

# Acoustic Measurements of Speech and Voice in Men with Angle Class II, Division 1, Malocclusion

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## Abstract

**Introduction** The acoustic analysis of speech (measurements of the fundamental frequency and formant frequencies) of different vowels produced by speakers with the Angle class II, division 1, malocclusion can provide information about the relationship between articulatory and phonatory mechanisms in this type of maxillomandibular disproportion.

**Objectives** To investigate acoustic measurements related to the fundamental frequency (F0) and formant frequencies (F1 and F2) of the oral vowels of Brazilian Portuguese (BP) produced by male speakers with Angle class II, division 1, malocclusion (study group) and compare with men with Angle class I malocclusion (control group).

**Methods** In total, 60 men (20 with class II, 40 with class I) aged between 18 and 40 years were included in the study. Measurements of F0, F1 and F2 of the seven oral vowels of BP were estimated from the audio samples containing repetitions of carrier sentences. The statistical analysis was performed using the Student *t*-test and the effect size was calculated.

**Results** Significant differences (*p*-values) were detected for F0 values in five vowels ([e], [i], [ɔ], [o] and [u]), and for F1 in vowels [a] and [ɔ], with high levels for class II, division 1.

**Conclusion** Statistical differences were found in the F0 measurements with higher values in five of the seven vowels analysed in subjects with Angle class II, division 1. The formant frequencies showed differences only in F1 in two vowels with higher values in the study group. The data suggest that data on voice and speech production must be included in the protocol's assessment of patients with malocclusion.

## Keywords

- ▶ speech
- ▶ voice
- ▶ speech acoustics
- ▶ malocclusion

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## Introduction

The Angle classification of malocclusions is widely used in the orthodontic field. Considering the types of dental malocclusions (classes I, II, [divisions 1 and 2] and III), this research focuses on class I and class II, division 1. The class I malocclusion has a normal molar relationship, but the teeth are not aligned along the line of occlusion. The class II, division 1, malocclusion has the lower molar distally positioned relative to the upper molar, and the central maxillary incisor buccally projected. Thus, while class I malocclusion indicates anteroposterior stability between the maxilla and the mandible, class II indicates projection of the maxilla in relation to the mandible.<sup>1</sup>

Angle Class II malocclusion influences the formation of the craniofacial skeleton and the distance between the upper and lower incisors; together with the imbalance in the orofacial musculature, it may cause modifications in speech.<sup>2</sup> The interrelationship between speech disorders and dental malocclusions is described in the literature, as well as the fact that the lips and the tongue adapt to unfavourable bone and muscle conditions.<sup>3-5</sup> Voice production can also be influenced by changes in the facial skeleton and the position of the tongue, since there are correlations between voice frequency control and speech articulation.<sup>6,7</sup>

Authors<sup>2,4,8,9</sup> describe that the most frequent speech disorders in Angle Class II are related to the sounds of the fricative [s] and [z] and bilabial [p], [b], [m] consonants. The investigation of vowel data is much more restricted in dentofacial disorders, despite their role on prosodic features, like stress and intonation, which are important elements for speech intelligibility.<sup>10</sup>

Among the various forms of speech and voice evaluation, acoustic analysis has been increasingly used by speech-language pathologists. As a non-invasive technique, it enables the establishment of relationships between speech and voice perception and production.<sup>11</sup> In this perspective, the parameters related to the fundamental frequency and formant frequencies are highlighted.<sup>11-13</sup>

Physiologically, the acoustic parameter of the fundamental frequency (F0) corresponds to the number of vocal fold vibrations per second. This measurement can also provide some information about the vertical position of the larynx, that is, the higher it is, the faster the vibration of the vocal folds, and the higher frequency will be; on the other hand, the slower the vibration, the lower the F0 will be.<sup>11-13</sup> The sound source generated by the vocal fold's vibrations will be modified by the resonances of the vocal tract cavities.<sup>13</sup>

Among the most relevant measurements for the studies on supralaryngeal mechanisms (resonances) are the formant frequencies, especially the first two. These resonances are related to the phonetic identity of the vowels.<sup>11-13</sup> The first formant (F1) is physiologically related to the dimension of the posterior cavity, which is affected by the height of the tongue and the degree of opening of the jaw. The higher the F1 frequency, the lower the tongue and jaw positions, and vice-versa.<sup>11-13</sup> It is worth noting that, in Brazilian Portuguese (BP), oral vowels are articulatorily classified in terms of

four positions related to the height of the tongue (low, medium-low, medium-high, and high).<sup>14</sup> The second formant (F2) is physiologically related to the dimension of the anterior cavity, and correlated to horizontal tongue movements (forward and backward). The higher the value of F2, the more anterior will be the constriction of the tongue in the oral cavity, and vice-versa.<sup>11-13</sup> In BP, oral vowels are articulatorily classified in terms of three categories (central, anterior and posterior).<sup>13</sup>

Few studies in the literature focus on speech parameters in subjects with class II malocclusion. The authors have observed compensations such as mandibular advancement, lingual interposition,<sup>15</sup> and unsystematic articulatory imprecision<sup>16</sup> during the production of consonants. Bilabial sounds have also been studied, because some compensatory strategies can be implemented in order to overcome the anatomical disproportion.<sup>2,8</sup> Distortions in the sounds of fricatives<sup>8</sup> have also been reported. Another study<sup>9</sup> reported tongue retraction during the production of the sound [s] in a man with class II, division 1, in relation to the control. These authors<sup>9</sup> also observed jaw and lower lip retractions as well as a more retracted and raised tongue position in all American English vowels produced by this individual compared to individuals with class I. In a Finnish study,<sup>3</sup> the authors compared F1 and F2 measurements of eight oral vowels produced by five speakers before and after orthognathic mandibular advancement surgery, and either slight changes were observed, or no differentiation was found. The results of a study<sup>17</sup> that analysed the production of consonants in various types of malocclusions did not find statistical significance when correlating only the Angle Classification of malocclusions with the articulatory errors of the investigated sounds.

Acoustic measurements of speech and voice samples from individuals with malocclusion are scarce in the literature, despite the tendencies reinforcing that maxillomandibular deformities can produce serious functional problems and present implications in vocal production.<sup>8</sup> In this field, lower F0 values and habitual pitch are related to increased facial width and length.<sup>18</sup> On the other hand, comparisons of F0 values before and after orthognathic surgery (five cases of retrognathic jaw) showed no significant changes.<sup>3</sup> In our previous study,<sup>19</sup> we detected higher F0 values for all BP oral vowels in men with Angle class III malocclusion when compared with cases of class I.

The study of these measurements can help the understanding of the clinical impacts, since higher values of the fundamental frequency may indicate a higher position of the hyoid-larynx complex, which may cause increased glottic adduction, laryngeal hyperfunction, and can contribute to the appearance of dysphonia in some cases.<sup>19</sup>

Our previous investigations support the hypotheasis that individuals with Angle class II, division 1, may develop muscular and functional compensations during the production of speech and voice that could be detected by acoustic analysis. Therefore, this may contribute to the establishment of therapeutic strategies that promote the development of more productive orofacial and laryngeal muscle adjustments.

Thereby, due to the lack of studies on the acoustic parameters of the oral production of speakers with Angle class II, division 1, the present study aimed at investigating the acoustic parameters (fundamental frequency and formant frequencies F1 and F2) of the oral vowels in BP.

## Methods

The project for this cross-sectional descriptive multicentre study was approved by the Ethics Committees of the institutions involved. All participants signed an informed consent form.

In total, 60 men aged between 18 and 40 years, 20 with Angle class II, division 1, malocclusion (mean = 22.9 years; standard deviation [SD] = 2.53 years) and 40 with Angle class I malocclusion (mean = 23.3 years; SD = 2.71 years), were included in the study. All subjects were speakers of Brazilian Portuguese from the city of Rio de Janeiro. The study group (SG) was composed by the men with Angle class II, Division 1, and the men with Angle Class I were the control group (CG).

The following inclusion criteria were adopted for the SG: Angle class II, division 1, malocclusion, with the mesio-vestibular sulcus of the lower first molars positioned posteriorly to the mesio-vestibular cusp of the maxillary first molars, with overjet between 4 mm and 7 mm, with an average of 5 mm. For the CG, the criteria were: Angle Class I malocclusion, with the mesio-vestibular cusp of the maxillary first molar occluded in the mesio-vestibular groove of the permanent mandibular first molar, without anterior or posterior crossbite and minor changes in tooth positioning. Thus, the participants presented dimensions of the oral cavity compatible with those with normal occlusion. The exclusion criteria adopted were dental absences, and the presence of open bite, supernumerary teeth, cleft palate, and smoking.

Class II participants were recruited from the Oral and Maxillofacial Surgery outpatient clinic of the Oral and Maxillofacial Surgery outpatient clinic of Rio de Janeiro State University, and the participants with Angle Class I were students at Fluminense Federal University.

For the acoustic analysis, the speech samples were obtained from the carrier sentences “Diga \_\_\_\_\_ para mim” (“Say \_\_\_\_\_ to me”), filled with the words “Pápa”, “Pépe”, “Pêpe”, “Pípi”, “Pópo”, “Pôpo” and “Púpu”, read four times randomly. The samples were recorded in a quiet room using the Praat (open access, available at <http://www.fon.hum.uva.nl/praat/>) software, version 6.0.16, and a single-channel recorder at a sampling rate of 22.050 Hz. A Pavilion 14 (Hewlett-Packard, Palo Alto, CA, US) laptop computer with a Core i5-7200U (Intel, Santa Clara, CA, US) processor, and Windows 10 (Microsoft Corp., Redmond, WA, US) operating system and a Shure SM 58 microphone (Shure, Niles, IL, US) were used for the recordings. The distance of the microphone was regulated 10 cm from the participant’s lips, and the loudness of the voice during the recordings was controlled through the horizontal bar recording present in the Sound Record window of the Praat software. No recording exceeded half the volume of this window, so they all

remained all in the green area without reaching the yellow or red areas, which indicate increased voice intensity.

Each vowel segment was saved in files with an .wav extension. All vowel segmentations were performed by the same researcher. The most stable section of each vowel was identified from Linear Predictive Coding (LPC) tracing overlaid on broadband spectrograms. Then the ten milliseconds of the intermediate portion of the vowel were selected.

Two scripts running in the Praat software were used to estimate the F0 and formant measurements. The most stable section of each vowel was considered to run an F0 script written for previous studies.<sup>19-21</sup>

To take the F1 and F2 measurements, four repetitions of each carrier sentence were considered to apply the AcousticParametersForVowelsExtractor.psc, version 1.3, script.<sup>22</sup> The seven oral vowels were manually labelled. The script applies the Lobanov Normalization Method, which is a procedure that calculates the z-scores of the frequencies of the formants of each vowel of a speaker using the mean and standard deviation of each formant. This method is considered extrinsic to the vowel and intrinsic to the speaker. This normalization procedure aims at excluding physiological differences.<sup>13</sup>

The values obtained using the script were transferred to an Excel (Microsoft) spreadsheet and manually checked by another investigator. After this step, the averages of the emissions of each vowel were calculated to estimate the final value.

## Statistical Analysis

The statistical analysis was performed using the Statistical Package for Social Sciences (SPSS, Inc., IBM Corp., Armonk, NY, US) software for Windows.

The Kolmogorov-Smirnov test was used to assess the normality of the data distribution, and there was no evidence of non-normal distribution of the variables.

The Student *t*-test was used to compare the means of F\*1 and F\*2 (normalized data) and F0 between the groups. The significance level adopted was  $\leq 0.05$  (5%). The effect size (ES) was also calculated for F0 to assess the degree to which the phenomenon was present in the study population, and, the higher its value, the more prevalent the phenomenon. The ES is represented by the letter “*d*” and its values are considered small ( $0.20 \leq d < 0.50$ ), medium ( $0.50 \leq d < 0.80$ ) and large ( $d \geq 0.80$ ).

## Results

### Fundamental Frequency

Higher F0 measurements with statistical differences were observed in five vowels ([e], [i], [o], [u]) in individuals with Angle class II, division 1, with a large ES value for vowels [e], [i], [o], and [u] and a medium value for vowel [o] (► **Table 1**).

### Formant Frequencies – F\*1 and F\*2

For F\*1, higher frequencies were observed for vowels [a] and [o] in men with Angle class II, division 1. No differences were

**Table 1** Comparison of fundamental frequency values in men with Angle class I and class II, division 1

Parameter	Class I (n = 40)		Class II (n = 20)		Student t-test	Effect size
	Mean (Hz)	Standard deviation	Mean (Hz)	Standard deviation	p-value	
F0 [a]	116	14.12	123	12.48	0.123	0.532
F0 [ɛ]	117	15.20	125	12.99	0.098	0.573
F0 [e]	123	16.10	138	15.85	0.004*	0.950
F0 [i]	131	18.62	146	18.39	0.015*	0.820
F0 [ɔ]	119	15.16	131	15.59	0.021*	0.790
F0 [o]	125	16.87	142	20.76	0.005*	0.910
F0 [u]	136	21.69	154	24.24	0.013*	1.012

Note: \*p-value < 0.05; Student t-test.

found between the F2 measurements in the two groups studied (→ **Table 2**).

## Discussion

Disorders of the stomatognathic system especially in dental occlusion, may cause several disorders, including of the speech and voice,<sup>9,24,25</sup> due to the interrelationship of speech articulation and phonation.<sup>6,7</sup>

The literature investigating acoustic parameters of vowels in individuals with Angle class II, division 1, is still restricted,

which limits the discussion regarding the data. Moreover, since the research in the literature was conducted in other languages, it is not possible to compare the studies, since these parameters are language-dependent.

### Fundamental Frequency

The higher fundamental frequency values detected in five of the seven vowels in the study group are indicative of higher longitudinal tension and faster vibration of the vocal folds, which may also suggest raised larynx adjustment.<sup>6,26</sup> When searching for the correspondence between physiological

**Table 2** Absolute and normalized data for F1 and F2, and comparison of the frequencies of the first two formants (normalized data) in men with Angle class I and class II, division 1

Parameters	Absolute measures				Normalized measures				Class I versus Class II (normalized)
	Class I (n = 40)		Class II (n = 20)		Class I (n = 40)		Class II (n = 20)		Student t-test
	Mean (Hz)	Standard deviation	Mean (Hz)	Standard deviation	F*(n) <sup>a</sup>	Standard deviation	F*(n) <sup>a</sup>	Standard deviation	p-value
F1 [a]	720	64.33	738	46.49	1.68	0.22	1.47	0.22	0.001*
F1 [ɛ]	538	42.09	563	55.05	0.62	0.22	0.56	0.21	0.298
F1 [e]	344	31.40	356	22.88	-0.62	0.15	-0.70	0.093	0.062
F1 [i]	266	21.03	279	22.69	-1.13	0.09	-1.18	0.11	0.092
F1 [ɔ]	542	43.73	594	47.84	0.69	0.21	0.85	0.30	0.018*
F1 [o]	379	27.43	406	37.77	-0.39	0.12	-0.45	0.32	0.291
F1 [u]	308	34.93	339	35.03	-0.92	0.30	-0.76	0.51	0.144
F2 [a]	1,255	75.36	1,248	63.09	-0.21	0.11	-0.24	0.10	0.438
F2 [ɛ]	1,811	140.67	1,823	97.52	0.68	0.15	0.71	0.12	0.427
F2 [e]	2,070	144.87	2,065	100.11	1.09	0.12	1.12	0.13	0.451
F2 [i]	2,180	152.08	2,160	94.15	1.27	0.14	1.28	0.12	0.847
F2 [ɔ]	868	64.98	898	50.43	-0.85	0.10	-0.85	0.12	0.871
F2 [o]	732	71.64	772	134.75	-1.04	0.24	-1.07	0.23	0.587
F2 [u]	668	76.10	702	73.59	-1.06	0.33	-1.03	0.56	0.782

Notes: \*p-value < 0.05; Student t-test.

<sup>a</sup> F\*(n): F= formant frequency; (n)= number

\* normalization –Lobanov method.

responses and the observed phenomena, the relationship between voice frequency control and articulation of the vowels was considered.<sup>6</sup> Thus, the hypothesis was that higher measurements of F0 may have occurred due to the anatomical condition inherent to class II, division 1, malocclusion, that is, increased overjet, increase of the vertical dimension of the face, reduction in the inferior anteroposterior space,<sup>8,9</sup> which may cause adaptations in the position of the tongue, such as elevated dorsum<sup>8,9</sup> and lowered tip,<sup>8</sup> as well as anterior mandibular sliding.<sup>9</sup> Thereby, the upper tongue dorsum may cause an elevation of the hyoid-larynx complex during the production of some sounds, which would explain the higher frequencies in the posterior vowels [ɔ], [o], and [u] in the study group. A hypothesis for the differences found in the anterior vowels [e] and [i] would be a muscular adjustment performed by individuals with class II in the articulation of this sound due to changes in the shape of the jaw and palate, which caused an elevation of F0 due to the interrelationship of articulation and phonation, in the case of intrinsic F0 variation due to tongue position.<sup>6</sup> Consequences on vocal production in cases of inadequate tongue posture were also mentioned in one study<sup>8</sup> as one of the functional impairments caused by maxillomandibular disproportion.

One research described that the magnitude of the jaw opening was inversely proportional to the average of F0, that is, the smaller the aperture, the greater the value of F0,<sup>18</sup> which may be also related to higher laryngeal elevation. Thus, when analysing F1 values, correlated with tongue height and degree of jaw opening, lower values were detected for three vowels ([i], [o], [u]) in subjects with class II. The F0 and F1 data suggest raised tongue body and lower jaw opening as recurrent adjustments in the speech and voice production of class-II speakers.

### Formants Frequencies

Higher levels of F1 were found for the vowels [a] and [ɔ] in the group with class II, division 1, which enables inference of a reduced dimension of the posterior cavity, essentially oropharyngeal space, due to many possible adjustments, such as the lowered tongue body or jaw; pharyngeal constriction (related to lowered tongue body, and/or raised larynx, and/or pharyngeal constrictor muscles) during the production of these vowels in the SG compared to the CG.

Higher values in the frequencies of F1 of the low vowel [a] and posterior low middle vowel [ɔ] can be attributed to compensations of tongue's position associated with the smaller size of the pharyngeal cavity. This fact is supported by a study<sup>28</sup> in which the authors observed a decrease in the nasopharynx, oropharynx and hypopharyngeal space in class II individuals when compared to participants with Angle class I malocclusion.

Some studies<sup>3,5</sup> have pointed to the possibility of the articulatory organs, especially the lips and the tongue, to adapt to unfavourable bone and muscle conditions.

Authors<sup>9</sup> have estimated the frequencies of the first two formants of American English vowels in an individual with class II, division 1, and compared them to the measurements

of a classic study<sup>29</sup> that investigated subjects without this disproportion and reported that no significant differences were found. However, they mentioned in their data elevation of the middle part of the tongue towards the hard palate in the vowel [i], and elevation of the tongue dorsum in the vowel [u].<sup>9</sup> They also reported a higher value of F2 for the vowel [a], which suggests a more anterior posture of the tongue constriction. The results of the present study demonstrate a different trend, with lower values of F1 for the vowels [a] and [ɔ], and without differences in the measurements of F2.

In a literature review,<sup>4</sup> the authors observed that individuals with vertical maxillary excess or Angle class III may produce a greater number of articulation errors than individuals with Class II. These authors emphasized that most of the studies reported elimination or drastic reduction in articulatory errors with orthognathic surgery; however, in some cases, speech deterioration was noted after the procedure, which was attributed to the individual's inability to adapt to their new anatomical and functional conformations.<sup>4</sup>

Although hypothetically a greater number of differences regarding F1 and F2 could be expected between Angle class I and class II, division 1, due to anatomical differences in the oral cavity, the reduced number of distinctions can be explained by the ability of the human vocal tract to make adjustments in speech production in the case of structural changes.<sup>19</sup>

### Limitations, Applications and Future Perspectives

The present study provides relevant information on vowel acoustic measurements in individuals with Angle class II, division 1; however, some limitations should be recognized. First, only men were included in the sample. Secondly, the F0, F1 and F2 measurements were analysed in one of the most used speech tasks in speech evaluation (carrier sentences). However, in the continuation of the study, the inclusion of females is expected, in addition to the comparison of these values with those of another classic speech task in the speech therapy clinic (sustained vowel emission). To broaden the analysis, we suggest that further studies be conducted with a larger sample of men with Angle class II, division 1. Another perspective will contemplate the approach of perceptual judgments, both in terms of speech intelligibility and vocal quality adjustments.

The results of the present research contribute to the understanding of some compensations that can be performed in the production of voice and speech in individuals with class II, division 1, since it was possible to observe structural and functional correlations. The analysis of acoustic parameters of speech and voice enables the inference of the articulators' conformation and aspects of the vertical position of the larynx.<sup>11</sup> Thereby, the investigation of these measurements can assist in the work of speech therapists, otorhinolaryngologists, orthodontists and maxillofacial surgeons in the care for these patients. These assessments enable the early detection of compensations that are being performed and direct a more

specific muscle and functional work, enabling the development of more appropriate adaptations.

Higher values for F0 may indicate a high laryngeal position that can cause laryngeal hyperfunction, with increased glottic adduction.<sup>30</sup> This overload in vocal fold adduction may be a risk factor for the development of benign laryngeal lesions, especially in people who use their voice as their main working instrument. Therefore, strengthening of the orofacial and intrinsic and extrinsic muscles of the larynx can contribute to a better functional adaptation, as well as to avoid the onset of secondary laryngeal alterations.

## Conclusion

Angle class II, division 1, subjects may present interferences in aspects of speech and voice production. The formant frequencies (F1 and F2) did not show relevant differentiations between the SG and CG. However, the fundamental frequency values showed greater distinction between the groups, with higher values in five of the seven vowels analysed in subjects with Angle class II, division 1. Thus, we recommend that voice and speech parameters be included in the protocols of speech-language pathology assessment, complementing the data related to speech production.

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### Conflict of Interests

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## References

- Grabe LW, Vanarsdall RL, Vig KWL, Huang GJ. *Orthodontics current principles and techniques*. 6th ed. St. Louis, Missouri: Elsevier; 2017
- Mezzomo CL, Machado PG, Pacheco AB, Gonçalves BFT, Hoffmann CF. The implications of class II angle and class II type skeletal disproportion on the myofunctional aspect. *Rev CEFAC* 2011;13(04):728–734
- Niemi M, Laaksonen JP, Peltomäki T, Kurimo J, Aaltonen O, Happonen RP. Acoustic comparison of vowel sounds produced before and after orthognathic surgery for mandibular advancement. *J Oral Maxillofac Surg* 2006;64(06):910–916
- Hassan T, Naini FB, Gill DS. The effects of orthognathic surgery on speech: a review. *J Oral Maxillofac Surg* 2007;65(12):2536–2543
- Nájera SL, Rodríguez FJM, Ledesma AF, Grajeda DI, Jiménez JC, Ruidíaz VC. Pronunciation of phonemes in relation to the degree of malocclusion and position of the incisal edges-lip vermilion border. *Rev Mex Ortod* 2016;4(04):e217–e224
- Honda K. Relationship between pitch control and vowel articulation. *Haskins Labor Status Report Speech Research*. 1983;73:269–282
- Shaw JA, Chen WR, Proctor MI, Derrick D. Influences of tone on vowel articulation in mandarin Chinese. *J Speech Lang Hear Res* 2016;59(06):S1566–S1574
- Coutinho TA, Abath MB, Campos GJL, Antunes AA, Carvalho RWF. Adaptações do sistema estomatognático em indivíduos com desproporções maxilo-mandibulares: revisão da literatura. *Rev Soc Bras Fonoaudiol* 2009;14(02):275–279
- Jesus LMT, Araújo A, Costa IM. Speech production in two occlusal classes. *Onomazein* 2014;29(01):129–151
- Gregio FN. *Configuração do trato vocal supraglótico na produção das vogais do Português Brasileiro: Dados de imagens de ressonância magnética [dissertação]*. São Paulo: Pontifícia Universidade Católica de São Paulo; 2006;87;
- Kent RD, Read C. *Análise Acústica da Fala*. 1a ed. São Paulo: Cortez; 2015
- Sundberg J. *Ciência da Voz: Fatos Sobre a Voz na Fala e no Canto*. 2a. ed. São Paulo: EdUSP; 2018
- Barbosa PA, Madureira S. *Manual de Fonética Acústica Experimental*. São Paulo: Cortez; 2015
- Escudero P, Boersma P, Rauber AS, Bion RAH. A cross-dialect acoustic description of vowels: Brazilian and European Portuguese. *J Acoust Soc Am* 2009;126(03):1379–1393
- Villanueva P, Morán D, Lizana ML, Palomino HM. Articulación de fones en individuos clase esquelética I, II y III. *Rev CEFAC* 2009;11(03):423–430
- Trench JA, Araújo RPC. Dentofacial deformities: orofacial myofunctional characteristics. *Rev CEFAC* 2015;17(04):1202–1214
- Leavy KM, Cisneros GJ, LeBlanc EM. Malocclusion and its relationship to speech sound production: Redefining the effect of malocclusal traits on sound production. *Am J Orthod Dentofacial Orthop* 2016;150(01):116–123
- Macari AT, Karam IA, Ziade G, et al. Association between facial length and width and fundamental frequency. *J Voice* 2017;31(04):410–415
- Viegas F, Viegas D, Serra Guimarães G, Ritto F, Simões-Zenari M, Nemr K. Acoustic Analysis of Voice and Speech in Men with Skeletal Class III Malocclusion: A Pilot Study. *Folia Phoniatr Logop* 2020;000:1–9
- Viegas F, Viegas D, Atherino CCT, Baeck HE. Frequência fundamental das 7 vogais orais do português em vozes de crianças. *Rev CEFAC* 2010;12(04):563–570
- Viegas F, Viegas D, Baeck HE. Frequency measurement of vowel formants produced by Brazilian children aged between 4 and 8 years. *J Voice* 2015;29(03):292–298
- Barbosa PA. Script: AcousticParametersforVowelsExtractor, Version 1.3 (2015). Disponível em: <https://github.com/pabarbosa/prosody-scripts>
- Loureiro LMJ, Gameiro MGH. Interpretação crítica dos resultados estatísticos: para lá da significância estatística. *Rev Enferm Ref* 2011;3:151–162
- Johnson NCL, Sandy JR. Tooth position and speech—is there a relationship? *Angle Orthod* 1999;69(04):306–310
- Martinelli RLC, Fornaro EF, Oliveira CJM, Ferreira LMDB, Rehder MIBC. Correlações entre alterações de fala, respiração oral, dentição e oclusão. *Rev CEFAC* 2011;13(05):17–26
- Viegas F, Viegas D, Serra GS, Ritto F, Simões-Zenari M, Nemr K. Acoustic analysis of fundamental frequency in men with skeletal Class II malocclusion. *Int Arch Otorhinolaryngol* 2019 18th Congress of Otorhinolaryngology Foundation, August 29–31, 2019. 9532; p.S161
- Bollhalder J, Hänggi MP, Schätzle M, Markic G, Roos M, Peltomäki TA. Dentofacial and upper airway characteristics of mild and severe class II division 1 subjects. *Eur J Orthod* 2013;35(04):447–453
- Kaur S, Rai S, Kaur M. Comparison of reliability of lateral cephalogram and computed tomography for assessment of airway space. *Niger J Clin Pract* 2014;17(05):629–636
- Peterson G, Barney H. Control methods in a study of vowels. *J Acoust Soc Am* 1952;24(02):175–184
- Oliveira LR, Camargo Z. *Análise acústica comparativa das vogais orais entre crianças respiradoras orais e nasais*. In: Camargo Z. *Fonética Clínica. 20 anos do LIAAC São Paulo: Pulso Editorial*; 2016