Article published online: 2022-08-01

Audiological, Phonatory and Cardiac Correlates of Individuals Exposed to Low-Frequency Noise or at Risk of Vibroacoustic Disease

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Int Arch Otorhinolaryngol 2023;27(3):e478–e486.

Abstract

Introduction Low-frequency noise (LFN) is hazardous to hearing. Long-term exposure to LFN may lead to vibroacoustic disease (VAD), which not only affects a specific organ but the physiological function of entire systems, such as the auditory, phonatory, respiratory, and cardiac systems. Moreover, VAD may lead to many psychological problems and hence affect the quality of life.

Objective To investigate the adverse effects of LFN on hearing, acoustic and perceptual correlates of the voice, blood pressure, cardiac rate, and anxiety level.

Method A total of 20 subjects exposed to LFN and 20 not exposed to LFN were included, and a detailed case history was recorded. The patients were submitted to pure tone audiometry, otoscopic examination, acoustic and perceptual analyses of the voice, maximum phonation time, and an assessment of the s/z ratio. We also assessed blood pressure, and the results of a voice-related quality of life questionnaire and of the Hamilton anxiety rating scale.

Results The results indicate that LFN had an adverse impact on the high-frequency threshold. The present study found a significant difference in shimmer and harmonics-to-noise ratio (HNR) values. Few subjects had high blood pressure and showed the sign of anxiety on the Hamilton anxiety rating scale.

Conclusion Low-frequency noise has adverse effects on entire systems of the body and causes many psychological issues, which, in turn negatively affect quality of life.

Keywords
- anxiety
- hoarseness
- hearing loss
- blood Pressure

received
August 5, 2021
accepted after revision
April 24, 2022
article published online
August 1, 2022

DOI https://doi.org/10.1055/s-0042-1750160.
ISSN 1809-9777.

Thieme Revinter Publicações Ltda., Rua do Matoso 170, Rio de Janeiro, RJ, CEP 20270-135, Brazil

Introduction

Noise is an unwanted sound that is detrimental to our auditory system. Low-frequency noise (LFN) ranging from 10 Hz to 500 Hz is hazardous to hearing and may cause permanent impairment. Long-term exposure to LFN may lead to vibroacoustic disease (VAD), which not only affects a specific organ but entire systems of the body, such as the auditory,[1–4] phonatory,[3,5] respiratory,[6,7] and cardiac systems,[7–9] as well as body metabolism,[10,11] and it can lead to psychological issues.[12,13] Excessive exposure to LFN results in abnormal growth of extracellular matrices (collagen and elastic), which may thicken blood vessels.[8] Hence, lower blood flow to the brain may cause dizziness,[1,4] vertigo,[1,2,4] headache,[2] depression,[12,13] reduction in concentration,[12] unusual tiredness,[7,12] and sleep disturbances.[10,11,13]

VAD and the Auditory System

Many studies[1,2,4] have discussed the adverse effect of VAD on the human and mammalian auditory systems. Studies[1,2] have reported that exposure to LFN mostly leads to high-frequency hearing loss and, if prolonged, it may gradually include the mid and low octave frequencies. In VAD, pressure in the eardrum increases due to LFN, resulting in unpleasant sensations in the ear, which affect the auditory system. Prolonged exposure to LFN leads to many histological changes[14–16] in the auditory system affecting cochlear function, increasing mitochondrial activity, and the production of free radicals. This increase in the levels free radicals reduce the cochlear blood flow and lead to excitotoxic neural swelling, causing the death of necrotic and apoptotic cells in the organ of corti. The longer the exposure to LFN, the greater the severity of the VAD symptoms.[1–4] Long-term exposure to LFN may also lead to the tinnitus[17,18] and affect the vestibular system.[19,20] A study[17] reported that the prevalence of tinnitus is 24% higher among individuals exposed to noise than among the overall population. Many studies[19–22] have provided evidence that exposure to LFN can give rise to vestibular deficiency, and one[19] has reported that LFN may damage the sacculocolic reflex pathway and damage the vestibular hair cells.

VAD and the Phonatory and Respiratory Systems

There are few articles on the effect of VAD on the phonatory[3,5] and respiratory systems.[6,7] Individuals working in the presence of LFN mostly abuse their voice[5] as they speak loudly for the auditory feedback. Prolonged vocal abuse leads to histological changes in the vocal folds and may give rise to infections and vocal pathologies.[23] Prolonged vocal abuse results in repetitive injuries to the laryngeal mucosa, which may lead to benign inflammatory lesions of the vocal cords.[23,24] Many studies[25–28] have reported that the prevalence of hyperfunctional voice disorders is higher in individuals with a history of vocal abuse.

There is a lack of studies on the effect of LFN on the human respiratory system; however, there is evidence from animal studies.[29–31] The respiratory cilia are composed of tubulin, and they are anchored to the actin cytoskeleton (CSK). With prolonged exposure to LFN, these cilia become shaggy, sheared, and clipped.[32] One study[33] found focal lung fibrosis on the autopsy of aircraft technicians exposed to prolonged LFN. Ferreira et al.[6] reported that a person exposed to LFN might develop respiratory disorders within the first four years of exposure and gradually progress into dyspnea and shortness of breath. The authors have also reported that these symptoms are independent of smoking habits.

VAD and the Cardiac System

In 1989, Araujo et al.[34] were the first to report the effect of LFN on the cardiac system of aircraft technicians. They used echocardiography (ECG) to assess pericardial thickening and reported that all aircraft technicians had abnormal pericardial or cardiac-valve thickening. Later, many studies[7–9,35–38] described and discussed the effects of VAD on the cardiac system. Pericardial thickening is the most prominent effect of VAD, and the cardiac cycle is affected by the thickening of the mitral and aortic valves. Due to this, blood flow is restricted from the left atrium to the left ventricle and then to the rest of the body.[7–9] A study[9] revealed that individuals with VAD most often suffer from sudden and violent tachycardia, which indicates sudden kinetic changes in the cardiac or pericardial rhythm.

Hypertension, Anxiety, and Psychological issues in VAD

There is evidence on the effect of prolonged exposure to LFN on blood pressure[10,11,38,39] and anxiety.[10,11,13,38,40] Many studies[11,12,41] have suggested that prolonged exposure to causes many psychological issues, such as mood swings, increased stress, irritation, annoyance, sleep disorders, and changes in behavior. Studies[38,39] have also revealed that LFN exposure may lead to the changes in blood pressure, most commonly high blood pressure. Most studies[40,41,43][superscript] report that individuals exposed to LFN develop high levels of anxiety. High levels of anxiety may be cause by different VAD symptoms.[40] The anxiety related to LFN exposure may be due to disturbance in daily activities, sleep, thoughts. High anxiety may also result from negative emotional responses, such as irritation, distress, and a wish to escape from the noise.[42,43]

Based on the review of the literature, we can see that VAD causes a plethora of symptoms and may affect the whole physiology of the body. In the recent literature, there are many studies[33–40] on the effect of VAD on the hearing and cardiovascular systems, and on psychological issues. On the other hand, the previous literature consists only of a handful of studies on the effect on the voice of prolonged exposure to LFN. After going through the previous literature[60–62], we were motivated to look into the adverse effects of VAD on the various systems and its correlation with the duration of LFN exposure. In the present study, we investigate acoustic and perceptual correlates of the voice, since in the previous literature most of the inference was drawn from animal model studies, not studies in humans. Therefore, the goal of the current investigation is to investigate the adverse effects of LFN on hearing, acoustic and perceptual correlates of the voice, blood pressure, cardiac rate, and anxiety level.

Methodology

Before data collection, consent was taken from all of the participants. All of the instrument analyses were performed using non-invasive procedures. In the present study, non-invasive instrumental analysis were conducted.

Participants

A total of 20 male subjects with ages ranging from 18 to 54 years (mean: 36.5 ± 10.4 years) who worked in noisy environments and 20 male subjects with ages ranging from 21 to 50 years (mean: 38.2 ± 9.67 years) working in non-noisy environments participated in the present study. We included subjects with a minimum of two years of working experience. Subjects with psychological, behavioral, neurological and other health-related issues were excluded. All the participants were recruited from a textile factory and gave written informed consent. The mean working experience of the noisy group was of 13.75 ± 9.01 years. The demographic details of the subjects exposed to LFN are described in ►**Table 1**. The mean daily working hours of the subjects was of 10.45 ± 1.14 hours. A detailed interview with the whole sample revealed a common habit of drinking tea five to six times per day on average. Seven subjects used to smoke (that is, more than four bidi/cigarettes per day), and all subjects had a habit of chewing tobacco while working.

Table 1 Age, years of work experience and daily working hours of the individuals exposed to low-frequency noise

Participants	Age (years)	Work experience in noisy situation (years)	Daily working hours
Participant 1	54	14	10
Participant 2	44	15	11
Participant 3	49	37	10
Participant 4	18	4	11
Participant 5	27	6	8
Participant 6	28	4	10
Participant 7	40	20	12
Participant 8	30	10	10
Participant 9	30	10	10
Participant 10	42	21	11
Participant 11	32	15	12
Participant 12	26	8	12
Participant 13	38	25	10
Participant 14	50	30	11
Participant 15	45	10	10
Participant 16	51	15	8
Participant 17	20	3	11
Participant 18	37	10	10
Participant 19	40	12	12
Participant 20	29	6	10
Mean ± standard deviation	36.5 ± 10.4	13.75 ± 9.01	10.45 ± 1.14

Tools and Instrumentation

Initially, we recorded the case history in detail, including the information regarding the duration of work, the daily exposure to noise, tinnitus, vertigo, and nausea, and we also asked questions that helped identify other health-related issues. To assess the hearing status, we performed pure tone audiometry (PTA) using the Elkon mini audiometer (Elkon Pvt. Ltd., Mumbai, Maharashtra, India). To assess the effect of LFN on voice, we performed an acoustic analysis using the Praat software (Paul Boersma and David Weenink, Phonetic Sciences, University of Amsterdam, Amsterdam, The Netherlands), and a perceptual analysis using the Buffalo III voice screening profile.[44]

To assess the effect of voice impairment on quality of life, we used the Voice-related Quality of Life (VRQOL) questionnaire.[45] The maximum phonation time (MPT) and the s/z ratio were assessed as an aerodynamic measure of the voice. Blood pressure and the cardiac rate were measured using the Omron HEM 7113 (Omron Corporation, Kyoto, Japan). In order to assess anxiety, we used the Hamilton Anxiety Rating Scale (HAM-A),[46] which consists of 14 questions scored from 0 to 4 (0: not present; 4: severe).

Procedure

Before data collection, noise levels were analyzed using a portable sound level meter (B&K 2250-L, Brüel & Kjær, Nærum, Denmark) three times a day randomly in the participants' workplace. The data were collected in two phases: first, the case history was recorded in detail, and it included health-related issues, changes in mood, the duration of work, daily exposure to noise, and the presence of tinnitus, vertigo, recruitment, and nausea. We further assessed the stress level (using the HAM-A), blood pressure, and cardiac rate. In the second phase, we conducted an outer-ear inspection using an otoscope, and PTA for the frequencies of 1 kHz, 2 kHz, 4 kHz and 8 kHz in a silent room with a minimal noise level. The silent room was located another building in the same campus due to the non-availability of a soundproof room/chamber. We made sure that the background noise was within permissible limits by measuring the noise level using sound level meter and applying the calibration factor as per the ANSI S3.-1999 (R2018) standard issued by the American National Standard Institute[47] for each participant. We could not include the frequencies of 500 Hz and 250 Hz in the PTA due to the higher calibration factor. The acoustic parameters of the voice were measured using the stimulus /a/. Along with these measurements, we further assessed the MPT, the s/z ratio, and the VRQOL.

Data Analysis

The data were analyzed using the Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, IBM Corp., Armonk, NY, US) software, version 20.00. The means and standard deviations were recorded, and the independent samples *t*-test was used to assess the mean differences regarding the parameters of the experimental and control groups. Multiple linear regression analysis was used to assess the effect of the years of working experience in environments with LFN and the amount of daily noise exposure on the hearing thresholds, acoustical voice parameters, anxiety level, and cardiac rate.

Results

In the present study, the factory's mean noise level in the subjects' working area was above 90 ± 5) dBA in three daily measurements made at different times. Descriptive analysis revealed that the subjects had a minimum of 3 years and a maximum of 37 years of experience working in noisy environments.

Effect of LFN on Hearing

An otoscopic examination revealed that the tympanic membrane was intact in all subjects. The hearing assessment revealed that all participants had poor threshold at high frequencies, and 3 of them had a dip at 4 kHz. The independent samples *t*-test revealed a significant difference between the right and left ear thresholds for all the frequencies between the experimental and control groups, as shown in ►**Table 2** and ►**Fig. 1**

The participants with longer exposure to LFN also reported the presence of high-frequency tinnitus and occasional vertigo. More than half of the population (that is, 16 subjects) reported tinnitus, but only 3 subjects reported bothersome tinnitus that caused them to have a disturbed sleep pattern. Eleven (55%) subjects reported intolerance to sounds which would be comfortable to a person not exposed to LFN. Multiple linear regression was calculated to predict the hearing loss based on the years of working in noisy environments and the daily hours of exposure. A significant regression equation was found for the frequency of 8 KHz in right and left ears, as shown in ►**Table 3**.

Effect of LFN on the Voice

The results revealed significant differences regarding shimmer ($p = 0.004$) and the harmonics-to-noise ratio (HNR; $p = 0.002$). ►**Table 4** shows a mean difference in the jitter values of both groups, which was not statistically significant. The multiple linear regression analysis was used to explore the effect of the years of work experience in environments with LFN and the daily hours of noise exposure on the acoustical parameters of the voice. A significant regression equation was only found for the HNR, as shown in ►**Table 5**.

►**Figure 2** shows that, regarding the voice, 55% ($n = 11$) of the sample had the normal quality, pitch, and intensity on the Buffalo III voice screening profile. However, the quality of the voice was mild in 20% ($n = 4$), moderate in 10% ($n = 2$), and severely hoarse in 5% ($n = 1$), whereas 10% had mildly breathy voice quality. Most participants ($n = 9$, 45%) had poor and limited pitch variation; however, only 6 (30%) had a limited intensity range. The analysis revealed a significant difference in the maximum phonation time ($p = 0.000$)

Table 2 Mean and standard deviation (SD) values for the right and left ear thresholds of both study groups for each frequency of the hearing assessment

Ear	Frequency	Group	Mean ± SD	*p*-value
Right	1 kHz	Control	24 ± 4.47	0.000
		Experimental	39 ± 5.02	
Left	1 kHz	Control	17 ± 2.51	0.003
		Experimental	38 ± 5.40	
Right	2 kHz	Control	24.75 ± 3.52	0.000
		Experimental	37.50 ± 5.05	
Left	2 kHz	Control	20 ± 2.80	0.000
		Experimental	38 ± 4.02	
Right	4 kHz	Control	25 ± 2.80	0.000
		Experimental	38.50 ± 4.38	
Left	4 kHz	Control	23 ± 2.82	0.001
		Experimental	39 ± 4.65	
Right	8 kHz	Control	26.25 ± 2.75	0.002
		Experimental	38.5 ± 5.22	
Left	8 kHz	Control	26 ± 2.22	0.000
		Experimental	40 ± 4.09	

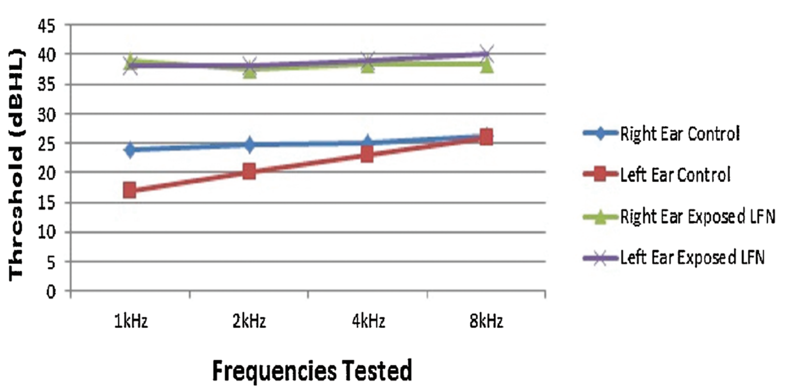

Fig. 1 Mean values of both groups for each tested frequency.

Table 3 Multiple linear regression analysis showing the effect of daily noise exposure and years of work in environments with low-frequency noise on the hearing thresholds

Variables		Model coefficient					
Dependent variables	Independent variables	Regression coefficient (B)	Standard error	Beta	*p*-value	R	R^2
Threshold of the right ear at 8 KHz	Daily noise exposure	0.513	1.85	0.067	.005*		
	Years of work in environments with low-frequency noise	0.41	0.23	0.042	0.03*	0.831	0.708
Threshold of the left ear at 8 KHz	Daily noise exposure	2.10	2.23	2.16	0.01*		
	Years of work in environments with low-frequency noise	0.33	0.28	0.26	0.04*	0.832	0.801

Note: *Significant at the level of 0.05.

Table 4 Mean and standard deviation (SD) values of the acoustic parameters of both groups

Acoustic parameter	Groups	Mean ± SD	*p*-value
F_0 frequency	Control	138 ± 10	> 0.05
	Experimental	122 ± 13	
Jitter	Control	0.45 ± 0.38	> 0.05
	Experimental	0.72 ± 0.68	
Shimmer	Control	3 ± 3	0.004
	Experimental	9.6 ± 3.2	
Harmonics-to-noise-ratio	Control	18 ± 5	0.002
	Experimental	12.33 ± 4	

between the individuals exposed to LFN (mean ± standard deviation [SD] = 13.65 ± 5.13 s) and not exposed to LFN (mean ± SD = 25 ± 7 s). Regarding the s/z ratio, it was higher than 1.40 in 9 (45%) participants, indicating laryngeal pathology.

On the VRQOL self-assessment questionnaire, most of the sample (*n* = 16, 80%) answered "No Problem in Voice". However, 3 (15%) participants reported "a small amount of problem", and 1 (5%) subject reported "a moderate amount of problem," as shown in ►**Fig. 3**.

Effect of LFN on Blood Pressure, Cardiac Rate, and Anxiety Level

All participants had normal blood pressure (systolic: mean ± SD = 134.95 ± 12.20; diastolic: mean ± SD = 85.9 ± 8.45). However, blood pressure was elevated 4 (20%) subjects and

Table 5 Multiple linear regression analysis showing the effect of daily noise exposure and years of work in environments with low-frequency noise on the harmonics-to-noise ratio

Variables		Model Coefficient					
Dependent variable	Independent variables	Regression coefficient (B)	Standard error	Beta	*P*-value	R	R^2
Harmonics-to-noise-ratio	Daily noise exposure	1.155	1.504	0.253	0.046*		
	Years of work in environments with low-frequency noise	0.010	0.169	0.020	0.004*	0.775	0.766

Note: *Significant at the level of 0.05.

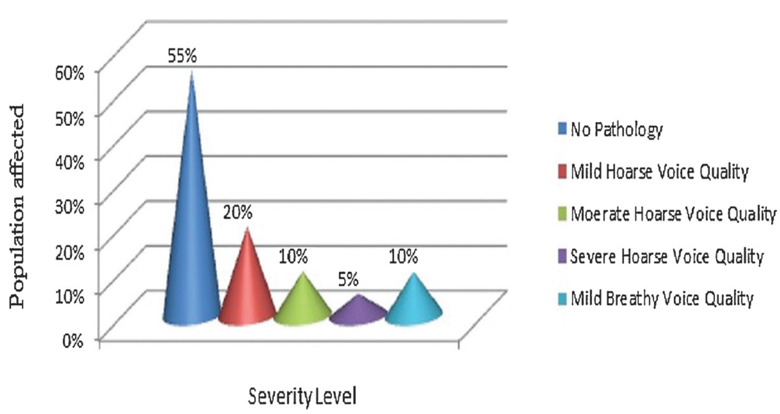

Fig. 2 Results of the Buffalo III Voice Screening Profile of individuals exposed to LFN.

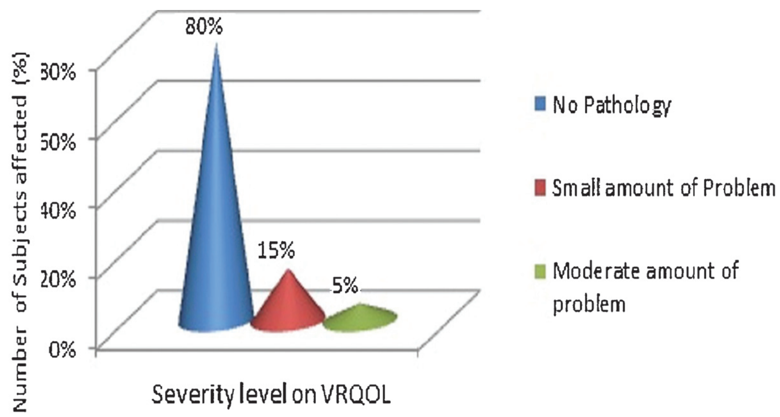

Fig. 3 Results of the VRQOL questionnaire.

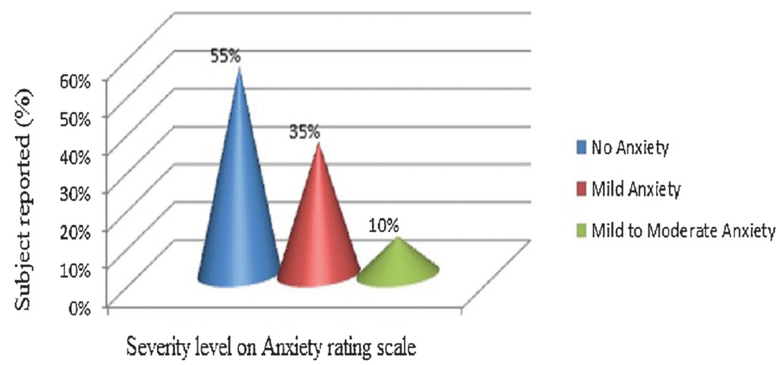

Fig. 4 Graphical representation of the HAM-A scale.

low in 1 (5%). The subjects with elevated blood pressure more than 20 years of LFN exposure. The results also revealed that most participants had normal cardiac rate (mean ± SD = 75.55 ± 10.43), but it was high (> 100) in 2 (10%). Participants who had high cardiac rate had longer periods of exposure to noise. On the HAM-A, 55% ($n = 11$) of the sample was classified as having "no anxiety," 35% had "mild anxiety," and 10% had a "mild to moderate" level of anxiety, as shown in ►**Fig. 4**.

To identify the effect of daily noise exposure and working experience on the cardiac rate and anxiety level, we performed a multiple linear regression analysis, and we found a significant regression equation for both dependent variables, as shown in ►**Table 6**.

Discussion

The present study investigated the hearing, acoustical and perceptual parameters of the voice, cardiac rate, blood pressure, and anxiety level in individuals exposed to LFN, and the results revealed that prolonged exposure to LFN gradually affects systems of the body.

Table 6 Multiple linear regression analysis showing the effect of daily noise exposure and years of work in environments with low-frequency noise on the Anxiety level cardiac rate

Variables		Model coefficient					
Dependent variables	Independent variables	Regression coefficient (B)	Standard error	Beta	*p*-value	R	R^2
Anxiety level	Daily noise exposure	0.737	0.859	0.158	0.043*		
	Years of work in environments with low-frequency noise	0.382	0.109	0.042	0.03*	0.651	0.424
Cardiac rate	Daily noise exposure	1.879	2.188	0.176	0.003*		
	Years of work in environments with low-frequency noise	0.679	0.278	0.499	0.026*	0.744	0.696

Note: *Significant at the level of 0.05.

VAD and the Audiological Profile

In the present study, we conducted PTA at the frequencies of 1KHz, 2KHz, 4KHz, and 8KHz, and the result revealed that exposure to LFN gradually affects the high frequencies and leads to high-frequency hearing loss as was also reported by Nair and Kashyap.[1] They conducted a study with Indian Air Force personnel, and reported a high prevalence of high-frequency hearing loss among technicians (who are more exposed to LFN) compared with non-technicians. Similar results were reported by Senturia,[4] who conducted a study on long-term exposure to aircraft noise which revealed that individuals exposed to aircraft noise developed high-frequency sensorineural hearing loss. Reduced hearing sensitivity at high frequencies results in deterioration in speech perception,[48] which also worsen in the presence of noise.[49] In the present study, individuals exposed to LFN also reported high-frequency tinnitus and recruitment, similar to what was reported by Castelo Branco,[9] Nair and Kashyap,[1] Shargorodsky et al.,[17] and Mazurek et al.[18] Previous studies have reported that LFN affects the histological structure of the cochlea[14–16] and results in hearing deterioration, tinnitus, and recruitment, and that increases in the amount of LFN exposure affect the high frequency threshold[19–21]. The results of the present study are in lines with those of the studies conducted by Senturia,[4] Castelo Branco et al.,[3] Ribeiro and Câmara,[2] and Nair and Kashyap,.[1] who reported that the longer the exposure to LFN, the greater the severity of the VAD symptoms. The results of previous studies have also pointed that exposure to LFN could affect the vestibular system; however, in the present study we were not able to assess the vestibular system.

VAD & the Voice Profile

During literature review, we found only a handful of studies[60–62] on the effect of LFN on the phonatory system, and this motivated us to explore this subject. In the present study, we used acoustical and perceptual assessment methods to explore the effect of LFN on the phonatory system. We also used subjective assessment methods, such as the MPT and the s/z ratio. In the literature, the usefulness of the s/z ratio assessment method is the topic of debate; however, many previous studies[50–56] have used this method to assess the vocal status in different pathologies, and it may be helpful in screening the laryngeal pathology due to the acoustic properties of the sounds used.[57–59] In the present study, we found a significant difference in the shimmer and HNR values between the two groups. A difference was also found in jitter values, but it was not statistically significant. These could be due to the use of louder voice in the presence of LFN for the auditory feedback and to that fact that the frequent vocal abuse affects the physiology of the vocal folds, leading to changes in voice quality.[23] Similar results were reported by Ribeiro and Câmara.[2] On the other hand, Mendes et al.[5] found no evident changes in acoustic parameters in a population exposed to LFN, but F0 parameter increased significantly with the number of years of professional activity. Mendes et al.[5] did report changes in other acoustic parameters, but they were not statistically significant. These differences in results among different studies may be due to the different subject groups. In the present study, the subjects were recruited from a factory, and they did not wear any ear-protection devices, whereas Mendes et al.,[5] recruited airline pilots, who wear such devices. The present study further revealed that subjects exposed to LFN had decreased MPT and increased s/z ratio (higher than 1.40). The studies conducted by Mendes et al.[60–62] and Alves-Pereira et al.[63] also reported these results. The current study also revealed that hoarse voice quality may be due vocal abuse and unhealthy dietary habits, which is in line with the study by Castelo Branco.[9] In the present study, we also found that the HNR decreases as the of the exposure to noise exposure increases with time. This indicates that, as the noise exposure increases, the probability of developing vocal pathology also increases due to the continuous vocal abuse, which cause changes in the histological morphology of the vocal folds.[24]

Effect of LFN on Cardiac Rate, Blood Pressure and Anxiety Level

In the current study, we assessed the cardiac rate, blood pressure and anxiety level along with changes in the auditory and phonatory systems in individuals at risk of developing VAD. The study showed that subjects exposed to LFN are at a higher risk of having increased cardiac rate, which could disturb the cardiac cycle. Similar findings were reported by Marciniak et al.,[8] Castelo Branco et al.,[7] and Araujo Alves et al.[38] Increased cardiac rate may lead to an episode of sudden tachycardia.[9] The current study also showed that an increase in the exposure to noise has direct effects on the cardiac rate, that is prolonged exposure of LFN hampers and disturbs the functioning of the cardiac system, which s in line with the reports by Albuquerque e Sousa et al.,[35] Carmo et al.,[36] Marciniak et al.,[8] and Araujo et al.[37] In the present study, we also found that individuals with a longer exposure to noise showed increased anxiety levels. Similar results were discussed in the health statement of the County of San Diego,[11] the Department of Health of the Commonwealth of Australia,[10] and Beutel et al.[13] Our results also indicate that the anxiety level is affected by the increased level and duration of the exposure to noise. Increased anxiety levels may lead to changes in blood pressure or increased heart rate. Abbasi et al.[40] reported that high levels of anxiety may lead to hypertension and vice versa. The current study also revealed that most of the experimental group had hypertension, which is in line with the studies by Leon Bluhm et al.[39] and Araujo Alves et al.[38]

Conclusion

Based on the current study, we can conclude that LFN has adverse effects on the whole body. Prolonged exposure to LFN not only affects different systems, but also leads to psychological issues. In the present study we tried to assess the effect of LFN on the different human systems using various methods. We predominantly aimed to explore the effect LFN exposure on the phonatory system using acoustical and perceptual methods. From the results of the present study, we can infer that VAD affects different body systems as well as quality of life. The present is a preliminary study, and future studies will require extensive research in this field.

Funding
The author(s) received no financial support for the research.

Conflict of Interests
The authors have no conflict of interests to declare.

Acknowledgment
We wish to express our sincere thanks and gratitude to Ms. Amulya, Mr. Rahul Bhagat, and Mr. Nitin Dogra (BASLP students of the Ashtavakra Institute of Rehabilitation Sciences & Research, Rohini, New Delhi, Batch 2015–19). We further extend our thanks to all the participants.

References

1 Nair S, Kashyap RC. Prevalence of Noise Induced Hearing Loss in Indian Air Force Personnel. Med J Armed Forces India 2009;65 (03):247–251

2 Ribeiro AM, Câmara VdeM. [Hearing loss by continuous exposure to high sound pressure among maintenance workers at a Brazilian Air Force helicopters unity]. Cad Saude Publica 2006;22(06): 1217–1224

3 Castelo Branco NA, Alves-Pereira M, Martins dos Santos J, Monteiro E. SEM and TEM study of rat respiratory epithelia exposed to low frequency noise. In Mendez-Vilas A, ed. Science and Technology Education in Microscopy: An Overview. Badajoz, Spain: Formatex; 2002

4 Senturia BH. Effect of aircraft noise on hearing. Arch Otolaryngol 1945;41(05):327–332

5 Mendes AP, Bonanca I, Jorge A, et al. Voice acoustic profile of males exposed to occupational infrasound and low-frequency noise. J Laryngol Voice. 2014;4(01):12–20

6 Ferreira RMJ, Couto AR, Jalles-Tavares N, Castelo Branco MSN, Castelo Branco NA. Airflow limitations in patients with vibroacoustic disease. Aviat. Space Environ. 1999;70(03):A63–A69

7 Castelo Branco NA, Monteiro E, Pereira MA, Águas AP, Sousa Pereira A, Grande NR. Morphological changes in the pericardia of military helicopter pilots. Proc. Microscopy Barcelona; 2001:318–319

8 Marciniak W, Rodriguez E, Olszowska K, et al. Echocardiographic evaluation in 485 aeronautical workers exposed to different noise environments. Aviat Space Environ Med 1999;70(3 Pt 2): A46–A53

9 Castelo Branco NA. The clinical stages of vibroacoustic disease. Aviat Space Environ Med 1999a;70(3 Pt 2):A32–A39

10 Commonwealth of Australia as represented by the Department of Health. The health effects of environmental noise. 2018 [cited 2021 May 14]. Available from https://www1.health.gov.au/internet/main/publishing.nsf/content/A12B57E41EC9F326CA257BF0001F9E7D/$-File/health-effects-Environmental-Noise-2018.pdf

11 County of San Diego. Public health position statement on human health effects of wind turbines. 2019 [cited 2021 May 14]. Available from https://www.sandiegocounty.gov/content/-dam/sdc/pds/advance/2019%20Public%20Health%20Position%20Statement%20on%20Human%20Health%20Effects%20of%20Wind%20Turbines.pdf

12 Leventhall HG. Low frequency noise and annoyance. Noise Health 2004;6(23):59–72

13 Beutel ME, Jünger C, Klein EM, et al. Noise Annoyance Is Associated with Depression and Anxiety in the General Population- The Contribution of Aircraft Noise. PLoS One 2016;11(05):e0155357

14 Nordmann AS, Bohne BA, Harding GW. Histopathological differences between temporary and permanent threshold shift. Hear Res 2000;139(1-2):13–30

15 Henderson D, Bielefeld EC, Harris KC, Hu BH. The role of oxidative stress in noise-induced hearing loss. Ear Hear 2006;27(01):1–19

16 Le Prell CG, Yamashita D, Minami SB, Yamasoba T, Miller JM. Mechanisms of noise-induced hearing loss indicate multiple methods of prevention. Hear Res 2007;226(1-2):22–43

17 Shargorodsky J, Curhan GC, Farwell WR. Prevalence and characteristics of tinnitus among US adults. Am J Med 2010;123(08): 711–718

18 Mazurek B, Olze H, Haupt H, Szczepek AJ. The more the worse: the grade of noise-induced hearing loss associates with the severity of tinnitus. Int J Environ Res Public Health 2010;7(08):3071–3079

19 Wang YP, Young YH. Vestibular-evoked myogenic potentials in chronic noise-induced hearing loss. Otolaryngol Head Neck Surg 2007;137(04):607–611

20 Tseng CC, Young YH. Sequence of vestibular deficits in patients with noise-induced hearing loss. Eur Arch Otorhinolaryngol 2013;270(07):2021–2026

21 Kumar K, Vivarthini CJ, Bhat JS. Vestibular evoked myogenic potential in noise-induced hearing loss. Noise Health 2010;12 (48):191–194

22 Stewart C, Yu Y, Huang J, et al. Effects of high intensity noise on the vestibular system in rats. Hear Res 2016;335:118–127

23 Montoya S, Portanova A, Bhatt AA. A radiologic review of hoarse voice from anatomic and neurologic perspectives. Insights Imaging 2019;10(01):108

24 Rosen CA, Murry T. Nomenclature of voice disorders and vocal pathology. Otolaryngol Clin North Am 2000;33(05):1035–1046

25 Martins RHG, Dias NH, Santos DC, Fabro AT, Braz JRC. Clinical, histological and electron microscopic aspects of vocal fold granulomas. Rev Bras Otorrinolaringol (Engl Ed) 2009;75(01): 116–122

26 Nunes RB, Behlau M, Nunes MB, Paulino JG. Clinical diagnosis and histological analysis of vocal nodules and polyps. Rev Bras Otorrinolaringol (Engl Ed) 2013;79(04):434–440

27 Comunoglu N, Batur S, Onenerk AM. Pathology of Non-neoplastic Lesions of the Vocal Folds. In: Ahmed M, ed. Voice and Swallowing Disorders, Intechopen, London; 2019:27–40

28 Vasconcelos D, Gomes AOC, Araújo CMT. Vocal Fold Polyps: Literature Review. Int Arch Otorhinolaryngol 2019;23(01): 116–124

29 Castelo Branco NAA, Alves-Pereira M, Martins dos Santos J, Monteiro E. SEM and TEM study of rat respiratory epithelia exposed to low frequency noise. In: Mendez-Vilas A, ed. Science and Technology Education in Microscopy. An Overview, vol. II. Badajoz, Spain: Formatex; 2003a:505–533

30 Castelo Branco NAA, Gomes-Ferreira P, Monteiro E, Costa e Silva A, Reis Ferreira JM, Alves-Pereira M. [Respiratory epithelia in Wistar rats after 48 hours of continuous exposure to low frequency noise]. Rev Port Pneumol 2003f;9(06):473–479

31 Castelo Branco NAA, Monteiro E, Costa e Silva A, Reis Ferreira JM, Alves-Pereira M. [Respiratory epithelia in Wistar rats born in low frequency noise plus varying amounts of additional exposure]. Rev Port Pneumol 2003g;9(06):481–492

32 Alves-Pereira M, Joanaz de Melo J, Castelo Branco NAA. Actin and tublulin-based structures under low frequency noise stress. Proceedings First International Meeting on Applied Physics, Badajoz, Spain, no. 355, 2003c, 5p.

33 Castelo Branco NA, Aguas AP, Sousa Pereira A, et al. The human pericardium in vibroacoustic disease. Aviat Space Environ Med 1999b;70(3 Pt 2):A54–A62

34 Araujo A, Ribeiro CS, Correia MJF, Pais F, Castelo Branco NAA. Echocardiographic appearances in patients with the whole-body

noise and vibration disease. MEDICEF-Direct Inform. (France) 1989;2:101–102
35 Albuquerque e Sousa J, Dinis da Gama A, Macedo MV, Cassio I, Castelo Branco NAA. Carotid angiodynographic studiesin individuals occupationally exposed to noise and vibration. Aviat Space Environ Med 1991;62:134(Abstract)
36 Carmo G, Albuquerque e Sousa J, Dinis da Gama A, Castelo Branco NAA. Carotid angiodynographic studies in helicopter pilots. Aviat Space Environ Med 1992;63:385(Abstract)
37 Araujo A, Pais F, Lopo Tuna JMC, Alves-Pereira M, Castelo Branco NAA. Echocardiography in noise-exposed flight crew. In: Proceedings of Internoise 2001, Aug 27–30; The Hague; Restov(VA); INCE- USA: 2001
38 Araujo Alves J, Paiva FN, Silva LT, Remoaldo P. Low-Frequency Noise and main effects on human health—A review of the literature between 2016 and 2019. Appl Sci (Basel) 2020;10(15):5205–5232
39 Leon Bluhm G, Berglind N, Nordling E, Rosenlund M. Road traffic noise and hypertension. Occup Environ Med 2007;64(02):122–126
40 Abbasi M, Monazzam MR, Ebrahimi MH, Zakerian SA, Dehghan SF, Akbarzadeh A. Assessment of noise effects of wind turbine on the general health of staff at wind farm of Manjil, Iran. J Low Freq Noise Vib Act Control 2016;35(01):91–98
41 Pohl J, Gabriel J, Hubner G. Understanding stress effects of wind turbine noise – The integrated approach. Energy Policy 2018; 112:119–128
42 Tarnopolsky A, Watkins G, Hand DJ. Aircraft noise and mental health: I. Prevalence of individual symptoms. Psychol Med 1980; 10(04):683–698
43 Babisch W, Houthuijs D, Pershagen G, et al; HYENA Consortium. Annoyance due to aircraft noise has increased over the years–results of the HYENA study. Environ Int 2009;35(08):1169–1176
44 Wilson DK. Voice problems of children. 3rd ed. Baltimore, MD: Williams & Wilkins; 1987
45 Hogikyan ND, Sethuraman G. Validation of an instrument to measure voice-related quality of life (V-RQOL). J Voice 1999;13(04):557–569
46 Hamilton M. The assessment of anxiety states by rating. Br J Med Psychol 1959;32(01):50–55
47 American National Standard Institute [Internet] New York: ANSI S3.-1999–R2018. [Cited 2021 May 16]. Available From https://webstore.ansi.org/preview-pages/ASA/preview_ANSI+ASA+S3.1-1999+(R2018).pdf
48 Kumar S, Verma H, Shukla B, Ravichandran A. Reason behind low adoption rate of HA among geriatric population. Pratibha. 2018; 38(01):155–160
49 Shukla B, Rao BS, Saxena U, Verma H. Measurement of speech in noise abilities in laboratory and real-world noise. Indian Journal of Otology. 2018;24(02):109–113
50 Cielo CA, Cappellari VM. Maximum phonation time in pre-school children. Rev Bras Otorrinolaringol (Engl Ed) 2008;74(04): 552–560
51 Banjara H, Mungutwar V, Singh D, Gupta A. Objective and subjective evaluation of larynx in smokers and nonsmokers: a comparative study. Indian J Otolaryngol Head Neck Surg 2014;66 (Suppl 1):99–109
52 Verma H, Solanki P, James M. Acoustical and perceptual voice profiling of children with recurrent respiratory papillomatosis. J Voice 2016;30(05):600–605
53 Sharma Y, Verma H, Sah J. Speech profile of myasthenia gravis: A case study. Research & Reviews. J Immunol 2019;9(02): 11–13
54 Krishnan B, Boominathan P, Mahalingam S, Arunachalam R, Meerasa SS. Assessment of altered voice physiology in hypothyroidism. Natl J Physiol Pharm Pharmacol 2019;9: 798–803
55 Verma H, Rana D, Kumari A, Dogra N. Acoustical & perceptual vocal profile of beatboxers. J Laryngol Voice. 2020;9(02): 47–50
56 Dogra N, Verma H. Speech Profile of Wilson's Disease: A case report. Arch Med Health Sci. 2020;8(02):287–289
57 Greene MCL, Mathieson L, Baken RJ. The voice & its disorders. 6th ed. Wiley, Michigan; 2010
58 Rao SMS, Koripalli K, Apoorva P, Malipatil V. Study of maximum phonation time and S/Z ratio in laryngeal paralysis. Int J Otorhinolaryngol Head Neck Surg. 2020;6:1627–1631
59 Shipley KG, McAfee JG. Assessment in speech-language pathology: A resource manual. 6th ed. Plural, San Diego; 2021
60 Mendes A, Alves-Pereira M, Castelo Branco NA. Voice acoustic patterns of patients diagnosed with vibroacoustic disease. Rev Port Pneumol 2006;12(04):375–382
61 Mendes AP, Santos CP, Graça A, et al. Voice acoustic analyses of commercial airline pilots. INTERNOISE, Shanghai, China; 2008
62 Mendes AP, Graça A, Jorge A, et al. The effects of ILFN-exposure on voice acoustic parameters of commercial cabin crewmmbers. J Laryngol Voice. 2012;2(02):70–80
63 Alves-Pereira M, Reis Ferreira JM, Joanaz de Melo J, Motylewski J, Kotlicka E, Castelo Branco NA. Noise and the respiratory system. Rev Port Pneumol 2003;9(05):367–379

