CoDAS
ISSN 2317-1782 (Online version)

Original Article
Artigo Original

Acoustic-articulatory configuration of women with vocal nodules and with healthy voice

Configuração acústico-articulatória das vogais de mulheres com nódulos vocais e vocalmente saudáveis

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Keywords

Voice
Larynx
Voice Disorders
Acoustics
Women

ABSTRACT

Purpose: To analyze the acoustic-articulatory configuration of vowels in women with vocal nodules and with healthy voice. **Methods**: Twelve women with vocal nodules (EG) and twelve vocally health women (CG) participated of this study. All women recorded vehicle phrases with the vowels /a/, /i/, and /u/ in stress position, preceded and followed by the occlusive consonant /p/: "Digo p**a**pa baixinho", "Digo p**i**pa baixinho", and "Digo p**u**pa baixinho". Subsequently, the first three formants (F1, F2, and F3) were extracted from these vowel targets. **Results**: Between the two groups studied, F1 measures differed for vowels /a/ and /u/, and F2 measures differed for the vowel /a/. Women with vocal nodules showed lower values for these measures compared to vocally healthy women. Patients with vocal nodules showed a smaller interval in F1 and F2 values between vowels /a/, /i/, and /u/ compared to vocally healthy women. **Conclusion**: Women with vocal nodules show lower F1 and F2 values and lower range of motion of the articulators during vowel production compared to vocally healthy women.

Descritores

Voz
Laringe
Distúrbios da Voz
Acústica
Mulheres

RESUMO

Objetivo: Analisar a configuração acústico-articulatória das vogais em mulheres com nódulos vocais e vocalmente saudáveis. **Método:** Participaram do estudo 12 mulheres com nódulos vocais (GE) e 12 vocalmente saudáveis (GC). Todas as mulheres gravaram frases-veículo com as vogais /a/, /i/ e /u/ em posição tônica, sucedidas e precedidas da oclusiva /p/: "Digo p**a**pa baixinho", "Digo p**i**pa baixinho" e "Digo p**u**pa baixinho". Posteriormente, foram extraídos os três primeiros formantes (F1, F2 e F3) dessas vogais. **Resultados:** Observou-se diferença nas medidas de F1 para as vogais /a/ e /u/ e F2 para a vogal /a/ entre os dois grupos estudados. Mulheres com nódulos vocais apresentam menor valor dessas medidas em relação às mulheres vocalmente saudáveis. Pacientes com nódulos vocais apresentaram menor intervalo nos valores de F1 e F2 entre as vogais /a/, /i/ e /u/ em relação às mulheres vocalmente saudáveis. **Conclusão**: Mulheres com nódulos vocais apresentam menores valores de F1 e F2, e menor amplitude de movimentação dos articuladores na produção vocálica em relação às mulheres vocalmente saudáveis.

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Received: September 26, 2018

Accepted: April 04, 2019

Study conducted at Programa de Pós-graduação em Linguística, Universidade Federal da Paraíba – UFPB - João Pessoa (PB), Brasil.

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Financial support: nothing to declare.

Conflict of interests: nothing to declare.

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INTRODUCTION

Voice disorders are pathological processes that directly affect vocal production, manifesting themselves in different ways, including sensory and auditory symptoms, deviations of vocal quality, and functional and/or structural changes in the larynx[1].

Assessment of voice disorders requires a multidisciplinary approach that includes specific anamnesis, auditory-perceptual voice assessment, self-assessment, visual laryngeal examination, and acoustic assessment[2].

In the acoustic analysis, one can investigate and infer about the correlation between the respiratory, phonatory, and articulatory subsystems involved in sound production. In turn, individuals with voice disorder may adjust articulator positioning and movement, either as a compensatory mechanism or as a co-occurrence of this disorder. Such adjustments, associated with the irregularity and noise present in dysphonic voices, may influence the production of vowel[3,4] or consonant phonemes[5,6], decrease speech intelligibility, and compromise verbal message transmission[3,4,7].

Articulator positioning and movement are mainly responsible for vowel distinctiveness and can be indirectly (acoustically) inferred from formant measurements[8]. Formants are influenced by the positioning of the jaw, lips, pharynx, larynx, and tongue. Different combinations in the positioning of these articulators provide acoustic-articulatory distinctiveness to vowel segments[9].

Acoustically, the most distinguishing vowel sounds are those of the vowel triangle /a/, /i/, and /u/, since they occupy the extremes of the triangle. Vowels /i/ and /u/ have low first formant (F1) frequency, while the vowel /a/ has high F1 frequency, since the tongue is higher in the production of the first two vowels and lower for /a/. The second formant (F2) has a high frequency in /i/, a low frequency in /u/, and a mean frequency in /a/, justified by the position of the tongue, which is more advanced to the first, indented to the second, and stable to the production of the third vowel[10].

In this sense, a study[11] investigated speech motor adaptations by individuals with Parkinson's disease. The vowel analysis shows a reduction in the vowel space, demonstrating a tendency to centralize the vowels for the group of parkinsonians. F1 and F2 extension tends to decrease more in the F2 axis, related to the anteroposterior movement of the tongue. Posterior vowels had the highest dispersion values, demonstrating the greater difficulty of these individuals in performing movements with the back of the tongue.

Other studies[9,12] have shown that a vocal alteration leads to multiple manifestations, either at the glottic and/or filter level. There is a larger number of studies investigating acoustic measurements related to the glottal source, such as disturbance and noise measurements[13-15], as they are more related to auditory perceived vocal deviation. However, the impact of voice disorders on vowel distinctiveness and its effects on verbal message transmission needs to be studied, considering that this finding can elucidate and reinforce the understanding of the communicative limitations of this kind of disorder.

From this perspective, a study[16] used magnetic resonance imaging to investigate vocal tract adjustments of dysphonic women with vocal nodules and nondysphonic women pre- and post-flexible resonance tube in water exercise, both at rest and during phonation. During vocal rest, women with vocal nodules have smaller laryngeal vestibule area, smaller distance from epiglottis to posterior pharyngeal wall (PPW), and smaller interarytenoid complex length. During phonation, in turn, the laryngeal vestibule area and the angle between PPW and vocal fold, between epiglottis and PPW, and between anterior commissure of the larynx and PPW are smaller, with a larger space in the tongue region. Exercise promoted positive changes in the vocal tract of women with vocal nodules, reducing the differences between groups.

In this context, considering the importance of vowel distinctiveness in the mechanism of verbal message transmission, and that individuals with voice disorders can implement compensatory adjustments in the articulators, this research analyzes the acoustic-articulatory configuration of vowels in women with vocal nodules and with healthy voice.

METHODS

Study design

This was a descriptive, observational, and cross-sectional study. The study was evaluated and approved by the Research Ethics Committee of the Federal University of Paraíba (UFPB), under opinion number 2.158.960. All participants received an explanation about the research and signed the Informed Consent Form (ICF).

Sample

Participated in this research, as experimental group (EG), the patients attended at the Integrated Laboratory for Voice Studies (LIEV) of UFPB, according to the following eligibility criteria:

- Otorhinolaryngological diagnosis of vocal nodules;
- Female gender, due to both the higher prevalence of voice disorders in this population and the relationship between this variable and the mean fundamental frequency and formant measures, which are linked to the anatomical characteristics of the vocal folds and vocal tract, respectively distinct between adult men and women[17];
- Age over 18 years and below 65 years, due to changes in the glottal source and vocal tract related to childhood, adolescence, and senescence[17];
- Absence of upper airways infection at the time of recording, which would modify the resonant cavities and, consequently, the formant measurements[18];
- Absence of shortened lingual frenulum, temporomandibular dysfunction, and/or structural and functional alterations of the articulators, which would modify supraglottic vocal tract adjustments[19];

- Absence of cognitive or neurological changes preventing collection procedures;
- Absence of previous speech therapy.

The control group (CG) comprised women who were available for the research, among them employees and students of the Speech Therapy Department of UFPB who met the same eligibility criteria above, except for the diagnosis of vocal nodules and:

- Absence of vocal complaint (currently or in the last six months), negatively answering the question "Do you have a voice problem currently or in had it the last six months?"

The CG was paired with the EG according to age (more or less five years), in a ratio of one control per case (1:1).

Thus, the sample consisted of 24 women, including 12 women in the EG, with mean age and standard deviation of 36.47 years ± 12.22, and 12 women in the CG, with mean age and standard deviation of 33.86 years ± 11.59. Patients in the EG were approached during speech-language screening at the LIEV.

Therefore, all patients assessed in the Laboratory and diagnosed with vocal nodules were approached about the possibility of participating in the research, signing the Informed Consent Form (ICF). Subsequently, they were subjected to the recording of the vehicle phrases "Digo papa baixinho", "Digo pipa baixinho", and "Digo pupa baixinho".

Participants in the CG were approached directly among the students and employees of the aforementioned course. They were instructed on the research objectives, signed the informed consent form, and were referred for laryngeal visual examination in a public reference service in the region, presenting the written diagnosis later. Those who were diagnosed with a "normal larynx" underwent the recording of speech tasks.

Data collection procedures

For the composition of the EG, weekly follow-up was performed at the LIEV vocal assessment service, with the objective of approaching women who had a conclusive diagnosis of vocal nodule(s) and who met the other eligibility criteria of this research.

These women then provided personal data such as name, date of birth, age, and profession. Subsequently, a brief evaluation of stomatognathic system structures was performed, observing the morphology and mobility of the lips, tongue, cheeks, and soft palate; the tonus of the lips, tongue, and cheeks; and issues related to temporomandibular joint and the presence or absence of upper airway infections (according to self-report). The objective of this evaluation was to rule out the presence of temporomandibular disorder, lingual frenulum alteration, or any structural and functional alteration that could influence the results of this study due to interference with articulatory adjustments[19].

Following this, speech tasks were recorded. For that purpose, we used the software Fonoview (version 4.5h; CTS Informática, Brazil), a Dell all-in-one desktop, and a unidirectional cardioid microphone (model E-835; Senheiser, Germany) located on a pedestal and coupled to a Behringer preamplifier (model U-Phoria UMC 204). The voices were collected at the LIEV, in a recording booth with acoustic treatment and noise levels below 50 dB SPL, at a sampling rate of 44,000 Hz with 16 bits per sample, and with a distance of 10 cm between the microphone and the speaker's mouth.

To collect the voices, the women stood up, placing the pedestal in front of them according to the recommended distance between the mouth and the microphone, as described above. They were instructed to breathe lightly, getting enough air so that the sound production did not happen in a forced way, which would alter the proposal of normal emission of sentences.

Participants were instructed on the separate recording of three vehicle phrases containing the vowel segments /a/, /i/, and /u/ ("Digo papa baixinho", "Digo pipa baixinho", and "Digo pupa baixinho"). Each phrase was recorded only once for each volunteer. The vowel segments were inserted in consonant-vowel (CV) contexts, in an initial unstressed syllable, with a vowel preceded and followed by the unvoiced bilabial occlusive phoneme. The choice of these phrases is justified by the little influence these consonants have on neighboring vowel formants[10] and the need to homogenize the context for all vowels. Thus, there will be minimal control of prosodic aspects, without interference in the emission of vowel sounds in the investigation of acoustic vowel distinctiveness.

The choice of vowels /a/, /i/, and /u/ was because these vowel sounds are the most acoustically distinguished, forming an articulatory triangle at their extremes (corner vowels)[10]. Moreover, they follow a formant pattern of consensus between researchers, which corresponds to the typical characteristics of vowels that present the maximum and minimum point of vowel opening and tongue movement (back and forth, lowering and raising)[20].

Participants in the CG were recruited after collection with the EG. Such procedure was defined to favor the same amount of informants in both groups.

The recruitment of women from the CG was based on the observation of the age range of each participant in the experimental group. Based on age, they were contacted by the researcher and directed to the session and collection procedures according to their availability. After scheduling, all CG volunteers followed the same steps as the EG procedures. For research feasibility and given the subjects' access to the Laboratory, students and employees of the Higher Education Institution where the research took place participated in the study.

The first and second formant of vowels /a/, /i/, and /u/ were extracted in Praat software (version 5.3.77h), from vowel representation in a broadband spectrogram. Praat is a voice analysis tool developed by Paul Boersma and David Weenink, from the Institute of Phonetic Sciences, University of Amsterdam.

The segmentation and, consequently, the duration of vocal sounds in CV contexts were established considering as initial

vocal limit the first regular peak after the consonant and the consonant-vowel transition period. For the final limit, we considered the last regular peak before the consonant and the vowel- consonant transition period[10], with an average analysis duration of 0.13 seconds.

From the selection and segmentation of vowel sounds in CV contexts, it was possible to obtain the average of the acoustic measures analyzed. For the extraction of average formant values in Praat, the option Formant was selected, obtaining the numerical value of F1, F2, and F3, expressed in Hertz (Hz).

Data analysis procedures

Descriptive statistical analysis was performed for all variables, considering mean and standard deviation.

In the comparison between EG and CG, F1 and F2 means were analyzed using the Mann-Whitney U test. All analyses were performed using the R software. The significance level considered was 5%.

To show how close or far the vowels are to each other on the graph, the difference/interval between the vowels was averaged from the F1 or F2 axis by subtracting the formant from one vowel to another.

RESULTS

The means, the standard deviation, and the comparison of the F1 and F2 of vowels /a/, /i/, and /u/ between EG and CG are presented in Table 1.

In the comparative analysis of these measures between groups, there was a difference in F1 for vowels /a/ (p=0.0145) and /u/ (p=0.0007) (Table 1). There was a lower F1 value for these vowels in the group of women with vocal nodules. In turn, F2 values differed for the vowel /a/ (p=0.0007), with lower values also in the group of women with vocal nodules (Table 1).

Table 2 shows F1 and F2 intervals between vowels /a/, /i/, and /u/. Women with vocal nodules presented lower values in the F1 and F2 intervals between the three vowels studied compared to vocally healthy women. These intervals can be visualized by comparing the configuration of the acoustic triangle of women in the EG and CG, according to the abscissa and ordinate of the graph in Figure 1. Vowels are more distinct in the acoustic-articulatory triangle of vocally healthy women.

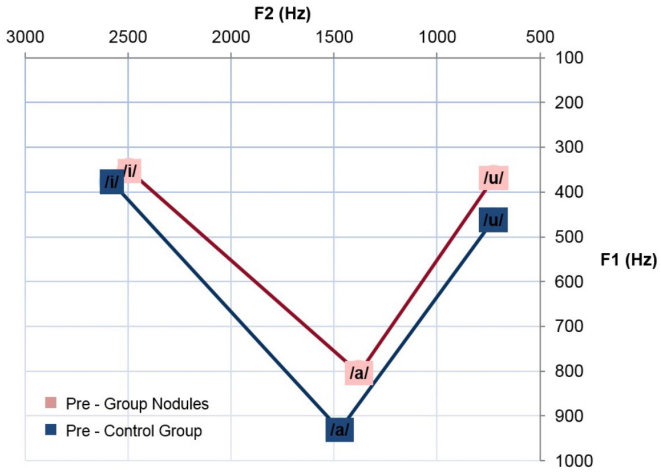

Figure 1. Acoustic-articulatory triangle of vowels /a/, /i/, and /u/ of the EG and CG

Table 1. Mean, standard deviation, and comparison between experimental and control groups

Formant	Vowel	Experimental Group Mean±SD	Control Group Mean±SD	p-value
F1	**/a/**	804.40±137.39	931.28±83.31	**0.0145**
	/i/	353.08±47.66	377.32±41.67	0.3474
	/u/	369.01±57.37	465.06±50.97	**0.0007**
F2	**/a/**	1377.63±120.70	1471.79±83.21	**0.0284**
	/i/	2491.65±170.93	2578.58±137.92	0.3777
	/u/	725.32±225.65	726.55±78.93	0.4776

Captions: SD: standard deviation; F1: first formant; F2: second formant

Table 2. Mean and standard deviation of differences between formants of the experimental and control groups

Formant	Vowel	Experimental Group Mean±SD	Control Group Mean±SD
F1	**/a/-/u/**	435.39±80.02	466.22±32.34
	/a/-/i/	451.31±89.73	553.96±41.64
	/i/-/u/	15.93±9.71	87.74±9.3
F2	**/a/-/u/**	652.31±104.95	745.24±4.28
	/a/-/i/	1114.02±50.23	1106.79±54.71
	/i/-/u/	1766.33±54.72	1852.03±58.99

Caption: SD: standard deviation; F1: first formant; F2: second formant

DISCUSSION

This experiment investigates acoustic-articulatory aspects among women with vocal nodules and with healthy voice from the perspective of acoustic analysis and, especially, from the relationship between the glottal source and the mechanism of articulatory speech production.

The main results of this research corroborate with studies that highlight the source-filter coupling and the change in the range of motion and posture of the articulators due to alteration in the glottal source[4,7,9,21,22].

Data in Table 1 show that the values of formants in women with vocal nodules are lower compared to those of vocally healthy women. These lower values of formants in CG compared to EG are due to the fact that, possibly, there are changes in the mandible position and, consequently, in the tongue and pharynx position during speech production[22]. Thus, vocal alteration is likely to interfere with the articulatory adjustments and, consequently, with the acoustic configuration of vowels during speech[9,12].

Women with vocal nodules produced vowels that need maximum (/a/) and minimum oral cavity opening (/u/) with a slightly higher jaw position, since the F1 value is directly related to mandible position in the vocalic quality of a segment[20]. Regarding the tongue position, women with vocal nodules presented lower F2 value, the main acoustic measure influenced by the shape of the tongue. Thus, there is a likelihood of change in the vocal tract due to the reduction of formant frequencies, resulting in a change in sound quality compared to vocally healthy women[10].

In contrast, a study[4] shows that individuals with alteration in the glottal source (unilateral vocal fold paralysis) have a higher F2 value, which could be related to a more anterior tongue position during vowel production. However, F1 frequency values are higher in these individuals, possibly interfering with lower tongue position during phonation.

Therefore, lower F1 value for vowels /a/ and /u/, and lower F2 value for the vowel /a/ in the group of women with vocal nodules (Table 1) suggest a higher, posterior position of the mandible and tongue. Such adjustments of the articulators interfere more with the epilarynx and the posterior region of the oral cavity[7].

The epilarynx area is responsible for initiating energy concentrations in the vocal tract[23]. It is located in the narrow portion of the pharynx, immediately above the vocal folds. The epilarynx area forms a resonant tube with a frequency between 2500 and 3000 Hz, which coincides with the frequency level of the second and third formants[23]. Thus, when there is a laryngeal lesion, the reasonably uniform configuration of this tube may change in energy peaks and alter formant frequencies[9].

These modifications of the articulators may have occurred due to tension in the cervical and laryngeal region, which may cause laryngeal elevation, reduced mouth opening, and epilarynx constriction[24]. Vocal nodules are benign mass lesions of the vocal folds, which may interfere with vocal fold closure and produce tense voices with aperiodic acoustic signal[17,25], justifying these changes in the positioning of the articulators in the present study.

The data in Table 2 and the presentation of Figure 1 show higher vowel intervals for F1 and F2 in vocally healthy women. The acoustic-articulatory triangle of women with vocal nodules (Figure 1) is smaller compared to that of vocally healthy women.

The triangle formed by the frequencies of the vowel formants, graphically represented by an F1/F2 diagram, has the purpose of evaluating the vowel articulation space. An extended triangle represents greater range of motion of the articulators during vowel production. In contrast, the reduction of the triangle indicates a restricted range of motion of the articulators. In general, the measures related to the vowel triangle constitute one of the markers of vowel distinctiveness and speech intelligibility. A larger vowel space is one of the indicators of greater vowel distinctiveness and greater speech intelligibility[26].

It should be noted that although "clear speakers" have a larger vowel space, the opposite is not straightforward, as other markers such as the presence of noise at emission, excessive nasality, or reduced intensity may be responsible for reduced speech intelligibility.

Women with vocal nodules are likely to have lower range of motion of the articulators compared to vocally healthy women. One hypothesis is that this decrease in amplitude is a consequence of hyperfunctional adjustment caused by laryngeal alteration[25]. Some authors[27] report that the reduction in the F1 and F2 intervals of high and low vowels is one of the factors for reducing the speech intelligibility of individuals.

A study[28] found smaller vowel spaces in children with cerebral palsy compared to children with typical development in both the word and phrase contexts. However, variations of the second formant did not differ between groups for word or phrase contexts, but presented smaller values in simple words, with phonetic contexts requiring large changes in vocal tract configuration.

Generally, the F2s of corner vowels in cochlear implant speakers are more divergent and lower than that of normal hearing speakers, resulting in horizontally compressed vowel space[20]. Similarly, another study[29] found that the vowel space is more compressed in cochlear implant individuals compared to those of normal hearing. In both studies[20,29], the reduction of the vowel space decreased the speech intelligibility of individuals.

Other authors state that the impact of a voice disorder may extend beyond the larynx. Women with muscle tension dysphonia show a reduction in the F1 and F2 of vowels after manual laryngeal massage. This may be related to better glottal closure and lower supraglottic compression[21].

Thus, changes in the glottal source would likely contribute to the development of compensatory adjustments at the supraglottic level, with modification of the vocal tract configuration and, consequently, interference with the formant frequency patterns in the vocal tract[30].

Overall, this study presented some exploratory insights in the field of acoustic-articulatory analysis regarding studies that use filter-source coupling to better understand laryngeal disorders and supraglottic adjustments in vocal production.

One of the limitations of the present study is the number of samples per participant (only one for each vowel). This reduced number allows only to make inferences about the vowel

production behavior in the studied groups, not being enough to state categorically that there is a reduction of the vowel space. For that purpose, we would need a greater number of repetitions per subject, the use of vowels in different speech tasks, and the monitoring of the vowel space of these individuals before and after vocal rehabilitation.

The results of this research and the methodological issues cited above suggest that further studies be conducted to broaden the understanding of reduced range of motion of the articulators in dysphonic individuals. It should be considered that the study was conducted with women only, so a comparative study between men and women using these and other traditional acoustic measures is necessary.

CONCLUSION

Women with vocal nodules presented lower F1 and F2 values for oral vowels /a/, /i/, and /u/ compared to vocally healthy women. In addition, women with vocal nodules have lower range of motion of the articulators, with reduced vowel space compared to vocally healthy women.

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Author contributions

FPF, LWL, and AAA helped build and develop the work. It is noteworthy that FPF was particularly involved in the collection, tabulation, interpretation of data, and in writing the article; LWL participated in the study design and in the orientation and final writing of the article; AAA participated in the review and final writing of the article.