology of the region between the alveolus and the palate, in which the contrast between the sibilants was analyzed, showed a greater influence on the contrast between the consonants, suggesting that the palate morphology is crucial for acquiring the contrast between /s/ and /S/.	The articulation of sibilant contrasts is influenced not only by auditory perception but also by the morphological movement of the palate, which affects the somatosensory feedback of the speaker.
6	An EPG analysis of /t/ in young people with Down Syndrome (DS).	Assess the phonetic detail in children with DS regarding the plosive /t/, considering that this sound is rarely reported as problematic for these individuals.	The analysis by EPG identified that individuals with DS used many contact patterns of the tongue with the palate in the production of the plosive /t/.	The speech patterns in individuals with DS are related to dyspraxia elements concerning the anatomical and physiological characteristics of the syndrome. Studies with EPG demonstrated relevant articulatory information that can be analyzed qualitatively.

Caption: EPG - Electropalatography; US - Ultrasonography; EME - Electromyographic evaluation (=EMA - Electromagnetic Articulatory); VOT - Voice-Onset-Time)

Chart 6. Continued...

Study	Title	Objective	Results	Conclusion
7	Effects of consonant manner and vowel height on intraoral pressure and articulatory contact at voicing offset and onset for voiceless obstruents.	Investigate how the intraoral pressure levels during phonation vary before and after voiceless obstruents (plosives, fricatives, affricates, and clusters), Following high or low vowels, and analyze the way supraglottic constrictions affect intraoral pressure.	Effects of consonants and high vowels at the beginning and end of the speech were significant, as well as the consonant-vowel interactions. The effects of the six consonant and vowel contexts were significant for a single plosive, fricative, and cluster /St/, higher levels of intraoral pressure phonation before low vowels. The standard for phonation beginning was more consistent for all consonant contexts. At the beginning of phonation higher levels of intraoral pressure before high vowels were found.	The study concluded that high vowels had an inhibitory effect on the vocalization of short consonants sequences, but a facilitator effect at the beginning of phonation, which was consistent in consonant contexts. The influences of vowels seem to reflect a combination of characteristics of the vocal folds and the impedance of the vocal tract.
8	Differentiating impairment levels in temporal versus spatial aspects of linguopalatal contacts in Friedreich's ataxia (FRDA).	Characterize the physiology of dysarthria associated with FRDA and identify diversion of differential patterns that may occur among the subsystems of speech production mechanism.	The variability in dysarthria associated with FRDA shows the existence of different profiles of speech impairment. A particular distinction between the presence of hyperfunction or dysfunction during phonation has been observed, as evidenced by the instrumental results.	The fricative phoneme is the most affected in the DS, and the linguopalatal articulation point in FRDA.
9	Electropalatography as an adjunct to nonspeech orofacial myofunctional disorder assessments: a feasibility study.	Determine whether EPG would be a useful and viable complement in performing clinical evaluation of patients with suspected nonspeech orofacial myofunctional disorders (NSOMD).	The participants showed unique patterns of lingual-palatal contact patterns that differed from the participants without NSOMD.	EPG shows that the contact of the tongue on the palate differs among those with myofunctional disorders from those without, serving as an aid to non-instrumental evaluations.
10	Speech-language pathologists (SLP) knowledge of tongue/palate contact for consonants.	Determine the knowledge of SLP about the contact between tongue and palate for English consonants.	The SLP presented good knowledge of the contact tongue/palate along the midline, but little knowledge of the contact along the side edges of the palate.	SLP presented good knowledge about the contact of the middle line, but poor knowledge about the side margins on the palate.
11	Amount of kinematic feedback affects learning of speech motor skills.	Test the influence of knowledge on the kinematic performance during practice (KP group), compared with no kinematic feedback (noKP group), in learning a speaking ability.	The group without intervention with kinematic feedback showed retention in speaking abilities in a week after treatment compared to the intervention group with kinematic feedback.	In the study, there was no difference between the before and after training with one hour of treatment, however, the findings infer that the extended training may interfere with the acquisition of skills.
12	Effect of speech rate manipulations on articulatory dynamics in severe traumatic brain injury: an EMA and EPG study.	To determine the effects of the manipulation of speech rate in tongue movement in adults who have suffered severe brain trauma, but who present preserved motor controls.	The results demonstrated that as the strategies selected to increase the rate of speech, the group suffered traumatic brain injury showed increased articulatory effort is estimated to increase the speech rate and thereby decrease exaggerated movement of the tongue, yet the control group showed no effect of fast speech rate in the kinematic articulation for the production of sentences.	When speaking at a fast pace, individuals with severe TBI seem to have a greater articulatory effort, possibly to preserve the distinctive character of phonetic segments.
13	Using EPG data to display articulatory separation for phoneme contrasts.	Assist the graphically represent EPG data in articulatory separation of certain phonemes using contrasts between them.	For the graphics to be represented and understood, it should be emphasized the extent and separation by contrast between phonemes, especially among glides and fricatives.	Electropalatographic graphic data emphasize the importance of establishing the presence and extent of separation contrasts produced by speakers.

Caption: EPG - Electropalatography; US - Ultrasonography; EME - Electromyographic evaluation (=EMA - Electromagnetic Articulography); VOT – Voice-Onset-Time

Chart 6. Continued...

Study	Title	Objective	Results	Conclusion
14	EPG in the description and treatment of speech disorders in five children with Cerebral Palsy.	Investigate whether the method of electropalatographic visual feedback instrument would serve as an effective tool for the treatment of children (5) diagnosed with cerebral palsy and dysarthria, exploring whether this training can improve the articulation of the alveolar phonemes.	Unusual articulatory results between tongue and palate were addressed. The results show an anterior movement in relation to phonemes.	The results showed that consonants like /t/, /d/, /d/ and /s/ are now produced more in the anterior after training with target phonemes, with some of the characteristics of the articulation of dysarthric children as a result of cerebral paralysis revealed few tongue contacts on the palate, and double articulation and abnormally retracted articulation.
15	Effects of medication and subthalamic nucleus deep brain stimulation on tongue movements in speakers with Parkinson's disease using electropalatography: a pilot study.	To quantify the effects of subthalamic nucleus-deep brain stimulation STN-DBS in the articulation of patients with Parkinson's disease by applying EPG.	The medicine showed significant improvement in motor scores in one of the patients, however, for the other patient, it was observed articulatory deterioration with the stimulation.	According to the findings in the evaluation with EPG, the use of medication helps articulatory accuracy.
16	Electropalatography in home training of retracted articulation in a Swedish child with cleft palate: effect on articulation pattern and speech.	Evaluate the effectiveness of electropalatography in the errors formed by a female 11-year-old child with cleft lip and palate.	Both the analysis of EPG and the perceptual analysis showed improvement in production of phonemes /t/ and /s/ in words and sentences after therapy.	The analysis of the contact between tongue and palate showed that after therapy with biofeedback (around 8 hours of home training) the production of phonemes /t/ and /d/ normalized.
17	Long-term outcomes of speech therapy for seven adolescents with visual <i>feedback</i> technologies: ultrasound and electropalatography.	To analyze the speech production in seven teenagers and young adults with hearing loss after two to four years of intervention using US and EPG.	The trials for phases 2 and 3 of the treatment found that five speakers produced the segment with the same rate of accuracy in both phases. And confirmed the maintenance of accuracy levels in an individual, besides the improvement in three individuals, as well as a slight regression in four individuals in the sample.	Some study limitations are identified as follows: restricted number of samples; short periods of intervention; use of perceptual analysis isolated, and lack of access to a normative database for comparison.
18	Physiological investigation of dysarthria: recent advances.	Describe and evaluate EPG techniques, EPG pressure sensitive, and EME, highlighting their relative advantages, disadvantages and specific applications in the evaluation of speakers with dysarthria associated with a variety of neurological disorders.	The benefits of 3D technologies are greater than 2D, they are more realistic and it provides more reliable results in diagnosis and therapy.	The need for objective physiological assessments is extremely important for therapeutic planning, suggesting that clinicians should be updated about the advent of these techniques to provide more effective therapies.
19	Cascading influences on the production of speech: Evidence from articulation	Show the influence of the phonetic similarity of the contact between tongue and palate and analyze ultrasound images showing the outline of mediossagittal tongue contour, as well as acoustic changes as VOT	These three resources show increased articulatory variability when onsets with phonemic competition differ by a phonological characteristic, intensifying as they differ in two phonological characteristics.	Using electropalatography to test three different articulatory variability measures in three different sentences, it was possible to show that the activation of the articulation of phonemes is influenced by the individual's speech activation.
20	Study electropalatographic study of nasal phones.	Describe the standard contact between the tongue and the palate for a speaker with cleft lip and palate, in the production of nasal consonant phones of Portuguese comparing it to a speaker without articulatory changes.	All phones analyzed, produced by the speaker with cleft lip and palate, showed variations in the articulation region on which there was constriction compared to a normal speaker.	All phones analyzed, produced by the speaker with cleft lip showed variations regarding the articulation region on which the constriction happened in relation to a normal speaker.

Caption: EPG - Electropalatography; US - Ultrasonography; EME - Electromyographic evaluation (=EMA - Electromagnetic Articulography); VOT – Voice-Onset-Time)

Chart 6. Continued...

Study	Title	Objective	Results	Conclusion
21	electropalatographic phonetic description of alveolar phones.	Perform the articulatory description of Brazilian Portuguese, examining the tongue contact with the palate in the production of consonant phones.	After the electropalatography procedure, it was observed that the phones assessed have contact with the alveolar region in its point of maximum constriction. The phones /t/, /d/, and /n/ had more alveolar contact, with total obstruction of the air current; fricative phones /s/ and /z/ were characterized by the absence of contact in the central longitudinal axis, however the side phone /l/ showed no contact in lateral longitudinal axis and non-lateral liquid characterized by tap had few contacts of the tongue with the palate and was produced with shorter duration.	EPG allows a detailed description of the way and the extent of the contact tongue-palate in different alveolar phones in Portuguese.

Caption: EPG - Electropalatography; US - Ultrasonography; EME - Electromyographic evaluation (=EMA - Electromagnetic Articulography); VOT – Voice-Onset-Time)

them even joined these two techniques to pressure sensitive EPG and EMA. All studies researched on the use of EPG in clinical assessment.

Two papers were found at Scielo platform with the descriptors electropalatography AND speech, both papers described and evaluated by EPG the study of nasal and alveolar phones in different individuals, study 21 also phonetically describes the results.

In Chart 6 below, the summary of each paper selected for this review will be presented, being approached the title, the objective, the results, and the conclusion of the research.

DISCUSSION

1) Studies that highlighted the use of EPG in speech therapy

Reading the studies, it is feasible to realize that EPG is an efficient method to highlight results of treatments for different causes. One of these cases is cited in E1, where EPG is used as a visual feedback to users of cochlear implants, assisting in the training of sounds and in the transfer in relation to these sounds for the production of connected speech.

Articulatory errors were supplied mainly in the target production of phoneme /g/, since it was possible, by means of visual feedback, the perception and production of this phoneme in therapy, since the phoneme /g/ is velopharyngeal and its visualization only happens through an intervention instrument, such as EPG, considering the fact that cochlear implant users need an enhanced biofeedback to perceive and produce speech correctly.

Speech requires the structures of the stomatognathic system (myofunctional) to be in conditions for the production and articulation, however, when there are changes in the structures and surrounding functions, articulation becomes difficult.

The differential treatment for myofunctional changes, both for structure and function can be improved when appropriate learning and training of movements is applied. (E3)

These therapeutic benefits stem from the possibility of investigating the dynamic characteristics of the articulation points observed by applying EPG.

Whenever changes that are not only of myofunctional origin happen, presenting neurological characteristics such as cerebral palsy, movement training should be different depending on the difficulties presented by this etiology. EPG as a visual feedback method investigates the main errors of articulation disorders of each individual. On E14, it is reported that /t/, /d/, and /s/ are produced anteriorly after training with the target phonemes, being some of the characteristics of the articulation in dysarthric children a result of cerebral palsy described as few tongue contact on the palate, double articulation, and abnormally retracted articulation. Some children, with individual characteristics caused by cerebral palsy can benefit from the EPG tool, diagnosing, treating, and particularly describing the articulation errors associated with cerebral palsy. Although the use of this tool is a limiting factor, it is necessary to highlight certain results considering etiologies that require a more complete and effective assessment, due to the complaints presented.

In E11, it is presented the study of “Performance of Knowledge”, showing that such knowledge enables biofeedback to the patient, being used to provide information on the nature and quality of response movements in order to guide the learning or restore motor act. In this study, twelve adult English speakers were selected, some of which should produce /r/ in words with kinematic feedback using EPG, and some should produce /r/ without the kinematic feedback. Then, for more than one week, they were provided five hours of therapy, divided into five sessions. A test before training and another test after a week were conducted to measure the accurate production.

It was concluded that the manipulation of speech rate is part of the treatment of dysarthrias, although the effect of changes in speech rate on the articulatory dynamics in people with traumatic brain injury (TBI) are poorly documented. Therefore, the authors of this study compared the effects of speech rate

manipulations in the contact of the tongue with the palate in adults with severe TBI and in a group of normal individuals.

The results showed that the group with TBI showed an increased articulatory effort from an increase in maximum rate and maximum acceleration/deceleration of tongue movement when speaking fast. The control group showed no effect of a fast speech rate in articulatory production to produce sentences.

EPG, when used as a therapy tool, can enhance the treatment of children with cleft lip and palate (E16). Persistent errors in the articulation were fundamental for the use of this tool in therapy. In this case, fricative phonemes isolated in words and sentences were subjected to visual feedback in eight months of treatment, showing that EPG is sufficient, sometimes with conventional therapy, to correct articulatory errors associated with cleft palate (E16), although further research is necessary on the interference of EPG treatment for speech intelligibility, which is affected in individuals with different types of cleft lip and palate.

These findings reinforce that, although the objective evaluation quantifies and points reliable results, it cannot be analyzed without the perceptual evaluation of a professional of the area.

These studies demonstrated the possibility of inferring diagnoses and results with better accuracy, helping the therapist to perform comparisons before and after the treatment and investigate possible improvements through visual feedback, and may also show the results to family members, optimizing treatment and coming to the conclusion that speech therapy can benefit from the use of EPG associated with conventional therapy for different approaches.

2) Studies that highlighted the use of EPG in speech evaluation

It is possible to apply EPG both in therapy and in assessment, although its use is more common in the scientific context of speech therapy, given the high cost of equipment and training for the use of this tool.

There were eight studies that used EPG within the research for phonetic description purposes. E2 aimed to characterize the articulation of phonemes that have the palate as passive articulator, noticing that the phonemes have different articulation points developed by all the articulators and among the articulating points, lateral movements of the tongue on the hard palate are essential for the production of plosives, fricatives, and certain high vowels.

E2 investigated the dynamic characteristics of the lateral contact of the tongue with the palate during the beginning of the alveolar occlusion of the phonemes /t/, /d/, and /n/ in typical adults, with the use of EPG. The lateral movements of the tongue seen on EPG allow for an intraoral “seal” to build the pressure necessary for the production of alveolar obstruents, which are important for providing acoustic transitions in the accurate identification of sounds, both for the adequate perception and in alveolar production.

According to the authors, it was surprising the lack of research, understanding, and knowledge on the subject. The explanation for this neglect was the lack of appropriate methodology to investigate the activity of the tongue in the oral cavity, being

EPG a useful technique to record the contact of the sides of the tongue with the palate.

This finding is in line with what was observed in most researched papers, because the lack of studies on the technique and the use of EPG and the few characteristic studies of this instrument show that it generates therapeutic benefits for different types of pathology and different people, assisting in the science of speech therapy.

In addition to the plosives and fricatives, vowels are also compared in typical and atypical children’s productions through EPG (E4). The contact of the tongue on the palate for the production of vowels is the object of study to infer articulatory production. Five vowels without their derivations have five different contacts of the tongue formant on the palate, and when the production of vowels occurs closer to the proper shape, typical children do not have complete contact of the tongue on the palate for the production.

However, atypical children showed complete contact tongue-palate during at least part of the production of certain members. The results suggest that the full contact of the tongue on the palate is a feature of atypical speech development, but the authors note that further research is needed to determine the causes and the consequences of this pattern, considering the small number of study participants, besides few studies about the position and the contact of the tongue in typical children in the production of vowels.

Understanding the atypical articulatory detail is a challenge, EPG is an instrumental procedure that allows you to record this detail, because during the production of speech, it is possible to determine the location and contact time of the tongue on the palate⁽²⁴⁾

Most studies involving the use of EPG highlighted, in typical English speakers, that the complete contact of the tongue on the palate during the production of vowels is characteristic of atypical speech patterns⁽²⁴⁾. In typical speakers, contact occurs between the sides of the tongue and the lateral margins of the palate, being related to factors such as the palate format, different vowels, and phonetic context in which they occur. However, there are few studies that demonstrate the contact and position of the tongue in typical and atypical children speakers of different languages.

Researches⁽¹⁰⁾ suggested future studies using EPG applying controlled speech stimuli and groups of individuals who are more specific and paired with typical groups of children for further investigation of these findings.

In atypical speech development, specific articulation strategies in the acquisition of a language are used, and the speech conveys sociolinguistic information and idiosyncratic characteristics, demonstrating that the idiosyncratic characteristic of a speaker can be partially explained by the learned behavior, as well as anatomical and physiological considerations. This is explained in E5, as well as the variability of speech among speakers, originated by relevant factors such as the impact of non-biological influences: individual and environmental language experiences. However, the biological determinants should not be disregarded. Biomechanical and physiological parameters directly affect speech production, such as the palate format.

There is evidence that specific strategies for the intervention of each individual depended on the degree of inclination provided between alveoli and the palate. The general inclination of the palate was also scored, mainly due to the fact that the tongue has to follow the palate format in order to stabilize its production as well as for the construction of a conduit for the flow of the air necessary to produce a sibilant. The EPG was shown to be important to examine the speaker's variability, regardless of the contrast. The articulatory engagement becomes, in some cases, a morphologic restriction⁽²⁵⁾.

Still in this assessment topic and in different individuals and demands, evaluation of speech in children with Down syndrome (DS) is a highlighted point among these evaluation criteria using EPG. It is known that individuals with DS have reduced speech intelligibility and a disorderly development of phonological system⁽¹⁸⁾. Few studies have provided more detailed phonetic analysis using instrumental techniques such as acoustic analysis and electropalatography. These techniques are relevant to provide answers about specific errors of speech, such as voiceless plosives, rarely detailed in individuals with DS.

The perceptual analysis (E6) found that the control group produced correctly 100% of the targets, and the group with SD produced on average 71.5% correctly. The analysis by EPG also found that individuals with DS used the contact patterns of the tongue-palate characterized as: posterior articulation, minimal contact, increased contact, anterior or absence of side seal.

It was found, therefore, that children with Down syndrome had less productions of the phoneme /t/ than typical children, although it is an initial acquisition phoneme. The increase in tongue contact on the palate observed in the production of /t/ could be explained by the reduced palate size in individuals with DS and its relationship with the tongue posture, while the minimum contact can be explained by the difficulties in motor and muscle control.

It was also observed that typical children may use different patterns of articulation for the correct production of /t/. The authors⁽¹⁶⁾ concluded that studies with EPG have shown relevant articulatory information that can be analyzed qualitatively. These data have raised questions about the way certain patterns relate to specific changes in speech and also how they can categorize different standards for typical children.

Another study involving phonetic description was the E19, which pointed to the possibility that phonological errors in speech may reflect the simultaneous activation of more than one phonemic representation. To solve these problems, the study aimed to quantify and compare the early articulation of consonants by means of three types of research: electropalatographic, ultrasonographical, and VOT (Voice-Onset-Time).

These three sources provided convergent evidence that the articulatory variability increases when onsets with competing phonemic differ by a phonological characteristic, intensifying when they differ by two phonological characteristics. It was possible to conclude in this study that the phoneme articulation is influenced by the activation of the cascading speech plan.

EPG has also served as a speech evaluation instrument in research E20 and aimed to analyze the nasal phonemes in individuals with cleft lip and palate. According to this study,

there was no research on nasal phones due to the expectation that individuals with cleft lip and palate would naturally produce such phonemes, given that these phones are not among the consonants that require intraoral pressure. But these phonemes have undergone variations in the articulation region in relation to typical speech, which generated important implications for clinical practice.

The study concluded that speech analysis based solely on perceptual evaluation associated with the description of articulatory movements is subject to many limitations. It is suggested the use of EPG to show the speakers what is inappropriate in their speech and the necessary changes, then EPG, besides being an objective instrument for speech evaluation, it is a therapeutic resource for visual feedback.

EPG has primarily examined speech with alveolar phones to analyze its point of contact. According to research E21, since they involve more contact between tongue and palate, alveolar phonemes are privileged in the electropalatographic description, generating fairly accurate results. The electropalatographic description of alveolar phonemes afforded actual contact images between the tongue and the palate, describing separately the phonemes /z/, /t/ and /d/, /n/, /l/, and tap /r/.

Through electropalatography it is possible to perform the detailed description of the form and extent of the contact of the tongue in the different alveolar phones of Portuguese. It is still necessary to conduct more studies and gather more scientific evidence to develop a standardization of procedures as well as quantify and qualify the results. Since this procedure does not have easy access both for clinic and research, the findings are limited.

Other studies analyzed in this systematic review addressed the use of EPG as a speech assessment method in many areas, such as voice, neurology, orofacial motor skills, hearing, among others.

It is known that speech production involves, besides the organization of the vocal tract for the production of consonants and vowels, the acoustic characteristics which define the laryngeal resonance and speech rate. The use of EPG in E7 and E8 showed the differences of the consonants in the production of the upper vocal tract with regard to pressure and rate to produce a given segment.

The effects of the production of consonants over speech thresholds can be explained mainly in terms of magnitude and abduction speed of the vocal folds, besides being used to describe linguopalatal consonants chosen to characterize the duration that they have a group of individuals with Friedrich's ataxia, highlighting the significant increase in the duration of the analyzed consonants. It was also concluded that, due to the neurological deficit, an articulatory deficiency in relation to the control group has happened.

These studies objectively described patterns of articulation and production that the literature shows as a theoretical characteristic both for Down syndrome and for Friedrich's Ataxia. However, it was possible to characterize the events objectively through the use of EPG, analyzing and describing a given segment that was more affected in each disease, being the fricative phoneme and the linguopalatal articulation point, respectively.

In E9, EPG can be a useful supplement and a viable option for individuals who underwent clinical evaluations with suspected myofunctional change in conjunction with an orthodontic evaluation. This study describes each phase and their contact patterns, highlighting the use of EPG as a clinical supplement, even with a difficult access.

Instrumental techniques such as EPG can provide an objective evaluation based on auditory perception, helping in the transcription of the speech data.

The E10 was conducted in order to determine the knowledge of SLP regarding the coronal contact between tongue and palate for English consonants and to determine factors that increase the knowledge of the speech on the contact tongue/palate⁽⁶⁾. Two hundred and forty (240) Australian SLP received a survey. A hundred and ninety-eight returned the survey, but 23 SLP answer all the questions.

Thus, 175 surveys were analyzed. All participants worked with children with speech sounds disorders: 61.39% had already seen EPG previously, but only 1.3% had not used EPG.

The SLP demonstrated good knowledge of the contact tongue/palate along the midline, but little knowledge of the contact along the side edges of the palate. Eight consonants (/ʃ, θ, s, z, ð, l, ɹ, ʒ/) were among those that the SLP demonstrated poor knowledge of the contact tongue/palate. Surprisingly, the same consonants that are considered “difficult” for children with speech sounds disorders, consequently are those considered targets for intervention.

The authors⁽¹⁰⁾ concluded that it is not feasible to require Speech Language Pathologist (SLP) to apply EPG in their clinics, although they suggested that the professionals knew the contact points obtained by EPG in typical speakers, familiarizing with the terms used to analyze the points of contact tongue/palate.

The manipulation of the speech rate is part of the treatment of dysarthria and the effects of changes in speech rate on the articulatory dynamics in people with traumatic brain injury (TBI) are poorly documented. Authors investigated the effects of speech rate manipulations (usual in relation to fast) in the contact of the tongue with the palate in adult speakers with severe TBI compared to a control group of normal individuals. The use of EPG in this study was associated with electromagnetic articulography, considering as evidence the fact that adults with TBI have different strategies to increase speech rate, such as articulatory effort, increased maximum rate, and maximum acceleration/deceleration of tongue movement.

It is important to use objective tools for speech analysis, especially for neurological pathologies in which the main goal is the recovery of primary functions, including speech and its comprehension and expression, using the instrument associated to the strategies, since an improvement in tongue movements to exercise motor commands necessary for speech was observed.

One of the recurrent difficulties for researchers in E13 that used EPG is the great variability in spatial patterns that happen among speakers, since there is no pattern. This high variability combined with a small number of participants makes it problematic to identify the differences of contact between the tongue and palate, as well as the definition of normal patterns during therapy with visual biofeedback.

Thus, EPG assists the evaluation and speech therapy, as it detects and reduces these problems due to the graphical data that provide information in terms of phonemes. The graphics emphasize the importance of establishing the presence and extent of separation by contrasts produced among speakers. When used with acoustic analysis and auditory perception analysis, it is proposed that the representation of articulation data in terms of separation is useful for a variety of clinical and research purposes.

EPG instrument is still considered a novelty for the speech therapy, both for clinical and for research, especially for being a piece equipment difficult to access with specific characteristics for use. It is difficult for researchers to describe the results since there is a high variability in spatial patterns among speakers, making difficult the graphic representation showing the phonemes that were evaluated and the separation among them. It points to the need for more research involving this instrument assisting in the scientific world, but mainly in an attempt to standardize results or description of characteristics.

Besides the pathology of cerebral palsy, EPG instrument was applied to E15 to analyze the speech in patients with Parkinson’s disease (hypokinetic dysarthrophonia), and compare the articulatory function in these patients before and after treatment. It is known that one of the treatments for reducing rigidity consists of deep brain stimulation in the subthalamic nucleus, however the effect of this stimulation is still variable in the treatment of dysarthrophonia.

The study showed that EPG is a valuable resource for the analysis of the articulation, since it enabled the conclusion that stimulation plus the medication has greater effects on the improvement of articulation when compared to stimulation without medication.

Another consideration that must be reported is that even with the use of drugs, both individuals showed different characteristics in relation to the effect of the stimulation of the medicine in the articulation. One of the individuals presented deterioration in the articulation with the medicine, in contrast, the other individual showed improvement in articulatory accuracy. It is concluded that EPG was extremely important to objectively demonstrate articulatory accuracy of velar sounds, contributing to the pathology of Parkinson’s disease and its comorbidities.

It is found, in study E17, that EPG was used in conjunction with ultrasonography as a visual feedback in the treatment of individuals with hearing loss, since they require strengthening in the other directions to perfect speech. It was noticed in these patients, significant improvements of fricatives, vowels, and rhotics /R/, being visible the generalization after treatment. Since it is a long-term, it could be inferred that the rehabilitation of speech with visual feedback characteristics has lasting effects especially in individuals with hearing loss, since the visual feedback becomes a refined sense.

Other researchers described three types of instruments to evaluate articulation function: electropalatography, electropalatography sensitive to pressure and electromagnetic articulography in E18. The objective of this research was to expand the knowledge of the articulation function, in view of the recent analysis of the

tongue movements during speech, which formerly were not held due to lack of proper instrumentation.

The advent of 2D and 3D technologies, as electropalatographic and electromagnetic articulography, has enabled the visualization of the movements of the tongue and other articulators. 3D technologies bring more benefits than 2D ones since they are more realistic and provide more reliable results, helping in the treatment planning. In cases of dysarthria, it is extremely important to conduct objective assessments due to the different manifestations of this speech change.

The use of electropalatography, electromagnetic articulography, pressure-sensitive electropalatography combined with ultrasonography found that the need for objective physiological assessments is extremely important for therapeutic planning, suggesting that therapists should be updated about the advent of these techniques to provide more effective therapies.

CONCLUSION

EPG has shown to be an important method for mapping the tongue contacts on the palate. It is important to highlight studies in normal individuals that aim to guide the research in different speech pathologies. Few studies^(18,12) related electropalatographic and ultrasonography analysis, both in normal individuals and in those with speech disorders.

One hypothesis for the lack of studies combining the two techniques is the high cost, the need to combine this equipment to an appropriate laboratory for the speech analyses, the need to harness the analysis to a synchronizing software for the acoustic and articulation signals, as well as trained professionals to use the instruments.

Static information of contact points of the tongue detected on the palate through an electropalatography associated with the dynamic evaluations in real time of the articulatory gestures obtained by ultrasonography complement the analysis of the task performed in the speech.

These tools bring considerable advances in the assessment, diagnosis, and intervention of many disorders that affect human communication, understanding the evolutionary process of the speech and perspectives of progress in the time and quality of the intervention. Speech therapy can be enhanced by the findings of the results of this papers review, since distinct pathologies were addressed and it is feasible to infer the clinical results of the interventions.

Subjective analyses will not be overcome by instrumental evaluations, which set parameters to reveal details that could complement the models of evaluation and treatment and existing comparisons.

REFERENCES

1. Ball M, Gracco V, Stone M. A comparison of imaging techniques for the investigation of normal and disordered speech production. *Adv Speech Lang Pathol.* 2001;3(1):13-24. <http://dx.doi.org/10.3109/14417040109003705>.
2. Barberena LS, Keske-Soares M, Berti LC. Descrição dos gestos articulatorios envolvidos na produção dos sons /r/ e /l/. *Audiol Commun Res.* 2014;19(4):338-44. <http://dx.doi.org/10.1590/S2317-6431201400040000135>.
3. Berti LC, Marino VCC. Marcas linguísticas constitutivas do processo de aquisição do contraste fônico. *Rev GEL.* 2008;5(2):103-21.
4. Mantie-Kozłowski A, Pitt K. Electropalatography as an adjunct to nonspeech orofacial myofunctional disorder assessments: a feasibility study. *Int J Orofacial Myology.* 2013;39:31-44. PMID:24946660.
5. Jesus M S, Reis C. Phonetic description of alveolar phones using electropalatography. *J Soc Bras Fonoaudiol.* 2012;24(3):255-61. PMID:23128174.
6. McLeod S. Speech-language pathologists' knowledge of tongue/palate contact for consonants. *Clin Linguist Phon.* 2011;25(11-12):1004-13. PMID:22106891. <http://dx.doi.org/10.3109/02699206.2011.620678>.
7. Öller Darelid M, Hartelius L, Lohmander A. Generalised EPG treatment effect in a cochlear implant user maintained after 2 years. *Int J Speech Lang Pathol.* 2015;1-12. PMID: 26120889. <http://dx.doi.org/10.3109/17549507.2015.1048827>.
8. Lee A, Gibbon FE, Oebels J. Lateral bracing of the tongue during the onset phase of alveolar stops: an EPG study. *Clin Linguist Phon.* 2015;29(3):236-45. PMID:25495013. <http://dx.doi.org/10.3109/02699206.2014.991449>.
9. Mantie-Kozłowski A, Pitt K. Treating myofunctional disorders: a multiple-baseline study of a new treatment using electropalatography. *Am J Speech Lang Pathol.* 2014;23(4):520-9. PMID:25178428. http://dx.doi.org/10.1044/2014_AJSLP-14-0001.
10. Lee A, Gibbon FE, Kearney E, Murphy D. Tongue-palate contact during selected vowels in children with speech sound disorders. *Int J Speech-Language Pathol.* 2014;16(6):562-70. PMID:24345004. <http://dx.doi.org/10.3109/17549507.2013.862857>.
11. Weirich M, Fuchs S. Palatal morphology can influence speaker-specific realizations of phonemic contrasts. *J Speech Lang Hear Res.* 2013;56(6):S1894-908. PMID:24687445. [http://dx.doi.org/10.1044/1092-4388\(2013\)12-0217](http://dx.doi.org/10.1044/1092-4388(2013)12-0217).
12. Timmins C, Hardcastle WJ, Wood S, Cleland J. An EPG analysis of /t/ in young people with Down's syndrome. *Clin Linguist Phon.* 2011;25(11-12):1022-7. PMID:22106892. <http://dx.doi.org/10.3109/02699206.2011.616981>.
13. Koenig LL, Fuchs S, Lucero JC. Effects of consonant manner and vowel height on intraoral pressure and articulatory contact at voicing offset and onset for voiceless obstruents. *J Acoust Soc Am.* 2011;129(5):3233-44. PMID:21568425. <http://dx.doi.org/10.1121/1.3561658>.
14. Folker JE, Murdoch BE, Cahill LM, Rosen KM, Delatycki MB, Corben LA, et al. Differentiating impairment levels in temporal versus spatial aspects of linguopalatal contacts in Friedreich's ataxia. *Mot Contr.* 2010;14(4):490-508. PMID:21051790. <http://dx.doi.org/10.1123/mcj.14.4.490>.
15. Ballard KJ, Smith HD, Paramatmuni D, McCabe P, Theodoros DG, Murdoch BE. Amount of kinematic *feedback* affects learning of speech motor skills. *Mot Contr.* 2012;16(1):106-19. PMID:22402216. <http://dx.doi.org/10.1123/mcj.16.1.106>.
16. Murdoch BE, Kuruvilla MS, Goozée JV. Effect of speech rate manipulations on articulatory dynamics in severe traumatic brain injury: an EMA and EPG study. *Brain Inj.* 2012;26(3):241-60. PMID:22372412. <http://dx.doi.org/10.3109/02699052.2011.650664>.
17. Gibbon FE, Lee A. Using EPG data to display articulatory separation for phoneme contrasts. *Clin Linguist Phon.* 2011;25(11-12):1014-21. PMID:21967129. <http://dx.doi.org/10.3109/02699206.2011.601393>.
18. Nordberg A, Carlsson G, Lohmander A. Electropalatography in the description and treatment of speech disorders in five children with cerebral palsy. *Clin Linguist Phon.* 2011;25(10):831-52. PMID:21591933. <http://dx.doi.org/10.3109/02699206.2011.573122>.
19. Hartinger M, Tripoliti E, Hardcastle WJ, Limousin P. Effects of medication and subthalamic nucleus deep brain stimulation on tongue movements in speakers with Parkinson's disease using electropalatography: a pilot study. *Clin Linguist Phon.* 2011;25(3):210-30. PMID:21158488. <http://dx.doi.org/10.3109/02699206.2010.521877>.
20. Lohmander A, Henriksson C, Havstam C. Electropalatography in home training of retracted articulation in a Swedish child with cleft palate: effect on articulation pattern and speech. *Int J Speech-Language Pathol.* 2010;12(6):483-96. PMID:20602582. <http://dx.doi.org/10.3109/17549501003782397>.

21. Bacsfalvi P, Bernhardt BM. Long-term outcomes of speech therapy for seven adolescents with visual *feedback* technologies: ultrasound and electropalatography. *Clin Linguist Phon*. 2011;25(11-12):1034-43. PMID:22106893. <http://dx.doi.org/10.3109/02699206.2011.618236>.
22. Murdoch BE. Physiological investigation of dysarthria: recent advances. *Int J Speech-Language Pathol*. 2011;13(1):28-35. PMID:21329408. <http://dx.doi.org/10.3109/17549507.2010.487919>.
23. McMillan CT, Corley M. Cascading influences on the production of speech: evidence from articulation. *Cognition*. 2010;117(3):243-60. PMID:20947071. <http://dx.doi.org/10.1016/j.cognition.2010.08.019>.
24. Jesus MS, Reis C. Electropalatography of nasal phones produced by an adult with cleft lip and palate. *Rev CEFAC*. 2012;15(3):697-706.
25. Zharkova N. Using ultrasound to quantify tongue shape and movement characteristics. *Cleft Palate Craniofac J*. 2013;50(1):76-81. PMID:22117937. <http://dx.doi.org/10.1597/11-196>.

Author contributions

LSB, CRP, SNS, and ACMP were in charge of the delimitation of the study, literature research, and writing; MKS and RM supervised the collection and analysis of data, as well as provided guidance during all steps of preparation of the study.