Artigo Original

Original Article

Ana Mendes[1]
Mariana Alves-Pereira[2]
Nuno A A Castelo Branco[3]

Padrões acústicos da voz em indivíduos com a doença vibroacústica

Voice acoustic patterns of patients diagnosed with vibroacoustic disease

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Resumo

Enquadramento: A exposição crónica ao ruído de baixa frequência (RBF) (≤ 500 Hz, incluindo infra-sons) pode conduzir ao desenvolvimento da doença vibroacústica (VAD – *vibroacoustic disease*), uma patologia sistémica caracterizada pela proliferação anormal das matrizes extracelulares. O aparelho respiratório é alvo do RBF, como foi observado em doentes com VAD através de biópsia e confirmado com modelos animais expostos a RBF, sendo um dos aspectos mais evidentes a fibrose intersticial da traqueia. A análise acústica vocal pode detectar pequenas variações na massa, tensão, actividade muscular e neuronal das pregas vocais através de parâmetros como frequência fundamental (F_0), *jitter*, *shimmer* e índice harmónico-ruído (H/R). Dado que o sistema respiratório é a fonte de energia do processo fonatório, e sabendo das alterações morfológicas na traqueia dos doentes com VAD, pode perguntar-se quais os efeitos destas alterações

Abstract

Background: Long-term low frequency noise exposure (LFN) (≤ 500 Hz, including infrasound) may lead to the development of vibroacoustic disease (VAD), a systemic pathology characterized by the abnormal growth of extra-cellular matrices. The respiratory system is a target for LFN. Fibrosis of the respiratory tract epithelia was observed in VAD patients through biopsy, and confirmed in animal models exposed to LFN. Voice acoustic analysis can detect vocal fold variations of mass, tension, muscular and neural activity. Frequency perturbation (jitter), amplitude perturbation (shimmer) and harmonic-to-noise ratio (HNR) are used in the evaluation of the vocal function, and can be indicators of the presence and degree of severity of vocal pathology. Since the respiratory system is the energy source of the phonation process, this raises questions about the effects of VAD on voice production. The purpose of this study was to determine if voice acoustic parameters of VAD patients

[1] Escola Superior de Saúde, Instituto Politécnico de Setúbal
[2] ERISA, Universidade Lusófona, Lisboa
[3] Centro da Performance Humana, Lisboa.
vibroacoustic.disease@gmail.com

na voz. O objectivo deste estudo foi determinar se os parâmetros acústicos dos doentes com VAD diferem dos dados normativos. **Métodos:** Nove indivíduos diagnosticados com a VAD (5 homens e 4 mulheres) foram gravados durante a produção de tarefas fonatórias e foram efectuadas as análises acústicas vocais. **Resultados:** Os doentes com a VAD apresentaram valores elevados de F_0, *shimmer* e H/R e valores reduzidos de *jitter* e extensão máxima de frequência vocal. **Conclusões:** Os doentes com a VAD, quando comparados com dados normativos, apresentaram diferentes parâmetros acústicos vocais, espectrais e de perturbação, podendo indicar alterações morfológicas no sistema fonatório.

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Palavras-chave: Ruído de baixa frequência, infra-sons, *shimmer*, *jitter*, acústica da voz, cordas vocais.

are different from normative data. **Methods:** Nine individuals (5 males and 4 females) diagnosed with VAD were recorded performing spoken and sung tasks. The spoken tasks included sustaining vowels and fricatives. The sung tasks consisted of maximum phonational frequency range (MPFR). Voice acoustic parameters analysed were: fundamental frequency (F_0), jitter, shimmer, HNR and temporal measures. **Results:** Compared with normative data, both males and females diagnosed with VAD exhibited increased F_0, shimmer and HNR. Jitter, MPFR and one temporal measure were reduced. **Conclusions:** VAD individuals presented voice acoustic parameter differences in spectral, temporal and perturbation measures, which may be indicative of small morphological changes in the phonatory system.

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Key-words: Low frequency noise, infrasound, shimmer, jitter, voice acoustics, vocal folds.

Introduction

Vibroacoustic disease (VAD) is a systemic pathology caused by long-term exposure to low frequency noise (LFN), specifically frequencies below 500 Hz, including infrasound[1,2]. This acoustical phenomenon affects organs and systems other than hearing, particularly the respiratory tract[3,4].

VAD is characterized by abnormal growth of extra-cellular matrices, namely collagen and elastin, as is reflected in thickening of cardiac structures seen through echocardiography[5]; pericardial thickening, as seen through light and electron microscopy[1]; thickening of respiratory system biopsy material, as seen through electron microscopy[6], and in autopsy findings[7]. LFN-exposed animal models also revealed thickening of respiratory tract structures due to the abnormal growth of collagen[8].

Respiratory complaints in VAD patients include non-productive cough, hoarseness, repeated upper and lower respiratory infections, bronchitis (in smokers and non-smokers alike) and respiratory insufficiency in older LFN exposed workers[2]. Standard lung function tests, such as vital capacity, tidal volume, forced expiratory volume and peak expiratory flow, were within normal limits. However, lung fibrosis was identified in a group of LFN-exposed workers, both with and without respiratory complaints[9,10].

The laryngeal system is composed of cartilage, muscle and mucosa. Histologically, the vocal folds are classified as a three layer model with five constituents: 1) cover with epithelium and lamina propria's superficial layer; 2) transition with lamina propria's intermediate and deep layers; and 3) body or vocalis muscle[11]. The stratified squamous epithelium and the lamina propria's superficial layer are held together by the basement membrane zone (BMZ), which is susceptible to injury caused by the impact of vibration and shearing forces. To strengthen this vibratory system, the BMZ is composed of three layers: the plasma membrane, the lamina densa and the sub-basement membrane area. Basal cells composed of proteins extend from the plasma membrane to the lamina densa, composed of Type IV collagen. From the lamina densa to the sub-basement membrane area, looping fibers are wrapped by Type III collagen. These fragile connecting links can be damaged by injury, nodules or other benign tumours[12].

Since the 1970s, voice acoustic analysis has been frequently used to track down changes in voice production as a consequence of physiological changes of the laryngeal system[13]. The most commonly used acoustic parameters are fundamental frequency (F_0), vocal intensity, perturbation of the frequency (jitter), perturbation of amplitude (shimmer), harmonic-to-noise ratio (HNR) and maximum phonational frequency range (MPFR). F_0 reflects the efficiency of the phonatory system in terms of its biomechanics and aerodynamics physical characteristics. Perturbation measures (jitter and simmer) reflect the slight differences of mass, tension, neural control and biomechanical characteristics of vocal folds[14]. HNR reflects the aperiodic signal or vibration generated at or near the glottal source. MPFR reflects the physical limits of the phonatory system. Temporal measures such as maximum phonation time (MPT) and S/Z ratio are complementary measures that reflect the efficient coordination between the respiratory and phonatory system. Lastly, voice tremor measures the integrity of the neural control for voice production.

Given the sensitivity of the above measures to changes in laryngeal/respiratory system coordination, voice acoustic analysis might reflect LFN-induced changes in respiratory tract morphology. If so, voice acoustic analysis may provide a fast, easy, low cost, user friendly and non-invasive method for screening, evaluating and monitoring VAD risk groups.

The goal of this study was to investigate whether voice acoustic parameters in VAD-diagnosed individuals differ from normative data cited in scientific literature. Specifically in the laryngeal system: 1) Since the respiratory system is the power source for voice production, we can detect changes in the voice production of VAD patients; 2) Knowing the fragile histology of the vocal folds (also composed by collagens fibres), the laryngeal system can be, in itself, a target for LFN; and 3) Is voice acoustic analysis a sensitive method to track down vocal changes as a consequence of VAD?

Methods

Subjects

Table I summarizes the data on the 9 individuals, diagnosed with VAD, who voluntarily participated in this investigation. Subjects consisted of five males (mean age 45.2 years, range 37-59 years) and 4 females (mean age 35 years, range 25-41 years). The male group had a mean noise exposure of 8.5 hours/day for 18 years. Two had smoking and alcoholic habits and one had respiratory as well as voice complaints. The female group had a mean noise exposure of 7.8 hours/day for 11.3 years. None presented smoking or alcoholic habits, nor respiratory or voice complaints.

Phonatory tasks

All subjects were asked to perform spoken and sung tasks while in a standing position. Before recordings, subjects briefly warmed-up their voice by performing phonational and dynamic ranges as well as reading aloud the text "*O Sol*".

The spoken tasks included sustaining vowels and fricatives. The subjects were asked to sustain the vowels /i/ and /u/ three times each for 6 seconds. Even though 6 to 10 trials are recommended for perturbations measures[15] only three trials of each task were performed due to subjects' fatigue. The sustained vowel task requires a stable condition of the pneumophonatory system allowing an evaluation of this function stability and permitting a comparison with the normative data. Subjects also sustained /a/, /s/ and /z/ three times each for as long as they could.

The sung tasks consisted of MPFR, which encompassed frequencies from the lowest modal register to the highest falsetto register. Vocal fry was not included[16]. A semitone chart and a piano-keyboard were used to provide reference frequencies and audio feedback to the researcher and the subject. The discrete-step task and the pitch-matching procedure were performed three times[17]. Subjects were allowed a 1-minute rest period between trials. The lowest and the highest sustained /a/ represented the 0% and the 100% levels of the MPFR[18].

Equipment

All phonatory tasks were recorded in a quiet environment (30-40 dBA) at the *Associação Nacional de Tuberculose e Doenças Respiratórias*, in Lisbon. All voice productions were obtained using a high-quality cardioid type headset microphone placed 3 cm from the right corner of the mouth and at a 45° degree angle[19]. An H-P350D Hewlett-Packard attenuator was activated for loud phonations to avoid peak clipping. Voice samples were recorded to a portable TCD-D10-PROII Sony digital audiotape recorder (DAT).

Table I – Characteristics of VAD subjects

Case No.	M/F	Age	Occupation	Smoker (Y/N)	Alcoholic Habits (Y/N)
1	M	40	Architect	N	N
2	M	37	Restaurant worker	Y	Y
3	M	38	Dentist	Y	Y
4	M	52	Military pilot	N	N
5	M	59	Flight attendant	N	N
6	F	37	Flight attendant	N	N
7	F	25	Flight attendant	N	N
8	F	41	Flight attendant	N	N
9	F	37	Flight attendant	N	N

For calibration purposes, a 500 Hz tone of 80 dB SPL, at 2 cm distance from sound source to microphone, was recorded onto each audiotape. Prior to measuring each subject's productions, the calibration tone was digitized and served as a reference tone calculated by Dr. Speech Software, Version 4[20]. Acoustic analyses were obtained using Dr. Speech Software, Version 4. A Pentium IV with an external sound card was used with the above software. Samples were digitized at a rate of 25.0 kHz. The frequency values of the MPFR were converted to semitone levels (Equation 1)[21] since the music frequency scale is logarithmic in nature:

Equation 1.

$$40*\log10 (f2/f1) \quad (f1) = (ST, re: 16.35 Hz)$$

Acoustic analysis

For the sustained spoken vowels, acoustic measurements included speaking F_0, jitter, shimmer, HNR and voice tremor. Temporal measures of the sustained /a/, /s/ and /z/ were taken in order to obtain the MPT and S/Z ratio, respectively.

The middle portion of the sustained sung vowel /a/ was analyzed with the Dr. Speech Software to derive the following dependent F_0 variables: 1) F_0 of 100% and 2) F_0 of 0% levels of the MPFR ($F_0$100 and $F_0$0, respectively); and 3) F_0 range between the 100% and the 0% levels ($F_0$100-0).

Statistical analysis

This is a comparative research study between a small group (N = 9) diagnosed with VAD and normative data. It was designed to measure and compare voice acoustic parameters and draw conclusions about the similarities and differences between these groups[22]. All numerical variables data were analyzed using descriptive statistics. Means and standard deviations of the VAD group were compared with the normative population stated in the scientific literature.

Results

For the sustained vowels /i, a, u/, the mean speaking F_0 of male VAD subjects were 135.3Hz, 120.9 Hz and 127.9 Hz respectively. The female VAD population obtained mean values of 241.7 Hz, 207.6 Hz and 233.1 Hz. Both gender groups presented mean speaking F_0 slightly above the normative data for age equivalent, however still within normal limits[23]. Study and normative data are compared in Table II.

Jitter, shimmer, HNR and voice tremor were also measures extracted from the sustained spoken vowels. Jitter mean values of males were 0.1 for the /i/ and 0.2 for the other two vowels. Females presented 0.1 for /i/, 0.2 for /a/ and 0.4 for /u/. Both gender groups presented jitter mean values below the normative mean for all the vowels[24]. Shimmer mean values of males were 1.0, 0.9 and 0.4 and for females were 0.8, 1.0 and 2.0 for the three vowels /i, a, u/, respectively. Shimmer mean values were all above the normative mean[14]. The means of HNR for males were 31.3 dB, 29.3 dB and 32.4 dB and for females were 31.6 dB, 28.5 dB and 25.6 dB. For the HNR variable, the scientific literature has only reference to the vowel /Y/ with 11.9 dB[25] or above 1.0 if we are just referring to a ratio[14]. The HNR means of both males and females VAD group were extremely high when compared with normal population. The mean values of voice tremor measures of the three vowels, for both

Table II – Summary of voice parameter data in VAD subjects

	VAD Subjects		Normative Data	
	Male	**Female**	**Male**	**Female**
F_0				
/ i /	135.3 Hz	241.7 Hz	125.6 Hz [1]	205.5 Hz [1]
/ a /	120.9 Hz	207.6 Hz	110.85 Hz [1]	198.75 Hz [1]
/ u /	127.9 Hz	233.1 Hz	123.2 Hz [1]	204.6 Hz [1]
Jitter				
/ i /	0.1	0.1	0.33 ± 0.11 [2]	0.44 ± 0.13 [2]
/ a /	0.2	0.2	0.56 ± 0.16 [2]	0.47 ± 0.18 [2]
/ u /	0.2	0.4	0.38 ± 0.2 [2]	0.44 ± 0.13 [2]
Shimmer				
/ i /	1.0	0.8	0.37 [3]	0.23 [3]
/ a /	0.9	1.0	0.47 [3]	0.33 [3]
/ u /	0.4	2.0	0.33 [3]	0.19 [3]
HNR				
/ i /	31.3 dB	31.6 dB		
/ a /	29.3 dB	28.5 dB		
/ u /	32.4 dB	25.6 dB		
/ Ψ /			11.9 dB [4]	11.9 dB [4]
MPT	23.6 sec.	17.0 sec.	25.69 sec.[3]	21.34 sec.[3]
S/Z	0.9	0.8	0.99 [5]	0.99 [5]
MPFR				
$F_0$0	32.4 ST	42.6 ST	28.2 ST [6]	37.3 [6]
$F_0$100	48.3 ST	55.65 ST	57.3 ST [6]	73.4 [6]
$F_0$100-0	15.9 ST	13.01 ST	29.09 ST [6]	36.1 [6]

[1]Sorensen & Horii, 1982; [2]Deem *et al.*, 1989; [3]Colton & Casper, 1996; [4]Yumoto *et al.* 1984; [5]Eckel & Boone, 1981; [6]Colton & Hollien, 1972.

males and females, were all below the 3-5 Hz normative mean value, revealing the integrity of the neural control of the phonatory system[14].

Two temporal measures were analyzed: MPT and S/Z. The MPD mean was 23.6 sec for males and was 17 sec. for females. These means were below normative values of 25.89 sec and 21.34 sec[26]. S/Z means was 0.9 and 0.8 for males and females, respectively. These means were within normal limits when compared with normative value of 0.99[14].

For the sung data, the means of the lowest, highest and range of the MPFR ($F_0$0, $F_0$100 and $F_0$100-0, respectively) of VAD individuals were all below the normative data. Males VAD individuals presented a mean of the $F_0$0 of 32.4 ST, a mean of $F_0$100 of 48.3 ST, and a mean of the $F_0$100-0 of 15.9 ST. For this gender and age group, Colton & Hollien[27] reported means of 28.2 ST, 57.3 ST and 29.09 ST, respectively. The female VAD group presented means of 42.6 ST, 55.65 ST and 13.01 ST for the same variables. Normative data for middle-aged females was 37.3 ST, 73. 4 ST and 36.1 ST, respectively[27]. Overall, the female VAD group presented a much-reduced range of frequencies than the male group.

Discussion

This group of nine individuals diagnosed with VAD presented a different pattern of spectral (speaking and singing tasks), temporal and perturbation measures when compared with normative data. The pattern differences were consistent in terms of VAD population gender, i.e., males and females presented the same voice acoustic differences when compared with the normative population.

The mean F_0 of three sustained vowels was slightly higher, which reflects a higher rate of vibration of the vocal folds, however still within normal limits. Jitter mean values were all below normative mean, very similar to the values of singers, who present a healthy voice. This finding is surprising finding because it suggests that VAD patients exhibit better jitter values than normal individuals, i.e., vocal pathology can be excluded. Instead, possible morphological changes of the vocal fold ligament might lead to a more periodic pattern of vibration because vocal folds are vibrating with less variability from cycle-to cycle in terms of frequency, i.e., the vibration cycles were similar and periodic. HNR means were very high revealing that there was a noise source with higher amplitude than the glottal source[14]. Since jitter values were better than norms one might infer that the noise source has to be above the vocal fold level. One of the temporal measures, i.e, MPT, was below norms, revealing that there is some inefficiency of the phonatory and respiratory systems. The MPFR was severely reduced at both ends and range included. This is indicative of reduced physiological limits of the laryngeal system probably due to muscular limitations of the cricothyroid and thyroarytenoid muscles, which are responsible for the increase and decrease of the fundamental frequency, respectively.

This study had some limitations: 1) a small sample size, which impedes generalizations; 2) a comparative design, i.e., conclusions can only be drawn about similarities and differences between the groups, not about the causes of the criterion variable differences that were found (causation or causality) (22); and 3) the source of normative data is the United States, instead of an age- and gender-matched norm group. Despite these limitations, descriptive statistics of the acoustic analysis discloses a distinctive voice pattern when comparing VAD patients with existent normative data, specifically in terms of spectral and perturbation measures. These voice acoustic differences may be related to the morphological changes that occur in the respiratory tract as a consequence of LFN exposure.

This is a preliminary study in this field of research. Further studies should: 1) look at a larger sample size; 2) compare VAD patients with non-VAD individuals; 3) perform inferential statistics and 4) look at histological changes in collagen fibres Type III and IV. LFN-exposed animal models could provide a first insight into the morphological changes of the LFN-exposed larynx.

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