Original Article

Artigo Original

Parameters Acoustic and High-speed kymography identified effects of voiced vibration and vocal fry exercises

Parâmetros acústicos e quimografia de alta velocidade identificam efeitos imediatos dos exercícios de vibração sonorizada e som basal

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Keywords

Voice
Voice training
Vocal quality
Acoustics
Speech therapy

ABSTRACT

Purpose: To identify the immediate effects of voiced vibration and vocal fry exercises on healthy subjects by means of acoustic parameters and high-speed kymography.
Methods: Thirty healthy subjects (18 women and 12 men, aged from 19 to 45 years old) participated in this study. The voices were recorded at the range of 44.100 samples/second, before and after of the vocal exercises. We developed a computational routine to extract jitter and shimmer. High-speed kymography was generated from laryngeal images for the analysis of the phase times: closed (CPh), open (OPh), of closing (cPh) and of opening (oPh) and used the paired t-Student test and the Mann-Whitney test, with a significance level of 0.05.
Results: After voiced vibrations, acoustic parameters showed reduced jitter for both genders ($p=0.018$ for men and $p<0.01$ for women) and reduced shimmer for female voices ($p<0.01$). There was a decrease in CPh ($p=0.046$) and cPh ($p=0.026$) and an increase in OPh ($p=0.05$) in female vocal folds. After vocal fry, we identified decreased jitter ($p<0.01$) in female voices and cPh ($p=0.026$) in male vocal folds. **Conclusion:** We observed more positive immediate effects of the voiced vibrations, mainly in voice quality and vocal folds among females. Nevertheless, studies with larger male sample and investigation of the appropriate time of vocal fry are necessary to confirm the results of this search.

Descritores

Voz
Treinamento da voz
Qualidade da voz
Acústica
Fonoterapia

RESUMO

Objetivo: Identificar efeitos imediatos das vibrações sonorizadas e do som basal em indivíduos saudáveis por meio de parâmetros acústicos e quimografia de alta velocidade. **Métodos:** Participaram 30 sujeitos, 12 homens e 18 mulheres (19 a 45 anos) sem alterações laríngeas. As vozes foram gravadas à taxa de 44.100 amostras/segundo e as videolaringoscopias de 4.000 quadros/segundo, antes e depois dos exercícios vocais. Foi desenvolvida uma rotina computacional para extrair *Jitter* e *Shimmer*. Foram geradas quimografias de alta velocidade a partir das imagens laríngeas para a análise dos tempos de fase: fechada (FF); aberta (FA); de fechamento (Ff) e de abertura (Fa), e usados o Teste *t* de Student pareado e o teste Mann-Whitney, com nível de significância de 0,05. **Resultados:** Após as vibrações sonorizadas, houve diminuição de *Jitter* (0,018 para homens e p<0,01para mulheres) para ambos os gêneros e diminuição de *Shimmer* (p<0,01) ao gênero feminino. Houve diminuição de FF (p=0,046) e de Ff (p=0,026) e aumento de FA (p=0,05) em pregas vocais femininas. Após o som basal, foram identificados diminuição de *Jitter* (p<0,01) em vozes femininas e da Ff (p=0,026) em pregas vocais masculinas. **Conclusão:** Foi possível verificar mais efeitos imediatos positivos após as vibrações sonorizadas principalmente em qualidade vocal e pregas vocais de mulheres. No entanto, são necessárias pesquisas com maior número de amostras masculinas e investigação sobre o tempo adequado do som basal para corroboração dos resultados desta pesquisa.

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INTRODUCTION

In the Speech Language Pathology and Audiology clinic, vocal techniques are used for vocal improvement or for treating vocal disorders. Therefore, speech language pathology and audiology aims at a healthy emission and at the prevention of phonotraumas during vocal production(1,2). In the past few years, researchers have been making efforts to prove the physiological effects that vocal exercises have on vocal quality and on the vocal folds of healthy individuals or those with dysphonia(3,4).

Out of the therapy techniques developed throughout history, two of them have been drawing the attention of researchers. The first one is the voiced vibration, which is commonly used for most of the vocal disorders(5,6) since its effects are easily noticed by the ears of the pathologist and the patient(2,5). The other one is the vocal fry, presenting several therapeutic indications, even though it is still not used much for presenting numberless divergences among researchers and speech language pathologists(4,7,8).

It is essential that the performance of vocal techniques be measured to prove their real effect on the vocal folds and on the vocal quality of healthy or dysphonic individuals. In this sense, the methods of evaluation allow describing the physiological aspects of the voice in several types of vocal production(9). The acoustic analysis contributes with both quantitative and qualitative data. Even if the jitter and shimmer parameters are not so robust to assess very deviated voices, they have been very much used in studies in which the participants contribute with experimental and control data at the same time(10). Another way of analyzing the voice is to assess laryngeal images. The most recent high-speed filming technique reveals the real vocal fold cycle. From the pictures of these images, it is possible to generate kymographs and extract objective parameters, in order to analyze the vibration behavior of the vocal folds in detail(11).

Extending the knowledge about the effects of vocal techniques is a current need of speech language pathology and audiology. Therefore, the objective of this study is to identify the immediate effects of voiced vibration and vocal fry in healthy individuals by means of acoustic parameters and high-speed kymography obtained from video laryngoscopy.

METHODS

This study was approved by the Research Ethics Committee of *Universidade Federal de São Carlos*. All the participants were delivered written material informing them of the objectives of the study, and then they signed the informed consent.

Data were collected in the outpatient clinic of the Voice Group at the Division of the Otorhinolaryngologic Clinic Division of *Hospital das Clínicas* in the School of Medicine, *Universidade de São Paulo*. Participants went through speech language pathology and audiology screening, when each one responded to an anamnesis that investigated vocal habits. Afterwards, they were submitted to auditory–perceptual assessment, where they performed according to the concepts of the visual analogue scale(12) by an experienced speech language pathologist. The global degree of vocal emission in continuous speech was accessed, and the interval between 0.0 and 34.5 mm(12) was considered as the normal variability of vocal quality for the study sample. Forty-four individuals were assessed from September 2010 to November 2011. Out of these, nine were excluded for failing the speech language pathology and audiology screening, and five for presenting alterations to the laryngeal examination (two with signs of gastroesophageal reflux, two with small nodules and one with laryngeal micro diaphragm). These participants were oriented as to their vocal health and the need for evaluation and adequate treatment.

The individuals included in this study were the ones who did not present with history of smoking and alcoholism, and who were free of digestive and hormonal changes, as well as inflammatory processes in the airways. Collection selected 30 individuals (12 men and 18 women), aged between 19 and 45 years, with good general health status. Voice recordings and high-speed video laryngoscopy were performed in two moments, before and after vocal exercises. In order to process and analyze the acoustic signals and the laryngeal images, algorithms developed by the Medical Engineering Research Group (GPEM/ National Council for Scientific and Technological Development – CNPq) were used.

In voice collection, the acoustic recording used the following equipment: notebook with Intel Dual-Core processor T4400 2,2 GHz, attached to an external USB sound card and a unidirectional microphone with minimum sensitivity of 44 dB and response frequency of 60 to 12 kHz. Collection was performed in an acoustically treated room, with the microphone placed 4 cm away from the mouth, forming an angle of 45 to 90°(13).

Voice signals were stored in the .wav format, with rates of 44,100 samples per second. High-speed video laryngoscopy was conducted by a laryngologist in which high-speed image recording system by Richard Wolf (Knittlingen, Germany) was used, with high-performance light source (AUTO LP 5132), rigid laryngoscope (90° angle) and head camera (HRES ENCODAM 5562). Examinations were stored at a rate of 4000 pictures per second and converted to the .AVI format for image processing.

The investigated parameters were isolated by controlling the frequency emission and intensity. The procedure was performed before and after the vocal exercises with the objective of promoting the same vibration conditions to the vocal folds and emissions. Therefore, it was possible to rule out the influences of these variables in the acoustic parameters and in video laryngoscopy(10). The comfortable emission intensity and frequency of each subject was extracted during the first acoustic recording of the sustained vowel /ɛ/. In the case of intensity, a sound pressure level measuring device from RadioShack (33-2055, Nova York, United States) was used and placed 30 cm from the labial commissure. The fundamental frequency was extracted by using the virtual keyboard of the SpeechPitch software.

For the emission of the same intensity in other stages of collection, each subject was oriented to reproduce the sustained vowel /ɛ/ according to the indications of the speech language pathologist in charge of this research. Intensity was controlled with the sound pressure measuring device, previously used to extract this data. The maximal variation of 2 dB during the other emissions was accepted, and for the reproduction of the fundamental frequency in the following stages of collection, each participant was oriented to emit the sustained vowel /ɛ/ according to the orientations of the speech language pathologist. The speech language pathologist presented auditory and visual support with the same virtual keyboard used in the data extraction stage.

As to the acoustic recording performed before vocal exercises, each individual remained sitting, with the spine erect, and emitted a sustained vowel /ɛ/ at comfortable frequency and intensity. Afterwards, high-speed video laryngoscopy was conducted.

Participants received topical anesthetic before the examination. Rigid laryngoscope was introduced into the mouth of the participant, while they emitted the sustained vowel /ɛ/ at controlled frequency and intensity, as previously described. In the next stage, a specialized speech language pathologist oriented the participants to perform vocal exercises. After the vocal exercises, their voice was recorded and high-speed video laryngoscopy was conducted, respectively. These records were in accordance with the same protocol described for the pre-vocal exercise moment.

Laryngological examinations were performed by the same laryngologist, the doctor who collaborated in this research, and the position of the rigid endoscope was controlled during examinations[14]. The rigid endoscope was placed parallel to the vocal folds, in the same angle and distance used in the pre-vocal exercises.

The 30 participants were randomly divided into two experimental groups. Since the exercises of lip or tongue vibration presented similar impacts on the voice[2], the 15 individuals (six men and nine women) were asked to perform voiced vibrations that they felt more able to execute with simultaneous voice emission, throughout the longest phonation time[6].

According to the recommendations by Menezes et al.[15], the voiced vibrations were exercised by male individuals for five minutes, with an average of 20 vibrations, and female participants exercised it for three minutes, with an average of ten vibrations. Another 15 individuals (six men and nine women) were told to perform vocal fry throughout the longest phonation time. With the objective of avoiding muscular fatigue, due to the severe contraction of the thyroarytenoid muscle, each individual exercised vocal fry for one minute, regardless of gender. In average, the emission of vocal fry was performed four times.

Pre- and post-acoustic recordings of vocal exercises were processed with an algorithm developed by means of programming language, C Sharp, which belongs to the software package, Visual Studio, by Microsoft. The algorithm begins the analysis process by normalizing the signals to standardize the amplitude levels. Afterwards, it extracts the perturbation parameters automatically.

Voice is an almost periodical signal that presents perturbations in the glottal cycles along the frequency (jitter) and intensity (shimmer)[16]. These two parameters have been described as robust measures of the biomechanical properties of the vocal folds in situations of vocal assessment, which compares the results of therapeutic interventions[10]. For this study, the algorithms developed to calculate the jitter and shimmer values were based on the proposal of Davis[17,18]. Normality values were validated in 0.18% (standard deviation of 0.1%) for jitter and 1.08% (standard deviation of 0.37%) for shimmer[19].

High-speed kymographs are obtained by the juxtaposition of a sequence of frames of laryngeal images[20,21]. To make the images, high-speed video laryngoscopies were converted to .AVI extension and processed by the system software that captures the images (HRES). This system enables the selection of one point to juxtapose the frames of laryngeal images. High-speed kymographs were obtained from the medial region of the laryngeal image for the juxtaposition of the image frames with time (Figure 1). Mean point was chosen due to the higher mobility of the vocal folds[22,23]. For the analysis of kymographs, an algorithm was developed using the programming language, C Sharp, of the software package, Visual Studio, by Microsoft, which extracts the following parameters in milliseconds: closed phase (CPh), open phase (OPh), of closing phase (cPh) and of opening phase (oPh) (Figure 2).

All data were statistically treated by the paired t-Student test. Data that did not pass normality or homogeneity were treated with the Mann-Whitney test, both with significance level of 0.05.

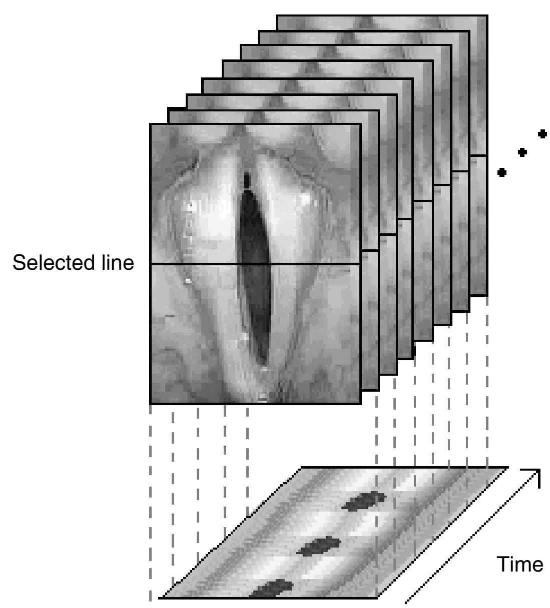

Figure 1. Schematic design representing the generation of a kymograph. Upper side shows laryngeal images recorded by video laryngoscopy. The selected line corresponds to the point chosen for the extraction and juxtaposition of each frame of the laryngeal image. Below, a kymographic image generated from the union of all the points of frames of juxtaposed images with time

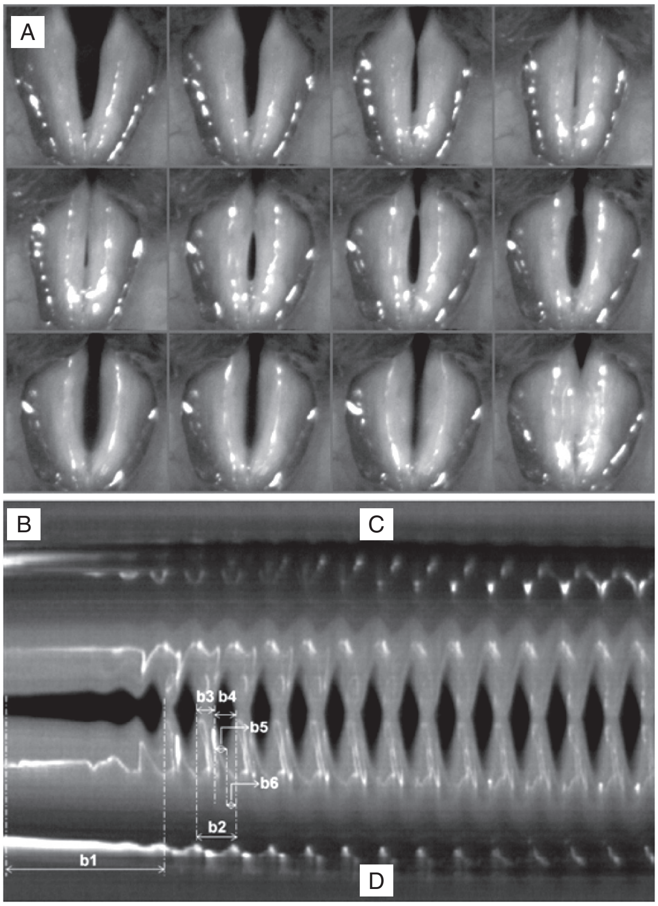

Figure 2. Images of a high-speed video laryngoscopy of healthy vocal folds of a female adult emitting the sustained vowel /ɛ/. (A) Frames of the sequence of a glottal cycle with the approximation of vocal folds to begin the vocal production and the sequence of sustained phonation; (B) High-speed kymography corresponding to the sequence demonstrated above, with the indications of (C) right vocal fold, (D) left vocal fold; (b1) vocal folds closing up to begin vocal production; (b2) total period of a vibration cycle; (b3) time of closed phase; (b4) time of open phase; (b5) time of opening phase; and (b6) time of closing phase of vocal folds

RESULTS

Perturbation parameters

The results of the voiced vibration exercise presented significant jitter changes for both genders; however, concerning shimmer, changes only happened among female participants (Table 1).

The group that performed the vocal fry exercise presented significant jitter changes among female voices. Statistical differences related to shimmer were not observed for any of the genders (Table 2).

High-speed kymography analysis

After the voiced vibration exercise, the statistical analysis identified significant changes for the following phases: close, open and closing in female vocal folds (Table 3). Figure 3 presents the vocal folds of a female sample, in which the times of each phase in the vibration are indicated, before and after voiced vibrations. After the exercise of vocal fry, a statistical difference was observed for the closing phase in male vocal folds (Table 4).

Table 1. Mean values, standard deviations and p values of perturbation parameters for individuals who performed the voiced vibration exercise

Parameters		*Jitter* (%)		*Shimmer* (%)	
		Pre	Post	Pre	Post
Men	M	0.23	0.20	1,24	1,27
	SD	0.06	0.05	0,50	0,41
	p-value	0.018*		0.780	
Women	M	0.32	0.27	1,24	1,01
	SD	0.12	0.11	0,48	0,40
	p-value	<0.01*		<0.01*	

*Values with significant differences
Paired Student´s *t*, with significance level of 0.05
Caption: M = Mean values; SD = standard deviation

Table 2. Mean values, standard deviations and p values of perturbation parameters for individuals who performed the vocal fry exercise

Parameters		*Jitter* (%)		*Shimmer* (%)	
		Pre	Post	Pre	Post
Men	M	0.18	0.19	1,08	1,33
	SD	0.06	0.05	0,38	0,56
	p-value	0.32		0.26	
Women	M	0.20	0.16	1,23	1,46
	SD	0.06	0.04	0,64	0,68
	p-value	<0.01*		0.07	

*Values with significant differences
Paired Student´s *t*, with significance level of 0.05
Caption: M = Mean values; SD = standard deviation

Table 3. Mean values, standard deviations and p values for the phases of the fundamental cycle of individuals who performed the voiced vibration exercise

Parameters		CPh		OPh		cPh		oPh	
		pre	post	pre	post	pre	post	pre	post
Men	M	3.20	2.71	3.81	4.00	1,74	2,19	2,22	1,93
	SD	0.87	1.23	1.62	1.75	0,91	1,01	0,97	0,93
	p-value	0.21		0.06		0.08		0.06	
Women	M	2.42	2.01	3.08	3.45	1,49	1,89	1,59	1,77
	SD	0.99	1.29	1.09	1.14	0,81	0,91	0,33	0,69
	p-value	0.046*		0.050*		0.026*		0.360	

*Values with significant differences
Paired Student´s *t* test with significance level of 0.05
Caption: CPh = closed phase; OPh = open phase; cPh = closing phase; oPh = opening phase; M = mean values; SD = standard deviation

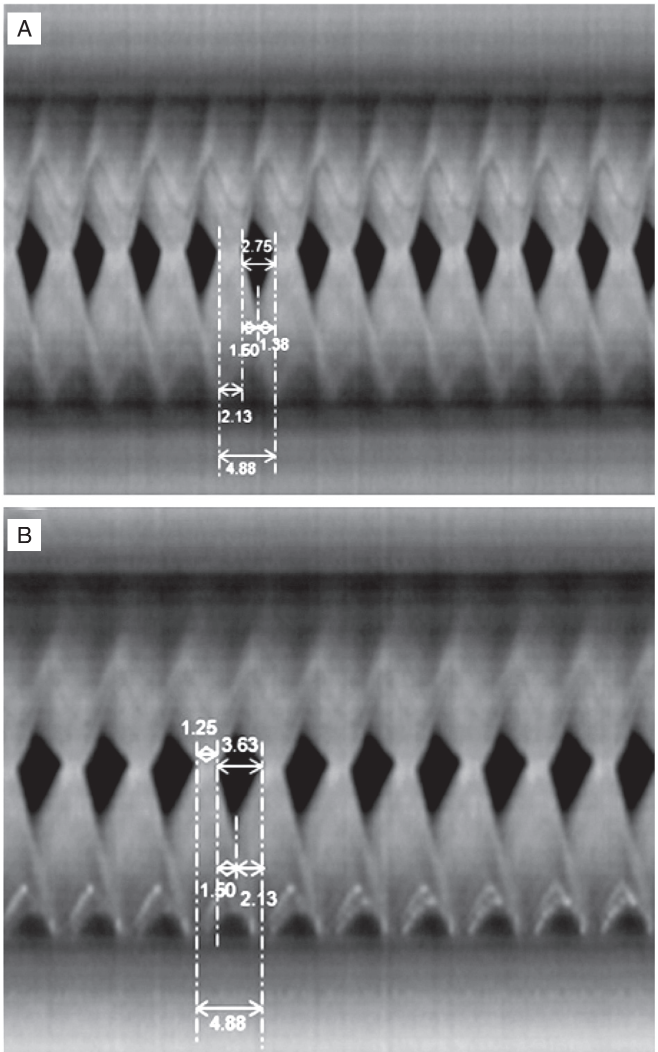

Figure 3. Images of high-speed kymography exemplify the phases of the glottal cycle of vocal folds in a female sample. (A) High-speed kymography before the voiced vibration exercise; (B) high-speed vibration after the voiced vibration exercised performed in the same frequency as the pre-vocal exercise emission (4.88 ms for the total vibration cycle). The decreased time of the closed phase is observed (from 2.13 to 1.25 ms), with increased length of the open phase (from 2.75 to 3.63 ms) and the closing phase (from 1.38 to 2.13 ms). Opening phase remained the same for both moments (1.50 ms)

Table 4. Mean values, standard deviation and p values of the phases of the fundamental cycle for individuals who performed the vocal fry exercise

Parameters		CPh		OPh		cPh		oPh	
		pre	post	pre	post	pre	post	pre	post
Men	M	3.84	3.87	3.98	3.84	2.20	1.83	1.79	2.01
	SD	0.93	0.87	1.05	0.91	0.72	0.65	0.48	0.44
	p-value	0.930		0.330		0.026*		0.210	
Women	M	2.41	2.62	2.55	2.39	1.18	1.08	1.41	1.26
	SD	0.45	0.34	0.55	0.59	0.37	0.28	0.26	0.38
	p-value	0.13		0.29		0.35		0.13	

*Values with significant differences

Paired Student´s *t* test with significance level of 0.05

Caption: CPh = closed phase; OPh = open phase; cPh = closing phase; oPh = opening phase; M = mean values; SD = standard deviation

DISCUSSION

This study was conducted with the objective of identifying the immediate effects of voiced vibration and vocal fry exercises on vocal quality and on vocal folds of healthy individuals. To achieve this, the study used perturbation parameters of acoustic analysis and parameters related to the duration of kymograph phases obtained from high-speed video laryngoscopies.

The results of the acoustic analysis demonstrated that the female voices were most influenced by vocal exercises after voiced vibration, and perturbation parameters significantly decreased for the female gender ($p<0.01$ for jitter and shimmer). With regard to male voices, the jitter significantly decreased ($p=0.018$) and there were no significant changes for the shimmer. According to literature[24,25], decrease of these parameters is an expected effect of the exercise. However, the shimmer results for the male gender are in agreement with some studies that did not find changes in the perturbation parameters after tongue vibrations[5,25]. Generally, our results indicate the immediate effect of voiced vibrations and lower mean perturbation of the voice signal in relation to the variation of frequency and amplitude. Lack of statistical corroboration concerning the shimmer of the male sample suggests the realization of more studies, with a larger sample for the gender.

After the vocal fry exercise, female voices presented significant jitter decrease ($p<0.01$) and increased shimmer values ($p=0.07$). There were no statistical differences for male voices. Literature describes the physiological effect of the vocal fry as the increment in perturbation measures during emission, both in frequency and amplitude[8,26].

A case study assessed the healthy voice of five adult women and did not find changes in the mentioned parameters[4]. Another study verified increased jitter in two adult women with hourglass-shaped glottal gap[4,8]. Our results diverge from the aforementioned ones; however, there is no consensus in current literature on the indication of time of execution of the vocal fry for therapeutic application[26]. The duration of the exercise may not have been sufficient to cause significant changes in the studied voices. Besides, the anatomical and physiological differences presented by the genders should be considered. For instance, male vocal folds may require longer time of execution of vocal exercises in order to cause any effect in its vibration pattern, once they are denser and longer due to the more prominent angle of the thyroid cartilage[27,28].

Regarding the analysis of high-speed kymographs, the search for studies investigating vocal folds under the immediate effect of vocal exercises found analyses that performed laryngological assessment by the visual analysis of video stroboscopy. In these studies, the parameters that were frequently evaluated were: glottic closure, laryngeal vestibule constriction and amplitude and symmetry of vocal fold vibrations. No studies that used video kymography were found for this purpose.

In this study, the analysis of high-speed kymographs presented similar behaviors in the vibrating cycles of both genders; however, different with regard to the type of vocal exercise. After the voiced vibrations, decreased mean values of CPh were observed, and the difference occurred specially in female vocal folds (p=0.046). There was increased OPh and cPh in both genders (OPh: p=0.06 for men and p=0.05 for women; cPh: p=0.08 for men and p=0.026 for women). oPh decreased in male vocal folds (p=0.06) and increased, however, not relevantly, in female vocal folds (p=0.36).

According to Titze[1], voiced vibrations are semi-occluded vocal tract exercises whose application aims at producing the following effects: normal vocal intensity, with energy saving, and minor mechanical trauma.

Voiced vibrations promote changes in vibration patterns, because during its performance the vocal folds gently get closer, adapting the glottic air flow and minimizing the impact of collisions. These aspects were described by mathematical models. The kymography generated from high-speed laryngeal images shows the same characteristics; however, it is used to analyze the effect of exercises on human larynxes.

In our results, the effects described by Titze[1] were observed in vibration cycles of male vocal folds, however, with no significant relevance. The findings for the gender suggested soft contact of the vocal folds during vocal production due to the slow approximation of vocal fold mucosa, and its faster separation and longer time of open glottis. In female glottal cycles, these changes were significant. Results suggest soft contact between vocal folds due to decreased speed of approximation of the vocal fold mucosa and the longest time of open glottis, spending less time in the closed position. The parameters without statistical corroboration indicate the need for research, with the participation of more male samples.

As to the analysis performed after vocal fry, the mean values presented slight variations, with increased CPh and decreased OPh for both genders. oPh increased in male vocal folds and decreased in female vocal folds. There was decreased cPh for both genders, and this was the only measure with significant changes for male vocal folds (p=0.026). According to literature[2,7,8,26], during the emission of vocal fry, vocal folds become shorter, in medial position, with firmer glottic closure due to maximal contraction of the thyroarytenoid muscle. Under these conditions, vocal fold mucosa presents more vibration amplitude, that is, it becomes looser along the free border, thus enabling more oscillatory movement. In our research, na effect indicated by vocal fry is the fast approximation of male vocal folds (p=0.026 cPh) in response to higher mobility of their mucosa. The result of the other phases, which did not present significant changes, need to be further investigated with a larger sample and longer duration of the exercise. The one minute emission of vocal fry may not have been sufficiently adequate to promote effective changes on the studied vocal folds.

The chosen equipment and methods, to extract parameters from acoustic signs and high-speed images, were efficient for the study of healthy voice under the effect of vocal exercises. It is believed that they can be useful to assess the different dimensional aspects of the voice in studies that investigate pathologies or therapeutic processes.

With the results of this study, it is possible to indicate the following therapeutic objectives in clinical practice: voiced vibration exercises can be more oriented when the intention is to reach more resistant vocal quality, more periodical cord vibrations, and soft contact between vocal folds. Both patients with mass lesions in vocal folds and individuals with occupational use of the voice can benefit from this technique. The vocal fry exercise, despite presenting a few expressive results, proved to be efficient for vocal objectives with the indication to promote increased mobility of vocal folds; and the vocal emission of patients who present with glottic insufficiency is favored by this technique.

CONCLUSION

It was possible to identify the immediate effects of voiced vibrations and vocal fry on healthy voices by means of the analysis of acoustic parameters and high-speed kymographs. Some immediate effects of voiced vibrations were identified, such as decreased jitter in vocal emission in both genders; decreased shimmer in vocal emission in females; and decreased effort with increased efficacy with regard to vocal production among females, which was observed in high-speed kymography parameters.

After the vocal fry exercise, the immediate effects of decreased jitter among female participants were identified, as well as increased glottic closure among male participants, indicated by the closing phase parameter of high-speed kymography.

It was also possible to identify more positive immediate effects after voiced vibrations, especially concerning quality and female vocal folds. However, studies with larger male samples, and investigation on adequate duration of vocal fry to corroborate the results of this research, are necessary.

**RAP was in charge of the elaboration of the project; study design and data collection, tabulation and analysis; and elaboration and execution of the manuscript. MED supervised the elaboration of the project, study design and data collection and analysis and gave intellectual contribution for the execution of the manuscript. AH was in charge of data collection and gave intellectual contribution for the writing of the manuscript. DHT supervised data collection and gave intellectual contribution for the writing of the manuscript. ANM idealized the research project; was in charge of study design and general orientation in all of the stages of elaboration and execution of the research; oriented and gave intellectual contribution for the elaboration and execution of the manuscript.*

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